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Executive functions, self-regulation and external-regulation: Relations and new evidence

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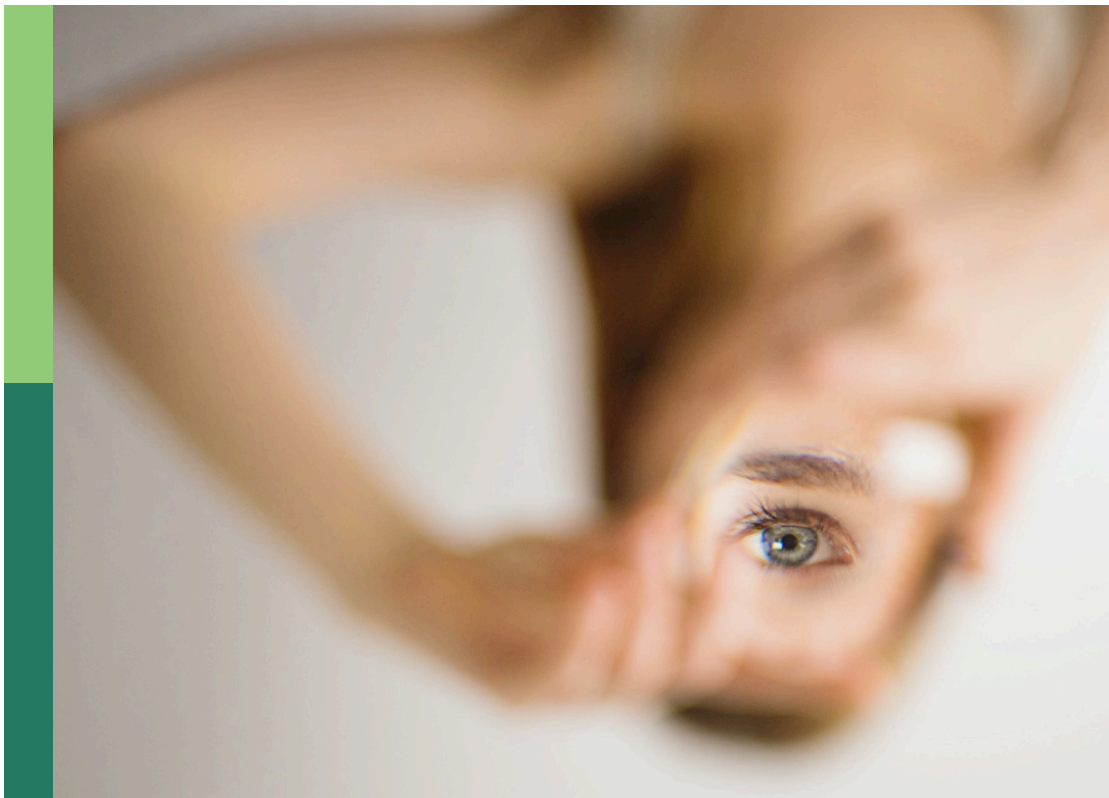

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Executive functions, self-regulation and external-regulation: Relations and new evidence

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Editorial: Executive functions, self-regulation and external-regulation: relations and new evidence

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Editorial on the Research Topic
Executive functions, self-regulation and external-regulation: relations and new evidence

Recent research evidence has shown the importance of different psychological constructions for analyzing problems associated with lack of adequate behavior management in human beings. The model of the different levels of behavioral analysis – microanalysis level, molecular level and molar level – allows us to approach the study of executive functions, in relation to other constructions of said levels (de la Fuente et al., 2019).

The aim of this Research Topic was is to establish the necessary connections between the three levels of analysis with respect to the issue of human behavioral regulation. Many questions remain to be answered concerning the relationships and connections between the models mentioned: Does the construct of executive functions correspond linearly to that of self-regulation or self-regulated learning? How do they differ? What effect does the context have, when it is more or less regulatory? How do the types of relationships proposed by the molar theory relate to relationships identified at the molecular and microanalysis levels?

1) On the one hand, the *neuropsychological model* and its central variable, *executive functions* (EF) have become an essential construct for explaining learning difficulties and self-regulation of behavior in the lives of individuals. This well-documented construct represents the *level of microanalysis* of human behavior, which means that it focuses on the interaction between brain and behavior on cognitive performance, including decision-making across the lifespan. In parallel and complementary, other psychological models from research at the molecular and molar levels have been developed aiming to fill out the analysis and definition of behavior regulation, especially in the educational and health fields. A paper analized "*The executive function and effortful control, with similar and different evidence from big data analysis*" (Chae). Another article has analyzed the "Ice Cream," a new virtual reality tool for the assessment of executive functions in children and adolescents, with a normative study (Fernandez et al.).

2) The behavioral models of *Self-Regulated Learning*, SRL, and general Self-Regulation modeled after the information processing paradigm have enabled us to accurately understand self-regulatory processes in the human being. These models, placed at a *molecular level of analysis*, give us a sequential, discrete understanding of self-regulatory behaviors, in the sphere of education and health. By analyzing across the behavioral sequence of before-during-after each act, the models have provided evidence of their value in assessment and intervention. Two works analyze the effect of Executive Functioning on school learning, both in Reading Comprehension (Leshem and Altman), and in English (Akhmedjanova and Moeyaert). Additionally, three articles have focused on the effect of self-regulated learning: the first, in asynchronous online learning situations (Sun et al.); the second report has analyzed the combined value of executive functions and self-regulated learning to predict differences in study success within higher education students (Manuhuwa et al.); a third work focused on noise reduction in preschool from a self- regulated learning perspective—implementation of a game-based voice regulation training program (Sarfaty and Ben-Eliyahu).

3) Finally, the behavioral model of *Self- vs. External Regulation, SR vs. ER Theory* takes its place at the *molar* level of analysis and has postulated the relevance of an interactive subject x environment analysis. This model has confirmed the relevance and value of the interaction of levels of regulation present in the subject and in their context, for predicting human behaviors in the fields of education and health. The continuum of Self-Regulation, Non-Regulation, Dys-Regulation (SR-NR-DR) has helped to operationally define the types of regulatory behavior, whether at the personal level or the contextual level. Two works focused on the effect of context on regulation have analyzed the factors affecting faculty conformity in South China universities (Xu and Chang) and the importance of teachers' supportive vs. undermining behavior for developments in early adolescents' self-regulation (Opdenakker). Additionally, two research reports have provided evidence regarding the combination of predictive factors of contextual and personal regulation regarding the variability of executive functions in university students (de la Fuente et al.) and the learning specific regulatory behavior (Pachón- Basallo et al.).

In conclusion, this Research Topic has provided a multilevel view of the executive functions construct, in relation to other related constructs, from a multilevel perspective. Future work should delve into this problem, since it is neither closed nor exhausted.

Author contributions

JF: Conceptualization, Funding acquisition, Investigation, Project administration, Writing – original draft. LF: Conceptualization, Supervision, Writing – review & editing. FS: Resources, Supervision, Validation, Writing – review & editing. MP: Formal analysis, Methodology, Writing – original draft. UD-O: Conceptualization, Methodology, Validation, Writing – review & editing.

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Conflict of interest

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BRIEF RESEARCH REPORT
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Distinct Effects of Executive Functioning, Impulsivity and Anxiety on Global and Local Reading Comprehension

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Reading comprehension (RC) is a cognitive ability linked with higher-order cognitive functions referred to as executive functions (EFs) and is also associated with educational achievement. To date, there is little research exploring links between reading comprehension, EFs, and personality traits. This study attempts to fill this gap by elucidating the role of EFs, trait impulsivity, and trait anxiety in RC among university students. To achieve a more in-depth examination, RC is divided into its global and local subskills. Ninety university students (83% female) completed self-report questionnaires on EFs, impulsivity, and anxiety, a neuropsychological task for cognitive flexibility, and global/local RC assessments. Our results indicated distinct associations between poor general EFs and poor global RC, poor cognitive flexibility and poor local RC, and, finally, between high impulsivity and adequate global RC. Individual differences in global and local information processing strategies in the context of attentional processes and personal traits of the university students, is discussed.

Keywords: reading comprehension, executive functions, cognitive flexibility, impulsivity, anxiety, global/local information processing

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INTRODUCTION

Reading comprehension (RC) is considered a cognitive ability closely related to executive functions (EFs) (Follmer, 2018; Nouwens et al., 2021). EFs are a set of higher-order cognitive functions consisting of three key components–working memory, inhibition, and cognitive flexibility–from which more complex and higher-order EFs are built (e.g., reasoning and planning) (Miyake et al., 2000; Diamond, 2013). EFs are essential for controlling unregulated behaviors including impulsive and anxious behaviors (Snyder et al., 2019; Buzzell et al., 2020; Friedman et al., 2020). Note, the multidimensional nature of EFs raises complexity regarding its theoretical conceptualization. This complexity is particularly pronounced in the examination of the relationship between EFs and other multidimensional constructs, such as anxiety and impulsivity. It is particularly evident in the examination of latent components of EFs (e.g., shifting, inhibition) in relation to impulsivity and/or anxiety. That is, the convergent and discriminant validity of these constructs is not clear, and the nature of their differences remains to be determined. However, based on the conceptualizations of common unity and diversity models of EFs (Miyake et al., 2000; Miyake and Friedman, 2012; Friedman and Miyake, 2017; Zelazo and Müller, 2002), growing evidence suggests relationships

between impulsivity and anxiety traits and EFs, among them cognitive flexibility (Kenemans et al., 2005; Eysenck et al., 2007; Bickel et al., 2012; Pacheco-Unguetti et al., 2012; Leshem, 2016a; Shields et al., 2016; Friedman et al., 2020; Wegmann et al., 2020; Warren et al., 2021), which is the ability to shift between multiple tasks or mental strategies (Miyake and Friedman, 2012; Zelazo, 2015). Research has shown that individuals with high impulsivity or anxiety experience difficulties in EFs, including cognitive flexibility (Edwards et al., 2015; Müller et al., 2015; Leshem, 2016b; Leshem, 2018; Park and Moghaddam, 2017).

Impulsivity and anxiety are also linked to RC (Follmer, 2018; Miller et al., 2020; Tynan et al., 2020), which plays a crucial role in educational and professional success of university students (Sadeghi et al., 2012). A deeper understanding of these rarely researched associations is needed. Indeed, two separate bodies of research relate to this enquiry: one linking EFs to language skills and another linking EFs to impulsive and anxious behavior regulation. To date, there has been no explicit attempt to link the evidence between these two interdisciplinary paradigms. This study aims to fill this gap by elucidating the role of EFs and impulsive and anxiety traits in RC among university students.

THE READING COMPREHENSION LINK TO EXECUTIVE FUNCTIONING

Reading comprehension is integral to learning processes (Fiorella and Mayer, 2016; Barnes et al., 2020). It involves knowledge of relevant vocabulary, background information, grammatical formulations, metaphorical language, and inferential reasoning-all of which must be applied in a coordinated manner to adequately comprehend written text (Sesma et al., 2009). Thus, RC as a multifaceted, complex skill comprised of subskills and cognitive processes acting in concert (e.g., encoding, instantiation, inference, retrieval), and related to integration, planning, editing, summarizing, and reconstructive processes (Butterfuss and Kendeou, 2018; Cutting, et al., 2009; Meixner et al., 2019; Pazeto et al., 2014; Sesma et al., 2009). The interplay of these subskills requires cognitive functions including updating, focused attention, shifting of attention, and inhibition of irrelevant text information (Cutting et al., 2009; Follmer, 2018).

Much previous research has focused on EF effects on RC, in particular as assessed during preschool and primary school (Meltzer, 2018; Meixner et al., 2019; Spencer et al., 2020; Nouwens et al., 2021), showing that EF deficits are related to RC difficulties (see Cutting et al., 2009; Engel de Abreu et al., 2014). s (Huizinga and Smidts, 2010; Georgiou and Das, 2018; Follmer and Sperling, 2019). Specifically, in typical development, reading abilities are expected to improve as a function of age, in part because of the developmental course of EFs–from a more "unitary" construct in early childhood to a multi-faceted construct in adulthood (Georgiou and Das, 2018; Ober et al., 2019) consisting of lower-level components (e.g., WM, inhibition, cognitive flexibility) and higher-level components (e.g., reasoning, problem solving, and planning). Accordingly, EFs have been found to make unique contributions to RC at different grade levels and ages, from preschool children to adult learners (Potocki et al., 2017). It has been demonstrated that, in addition to word decoding and language skills, EFs help explain the significant variance in RC seen in the upper grades of primary school; indeed, several longitudinal studies documented that the contribution of EFs to reading comprehension increases in the upper primary grades when decoding skills are more developed (Nouwens et al., 2021). In essence, the examination of the relationship between EFs and RC is important as skilled adult readers must flexibly coordinate multiple aspects of reading tasks for successful comprehension which requires integration of information across multiple paragraphs, inhibition of irrelevant information, and monitoring of comprehension (Georgiou and Das, 2018). As skilled adult readers, reading speed and consequently RC speed is expected to be intact since both speed and accuracy underlie RC skills (Juul et al., 2014).

This corresponds with the various models that conceptualize RC through lower-level reading processes (e.g., Simple View of Reading) to higher-level reading processes (e.g., the lattice model, structure-building framework), reflecting the contribution of EF components to RC processes (see Haft et al., 2019 for further reading). Furthermore, compared to research on updating and inhibition, relatively little research exists on the relationship between shifting functions–a central part of cognitive flexibility–and RC (Butterfuss and Kendeou, 2018). Indeed, successful RC depends on cognitive flexibility by enabling focus shifting from word-level processing to overall text meaning (Butterfuss and Kendeou, 2018; Follmar, 2018).

Researchers have investigated the contributions of EFs to reading comprehension beyond the skills of decoding (Follmer, 2018). For example, inferencing and selective attention to specific parts of the text increase attentional resources which subsequently facilitate the development of comprehension (Reynolds, 1992, 2000). Even if not explicitly indicated, the importance of the role of EFs have been acknowledged in reading comprehension models (see Butterfuss and Kendeou, 2018 for a review). One such example may be taken from The Structure-Building Framework (Gernsbacher, 1991) which depicts comprehension as the result of three processes: laying foundation (using information from the text to base a mental representation), mapping (finding text information to build structures) and shifting (allocating to a different structure when unable to map to an existing structure). The shifting, which leads to suppression, may account for individual differences in which skilled readers know whether and when to suppress information while less-skilled readers do not.

Moreover, the distinction between RC's global and local subskills should be considered, as they rely on different perceptual organization and attentional processes (i.e., attentional bias to focus on small local or global information; Chamberlain et al., 2017). Global perceptual processing has been suggested as abstraction "reflecting a construal or meaning-making process whereby individuals distill the essence or gist of some stimulus" (Darwent et al., 2010, pp 199) and is presumed to require a broader focus of attention (i.e., more spatially distributed attentional scope). In contrast, local processing, has been associated with a smaller

focus of attention (Hagenaars et al., 2016). It should be noted that many studies have focused on English as the target language and therefore may be less generalizable to other languages such as Hebrew in the current study.

GLOBAL AND LOCAL STRATEGIES IN RC

Fuzzy-trace theory (FTT, Reyna, 2012), a comprehensive, dual-process model of information perception, posits two types of representations of a written stimulus that are encoded in memory: verbatim representation, capturing the text's exact words, numbers, or images, and gist representation, capturing essential "bottom-line" meaning (Reyna, 2012; Blalock and Reyna, 2016). Both verbatim and gist information-based representations are indicative of different language skills/techniques, termed "local comprehension" and "global comprehension." To read and answer questions about a text, one must distinguish between global and local main ideas. Following (Wang, 2009), the local main idea is derived from the sentence level while the global main idea is derived from the overarching text level (Meyer, 2003). Similarly, Follmer (2018) offers that local cohesion refers to the sentence level (in which pieces of information overlapping between sentences in close proximity are needed for synthesis), while global cohesion refers to the overarching text level (in which information overlapping whole sections or the totality of the text are needed for synthesis). Thus, global comprehension is the notion of understanding a text in its entirety. It requires greater proficiency identifying the general overall meaning, rather than specific details (Cartwright, 2009). In contrast, local comprehension is detail-intensive reading to extracting specific information (Aragon et al., 2002; Cartwright, 2009; Israel and Duffy, 2009; Shi, 2011).

Individual differences are seen in global or local information processing, with personality differences seeming to induce different perceptual styles. Some studies suggest a local/global bias as a general personality trait (de-Wit and Wagemans, 2015); for example, trait-anxious individuals show relative preference for local processing during negative states (Derryberry et al., 1998; Hagenaars et al., 2016; Shilton et al., 2019; Veerapa et al., 2020) and attentional narrowing (focused attention) is related to anxiety and emotion intensity. In contrast, impulsive individuals tend to adopt a broad attentional scope, especially in emotionally arousing situations (Patton et al., 1995; Uncapher et al., 2016).

THE READING COMPREHENSION LINK TO IMPULSIVITY AND ANXIETY TRAITS

Classification of RC into global and local subskills is also found in personality literature as "a holistic dimension" (Peterson and Deary, 2006; Milne and Szczerbinski, 2009), a pattern emerging from combining local and global elements. Accordingly, *processing* information takes place at the global (broad) level, while *organizing* detailed information takes place at the local (detailed) level. Further, evidence suggests global/local RC may be oriented toward certain personality traits: impulsive individuals seem to possess a more global focus and anxious individuals a more local focus (Becker et al., 2018; Dickman, 1985; Rivers et al., 2008).

Notwithstanding, both impulsivity and anxiety personality traits may manifest due cognitive ability deficits (e.g., attentional control) that may, in turn, affect RC competence. Individuals with impulsive tendencies may rapidly process information and quickly respond with little forethought, sometimes hindering academic performance (Vigil-Colet and Morales-Vives, 2005). Indeed, absence of reflection between stimulus and response, as occurs with impulsivity, may prevent maintaining focus during reading; this may occur due to distraction or particularly speedy processing. Note, some studies suggest that consequences of impulsivity are not always negative and may even be advantageous depending on cognitive demands of a task, such as the degree of difficulty, complexity, cognitive load, and time limit (Claes et al., 2000; Dickman, 2000; Eysenck et al., 2007; Eysenck and Derakshan, 2011; Leshem, 2018). Trait anxiety is linked to multiple cognitive processes important for adequate RC skills, including directing attention and cognitive resources toward achieving one's goals (Fales et al., 2008; Grant and White, 2016; Raymond et al., 2017; Jaiswal et al., 2018). Much anxiety research has focused on distracting effects of worry, anxiety disorder, and threat-related attentional biases, especially in the context of academia (i.e., test anxiety) (Bar-Haim et al., 2007; Brandt et al., 2020; Gustavsonet al., 2019; Macher et al., 2012; Moser et al., 2013; Tysinger et al., 2010). Bearing in mind that although trait anxiety may predispose individuals to develop anxiety disorder or threat-induced state anxiety, anxiety as a stable personality trait should be distinctive in terms of its underlying biopsychological mechanisms and its possible effects (positive or negative) on different cognitive-performance tasks (Bishop, 2008; Eysenck et al., 2007; Raymond et al., 2017; Robinson et al., 2013; Saviola et al., 2020; Vytal et al., 2012, 2013).

THE PRESENT STUDY

This study attempts to elucidate the role of EFs and specific personality traits-impulsivity and anxiety-in global and local RC subskills. EF evaluation consisted of a behavioral rating of daily EFs (higher-order cognitive functions such as behavioral regulation and metacognition). Considering the multidimensional nature of EFs, as well as impulsivity and anxiety, we used validated instruments to measure trait impulsivity and anxiety and we used a validated self-report questionnaire to measure EFs (BRIEF-A; e.g., Gioia and Isquith, 2004; Olsson et al., 2020; Toplak et al., 2013). Because these are context-dependent, multivariate constructs, such that different forms of impulsive or anxiety behavior and EFs are influenced by different situational and cognitive processes, using self-report measures of personality traits in addition to the BRIEF-A (Roth et al., 2013; Baars et al., 2015; Rike et al., 2015; Friedman et al., 2016; Lantrip et al., 2016) is relevant to obtaining a comprehensive understanding of how they separately relate to RC subskills. In addition, a neuropsychological

performance task assessed cognitive flexibility through analyzing response perseveration and error recurrence, as preservative errors vary among individuals with impulsivity and/or anxiety (Bishara et al., 2010) and may not be captured in standard behavioral ratings of daily EFs. Thus, both types of EF measurements may tap into related, yet separate, constructs (Dajani and Uddin, 2015; Miranda et al., 2015).

Accordingly, we predicted that adequate general EFs, measured by the daily EF behavior rating, would be associated with good performance in global and local RC. We further predicted that cognitive flexibility, measured by the neuropsychological performance task, would influence RC skills on the local, but not global, level. Since research into the relationship between personality traits and RC is scant, if any connection were found between RC subskills and personality traits, we expected that high impulsivity would be associated with better global skills and high anxiety would be associated with better local skills.

MATERIALS AND METHODS

Participants

Ninety undergraduate university students enrolled a course in the social sciences (75 females; M_{age} = 22.84; age range: 19–29 years) participated in this study voluntarily. All participants rated their Hebrew competence in speaking, understanding, reading, and writing on a 5-point scale. Those indicating a learning disorder (n = 4) and/or being bilingual (n = 2) were excluded, as this study focused on monolingual typically-reading adults (namely, the originally-recruited cohort totaled 96). No history of neurological, psychiatric illnesses, language-related disorders, including attention deficit hyperactivity disorder, was reported. The sample size was determined based on commonly used rule of thumb recommended for linear regression analysis based on predictor variables (Green, 1991). We conducted a post-hoc test to determine the static power of the current sample using G*Power 3.0.10 (Faul et al., 2007; Faul et al., 2009). It was found that using 90 participants and a linear multiple regression of a fixed model, R^2 deviation from zero design with three predictors, an a-priori α of 0.05 and a medium effect size, we could detect effects of power that equals to 0.87. This effect size exceeds the accepted 0.80 in the literature (MacCallum et al., 1996). The study was approved by the university's human subject protection Institutional Review Board (i.e., Helsinki committee) and all participants provided signed informed consent.

Measures

Barratt Impulsiveness Scale (BIS-11; Patton et al., 1995) consists of 30 items scored on a 4-point scale (1 = rarely/never to 4 = always) including three subscales: motor, attentional, and non-planning. The BIS-11 provides a total score serving as a global impulsivity measure, ranging from 30 to 120. A total score between 52 and 71 is considered within normal limits for impulsiveness. A total score of ≥72 is used to classify an individual as highly impulsive (Stanford et al., 2009). A validated translation to Hebrew (Glicksohn and Nahari, 2007; Leshem and Glicksohn, 2007; Leshem, 2016b; Leshem and Yefet, 2019) was utilized and had adequate reliability (α = 0.72).

State-Trait Anxiety Inventory–Trait Anxiety (STAI-TA; Spielberger et al., 1983) includes 20 items on a 4-point scale (1 = Not at all to 4 = Very much so). The STAI-TA score varies from 20 to 80. STAI scores are commonly classified as "no or low anxiety" (20–37), "moderate anxiety" (38–44), and "high anxiety" (45–80). A validated translation to Hebrew (Leshem, 2018) was utilized and had adequate reliability (α = 0.89).

Behavior Rating Inventory of Executive functions- Adult version (BRIEF-A, Roth, Isquith, and Gioia, 2005) contains 75 items scored on a 3-point scale (higher scores indicate poorer executive function) and two index scores: Behavioral Regulation Index and Metacognition Index. The Behavioral Regulation index is comprised of four scales (Inhibition, Shifting, Emotional Control, and Self-Monitoring) and the Metacognition Index is comprised of five scales (Initiation, Working Memory, Planning/Organization, Task Monitoring, and Organization of Materials). The BRIEF-A provides a total score that serves as a general index of EFs, and ranges from 75 to 225, with higher scores indicating greater impairment. For clinical evaluation, a T-score is calculated for each scale, in which a total score of <65 signifies clinical impairment. A validated translation to Hebrew was utilized (Sharfi, and Rosenblum, 2016; Stern et al., 2017) in the current study and had adequate reliability (α = 0.94).

The Wisconsin Card Sorting Task-computerized version (WCST: Heaton et al., 1993; Leshem and Glicksohn, 2007) is a neuropsychological test for assessing cognitive flexibility, and includes adaptation to changes in task contingencies and set-shifting (Smillie et al., 2009; Bishara et al., 2010; Gray-Burrows et al., 2019). In this computerized version, participants are presented four sample cards, each with geometric designs that vary along three dimensions: color, shape, and number. Participants sequentially pick a card from a pre-sorted deck of 64. Instructions are given to match each card to one of the sample cards, with the goal to get as many correct matches as possible. Participants decide whether the (unknown) criterion for matching cards on that trial relates to color, shape, or number; feedback is given after each trial. After 10 consecutive correct matches are made, the criterion for matching is switched. This is repeated with a second deck of cards in the same order. Previous studies demonstrated equivalence in validity between the manual test and the computer-based version used in this study (Wagner and Trentini, 2009; Çelik et al., 2021).

Reading Comprehension Tests

The RC questions were constructed by the Israeli National Institute for Testing and Evaluation and are directly linked to thinking methods that are required in different academic studies. These questions solicit specific details from a complex text and aim to arrive at conclusions by examining the internal logic underlying the assumptions and sets of logical rules. For example, the ability to understand complex claims is needed in the field of psychology and economics. The ability to complete sentences requires comprehension at the sentence level, which is based on understanding content words (e.g., nouns, verbs) and function words (e.g., prepositions, conjunctions); this ability is needed in

academic studies. Three short academic texts were chosen for participants to read and then answer 16 comprehension questions. There were two texts followed by 5 questions and one text followed by 6 questions. Questions included information related to details explicitly provided in the text, reference questions, and conclusive questions that required implicit understanding. Multiple-choice questions were divided into globally-oriented 7) and locally-oriented 9) questions. Global question examples were: "Why is it difficult for us to direct someone?"; "The sentence "I decided to do something and so I did it" is brought in the text as an example of. . .", and "What is the meaning of "Theory of mind"?" In contrast, a local question example was: "According to the text, "negligence" means. . ." Each correct answer received one point with a maximum score of 16. The Psychometric Entrance Test (PET) used for admission to higher education in Israel consists of three timed sections. The reading comprehension questions used in this study (primarily represented by multiple-choice [MC] questions) examine verbal skills and analysis, and comprehension of complex written text. They require one to think clearly and systematically, and to perceive fine distinctions between word and concept meanings. All the PET test components (the verbal domain among them) were consistently found to have high validity (Oren et al., 2014; Allalouf at al., 2020).

Procedure

Participants were tested individually in a quiet room, completing the tests in one session lasting approximately 1 hour. First, they completed the computerized task—the WCST. Next, they completed the three language comprehension tests; their order was randomized across participants. Finally, they were asked to complete the self-report personality measures for impulsivity and anxiety (BIS-11 and STAI-TA, respectively) and the BRIEF-A for assessment of general EFs. Self-report questionnaires were presented in a counterbalanced order.

Statistical Analysis

SPSS™ version 25 was used for statistical analysis. Four indices of predictors were calculated. Two were: the daily EF behavioral rating (BRIEF-A total score-high scores indicative of poor general EFs), and cognitive flexibility [labeled as WCST Lg10(PE); calculated as the log transformation of the number of perseverative errors on the Wisconsin Card Sorting Task, involving continued use of a criterion that would be correct if the immediately preceding criterion continued]. The other two predictors, the impulsive and anxious personality trait indices, were calculated by the total scores on the BIS-11 and STAI-TA, respectively.

To evaluate the outcome measure, RC, a distinction between the Language Comprehension Test's global and local reading comprehension questions was made by three raters. The raters were asked to determine which questions measured global skills and which measured local skills. Interrater reliability was 87.5 and discrepancies were discussed with a third rater to reach a unified final decision. Separate scores were calculated for local and global RC. The local comprehension score was calculated by dividing the number of correct local questions by 7, resulting in the total local score. The global comprehension score was calculated by dividing the number of correct global questions by 9, resulting in the total global score.

First, Spearman correlations were conducted to examine correlations between the variables. Then, hierarchical regression analyses were conducted with global and local RC as the outcome variables (y). Each regression equation had two steps whereby the variables of BRIEF-A (general EFs) and WCST Lg10(PE) (cognitive flexibility) were entered as independent variables (x) in the first step and personality traits (impulsivity and anxiety) in the second step. Overall, four regression models exhibited the full model statistics for each model estimated. As recommended by Preacher and Hayes (2008), we used a bootstrapping method effective with this sample size and least vulnerable to Type I errors. Bootstrapping does not assume normal distributions and is also a nonparametric resampling procedure appropriate for this sample. We resampled the data 10,000 times as recommended by Hayes (2013).

RESULTS

Data Screening

Initial screening of the data for normality was conducted by testing the significance of skewness and kurtosis of the distributions for each measure, resulting in rejecting the assumption of normality for WCST(PE) and anxiety variables. In the WCST task, premature anticipatory responses with latencies shorter than 150 ms (Whelan, 2008) as well as responses with latencies more than three *SD*s above the sample mean, were excluded from the analyses. This resulted in the removal of two participants from the study, who were then replaced with two matching participants to maintain a sample of ninety participants. Performing descriptive statistic and regression analyses excluding the two participants prior to replacement yielded no change in the results. After removing two outliers with extreme values in the WCST, we retested the assumptions of normality in each variable. Due to violation of the assumption of normality for the WCST, we performed log transformations to normalize the distribution. In addition, anxiety and RC subskills measures showed non-normal distributions. As such, statistical analysis for non-normal distributions were used.

Descriptive statistics of variables and Spearman correlations are reported in **Table 1**. Local RC was positively correlated with global RC and negatively correlated with cognitive flexibility [WCST Lg10(PE)]. Also, there were positive correlations between anxiety and impulsivity traits (STAI-TA and BIS-11 scores, respectively), and general EFs (BRIEF-A). There were no other significant correlations ($rs < 0.3$, $p > 0.1$).

The Effects of General EFs, Impulsivity, and Anxiety on Global and Local RC

The first regression model was significant, showing 5% of the variance in global RC was accounted for by general EFs in the

TABLE 1 | Descriptive statistics[1] and Spearman correlations for the research variables.

Variable	Range	M	SD	1	2	3	4	5	6	7
1. Local RC	0.64–1	0.91	0.08							
2. Global RC	0.70–1	0.93	0.07	0.23*						
3. BRIEF-A sum	77–155	106.97	18.26	0.02	-0.19					
4. BRIEF-A T-score	32.48–76.38	50	10							
5. WCST Lg(PE)	0.60–1.61	1.10	0.24	-0.22*	-0.14	0.06	0.07			
6. WCST PE sum	4–41	14.6	8.8							
7. STAI-TA	24–62	37.98	9.68	0.12	-0.03	0.59**	0.60**	0.15	0.15	
8. BIS-11	41–75	58.66	8.26	0.02	0.02	0.64**	0.62**	0.03	0.03	0.27**

Note: RC, reading comprehension; BRIEF-A, Behavior Rating Inventory of Executive Functions- Adult; BIS-11, Barratt Impulsiveness Scale; STAI-TA, State-Trait Anxiety Inventory—Trait Anxiety; WCST, Lg10(PE) = The Wisconsin Card Sorting Task log transformation of the number of perseverative errors; WCST(PE) = Untransformed perseverative errors.
[1]The Means(SDs) for the variables after excluding the two participants prior to replacement (N = 88): Local RC = 0.91 (0.07); Global RC = 0.93 (0.07); BRIEF-A sum = 106.31 (17.86); WCSTLg(PE) = 1.09 (0.23); STAI-TA; 37.7 (9.6); BIS-11 = 58.6 (8.3)

base model, whereas, in the full model, approximately 11% of the variance in global RC was accounted for by general EFs, impulsivity, and anxiety. Specifically, a high general EF score predicted a low global RC score, with other effects held constant. Furthermore, as the impulsivity score increased, the global RC score increased as well, with other effects held constant (see **Table 2**).

In the second regression model, general EFs, impulsivity, and anxiety were not found significant predictors for local RC (see **Table 2**).

The Effects of Cognitive Flexibility, Impulsivity, and Anxiety on Local and Global RC

The third regression model showed no significant results; that is, cognitive flexibility and personality traits did not constitute significant predictors of global RC (see **Table 3**). However, the fourth regression model, which predicted local RC by examining the independent variables of cognitive flexibility [WCST Lg(PE)] and personality traits (BIS-11, STAI-TA), although not found significant, the effect of cognitive flexibility on local RC was found significant. Specifically, poor WCST performance predicted poor local RC, with other effects held constant. Impulsivity and anxiety were not found significant predictors of local RC (see **Table 3**).

DISCUSSION

This study examined the effects of general EFs, cognitive flexibility, and impulsivity and anxiety traits on local and global RC subskills among university students. The main findings indicated distinct effects of general EFs, cognitive flexibility and impulsivity, on global and local RC subskills. Results showed poor general EFs associated with poor global RC, and poor cognitive flexibility associated with poor local RC. Impulsivity was associated with better global RC performance, whereas anxiety showed no effect on local or global RC.

General Executive Functions and Cognitive Flexibility Link to Global and Local RC

The hypothesis regarding the association between adequate general EFs and good performance in global and local RC was partially supported, showing that general EFs abilities influence performance in global RC but not in local RC. Based on information processing strategies in RC, global and local questions require different processing demands. When asked a specific "local question" relating to a text, a particular set of cognitively flexible resources are recruited compared to a "global question" that taps into a general gist-based processing information strategy for text comprehension (Cartwright, 2009). This may explain the distinct effects of general EFs and cognitive flexibility on global and local RC performance. Specifically, our findings showed that difficulties in general EFs predicted poor global RC performance, suggesting that global reading presumably relies on more extensive EFs, such as working memory, metacognition, and reasoning, which one has to recruit in order to synthesize the pieces of text to arrive at the gist (Israel and Duffy, 2009; Nicolielo-Carrilho et al., 2018). In contrast, and in accordance with the hypothesis on the influence of cognitive flexibility on local RC, difficulties in cognitive flexibility predicted poor local RC performance, suggesting that cognitive flexibility is critical for RC at the word-sentence level (Cartwright, 2009; Colé et al., 2014; Follmar 2018). That is, local reading processing may rely more on cognitive flexibility that determines when, where, and in what manner particular processing strategies are used for a given situation (Kozhevnikov, 2007; Juntorn et al., 2017).

Furthermore, the markedly distinct findings between general EFs and cognitive flexibility suggest that cognitive flexibility is not merely the sum of implementing various EFs, but also requires shifting, or reconfiguration of one's response set to a new goal (Dajani and Uddin, 2015). In RC, skilled "comprehenders" actively shift focus across several levels (i.e., shifting between micro- and macro-level text comprehension) (Butterfuss and Kendeou, 2018; Cartwright, 2015; Colé et al., 2014; Follmer, 2018; Kieffer et al., 2013). Our finding may support the claim that general EFs and cognitive flexibility should be treated differently because they tap into different processing

TABLE 2 | [1]Hierarchical regression model with global and local reading comprehension as the outcome variables and general EFs, impulsivity, and anxiety as independent variables.

Model 1: Outcome variable: Global reading comprehension

	Base model R^2 = .05, F (1, 88) = 4.82, p = .03				**Full model** R^2 = .11, F (3, 86) = 3.58, p = .02 ΔR^2 = .06, F (2, 86) = 2.86, p = .06			
Variable	**b(se)**	**β**	**P**	**95%CI**	**b(se)**	**B**	**p**	**95%CI**
BRIEF-A	–0.001 (0.00)	–0.23	0.03	[–0.002, 0.00]	–0.002 (0.00)	–0.51	0.002	[0.003, 0.001]
BIS-11					0.002 (0.001)	0.26	0.04	[0.00, 0.004]
STAI-TA					0.002 (0.001)	0.21	0.12	[–0.00, 0.004]
Constant	1.03 (0.05)		<0.001	[0.94, 1.12]	0.96 (0.05)		<0.001	[0.85, 1.06]

Model 2: Outcome variable: Local reading comprehension

	Base model R^2 = .002, F (1, 88) = .17, p = .68				**Full model** R^2 = .04, F (3, 86) = 1.13, p = .34 ΔR^2 = .036, F (2, 86) = 1.60, p = .21			
Variable	**b(se)**	**β**	**P**	**95%CI**	**b(se)**	**B**	**p**	**95%CI**
BRIEF-A	0.00 (0.00)	–0.04	0.68	[–0.001,0.001]	–0.001 (0.001)	–0.26	0.12	[–0.003, 0.000]
BIS-11					0.001 (0.001)	0.12	0.36	[–0.001, 0.004]
STAI-TA					0.002 (0.001)	0.23	0.10	[–0.00, 0.004]
Constant	0.93 (0.05)		<0.001	[0.83, 1.02]	0.89 (0.06)		<0.001	[0.77, 0.99]

Notes: BRIEF-A, Behavior Rating Inventory of Executive Functions- Adult version; BIS-11, Barratt Impulsiveness Scale; STAI-TA, State-Trait Anxiety Inventory—Trait Anxiety.
[1]Regression analyses excluding the two participants and prior to replacement. Model 1: Regression model with global reading comprehension as the outcome variable. Base model: R^2 = .05, F (1, 86) = 5.02, p = .03. Full model: R^2 = .11, F (3, 84) = 5.02, p = .02. ΔR^2 = .06, F (2, 84) = 2.60, p = .08. Model 2: Regression model with local reading comprehension as the outcome variable: Base model: R^2 = .00, F (1, 86) = .19, p = .89. Full model: R^2 = .03, F (3, 84) = .91, p = .44. ΔR^2 = .03, F (2, 84) = 1.34, p = .27

strategies (Bakar, et al., 2011; Mangeot et al., 2002; McAuley et al., 2010; Vriezen and Pigott, 2002).

Impulsivity and Anxiety Link to Global and Local RC

The hypothesis that high impulsivity would be associated with better global skills and high anxiety would be associated with better local skills, was partially supported. The results showed that adding personality trait impulsivity to the regression model, along with general EFs as an independent variable, increased the explained variance in global RC performance. Specifically, while difficulties in general EFs predicted reduced global RC performance, high impulsivity increased global RC performance, suggesting that in non-clinical populations the consequences of impulsivity are not negative in certain tasks. In this regard, Dickman (1993) posits that impulsivity is composed of two subconstructs: dysfunctional and functional impulsivity. Dysfunctional impulsivity refers to speedy and unreflective decision making, similar to most definitions of impulsivity that connote maladaptively. In contrast, functional impulsivity refers to fast information processing that is beneficial and even an optimal cognitive style (Dickman, 1993; Dickman, 2000); these aspects of impulsivity include the tendency to make quick decisions and react without going "into the details," which may help with quick, successful task completion. Indeed, global RC questions solicit 'bottom-line' gist representations without need for detailed analysis.

To the best of our knowledge, there are no studies that have examined the relationship between functional impulsivity and RC. Thus, further research is needed to clarify the impulsivity-RC relationship, taking into consideration functional impulsivity, and to account for possible interference of impulsivity in learning processes. This may help us understand whether impulsivity is directly related to RC skills or acts as a moderator between individuals' resources and achievements.

As for anxiety, it was not found to be associated with global or local RC. This does not corroborate with previous research on the distinct effects of anxiety on language-related cognitive functions, including learning processes (Fales et al., 2008; Basten et al., 2012; Vytal et al., 2012; Visu-Petra et al., 2013). The non-significant effect of anxiety on RC subskills may be explained by the notion that there is less vulnerability to disturbances from worrying thoughts during high-cognitive load tasks that occupy executive resources. Alternatively, more effort may be allocated to high-load tasks at the expense of processing efficiency (related to longer reaction times) but not at the expense of accurate performance (related to intact accuracy) (Eysenck and Calvo, 1992; Eysenck et al., 2007). This is supported by the dual-pathway compensatory effort idea of Eysenck and colleagues' (2007, 2011) attentional control theory (ACT), according to which anxious individuals often perform just as well as their non-anxious peers. Although worries are distracting and make processing less efficient, they may also motivate anxious individuals to employ compensatory efforts to overcome negative effects of anxiety, resulting in enhanced performance comparable to their non-anxious peers (Ansari and Derakshan, 2010; Basten et al., 2012). Indeed, highly anxious individuals may expend compensatory effort on task processing (in this case, RC) to make up for poorer attentional control.

TABLE 3 | Hierarchical regression model with global reading comprehension and local reading comprehension as the outcome variables and cognitive flexibility, impulsivity, and anxiety as independent variables.

Model 3: Outcome variable: Global reading comprehension

	Base model R^2 = .03, F (1, 88) = 2.95, p = .09				**Full model** R^2 = .03, F (3, 86) = .99, p = .40 ΔR^2 = .001, F (2, 86) = .05, p = .95			
Variable	**b(se)**	**B**	**P**	**95%CI**	**b(se)**	**β**	**P**	**95%CI**
WCST Lg10(PE)	−0.06 (0.03)	−0.18	0.09	[−0.12,0.01]	−0.05 (0.03)	−0.18	0.10	[−0.13,0.02]
BIS-11					0.00 (0.00)	0.02	0.83	[−0.002,0.002]
STAI-TA					0.00 (0.00)	−0.03	0.79	[−0.002,0.001]
Constant	0.99 (0.04)		<0.001	[0.92,1.06]	0.99 (0.07)		<0.001	[0.86,1.11]

Model 4: Outcome variable: Local reading comprehension

	Base model R^2 = .06, F (1, 88) = 5.45, p = .02				**Full model** R^2 = .08, F (3, 86) = 2.33, p = .08 ΔR^2 = .02, F (2, 86) = .78, p = .46			
Variable	**b(se)**	**B**	**P**	**95%CI**	**b(se)**	**β**	**P**	**95%CI**
WCST Lg10(PE)	−0.08 (0.03)	−0.24	0.02	[−0.14, −0.01]	−0.08 (0.03)	−0.26	0.02	[−0.17, −0.002]
BIS-11					0.00 (0.001)	−0.00	0.99	[−0.002, 0.002]
STAI-TA					0.001 (0.001)	0.13	0.23	[−0.001, 0.003]
Constant	0.99 (0.04)		<0.001	[0.92, 1.06]	0.96 (0.07)		<0.001	[0.83, 1.08]

Notes: WCST, Lg10(PE), The Wisconsin Card Sorting Task log transformation of the number of perseverative errors; BIS-11, Barratt Impulsiveness Scale; STAI-TA, State-Trait Anxiety Inventory—Trait Anxiety.

In sum, the connections between EFs and impulsivity/anxiety traits, and the way they affect RC subskills, appears to depend on the cognitive demands of the task at hand. In particular, global and local reading comprehension subskills appear to engage different aspects of the cognitive domain of RC; they, in turn, are associated differently with general EFs, cognitive flexibility, and personality traits. This distinction may provide an important contribution to theoretical interdisciplinary and applied educational research.

Limitations

There are a few limitations need to be considered for future study. As a preliminary evaluation of the effects of EFs and personality traits (impulsivity and anxiety) on global and local RC, the current work has some limitations. It would be valuable to examine general EFs and specific aspects of EFs (e.g., working memory) at a fine-grain functional level using additional performance-based tasks as well as using behavioral questionnaires with ecological validity that provide important information on the role of EFs in daily life functioning. Incorporating multivariate indices for EFs will enable more complex models about possible relationships between EFs and RC. The same holds for multifaceted personality traits as impulsivity and anxiety, in which a multi-method approach that incorporates both performance-based tests and self-reports should be considered in future studies. Also, the sample consisted of undergraduate students enrolled in psychology and education courses, which resulted in a predominantly educated female sample. This limits the extent to which generalizations can be made. Thus, it would be beneficial to confirm and extend these conclusions by a more diverse sample (e.g., education level and sex). Clinical samples with different disorders should also be examined as they could assist in understanding the impact of the traits more than typically developing individuals. Finally, it is important to note that idiom specificity and generalizations should be cautioned the current data concerns the Hebrew language while most studies refer to English speaking samples.

CONCLUSION

The findings suggest distinct roles of general EFs, cognitive flexibility, and trait impulsivity on global and local RC subskills. Information about university students' global and local information processing styles/levels may be useful for pedagogical staff to take into consideration in order to tailor instruction methodologies. Further, the evidence from the current study suggests that impulsive individuals may be less prone to RC difficulties when global information is required; this finding may be quite important when building educational programs and identifying teaching methodologies better suited to students exhibiting impulsive behavior. Indeed, both global and local information strategies could be particularly useful for tailoring instruction to specific students while simultaneously introducing complementary strategies that provide scaffolding for enhanced RC skills Anderson, 2002, Blair and Diamond, 2008, Carlson and Meltzoff, 2008, Eysenck and Derakshan, 2011, Kieffer et al., 2013, Murdock et al., 2013, Nitschke et al., 2000, Pham, 2016, Riggs et al., 2014, Roth et al., 2014, Rozencwajg and Corroyer, 2005, Sadeh and Bredemeier, 2011, Salthouse et al., 2003,

Sweitzer et al., 2008, Ursache and Raver, 2014, Zelazo and Mü ller, 2002.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusion of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by The studies involving human participants were reviewed and approved by authors' Bar-Ilan university IRB. The participants provided their written informed consent to participate in this study. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

The manuscript was written by RL and CA. Research design was conducted by RL and CA. Data was collected and analyzed by RL and CA. RL was the corresponding author for the paper. All authors contributed to the article and approved the submitted version.

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METHODS
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Self-Regulated Writing of English Learners: Intervention Development

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The goal of this study was to develop and test an intervention in order to improve academic writing and SRL skills of English learners (ELs). ELs are well-represented across university and college campuses in the United States. While most of them thrive academically and receive their undergraduate and graduate degrees, a majority of ELs experience difficulties with academic writing such as limited English proficiency levels and opportunities to practice academic writing. Therefore, there is a need to develop and examine evidence-based interventions to promote the development of academic writing skills of ELs. One promising line of research involves adding instruction in self-regulated learning (SRL) to writing courses. In this study, the SRL writing intervention was delivered as a one-credit semester-long course taught at a medium research university. A mixed-methods research design, combining single case quasi-experimental design to collect quantitative data and focus group interviews to collect qualitative data, was used with undergraduate ELs (n = 8) from Southeast Asia. The results of this study revealed that the SRL writing intervention had a small positive effect on the quality of students' persuasive writing skills, but no effect on students' SRL skills. Focus group interviews suggested that students appreciated learning about SRL skills, but found the SRL journal confusing and frequent. These findings suggest that both writing and SRL skills are teachable, but may require more time and adjustments to the teaching and learning methods employed in the study. Recommendations for the development of the improved intervention are also provided.

Keywords: intervention development, single-case experimental design, mixed-methods design, self-regulated learning, multilingual writing, English learners

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INTRODUCTION

The number of international English learners (ELs) pursuing their degrees in the United States was 1,075,496 in 2020 (Project Atlas, n.d.). These students face a host of challenges while pursuing their degrees in American universities such as limited English proficiency levels, limited experience with academic writing, and cultural differences in writing expectations in the United States as compared to their home countries (Cheng et al., 2004; Phakiti and Li, 2011; Lillis, 2012; Tang, 2012; Atkinson, 2016; Hyland, 2019). In addition, students are required to write a great deal to meet course requirements. As a result, high quality academic writing is often the skill that determines students' success. ELs, therefore, need a strong support system to succeed in writing. To create such a support system, it is important to develop and evaluate interventions that can help ELs succeed in American universities such as combining the constructs of *multilingual writing* (MW) and self-regulated learning (SRL).

Many researchers refer to multilingual writing as second language writing (SLW) or foreign language writing (FLW; Matsuda et al., 2013; Manchón, 2016; Silva, 2016; Hyland, 2019). For

example, Hyland (2013) defines SLW as "writing performed by non-native speakers" (p. 426). Reichelt (2011), however, distinguishes FLW from SLW. In her view, "foreign language writing. . . is the phenomenon of writers composing in a language that is neither the writer's native language nor the dominant language in the surrounding context" (p. 3). Other scholars recognize the diversity ELs bring to academic writing and introduce concepts of multilingual and translingual writing (Canagarajah, 2002, 2013), which is performed in more than one language. Canagarajah (2013) contrasts multilingual writing with translingual writing, which allows for the use of different varieties of a language or different languages in a written text. In this study, we refer to the construct as MW, which refers to any piece of writing produced by nonnative speakers of English in academic settings. The types of writing may include but are not limited to paragraphs, essays, papers, literature reviews, bibliographies, position papers, online posts, and even email communication with peers and instructors.

Another construct in a current study is SRL – a dynamic process during which learners set goals, monitor, and control cognitive, metacognitive, emotional, motivational, behavioral, and environmental processes in their attainment of goals (Winne, 1995; Pintrich, 2004; Greene et al., 2011; Zimmerman and Schunk, 2011). SRL has been extensively researched over the past 30 years, generating numerous definitions, models, and theories (Winne and Perry, 2000; Zimmerman, 2000; Pintrich, 2004; Zimmerman and Schunk, 2011). Irrespective of the theoretical bases, SRL generally refers to the processes of: (a) setting goals; (b) monitoring of progress; (c) adjusting strategies; and (d) revising goals as needed (Winne, 1995; Pintrich, 2004; Zimmerman and Schunk, 2011; Andrade, 2013). SRL is a mega-theory of sorts that includes multiple psychological, motivational, affective, and cognitive processes working in sync to facilitate achievement of goals (Andrade, 2013).

Research has shown that learners tend to regulate their learning, and effective SRL is related to academic achievement of students across ages and education levels (Winne, 2005; Mullen, 2011; Dent and Koenka, 2016). Since SRL has properties of a skill, it is teachable; however, it is important to provide enough scaffolding for learners to become proficient in SRL. The time it takes to become an expert user of SRL varies, depending on the types of SRL skills targeted and metacognitive monitoring performed (Winne, 2005). SRL interventions have been developed and applied across domains, including math, science, reading, writing, history, and online learning environments (Dignath and Büttner, 2008; Greene et al., 2015; Wong et al., 2019).

Writing is susceptible to self-regulation. A meta-analysis examining the effectiveness of the *Self-Regulated Strategy Development* (SRSD; Harris et al., 2011) intervention on the quality of writing done by adolescents indicated that it significantly contributed to improved writing quality (Graham and Perin, 2007). At least for native English speakers, SRL instruction combined with writing instruction results in improved writing skills (Graham and Perin, 2007; Harris et al., 2011). According to Harris et al. (2011), years of research with typically developing students and students with special needs show that (a) better writers tend to be more self-regulated; (b) novice writers become more self-regulated with age and practice; (c) level of self-regulation is related to writers' performance; and (d) struggling writers can become successful through targeted writing and SRL instruction with multiple opportunities to practice new skills. SRL is teachable and, when embedded into writing interventions, helps struggling students become better writers.

Although research has shown that SRL is associated with improved performance by native speakers of English across disciplines and age-groups (Graham, 2006; De Corte et al., 2011; Kitsantas and Kavussanu, 2011; Tonks and Taboada, 2011), research on the usefulness of SRL instruction in developing scholarly writing skills in college students, especially ELs, is scarce and under-developed. A small number of scholars have recognized the importance of SRL in developing writing skills of ELs (Oxford, 2011; Andrade and Evans, 2013; Teng and Zhang, 2016, 2018, 2020; Fathi and Feizollahi, 2020; Altas and Mede, 2021; Han et al., 2021). Research shows that the SRL processes that occur during writing by ELs are similar to those of native speakers. For example, a validation of the *Writing Strategies for Self-Regulated Learning Questionnaire* (WSSRLQ) with Chinese undergraduate students (n = 780) revealed that the strategies of deep processing, emotional control, motivational self-talk, and feedback use were strong predictors of students' writing proficiency (Teng and Zhang, 2016). Farsani et al. (2014) reported a statistically significant, yet small and negative correlation between SRL and writing performance ($r = -0.294$, $p = 0.043$) in their sample of Iranian students (n = 48), using the *Motivated Strategies for Learning Questionnaire* (MSLQ). Although the authors acknowledged the importance of embedding SRL instruction in writing courses for ELs, their anomalous findings had indicated that the relationship between SRL and writing performance of ELs warrants additional rigorous research.

A handful of scholars conducted the quasi-experimental intervention studies measuring undergraduate students' gains in multilingual writing and SRL skills (Fathi and Feizollahi, 2020; Teng and Zhang, 2020; Altas and Mede, 2021; Chen et al., 2021). For instance, Chen et al. (2021) conducted a quasi-experimental study with undergraduate students (n = 102), targeting the revision instruction of the Self-Regulated Strategy Development (SRSD; Harris et al., 2011) in control, SRSD + genre-specific criteria, and SRSD + generic criteria conditions. The results showed that both SRSD conditions were more effective in improving students' text quality and revisions than the control group. However, Chen et al. (2021) did not measure students' SRL skills. In contrast, Teng and Zhang (2020) examined the effects of the SRL strategies-based writing intervention on Chinese undergraduate students (n = 80) multilingual writing proficiency, reported use of SRL strategies, and academic self-efficacy. The results indicated students' improvements in the use of various SRL strategies and increased levels of linguistic self-efficacy (ES = 0.39) and performance self-efficacy (ES = 0.21) as well as in the improvement of writing performance (d = 2.11).

Some experts in MW recognize the importance of developing self-regulated writing curricula. For example, Andrade and Evans (2013) laid out a comprehensive writing program, embedding

direct instruction of SRL skills with opportunities for learners to engage in SRL in pre-, during, and post-writing tasks. Similarly, Oxford (2011) suggested directly teaching SRL skills, emphasizing the importance of learning strategies for each of the English skills: speaking, listening, reading, writing, grammar, and vocabulary. To date, none of these programs have been empirically tested.

This review of the small body of literature combining SRL and MW shows the mixture of correlational studies that examined relations between SRL and writing performance/quality (Farsani et al., 2014; Teng and Zhang, 2016, 2018; Han et al., 2021), four intervention studies reporting on students' writing quality and some SRL skills (Fathi and Feizollahi, 2020; Teng and Zhang, 2020; Altas and Mede, 2021; Chen et al., 2021), or proposed untested SRL writing programs/instructional practices (Oxford, 2011; Andrade and Evans, 2013). While these lines of research contribute to our understanding of how SRL associates with MW and four intervention studies provide initial evidence of improvement in MW and SRL skills, they do not provide conclusive results on how SRL writing instructional methods work in authentic settings. Therefore, there is a need for continuing empirical research on the effects of embedding SRL training in multilingual writing instruction and developing targeted interventions for ELs.

This study contributes to the growing body of the intervention research on combining SRL and writing instruction. Unlike the intervention studies discussed above, the use of the single case quasi-experimental design in this study allowed for identification of MW and SRL gains, if any, for each participant and across all participants combined. In addition, this study promoted the intervention development (Hayes et al., 2013) since the detailed analysis of both quantitative and qualitative data indicated the potential areas for improvements. All of these aspects are discussed in details in the remainder of this article.

THEORETICAL FRAMEWORK

The *Model of Self- and Socially-Regulated Multilingual Writing* (Akhmedjanova, 2020; **Figure 1**) was used to describe the interactions between SRL and writing in authentic classroom settings. The model is organized around three broad areas: processes internal to a student (C–I, M, and N), processes external to a student (A, B, and J–N), and culture (O). Each area has its own set of processes contributing to the development of writing and self-/socially-regulatory skills. Thus, processes external to the student include instructional techniques (A, B) and formative assessment, occurring in classrooms (J–N). The processes internal to a student focus on activation of student's background knowledge and motivational beliefs, which lead to the choice of strategies and techniques to do the writing task (C–I, M, and N). Finally, culture (O) situates both types of processes within a socio-cultural context or "writing communities" (Graham, 2018, p. 258), which function under certain social, political, economic, environmental, and cultural affordances. As a result, writing becomes a cultural activity of jointly constructing meanings to communicate them within various genres (Rose and Martin, 2012; Atkinson, 2016).

Typically, writing instruction starts with how to write in a specific genre (A). As part of the instruction (A), the teacher sets the writing task (B) and articulates the criteria for it. The writing task activates students' prior knowledge, strategy knowledge, and motivational beliefs (C). Task interpretation (D) acknowledges that students interpret tasks in idiosyncratic ways, and their interpretations influence their personal goals and task management (F), as well as their self-efficacy and motivation (Butler and Winne, 1995). Based on their task interpretation, students set mastery or performance goals (E) in relation to their writing tasks. Task management (F) includes task specific strategies as well as strategies for managing students' time, environment, and motivation. In the case of writing, task management (F) involves the selection of various writing strategies (G): planning, translating ideas into a written text, reviewing and generating feedback, and revising an essay, which correspond with the elements of the cognitive model of writing (Elbow, 1981; Flower and Hayes, 1981; Hayes, 1996). This phase helps students to apply knowledge of a new writing genre and writing strategies that can be used within this genre (Rose and Martin, 2012).

As students write, they monitor their progress (H) by self-assessing their work on a task and using metacognitive strategies. They also adjust their motivational beliefs, depending on how well they are doing. The progress monitoring phase informs the task management phase (F) because it allows students to identify which of the writing strategies (G) work well and which do not. Based on this information, students make adjustments to the way they approach the task by choosing new strategies or modifying the old ones. This leads to internal learning outcomes (I). In the case of writing a persuasive essay, students internalize the elements of genre and other writing conventions to write high quality persuasive texts. As a result of actions in phases A–I, M (**Figure 1**), students generate externally observable outcomes, such as persuasive essays (J). At this stage, teachers can enact social-regulation by creating opportunities for students to provide and receive peer feedback, as well as feedback from teachers and technology (K). In this study, students received feedback on their persuasive essays from their peers and the teacher. Feedback allows students to make adjustments to their finished products before they are summatively assessed (L).

Reflection (N) occurs throughout the whole process of writing; however, it is placed toward the final stages of the writing process because its primary purpose is to inform students and teachers about what worked well and what did not. In the case of writing, self-regulated students reflect on the writing strategies (G) that were helpful or not helpful for them. This reflection can facilitate students' improved knowledge of the domain and strategies as well as their motivational beliefs (C). In addition, reflection can facilitate adjustment to instruction for teachers (A). For example, reflection can lead teachers to see what aspects of persuasive writing to reteach. Finally, the processes described above occur within multilingual classrooms that bring together teachers and students from various cultural backgrounds to form writing communities (Graham, 2018). All participants in such writing communities bring their own cultural views and perceptions on how writing should be practiced. Therefore, both

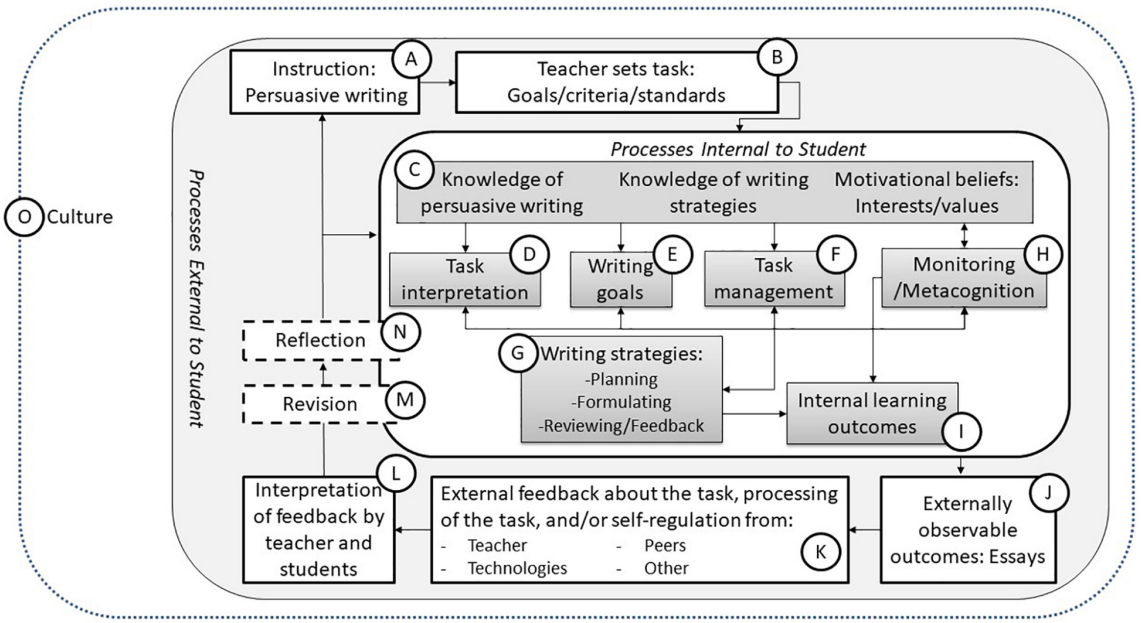

FIGURE 1 | Model of self- and socially-regulated multilingual writing.

the processes internal and external to a student operate within a complex culture (O).

All of the elements in **Figure 1** are grounded in models of writing. For example, the processes external to a student (A, B, and J–N) mirror sociocultural theory since they occur in an environment that includes a task, a learner, peers, a teacher, and interactions among these agents (Prior, 2006; Rose and Martin, 2012; Cumming, 2016). The processes internal to a student (C–I, M, and N) combine the elements of genre since students develop the knowledge of writing genres and the cognitive model of writing because students use cognitive processes of planning, transcribing, and revising while writing (Elbow, 1981; Flower and Hayes, 1981; Hayes, 1996; Rose and Martin, 2012; Hyland, 2019). Culture (O) is represented in the *Writers within Communities* model of writing (Graham, 2018). In addition, each aspect of this model enjoys support from the research literature; however, there is very little research on how well these processes work in the population of English learners (ELs). Therefore, the current study addresses the gap in the research literature by targeting the population of ELs and applying quasi-experimental design to identify the effects of the SRL writing intervention on two constructs: writing and SRL skills.

MATERIALS AND METHODS

Current Study

To address this research gap, we have adapted the *Self-Regulated Strategy Approach to Writing* (*SSAW*; MacArthur and Philippakos, 2012). This curriculum focuses on self-regulated strategy instruction in developmental writing courses. It covers a variety of genres including narrative, classification, compare/contrast, cause and effect, and persuasive writing. In addition, the *SSAW* emphasizes the use of planning, drafting, and revising writing strategies along with SRL strategies (MacArthur and Philippakos, 2012). A quasi-experimental study of the effectiveness of the curriculum for community college students (n = 276) indicated improved writing quality [Glass Δ = 1.22, $F(1,7.3) = 40.0$, $p < 0.001$] and increased length of essays [Glass Δ = 0.71, $F(1, 7.6) = 75.2$, $p = 0.027$; MacArthur et al., 2015). The findings also showed increases in students' self-efficacy for writing, [Cohen's d = 0.27, η_p^2 = 0.03, $F(1, 249) = 7.58$, $p = 0.006$] and adoption of mastery goals [Cohen's $d = 0.29$, η_p^2 = 0.027, $F(1, 249) = 7.01$, $p = 0.009$]. Unfortunately, only 10% of the sample in MacArthur et al. (2015) study were ELs. The results for ELs were not reported because they were not statistically significant.

The intervention developed by MacArthur and Philippakos (2012, 2013) and MacArthur et al. (2015) produced gains in both writing quality and SRL skills. However, it is not clear how well this intervention can work with ELs (MacArthur et al., 2015). Therefore, we adapted and tested the *SSAW* intervention with a small group of undergraduate ELs. The adaptation of the *SSAW* intervention was treated as intervention development (Hayes et al., 2013) because it was implemented with the population of ELs. As a result, the application of the *SSAW* intervention led to identification of future changes to the intervention in order to meet the needs of ELs. For the purpose of this study, we chose instruction of only persuasive essays since it is one of the genres that is assigned the most in higher education (Gardner and Nesi, 2013).

The rationale for targeting the population of the undergraduate ELs is that they represent the largest proportion in comparison with the graduate ELs (Project Atlas, n.d.).

Undergraduate ELs are in a greater need so that they do not fall behind early in their academic careers. The aim of this study is to investigate the effectiveness of the SRL writing intervention in improving SRL and writing performance of undergraduate ELs in the context of an authentic multilingual classroom by addressing the following research questions:

(1) Does the SRL writing intervention improve the quality of persuasive essays done by ELs?
(2) Does the SRL writing intervention improve the self-reported SRL skills of ELs?
(3) What are students' perceptions of the SRL component of the SRL writing intervention?

Research Design

A mixed-methods research design, combining both quantitative and qualitative data collection methods, was implemented in this study (Casanave, 2016; Manchón, 2016; Onghena et al., 2019). The single-case quasi-experimental design (SCED) was used to collect quantitative data. The SCED has been extensively used in various fields such as medicine, neurosciences, physical therapy and special education (Kratochwill et al., 2014; Moeyaert et al., 2014), but it is new to the field of multilingual writing. SCEDs share three main characteristics: (1) the focus is on one unit: a person or case, (2) one or more dependent variables are measured repeatedly across time, and (3) one or more independent variables are actively manipulated (Kratochwill et al., 2010; Horner and Odom, 2014).

A typical single-case design study involves an active manipulation of an independent variable to identify how this manipulation affects a dependent variable (Kratochwill et al., 2010; Horner and Odom, 2014). The dependent variable is measured repeatedly and systematically in successive phases before, during, and/or after the intervention. This design can be used to examine causal relationship between the independent variable, represented as intervention, and changes in outcome variables (Kratochwill et al., 2010; Smith, 2012). The relationship between dependent and independent variables is causal when a change in outcome data between the intervention and baseline conditions can be solely attributed to the manipulation of the intervention and not to outside experimental factors (i.e., confounders; Kratochwill et al., 2010). Hence, an intervention effect should be replicated across multiple participants and, ideally, the intervention effect should be demonstrated at different points in time. A unique strength of using an SCED is that participants serve as their own control as they are observed during a control condition preceding an intervention condition (i.e., no matched comparison group is needed). In addition, because of the repeated observations, participant-specific changes in data across time during both the baseline and intervention conditions can be evaluated, in addition to estimating an individual-specific intervention effect (Molenaar and Campbell, 2009; Velicer and Molenaar, 2012). For these reasons, an SCED was implemented in the current study.

A replicated AB phase design was used (**Figures 2**, **3**), which has the potential to demonstrate intervention effectiveness across individuals. To increase the internal validity of the replicated AB phase design, it is recommended to start the intervention at different time points across the participants (i.e., participants have different baseline lengths, What Works Clearinghouse, 2020). In that way, it can be concluded that the intervention is effective, regardless of the starting time. Changes in data patterns should only be observed for participants starting the intervention, whereas participants still in the baseline should not experience any changes. A staggered starting point of the intervention was not possible in this study given the nature of the intervention and the university setting (predetermined class sessions, and start/end of the semester). However, we increased the internal and external validity of our replicated AB phased design by including a large set of participants and measurements within participants. As suggested by the *What Works Clearinghouse* (i.e., *WWC*, Kratochwill et al., 2010; What Works Clearinghouse, 2020) design standards, the minimum number of observations should be three per phase across at least three participants to meet the standards with reservations. In current study, we exceeded these minimum criteria by including eight participants and a total of eight observations. Particularly, our SCED includes three measurements of writing skills in the baseline phase, and five measurements in the intervention phase; eight in total. We collected four measurements of SRL skills in the baseline phase, and at least nine in the intervention phase; thirteen in total. The first author manipulated the independent variable – the SRL writing intervention; all outcome variables were measured repeatedly over time; and at least 20% of essay and SRL journal data were double-scored to establish the evidence of reliability and validity. We can conclude that this study meets the What Works Clearinghouse (2020) requirements with reservations. Finally, qualitative data was collected through two focus group interviews. Those interviews were designed to collect detailed information about students' perceptions of the SRL components of the intervention. This has the potential to explain why the intervention was effective or not effective.

Participants

The participants were international ELs, who were in the first or second semesters of their undergraduate programs. The sample (n = 8) included students in their early twenties, predominantly from Korea (87.5%); half of the sample were female (n = 4; see **Table 1**).

All participants (n = 8) were enrolled in a 1-credit tutoring course offered by the School of Education in a medium public research university. The course was part of the larger study focusing on the written and spoken discourse of ELs. However, the primary goal of the course was to help ELs improve their academic discourse skills: Speaking, listening, reading, and writing in order to succeed in their undergraduate studies. The section of the course taught by the first author focused on helping ELs develop their writing and SRL skills. Due to low enrollment, the course was taught during two semesters: In the fall semester with five students, and in spring with three. To control for the outside confounding variables, the course was taught by the same instructor (first author), on the same days and times

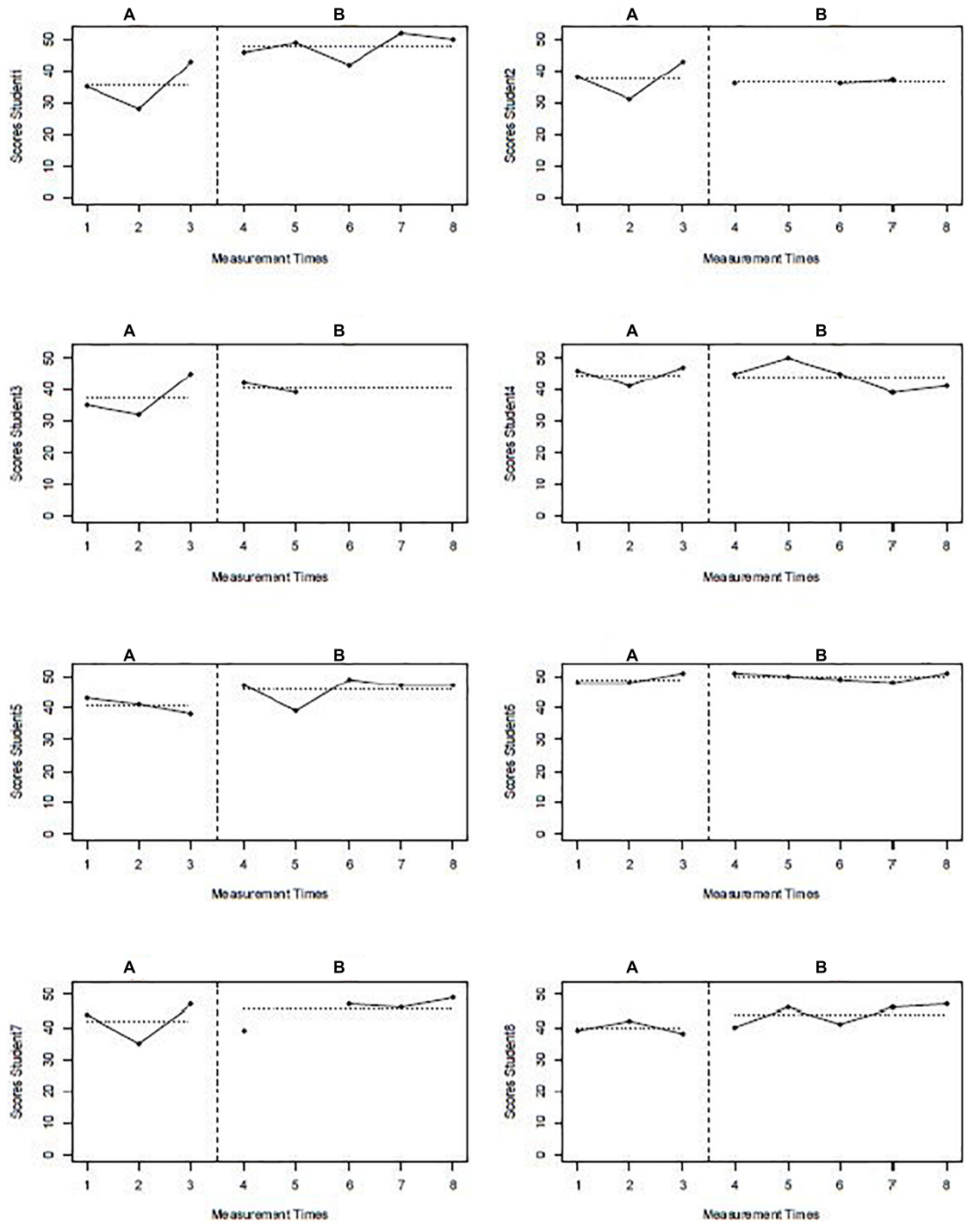

FIGURE 2 | Baseline **(A)** and intervention **(B)** phases for essay total score for each participant (n = 8).

(Wednesdays, 4:15–5:35 p.m.), and using the same curriculum and teaching methods. Since the course was part of the larger study described above, it had to include assignments such as prompted discussions of the moral dilemmas, which otherwise would not have been included in the SRL writing intervention. The study was granted the IRB approval to collect data, and all participants signed the consent forms at the beginning of the intervention.

Instruments

Three types of instruments were used to collect outcome data: essays, SRL journals, and two focus group interviews.

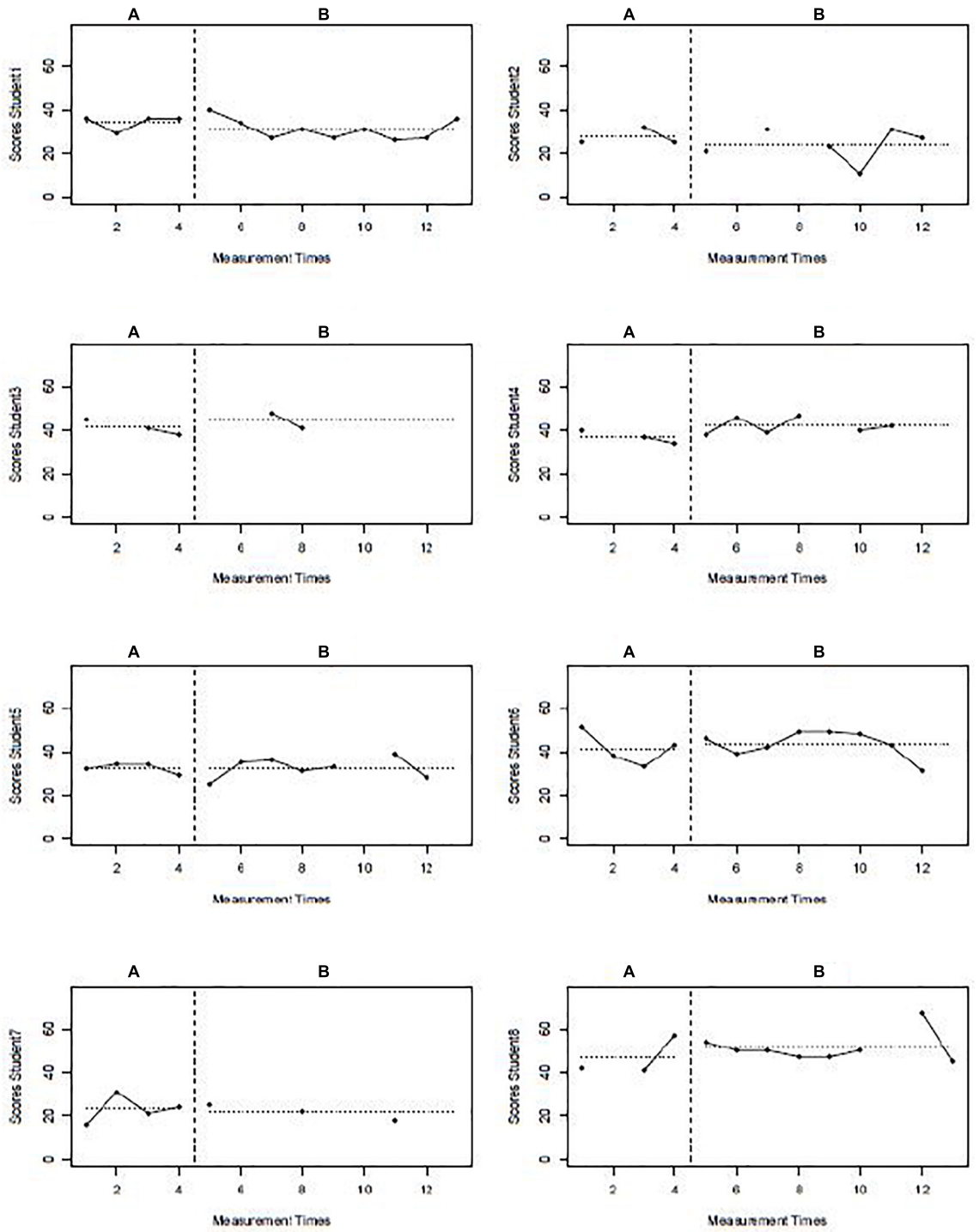

FIGURE 3 | Baseline **(A)** and intervention **(B)** phases for SRL total score for each participant (n = 8).

Essays

Students wrote eight persuasive essays during the semester on the prompts provided in *the SSAW* curriculum (**Supplementary Appendix A**).[1] Three of the essays were written during the baseline phase and were used to assess the quality of students' writing before the intervention. Five of the essays were generated after students had received instruction on how to write persuasive essays and self-regulate their learning. Since some of the students did not submit all of the essays, the final number of essays was 58.

[1] Appendices can be found in the Supplementary Material document.

TABLE 1 | Sample demographics (n = 8).

Category	*n*	% of total sample
Age		
18–19	4	50%
20–25	4	50%
Gender		
Female	4	50%
Male	4	50%
Country		
Korea	7	87.50%
China	1	12.50%
Length of stay in the United States		
1 year	4	50%
1–3 years	3	37.50%
3 years	1	12.50%
Class standing		
Freshman	7	87.50%
Sophomore	1	12.50%
School/Program		
Undeclared major	3	37.50%
Psychology	1	12.50%
Biology	1	12.50%
Business	3	37.50%
TOEFL scores		
65–80	3	37.50%
80	1	12.50%
N/A	4	50%
Took a writing course		
In English	7	87.50%
In native language	4	50%
Learned about strategies	8	100%

The essays (n = 58) were scored by two independent raters, using the rubric that included such criteria as development, focus/organization, language, and conventions (**Supplementary Appendix B**). The raters were experienced writing instructors who taught at local community and liberal arts colleges. The first author trained the raters using benchmark essays (n = 2). Raters' percent agreement was 86%. After the training, raters scored four essays individually, resulting in 56% percent exact agreement, disagreeing with each other only by one point across the criteria. Raters and the first author discussed discrepancies and scored one more essay to establish higher agreement in scores. After the second day of training, raters scored five essays and reached 77% percent agreement, which was acceptable to let them score individually (Stemler, 2004). While it is recommended to double-score around 20% of the data, raters double scored 43% of the essays (n = 25) to increase their agreement. The first author served as a third rater to resolve discrepancies in the scores. As a result, the exact percent agreement was moderate (63%), the adjacent percent agreement was high (95%), and Cohen's kappa was weak (κ = 0.315; Stemler, 2004). A possible explanation of low and moderate inter-rater reliability is that the raters were not experienced in scoring essays of multilingual writers.

Self-Regulated Learning Journals

In order to capture the development of SRL skills in students during the semester, a self-report measure was used: SRL journals (**Supplementary Appendix C**). One of the goals of this study was the development of SRL skills. Therefore, the participants were encouraged to set goals, manage their tasks, monitor their progress, and reflect on their end products in the SRL journals. Each participant was expected to fill out 13 journals throughout the semester. Four of the journals were assigned during the baseline phase, and nine during the intervention phase. Due to some students skipping some of the classes, the total number of SRL journals was 77.

Similar to the quality coding of essay data, two different independent raters coded the SRL journal data (n = 77). The coding protocol included the categories within each of the four SRL constructs of goal-setting, task management, progress monitoring, and reflection, which were coded for specificity, relevance to the writing task or SRL, and alignment with the goals (**Supplementary Appendix D**). Two independent raters, both doctoral students in educational psychology and methodology with expertise in SRL and classroom assessment, scored the SRL journal data.

The raters received an intensive 2-day training, resulting in 86% agreement. The raters double-scored 29% of the journals (n = 23) in an attempt to increase their agreement, with exact percent agreement of 78%, adjacent percent agreement of 95%, and Cohen's kappa value of κ = 0.617, which are considered to be good reliability estimates (Stemler, 2004). The first author served as a third rater to resolve discrepancies in the scores.

Focus Group Interviews

Focus group interviews were conducted with the participants to inquire about their perceptions of the SRL component of the writing intervention at the end of each semester. A trained interviewer, a doctoral student in educational psychology and methodology, conducted two focus group interviews that included six out of eight participants: The focus group in the fall included four students, and the one in spring two students. During the focus group interviews, the students were asked to reflect on their experiences with the SRL components of goal-setting, task management, progress monitoring, and reflection while working on their persuasive essays. In addition, students shared their thoughts about their experiences with the SRL journals (**Supplementary Appendix E**).

Research Procedures

As part of the study, students wrote three essays and filled out four SRL journals in the baseline phase before the start of the intervention. These measurements served as students' baseline skills in writing and SRL. **Supplementary Appendix F** shows the timeline of the intervention and data collection.

Most students wrote five persuasive essays during the course. Those essays served as five measures of writing quality during the intervention phase of this study. Unit 3, focusing on persuasive writing, of the *SSAW* (MacArthur and Philippakos, 2012) curriculum was used for this study. Unit 3 included ten lessons during which students learned how to write persuasive essays and self-regulate their writing behaviors (See **Supplementary Appendix G** for the syllabus). The first five lessons of the intervention focused on teaching students how to write a persuasive essay using all the elements of the genre – introduction, reasons, and conclusions. It also included a session when the first author modeled the process of writing by setting

goals, brainstorming ideas for and against a controversial issue, organizing them in a graphic organizer, and drafting the whole essay. The remaining three sessions were spent on collaborative and guided practice. Students worked on their individual essays, peer review, and editing, applying knowledge and skills they acquired during the intervention. The second half of the intervention (five sessions) focused on the development of the opposing position in a persuasive essay. The first two sessions were spent on introducing a concept of opposing positions and writing opposing position paragraphs. During the remaining three sessions students wrote an essay with an opposing position, peer reviewed, and edited it.

During the intervention, students wrote four essays. Two essays were written during the first five lessons, and two during the last five lessons. An additional essay was assigned as a final exam and served as a maintenance data point 2 weeks after the intervention had finished. In total, each student was expected to write eight essays during the study to the prompts suggested in Unit 3 of the *SSAW* curriculum (**Supplementary Appendix A**; MacArthur and Philippakos, 2012).

In terms of the SRL, students filled out the remaining nine journals after the first author taught them about SRL skills. After the SRL instruction, various writing and learning strategies were discussed during each class. As a result, journals documented thirteen measures of goal setting, task management, progress monitoring, and reflection both in baseline and intervention phases.

Data Analyses

The writing and SRL data from the journals were quantitatively analyzed using regression-based statistics. The focus group interview data were analyzed qualitatively.

Regression-Based Statistics

The regression-based analysis was performed to estimate the overall effect of the intervention for the whole group as well as individual effects for each participant.

First, a single-level regression analysis was run to estimate the effect of the intervention on the outcomes of each participant separately. Using the simple linear regression equation presented in Eq. 1, a change in outcome level between the baseline and intervention phase can be estimated.

$$\text{Level 1}: Y_t = \beta_0 + \beta_1 D + e_t \quad \text{and} \quad e_t \sim N(0, \sigma_e^2), \qquad (1)$$

In Eq. 1, the outcome variable Y_t is regressed on a dummy-coded variable (i.e., D). The dummy variable, D, indicates whether Y_t belongs to the intervention ($D = 1$) or baseline phase ($D = 0$). Therefore, β_0 refers to the outcome level during the baseline phase, and β_1 indicates the change in level, representing the intervention (Rindskopf and Ferron, 2014).

Second, the single-level regression analysis is expanded to a two-level hierarchical linear modeling analysis (HLM). HLM was used to identify the average treatment effect across the participants, variance of the effect across participants, and possible factors that relate to the average treatment effect.

A two-level hierarchical linear model was fitted, assuming a stable level during the baseline phase and a change in level during the intervention phase. The mathematical model is a straightforward extension of the single-level regression model introduced in Eq. 1:

$$\text{Level 1}: Y_{ij} = \beta_{0j} + \beta_{1j} D_{1j} + e_{ij} \qquad (2)$$

Y_{ij} is the outcome score for observation i, nested within participant j and is regressed on a dummy coded variable, D_{ij}. D_{ij} equals 0 when observation i within case j belongs to the baseline phase, 1 to the intervention phase. Therefore, β_{0j} indicates the baseline level for participant j, and β_{1j} indicates the change in level (i.e., intervention effect). The within-case variance is assumed to be normally distributed with mean zero and variance σ^2_e. A first order autoregressive residual variance is assumed. Because it is unlikely that the baseline level and the intervention effect will be the same for all participants, a second level was added to the model.

Level 2:

$$\begin{matrix} \beta_{0j} = \theta_{00} + u_{0j} \\ \beta_{1j} = \theta_{10} + u_{1j} \end{matrix} \begin{bmatrix} u_{0j} \\ u_{1j} \end{bmatrix} \sim N(0, \ \Sigma_u) \qquad (3)$$

θ_{00} is the overall average level in the baseline phase across all participants, and u_{0j} is the deviation of participant j from the overall average baseline level (θ_{00}). u_{0j} is assumed to be multivariate normally distributed [with mean equaling zero and the between-case variance in baseline level ($\sigma^2_{u_o}$)]. θ_{10} is the overall average treatment effect; it is the change in outcome level between the intervention and baseline. u_{1j} represents the deviation of participant j from this overall average immediate intervention effect [and u_{1j} is multivariate normally distributed with mean equaling zero and between-case variance in intervention effect ($\sigma_{u_1}{}^2$)].

The two-level HLM generated effect size estimates across all and per individual participants (Moeyaert et al., 2014). The data were analyzed using the *nlme* (Pinheiro et al., 2019) and *lme4* (Bates et al., 2019) R packages.

Qualitative Analysis

The analysis of the interview data included several iterations of reading (Creswell, 2013; Maxwell, 2013). The first author transcribed the interview data, using the Rev converter (Rev, n.d.), and checked the transcripts for accuracy. Ten months after the interviews, the transcriptions were emailed to students for member-checking (Anderson, 2017). Only one student responded, stating that the transcription reflected the content of the focus group interview. The thematic analysis (Braun and Clarke, 2006; Lester et al., 2020) was implemented to analyze data. Two raters, the focus group interviewer and the first author, coded both interviews together to identify students' perceptions regarding the SRL component of the intervention. The coding procedures included: (1) Developing a-priori codes; (2) identifying meaningful units; (3) coding and refining the codes; (3) narrowing down the codes; and (4) making interpretations and looking for meanings. The themes, codes, and example quotes are provided in **Supplementary Appendix H**.

After coding data from both focus group interviews, the first author went through all of the codes, identified the duplicate codes and condensed them. It took three rounds of reading, identifying similarities and differences, and deciding which codes belonged in what categories.

RESULTS

The results are organized around the research questions, which examine the effects of the SRL writing intervention on: (1) the quality of students' persuasive essays and (2) students' SRL skills, and (3) the students' perceptions of the SRL instruction in the writing course.

Does the Self-Regulated Learning Writing Intervention Improve the Quality of Persuasive Essays of English Learners?

The two-level analysis was conducted to test the effect of the SRL writing intervention on the quality of students' persuasive essays for each student individually (single-level analysis) and all of them combined (two-level analysis). **Figure 2** shows individual student's total scores across eight essays; the maximum score could be 52 in accordance with the rubric in **Supplementary Appendix B**.

Single-Level Analysis

Student 1 had medium and statistically significant gains in the quality of her persuasive writing, [$\beta_1 = 12.47$, $t(49) = 3.17$, $p = 0.02$]: There is a 24% increase in her score. Students 5 and 8 had small and marginally statistically significant[2] gains in the quality of their persuasive essays [$\beta_1 = 5.13$, $t(49) = 2.01$, $p = 0.091$ and $\beta_1 = 4.33$, $t(49) = 2.04$, $p = 0.087$, respectively]. Students 3, 6, and 7 had small increases in their essay scores but they were not statistically significant (**Supplementary Appendix H**). In contrast, Students 2 and 4 had small decreases in their essay scores as a result of the intervention; however, they were not statistically significant. The analysis by criteria revealed that Students 1 and 5 had small but statistically significant gains in language and conventions, and Students 1 and 7 had small but marginally statistically significant gains in development and conventions. Students 2 and 4 had small decreases in their scores on the focus and organization and language criteria, but they were not statistically significant (**Supplementary Appendix I**). The remaining students had small increases in their scores across four criteria, but they were not statistically significant.

Two-Level Analysis

The SRL writing intervention had a small and significant effect on the quality of students' persuasive essays [$\theta_{10} = 3.66$, $t(49) = 2.38$, $p = 0.021$]. That is, there was 7% or 3.66 points increase in persuasive writing scores across all students in the intervention phase. In addition, the estimates of the between-case variance ($\sigma^2_{u_1} = 80.5$) suggest less variability in students' scores in the intervention phase than in the baseline phase ($\sigma^2_{u_o} = 201.64$).

In terms of criteria (**Table 2**), *Development* had a small but statistically significant improvement as a result of the intervention [$\theta_{10} = 1.72$, $t(49) = 3.22$, $p = 0.003$]. As a result of the intervention, there were gains in such sub-criteria as *Claims and Counterclaims* [$\theta_{10} = 0.58$, $t(49) = 2.67$, $p = 0.015$], *Explanation of Counterclaims* [$\theta_{10} = 0.91$, $t(49) = 3.30$, $p = 0.002$], *Introduction* [$\theta_{10} = 0.45$, $t(49) = 2.14$, $p = 0.045$], and *Punctuation* [$\theta_{10} = 0.39$, $t(49) = 2.35$, $p = 0.047$]. The remaining sub-criteria also had incremental increases, but they were not meaningful. However, the sub-criteria of grammar and spelling indicated incremental decreases, which were not meaningful as well. The data were less variable across students in the intervention phase for the majority of the sub-criteria except for *Introduction* ($\sigma^2_{u_o} = 1.82$, $\sigma^2_{u_1} = 2.19$), *Sentence Structure* ($\sigma^2_{u_o} = 0.02$, $\sigma^2_{u_1} = 0.16$), and *Spelling* ($\sigma^2_{u_o} = 3.31$, $\sigma^2_{u_1} = 6.55$). The regression-based estimates indicate a small effect of the intervention on both individual and overall students' persuasive writing.

Does the Self-Regulated Learning Writing Intervention Improve the Self-Reported Self-Regulated Learning Skills of English Learners?

The two-level analysis was conducted to examine the effect of the SRL writing intervention on students' SRL skills both for each student individually (single-level analysis) and all of them combined (two-level analysis). **Figure 3** shows individual student's total scores across thirteen SRL journals; the maximum score could be 76 in accordance with the rubric in **Supplementary Appendix D**.

Single-Level Analysis

The SRL writing intervention resulted in a small, positive, and marginally statistically significant effect on the overall SRL skills of Student 4, [$\beta_1 = 5.00$, $t(68) = -1.99$, $p = 0.086$]: There is a 6.6% increase in his scores. Students 3, 5, 6, and 8 also resulted in small and positive increases in their SRL skills. In contrast, the results of Students 1, 2, and 7 indicated small and negative effects on their SRL skills; however, none of these effects were statistically significant (**Supplementary Appendix J**). The results for Students 3, 5, and 7 should be interpreted with caution since these students had missing data.

The examination of students' results for each SRL domain revealed some instances of small and statistically significant effects. For example, Student 5 had a small positive and marginally statistically significant effect of the SRL writing intervention on his goal-setting skills, [$\beta_1 = 1.46$, $t(68) = 2.19$, $p = 0.056$]. The *Progress Monitoring* domain of the SRL turned out to be the most problematic criterion for the majority of students. For instance, Students 1 [$\beta_1 = -2.87$, $t(37) = -2.73$, $p = 0.021$] and 2 [$\beta_1 = -3.3$, $t(37) = -5.00$, $p = 0.04$] had a small negative and statistically significant effects of the intervention on their progress monitoring skills. The analyses for this criterion, however, could not be performed for Students 5 and 7 because there were many instances of missing data.

[2]Marginally statistically significant refers to *p*-values in the range of 0.05–0.10 (Olsson-Collentine et al., 2019).

TABLE 2 | Results of the Two-level analyses of essay data by sub-criteria, criteria, and essay total.

	Parameter	Estimate (SE)	*T*	*p*
DEV1: claims /counterclaims	$\hat{\theta}_0$	2.87 (0.23)	12.28	< 0.0001
	$\hat{\theta}_1$	**0.58 (0.22)**	**2.67**	**0.015**
DEV2: claims	$\hat{\theta}_0$	3.54 (0.16)	21.34	< 0.0001
	$\hat{\theta}_1$	0.22 (0.18)	1.22	0.261
DEV3: counterclaims	$\hat{\theta}_0$	2.12 (0.27)	7.77	< 0.0001
	$\hat{\theta}_1$	**0.91 (0.28)**	**3.3**	**0.002**
DEV: total	$\hat{\theta}_0$	8.54 (0.56)	15.29	< 0.0001
	$\hat{\theta}_1$	**1.72 (0.53)**	**3.22**	**0.003**
FO1: introduction	$\hat{\theta}_0$	3.16 (0.17)	18.82	< 0.0001
	$\hat{\theta}_1$	**0.45 (0.21)**	**2.14**	**0.045**
FO2: conclusion	$\hat{\theta}_0$	3.00 (0.22)	13.75	< 0.0001
	$\hat{\theta}_1$	0.19 (0.21)	0.88	0.405
FO3 sequence	$\hat{\theta}_0$	3.54 (0.21)	16.93	< 0.0001
	$\hat{\theta}_1$	0.18 (0.19)	0.93	0.373
FO4: paragraphs	$\hat{\theta}_0$	3.42 (0.22)	15.7	< 0.0001
	$\hat{\theta}_1$	0.34 (0.22)	1.57	0.147
FO: total	$\hat{\theta}_0$	13.12 (0.65)	20.03	< 0.0001
	$\hat{\theta}_1$	**1.18 (0.64)**	**1.85**	**0.09**
LAN1: style and tone	$\hat{\theta}_0$	3.83 (0.08)	46.39	< 0.0001
	$\hat{\theta}_1$	0.02 (0.12)	0.21	0.837
LAN 2: word choices	$\hat{\theta}_0$	2.71 (0.23)	11.73	< 0.0001
	$\hat{\theta}_1$	0.32 (0.20)	1.6	0.15
LAN3: sentence structure	$\hat{\theta}_0$	2.83 (0.17)	15.9	< 0.0001
	$\hat{\theta}_1$	0.18 (0.27)	0.68	0.518
LAN: total	$\hat{\theta}_0$	9.37 (0.43)	21.84	< 0.0001
	$\hat{\theta}_1$	0.54 (0.46)	1.17	0.279
CON1: punctuation	$\hat{\theta}_0$	3.46 (0.15)	22.52	< 0.0001
	$\hat{\theta}_1$	**0.39 (0.16)**	**2.35**	**0.047**
CON2: grammar	$\hat{\theta}_0$	2.29 (0.20)	11.34	< 0.0001
	$\hat{\theta}_1$	−0.02 (0.12)	−0.13	0.896
CON3: spelling	$\hat{\theta}_0$	3.96 (0.05)	84.91	< 0.0001
	$\hat{\theta}_1$	−0.02 (0.06)	−0.27	0.791
CON: total	$\hat{\theta}_0$	9.71 (0.29)	33.28	< 0.0001
	$\hat{\theta}_1$	0.35 (0.23)	1.52	0.171
Essay: total	$\hat{\theta}_0$	40.75 (1.57)	25.88	< 0.0001
	$\hat{\theta}_1$	**3.66 (1.53)**	**2.38**	**0.021**

Values in bold indicate marginally and statistically significant effects. DEV, development; FO, focus and organization; LAN, language; CON, conventions.

Therefore, the results of the *Progress Monitoring* domain should be interpreted with caution.

Two-Level Analysis

Based on the two-level analysis, the SRL writing intervention had a small and not statistically significant effect on students' SRL skills, [$\theta_{10} = 0.76$, $t(68) = 0.46$, $p = 0.645$]. The results by domains did not indicate statistically significant increases. In fact, *Goal-setting*, *Task Management,* and *Progress Monitoring* resulted in small and negative effects (**Table 3**). The between-case variance in the intervention phase for *Goal-setting*, *Task Management,* and *Reflection* resulted in small estimates, suggesting low levels of variability for these domains. In contrast, *Progress Monitoring* resulted in a high degree of variability in the intervention phase, $\left(\sigma^2_{u_0} = 1.6,\ \sigma^2_{u_1} = 9.42\right)$, which may be the result of a large amount of missing data in that domain.

TABLE 3 | Results of the two-level analyses of self-regulated learning (SRL) journals data by domains.

	Parameter	Estimate (SE)	*t*	*p*
Goal-setting	$\hat{\theta}_0$	5.89 (0.44)	13.26	<0.0001
	$\hat{\theta}_1$	−0.16 (0.34)	−0.47	0.64
Task management	$\hat{\theta}_0$	16.97 (1.36)	12.42	<0.0001
	$\hat{\theta}_1$	−0.03 (0.72)	−0.04	0.968
Progress monitoring	$\hat{\theta}_0$	5.1 (0.61)	8.39	<0.0001
	$\hat{\theta}_1$	−0.37 (0.85)	−0.43	0.67
Reflection	$\hat{\theta}_0$	10.61 (1.02)	10.36	<0.0001
	$\hat{\theta}_1$	0.71 (0.75)	0.95	0.466
SRL: total	$\hat{\theta}_0$	35.41 (2.88)	12.27	<0.0001
	$\hat{\theta}_1$	0.76 (1.65)	0.46	0.645

What Are Students' Perceptions of the Self-Regulated Learning Component of the Persuasive Writing Intervention?

Based on the thematic analysis (**Supplementary Appendix H**), three broad themes were identified in regard to the students' perceptions of the SRL component of the course: (1) SRL journal; (2) SRL knowledge and skills; and (3) suggestions.

Self-Regulated Learning Journal

All of the interviewed students (n = 6) talked about the SRL journal since it was one of the assignments that they had to do every class. Based on their responses, it can be concluded that students developed some understanding of the purpose of the task, and some of them were confused during the first classes. From Students' 1 and 4 perspectives, the purpose of the SRL journal was as follows:

> *S1: I mean, I think all we forgot about the purpose of this activity, we just, "Oh we have to finish this, we have to finish that."*
> *I(nterviewer): What is the goal of this activity?*
> *S4: It's setting your goal and reflecting your strategies.*

Generally, students had mixed feelings about this task: On one hand, they recognized its value. For example, Student 4 described his experience with the journal in the following terms: *". . . it's helpful to view yourself back. What you're wrong, and what you're right"*. On the other hand, they were dissatisfied with the length of the journal and frequency with which they had to work on it: *"It is useful, . . . but just too many"* (Student 4).

This overview of the SRL journal theme indicates that students did not have a clear understanding of what they were supposed to do with this task, even though they could articulate a primary goal of the SRL journals.

Self-Regulated Learning Knowledge and Skills

Students also reflected on the SRL knowledge and skills that they had used during the intervention. One of the re-occurring topics in both focus group interviews was strategy use and how it takes time to develop a habit of using new strategies. For example, Student 5 mentioned that *". . . it remind(s) me that I need use some strategies, I can't just write."*

Nevertheless, several students expressed their concern regarding the use of new strategies. Thus, Student 2 said: "*For me*

it's hard to change my writing strategy so . . . It's hard to get used to it . . . the new things so. I tried but it doesn't go long, it goes only one or 2 days." Student 7, in turn, repeated multiple times that it takes time to develop new strategies: *"I believe that creating and applying the new strategy, a new logic is . . . uh, is uh, it takes a very long time."*

Another finding is students' appreciation of feedback they received from their peers and teacher. All of them enjoyed participating in the peer review activities, which were part of the class. Some students felt uncomfortable providing feedback to each other at first. They felt as if they were judging their peers, and it made them feel awkward because they did not know each other well, *"So, we did a lot peer review. . . . We switched like, our essay and reading, and after reading, we have to talk about like, "That part is good, this part is not that good" But I understand that, the purpose, but it's really awkward to say like-... You have to do better at that part, because we're not really friendly each other.... I kind of feel bad, you know what I mean"* (Student 1). However, as they had more exposure to peer feedback, they valued this experience because it gave them an opportunity to see how other people write and what kind of writing techniques they use. For example, Student 1 mentioned *"I thought I did like, perfectly, and when I get that part review, oh I missed that part. So I can realize what parts I have to improve."*

Suggestions

All of the students were unhappy about the frequency with which they had to fill out the SRL journal and its length. Students provided suggestions for ways in which the journal could be improved. For example, three students suggested making the SRL journal assignment less frequent and reducing the number of questions in it. Thus, Student 1 commented on the frequency of the assignment, *"I mean, every week we have to do that . . . I wanna reduce that."*

Another set of suggestions focused on the writing genres and strategies used in the course. For example, Student 6 expressed her concern about writing only persuasive essays, and she wanted to learn how to write in other genres as well, *"I think it should be more various. So it can be boring. I want to practice some various writing . . ."*

Finally, most of the students were confused about the SRL strategies and expressed their concern regarding the knowledge of various strategies. Student 6 explained, *"In my case, the last question* [regarding new strategies to use] *was hard to answer. . . Because like I have, like, no idea about the other strategies, um, yeah. So I am not sure what to write... That I, I didn't know many strategies. I know only few strategies that I tried."* In this way, they suggested providing a more detailed instruction of the SRL strategies in future.

These results suggest that students' perceptions of the SRL component were mixed. On the one hand, they appreciated the experience of reflecting on their learning and self-regulation in writing. On the other hand, they did not like the format: They considered the journal to be too frequent, long, and repetitive. In addition, some of the students did not know of new strategies, or they needed more time to get used to new strategies. In spite of these setbacks, students admitted to using some SRL strategies in other courses.

DISCUSSION

The goals of this study were: (1) to help multilingual students improve their persuasive writing and SRL skills, (2) to examine the effectiveness of the SRL writing intervention in an authentic classroom setting, and (3) to suggest modifications to the *SSAW* intervention in an attempt of the intervention development.

Persuasive Writing Skills

The results of the statistical analyses provided weak evidence of an effect of the intervention on persuasive writing skills across all students. There was an average of 7% increase in students' scores, which is an incremental improvement in comparison with other writing interventions (MacArthur and Philippakos, 2013; Harris et al., 2015; MacArthur et al., 2015; Ennis, 2016; Teng and Zhang, 2020). Even though the increase in scores is small, it still indicates improvement in students' writing skills.

Examination of the results by criteria and sub-criteria across all students also indicated increases for some of them. The criteria of *Focus and Organization, Language,* and *Conventions* did not indicate large increases. However, a statistically significant increase in scores was observed for the *Development* criterion. A plausible explanation of these increases is related to the nature of the intervention: Students were taught how to write persuasive essays, practiced writing about the *Claims and Counterclaims,* and learned how to effectively explain *Counterclaims* during the course. That is, students learned how to produce texts within the genre of persuasive writing. Overall, the two-level analysis results suggest that improvements were observed for the criteria and sub-criteria which were explicitly taught and repeatedly practiced during the course.

The results of the statistical analyses provided weak evidence of intervention effectiveness in improving persuasive writing skills for Students 1, 5, and 8. The largest improvement in terms of the effect size and statistical significance was observed for Student 1: There was a 24% increase in her score. Interestingly, this is the only student in the sample (n = 8) who graduated from an American high school and did not have to take the standardized assessment of proficiency in English. It is possible that the gains of Student 1 could be due to familiarity with the American educational system and culture (Foster, 2004), which made it easier for her to adapt to the tasks and environment. The other two students who benefitted from the intervention scored in the 65–80 range on the TOEFL. Writing interventions are typically effective for students with medium English proficiency levels (Manchón, 2011; Pasquarella, 2019), which explains the gains of Students 5 and 8.

Lack of improvement in other students' persuasive writing skills can possibly be attributed to their unfamiliarity with the cultural and language expectations of American classrooms (Elbow, 1999; Ramanathan and Atkinson, 1999; Foster, 2004). For example, most of the students admitted during the focus group interview that it was their first time participating in peer

review activities. Some of the students felt "awkward" or that they were "judging each other" when providing feedback on their essays. They were shy and reserved at the beginning of the course because of their language skills: It took some time to encourage the students to speak and contribute to discussions during classes. These findings echo research on Asian students' reactions toward peer review in American classrooms (Atkinson, 2016).

Self-Regulated Learning Skills

The results of the statistical analysis of the SRL journal data indicated no evidence of the effectiveness of the intervention on students' SRL skills. This result must be interpreted with caution, however, given evidence of the psychometric weaknesses of the SRL journal used in this study. Examination of the SRL journals and focus group interviews suggested that the journal was not a valid measure to assess students' SRL skills because they either did not (1) understand how to respond to some of the questions, or (2) take it seriously. Typically, journals are used both to promote and measure SRL skills (Schmitz et al., 2011), and their use is associated with improvement in students' reflection, SRL skills, and learning outcomes (Schmitz and Wiese, 2006). Journaling is also associated with positive attitudes to schooling and development of reflective and literacy skills among multilingual students (Walter-Echols, 2008; Linares, 2019). In contrast, in this study, the use of journals to promote and measure SRL skills turned out to be unsuccessful because students failed to monitor and reflect on their learning, at least in writing.

Possible explanations of this failure include the influence of culture and students' attitudes toward and experiences with this activity (Atkinson, 2016). All eight students were from Southeastern Asia; they might not have felt comfortable freely expressing their thoughts and ideas (Walter-Echols, 2008). It seemed that some of them lacked guidance on how to fill out the journals. Finally, all of them admitted that it was their first experience journaling in their academic careers, which was probably one of the reasons they did not take full advantage of learning from the SRL journals.

These findings are in a stark contrast with the findings of other studies. For example, Santangelo et al. (2016) reported medium effect sizes for goal-setting and cognitive strategy instruction combined with self-evaluation and self-monitoring, and large effect sizes for the cognitive strategy instruction in their meta-analysis of 79 quasi- and experimental studies, examining the effectiveness of the SRL and writing instruction. MacArthur and Philippakos (2012, 2013) and MacArthur et al. (2015) reported increases in students' mastery goals and self-efficacy for writing. In this study, in contrast, the domains of goal-setting, task management, and progress monitoring resulted in small negative effects, and reflection in small positive effects, even though not statistically significant. Similarly, Altas and Mede (2021) investigated the effect of the flipped classroom on pre-service teachers' (n = 55) writing achievement and SRL. The results indicated increases in writing achievement, but no effects on SRL, which was measured using the self-report survey. It is worth reiterating that in the current study, the results are based on the data from the SRL journal, which turned out to be an invalid measure. Therefore, a further investigation of the effectiveness of the SRL writing intervention on students' SRL skills is warranted since existing research shows that teaching students to self-regulate writing improves their writing outcomes and some of the SRL processes (MacArthur et al., 2015; Graham et al., 2016; Santangelo et al., 2016; Teng and Zhang, 2020).

Students' Perceptions

The focus group interviews shed light on the mixed results of the SRL writing intervention on students' SRL skills. Overall, students did not value the use of the SRL journal during the writing intervention, which is likely the reason the SRL journal turned out to be a flawed measure. At least five students mentioned in the interview that the SRL journal assignments were too frequent, repetitive, and long. Students perceived the SRL journal as an "annoying" and "boring" activity they had to do every class. This can explain the negative effects on students' goal-setting, task management, and progress monitoring domains of SRL: The quality of students' journal entries became worse toward the end of the semester at least in part because they disliked having to write them.

Also, only Student 6 understood aspects of the SRL-related content of the journals. That is, she recognized that her goals for the new writing assignments should be based on the feedback she had received on her previous assignments. This means that Student 6 could understand the feedback she received and chose to act upon it to improve her performance on following assignments (Ruiz-Primo and Li, 2013; Goldstein, 2016). In addition, Student 6 had the highest baseline scores for her essays, which suggests that she had a high level of knowledge (i.e., declarative, procedural, and conditional; Pressley and Harris, 2008) of persuasive writing and had the resources (i.e., cognitive and motivational) to reflect on what areas she still needed to improve on in her SRL journals (Harris et al., 2011). Consistent with the research on feedback and multilingual writing, this means that other students were confused on how to act upon the feedback they received (Goldstein, 2016), and that they should have been explicitly taught that some of the areas in need of improvement from the previous essay could serve as writing goals for a new essay (Cumming, 2012).

Examination of the SRL journals confirms that some students did not take the journal assignments seriously. Past mid-semester, students either wrote the same responses for the remaining journals (Students 1 and 2), or skipped some of the questions (Student 7). Their results were worse than for other students in the sample, or could not be calculated like for Students 5 and 7 in *Progress Monitoring* domain. A possible explanation for students' difficulty in addressing questions about progress monitoring could be that students lacked declarative knowledge about the SRL strategies (McCormick, 2003; Pressley and Harris, 2008), or when they tried to apply new strategies, they were inconsistent in their use (Harris et al., 2011). The interviews also revealed that at least four out of six interviewed students did not recognize that planning, formulating, reviewing, revising, and providing feedback on each other's essays were actually macro-level writing strategies (Manchón et al., 2007) that they could have written about in their journals.

Model of Self- and Socially-Regulated Multilingual Writing

If to situate the results of the SRL writing intervention within the *Model of Self- and Socially Regulated Multilingual Writing* (**Figure 1**), we can conclude that the instruction in persuasive writing (A) resulted in improved knowledge (C) on how to write persuasive essays (J) for some students in this sample. However, the focus group interviews revealed that at least five of the six interviewed students had difficulties with writing strategies knowledge (C). Students had gains in discussing claims and counterclaims as well as in developing counterclaims sub-criteria, which contributed to their domain knowledge of persuasive writing (C). In addition, they enjoyed the formative feedback provided/received (K) because it gave them an opportunity to learn from each other (L). It is also worth noting the influence of students' cultural and educational backgrounds (O) during the intervention: Students started as passive participants of the learning process, feeling shy and awkward while participating in classroom discussions and peer review activities. As the semester progressed, they developed some confidence and recognized the value of learning from each other. This observation warrants further examination of the cultural changes, if any, happening in writing classrooms with multilingual students (Atkinson, 2016).

In contrast, the SRL writing intervention had mixed and hard to interpret effects on student's goal-setting (E), task management (F–G), progress monitoring (H), and reflection (N) skills. Based on the results, the use of journals to promote and measure SRL skills turned out to be unsuccessful because students failed to monitor (H) and reflect (N) on their learning, at least in writing. Nevertheless, students reported appreciating the SRL knowledge and skills (F) they gained.

Limitations

The results described above should be interpreted with caution due to the limitations of this study, which may prevent generalizing its findings to a wider population of ELs and other settings. Limitations include: (1) convenience sampling, (2) use of self-report data to measure SRL skills, (3) small sample size, and (4) the curriculum which was developed for native speakers of English.

Due to the use of convenience sampling in this study, findings may not be generalizable to a wider population of ELs (Gall et al., 2007). Convenience sampling might have introduced sampling error in terms of having a non-representative sample of students coming from a particular country – South Korea. Meanwhile, there were a large number of students coming from India, Pakistan, and some Middle Eastern countries on campus.

The SRL journals were used in this study to measure SRL skills, which is a self-report measure that provides a limited view of students' SRL from a retrospective viewpoint (Winne and Perry, 2000; Greene et al., 2011). The SRL journals used in this study proved to be an invalid instrument to measure SRL skills because students did not take them seriously. As a result, it is desirable to triangulate SRL data from the self-report with additional data such as think aloud protocols or trace data (Winne and Perry, 2000; Greene et al., 2011; Azevedo et al., 2013). While these techniques could help with triangulating SRL measurements, it was not feasible to use them in the current study due to difficulty of a writing task.

Another limitation of this study is a small sample size and attrition. While eight participants were enough to run parametric tests for SCED data, this number was not large enough to run moderator analyses. There were instances of missing data both for essays and SRL journals, which affected the overall results. Finally, the curriculum *SSAW* (MacArthur and Philippakos, 2012) was originally developed for the native writers of English. While it has been appropriate for the English learners in this study and generated similar results in terms of improving students' persuasive writing skills, it still needs to be tailored to the needs of multilingual writers.

Intervention Development

Despite these limitations, this study contributes to its field in terms of intervention development, which is the creation of new methods to change/improve desired behaviors and outcomes (Hayes et al., 2013). In this study, intervention development refers to the adjustments that should be made to the SRL writing intervention based on the findings. The use of the SCED resulted in the collection of the detailed information on all eight participants: Their writing and SRL outcomes, which were measured repeatedly during the semester. While we did not modify the SRL writing intervention based on the students' needs during the study, an in-depth analysis of both quantitative and qualitative data provided evidence on how diverse participants and their needs were. For example, while most of the students had high baseline overall writing scores, a closer examination by sub-criteria revealed that they needed targeted instruction for particular sub-criteria, including *Spelling, Grammar, Word Choices,* and *Sentence Structure*. The criteria and sub-criteria that improved as a result of the intervention were explicitly taught during the course. Therefore, modifications to the SRL writing intervention should incorporate explicit instruction of sub-criteria of interest. As is evident from the narrative above, strength of this study is intervention development which provides evidence for the informed adjustments to the SRL writing intervention.

Future Steps

As future steps, we recommend making changes to the intervention such as: (1) using a more rigorous SCED or a traditional experimental design; (2) conducting moderator analyses; (3) identifying cut-off scores for effect sizes; (4) making changes to the SRL journal; and (5) examining the nature and quality of feedback to oneself and peers. Hence, the observation of the largest improvement in Student 1's writing skills warrants further examination of the nature of writing skills that multilingual students gain in secondary schools in the United States, and possibly tailoring the interventions to the needs of this particular group of students when they start college.

Finally, the *Model of Self- and Socially-Regulated Multilingual Writing* incorporates various cognitive, behavioral, affective, and socio-cultural processes, most of which are grounded in research in educational psychology and multilingual writing. There are some of the elements in the model that have not been rigorously examined from the perspective of multilingual

writing. For example, Kormos (2012) calls for research in the area of motivation in multilingual writing. Similarly, there are not any research studies examining task interpretation of writing tasks, and very little research on goal-setting (Cumming, 2012), self-assessment, progress monitoring, reflection, and metacognition in multilingual writing. In addition, it is important to examine the influence of culture and students' previous cultural experiences with writing in English both in their home countries and in countries where English is used as the medium of communication (Atkinson, 2016; Bazerman et al., 2018). Therefore, future researchers should consider designing rigorous studies to examine these processes with the population of ELs in terms of multilingual academic writing.

CONCLUSION

In sum, the SRL writing intervention had a weak effect on improving students' persuasive writing skills but the results regarding their SRL skills were mixed and difficult to interpret because of problems with the measures. It is hard to tell what part of the intervention contributed to students' gains in writing: (1) Writing instruction, (2) SRL instruction, or (3) a combination of both, because SRL was embedded in the persuasive writing curriculum. This warrants a further examination of the effectiveness of the intervention using a different research design and SRL measures. Nevertheless, this study contributes to the growing body of literature introducing and encouraging SRL instruction along with multilingual writing skills among ELs. Given the promising results from other studies (Fathi and Feizollahi, 2020; Teng and Zhang, 2020; Altas and Mede, 2021; Chen et al., 2021), and some evidence of students' appreciation of SRL knowledge in this study, we can conclude that SRL instruction, can potentially make writing courses enriching. To detect changes in ELs' SRL skills, however, future studies should employ more valid and powerful measures than the self-report surveys and journals.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by the University at Albany Institutional Review Board, University at Albany - State University of New York (SUNY). The participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

DA performed material preparation, data collection, analysis, and wrote the first draft of the manuscript. Both authors contributed to the study conception and design, commented on previous versions of the manuscript, read, and approved the final version.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/feduc.2022.841395/full#supplementary-material

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Differential Predictive Effect of Self-Regulation Behavior and the Combination of Self- vs. External Regulation Behavior on Executive Dysfunctions and Emotion Regulation Difficulties, in University Students

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The aim of this research was to establish linear relations (association and prediction) and inferential relations between three constructs at different levels of psychological research – *executive dysfunction* (microanalysis), *self-regulation* (molecular level), and *self-* vs. *external regulation* (molar level), in the prediction of emotion regulation difficulties. We hypothesized that personal and contextual regulatory factors would be negatively related to levels of executive dysfunction and emotion regulation difficulties; by way of complement, non-regulatory and dysregulatory personal, and contextual factors would be positively related to these same difficulties. To establish relationships, we used a retrospective, *ex post* facto design, where 298 university students voluntarily participated by completing standardized self-reports. Linear and structural correlational, predictive analyses were performed, as well as inferential analyses. Results were consistent and validated the proposed hypotheses, for both association and prediction. The most important result refers to the discriminant value of the five-level combination heuristic for predicting Executive Function and External (contextual) Dys-Regulation. In conclusion: (1) both personal and contextual regulation factors must be analyzed in order to better understand the variation in executive functions and emotion regulation difficulties; (2) it is important to continue connecting the different levels of the constructs referring to self-regulation, given their complementary role in the behavioral analysis of regulation difficulties.

Keywords: executive functions, self-regulation, self- vs. external regulation, emotion regulation difficulties, university students

INTRODUCTION

Self-regulatory behavior as a behavioral meta-skill is exclusive and inherent to human beings. Given its importance, it has been a classic study variable in the realm of psychology (Baumeister and Heatherton, 1996). From the perspective of the evolution of our species, this behavior has come about thanks to the development and plasticity of the prefrontal area of the brain, as has been amply demonstrated in phylogenetic, ontogenetic, neurological, and psychological research (Bull and Espy, 2006; Zelazo and Carlson, 2012; Friedman and Robbins, 2022). In fact, exploration of missing or delayed prefrontal development, characteristic of executive dysfunctions, has helped us understand the biological basis for the self-regulation process (Gioia et al., 2000a). This superior neurological foundation, however, with its associated cognitive and emotional processes, does not *per se* guarantee adaptability and success in the behavioral execution of different human tasks. Numerous contextualized learning and relearning experiences are required throughout life, in different adaptive situations, for this meta-skill to reach an optimal level of development (Duckworth and Carlson, 2013). Such training results from exposure to appropriate experiences, models and contingencies that promote a complete, rich behavioral repertoire.

From all the foregoing, we infer the need: (1) to investigate the relationship between different constructs used in reference to self-regulation – constructs which come about at different levels of psychological analysis; (2) to precisely define such relationships, as well as the summative or interactive effects of the different variables involved, in order to more accurately identify the contextual factors of executive function (EF).

Different Levels of Psychological Analysis of Regulatory Constructs

The evolution of research on behavioral self-regulation has led to different types and subtypes of psychological constructs that seek to explain this type of behavior in a given research domain (de la Fuente et al., 2019a,b).

Level of Microanalysis: Executive Functions as a Neurological Construct (Neuropsychological Level)

The most basic level of behavioral analysis, called microanalysis, or the neuropsychological level, has suggested the concept of EFs to refer to the neurological foundation of self-regulation (de la Fuente et al., 2019a). The term "executive functions" is a many-faceted concept, often considered an "umbrella term" that encompasses a group of processes, interrelated among themselves, and responsible for "guiding, directing, and controlling cognitive, emotional, and behavioral functions, especially during the active solution of novel problems" (Gioia et al., 2000b). It is a broad construct that encompasses both goal-directed processes (Knight and Stuss, 2002) and the emotion and behavior regulation necessary to adapt to the environment where the goals are to be achieved (Bechara et al., 2000; Stuss and Alexander, 2000). The study of EFs presents significant difficulties (Levy and Anderson, 2008; Anderson and Reidy, 2012), such as lack of consensus on its definition and the emergence of multiple models. There is no single definition for EFs; on the contrary, nearly every model proposed involves a different conceptualization.

Executive function is commonly conceptualized in terms of cognitive processes that enable future goal-directed behaviors, and involves the processes of planning, organization, inhibitory control, cognitive flexibility, and problem solving (Carlson et al., 2013; Diamond, 2013). Zelazo and Carlson (2012) consider EFs to be comparable to cognitive control; they refer to "top-down neurocognitive processes involved in the conscious, goal-directed control of thought, action, and emotions." The main components are cognitive flexibility, inhibitory control, and working memory (Miller and Cohen, 2001; Miller and Wallis, 2009). This construction has been used to evaluate the learner's discrete cognitive behaviors, such as executive memory, attention, behavior inhibition, and processing speed. This construct is currently producing a large quantity of evidence, making it possible to explain learning problems associated with neurological deficits (Friedman and Robbins, 2022). In recent years, aspects such as theory of mind, emotion regulation, empathy, and the affective aspects of decision making have been included as the so-called "warm" or "hot" EFs (Gioia et al., 2000a; Mesulam, 2002, Tranel, 2002; Eslinger et al., 2004; Happaney et al., 2004; Kerr and Zelazo, 2004; Stuss and Anderson, 2004). The term "cool" EFs is thus reserved for the more cognitive aspects that have been studied traditionally (Zelazo et al., 2005).

Despite its relevant contributions, this construct is specific to the clinical or neurological field, and places the contextual variables of human learning at a distal level of analysis. It is reasonable to assume that this construct, as a neuropsychological substratum of self-regulation, is related to and associated with other personal characteristics at the molecular level, worth being considered as such. In this regard, relations between EF and personality have been found. Greater difficulty in subjective EF was registered by older adults with greater negative affect, and by older adults higher in neuroticism and lower in conscientiousness (Bell et al., 2020). As a complement, there is growing evidence that addresses cognitive deficits in EF. A relationship between EF and Borderline Personality Disorder (BPD) has long been suggested by evidence of high comorbidity between BPD and disorders characterized by poor EF, for example, attention deficit/hyperactivity disorder, ADHD (MccLure et al., 2015; Bell et al., 2020). However, recent studies have also documented prevalence in association with socioeconomic and cultural level (Fayyad et al., 2017), contextual aspects that are yet to be accurately defined. This study reported that the current prevalence of ADHD in DSM-IV/CIDI adults averaged 2.8% across all surveys and was higher in countries with high income (3.6%) or upper middle income (3.0%), than in low-income/lower-middle-income (1.4%) countries. ADHD in adults is significantly related to being male, having a previous marriage, and low education. Adult ADHD had high comorbidity with DSM-IV/CIDI disorders of anxiety, mood, behavior, and substance use; and was significantly associated with role impairments (days out of role, cognitive impairment, and social interactions), when controlling for comorbidities.

Molecular Level of Analysis: Self-Regulation Behavior (Personal and Clinical Level)

In a complementary approach, research has established self-regulation as an essential meta-behavioral skill, which guides the learning process (de la Fuente, 2017). Self-regulation is thus trainable, and is exclusive to human beings. The bidirectional relationship between EFs and self-regulation (SR) has been established in different contexts, such as in the level of childhood development (Finders et al., 2021), eating behavior (Hawkins et al., 2021), and persistent effort (Barkley, 2021). Some models of EFs have even centered on self-regulation (Granziera et al., 2021).

Also, from an eminently psychoeducational approach, the abundant prior research based on the model Zimmerman and Schunk (2001) has operationally specified the behaviors typical at each sequential phase of human learning (before, during, and after). Despite its goodness, however, this model belongs to a molecular level of analysis, and so does not rule out possibilities for investigation at other levels (de la Fuente et al., 2019a).

Analysis of Self-Regulation at the Molar Level: Self- vs. External Regulation Behavior (Personal and Contextual Level)

At the level of molar analysis, which is more interactive and context-oriented, a comprehensive model has been proposed that allows us to understand personal regulatory factors in interaction with the context. Only in this way, it is assumed, can teaching-learning processes be evaluated in real contexts and not only in the laboratory. In this line, evolving research has led to the proposal of two behavioral constructs, represented in the theory of self-regulated vs. externally regulated learning, or SRL vs. ERL Theory (de la Fuente, 2017; de la Fuente et al., 2019b, 2020a,b, 2021a).

First, a possible gradation of regulation levels has been established, for both the individual and their context. For the individual, a progressive range of regulatory behavior has been defined: Self-Regulation (SR) vs. Non-Regulation (NR) vs. Dys-Regulation (DR). Self-regulation (SR) would be characterized by an adequate level of skill and high execution; Non-Regulation (NR) would be characterized by a medium level of the former, or by behavior bereft of regulatory effort; finally, Dys-Regulation (DR), would be characterized by a low level of regulation, along with execution of maladaptive regulatory behaviors, such as behavioral excesses or deficits. Evidence has shown that self-regulation correlates negatively with non-regulation, while non-regulation correlates positively with dysregulation. This is to say, when a person stops making regulatory effort, they are more likely to ultimately develop dysregulatory behavior. This schema is applicable to behaviors in education and health.

Secondly, regulatory levels pertaining to the context have been defined. As in the former case, a progressive range of regulation contexts has been identified: Externally Regulatory (ER) vs. Externally Non-Regulatory (ENR) vs. Externally Dys-Regulatory (EDR). A regulatory context (ER) would be characterized by adequately promoting the individual's self-regulation, by means of helps, indications, or external contingencies to induce high execution of SR behavior. An externally non-regulatory (ENR) context would be characterized by a medium presence of external regulation, in other words, inconsistent promotion of self-regulation, leaving regulatory effort up to the individual. Finally, an externally dysregulatory context (EDR) would be characterized by actively promoting dysregulation in the individual, by means of negative modeling, inappropriate indications, and/or erroneous contingencies, that actively encourage behavioral excesses or deficits. The evidence in this aspect has shown that externally regulatory contexts encourage self-regulation, while non-regulatory contexts promote non-regulation and dysregulatory contexts promote dysregulation. Moreover – and most importantly – a regulatory context decreases the likelihood of a non-regulatory context, but a non-regulatory context increases the probability of a dysregulatory context. Preliminary research in the areas of education and health has shown that a dysregulatory context promotes dysregulatory behavior. Thus, when a teaching process is dysregulatory, students learn more poorly, and use poorer self-regulation strategies (de la Fuente et al., 2019b, 2020a, 2021b). A dysregulatory health context, in similar fashion, positively predicts more reactance behaviors and the practice of poorer health behaviors (Pachón-Basallo et al., 2021).

Third, we have considered the regulation factors from a joint or combined analysis: (1) the level of internal regulation: personal self-regulation; (2) the level of external regulation: regulation promoted by the context; (3) the possible interactions between the two. These types of interaction have been identified in a five-level heuristic. Different teaching-learning processes have been intensively analyzed and the goodness of the proposal has been empirically verified. Academic achievement, learning approaches, procrastination, student engagement, and motivational-affective variables have been shown to be dependent on this interactive combination of Personal factors × Contextual factors. The focus is not exclusively on students' individual variables, as in previous (mainly molecular-level) research, but also on the Learning × Teaching interaction, having a more molar nature. This information is very important in helping to conceptualize learning behavior from a broader view, not only from discrete cognitive processes, such as the regulatory behaviors of students. Prior evidence has shown that all combinations of the cognitive and emotional variables are observed (de la Fuente et al., 2019b, 2020b, 2021b).

Emotion Regulation Difficulties

In order to accomplish one's goals, emotions must be regulated through the use of intrinsic and extrinsic processes that monitor, assess, and adapt one's emotional reactions as needed (Thompson, 1994). This idea of emotion regulation assumes that emotions are functional, giving us information about our context and prompting behaviors that can help us adapt to situational demands (Izard and Ackerman, 2000). By contrast, if there is a deficit in awareness, understanding, or modulation of one's emotions, adaptation becomes more difficult and this may lead to negative outcomes in many different ways. More and more research is showing the role of emotion regulation difficulties in many types of psychopathology and maladaptive behaviors (Gross and Jazaieri, 2014; Sheppes et al., 2015). Self-report measures that assess emotion regulation have

thus become a priority in the clinical approach to emotion regulation, and many new instruments have been developed and validated. Dimensions of emotion regulation difficulties (ERD) (e.g., emotional non-acceptance, lack of emotional awareness, and clarity) and maladaptive strategies for regulating emotions (e.g., avoidance and suppression) are addressed in a number of empirically supported measures. One prominent scale in the scientific literature is the *Difficulties in Emotion Regulation* Scale (DERS; Gratz and Roemer, 2004, 2008; Gratz and Tull, 2010), which measures a broad range of emotion regulation difficulties. ERD is considered a multidimensional construct, consisting of a set of behaviors that range from lack of self-knowledge and awareness of one's emotions, to difficulty in managing them. Emotion regulation difficulties have been related to different adaptive issues, such as the use of technology devices (Horwood and Anglim, 2021), food and substance abuse (Barnhart et al., 2021), health-related behavior (Lewczuk et al., 2021), and psychopathological symptoms of depression (Melero et al., 2021).

Objectives and Hypotheses

Based on prior evidence, this study seeks to confirm the associations, predictions, and interdependence relations between the three levels of the constructs cited above, in order to establish their relationship to emotion regulation difficulties. Different types of hypotheses were posed:

Association hypothesis. (1) A significant negative association is expected between the molecular construct SR and the microanalysis construct of executive dysfunction. However, in the case of the molar construct Self-Regulation (SR)/External Regulation (ER), while the expected relationship is positive and significant for SR and ER, it is negative for Non-Regulation (NR), Dys-Regulation (DR), External Non-Regulation (ENR), and External Dys-Regulation (EDR). We also expect a positive association relationship between difficulties in EFs and emotion regulation difficulties (ERD).

Prediction hypothesis. (2) The components of SR will prove to be negative predictors of the EF score. SR-ER factors should prove to be differential predictors of EF: while internal and external regulatory factors (SR-ER) should be positive predictors, internal and external non-regulatory or dysregulatory factors (NR, DR, ENR, and EDR) should be negative. Finally, EF difficulties will be positive predictors of emotion regulation difficulties.

Structural prediction hypothesis. (3) The combined level of internal and external regulation (SR-ER) will be a strong predictor of EF, differentially and significantly, as will SR alone, to a lesser degree. SR-ER will be a positive predictor; NR-ENR and DR-EDR, negative predictors. EF difficulties positively predict emotion regulation difficulties.

Inferential hypothesis. (4) EF levels (low–medium–high) will positively determine levels of SR and ER, and differentially determine levels of SR-ER (positively) and NR-ENR, DR-EDR (negatively). In complementary fashion, the five combination levels of internal and external regulation (SR-ER) will be significant, negative determinants of EF and the degree of emotion regulation difficulties, though differentially. Combined low levels of SR-ER will determine higher levels of EF difficulties and EDR, and vice versa, in gradient manner.

MATERIALS AND METHODS

Participants

The study sample contained a total of 298 undergraduate students from 15 different degree programs enrolled in Spanish or Latin American universities. The students were pursuing degrees in Psychology, Primary Education, or Educational Psychology; 63.5% were female and 36.5% were male. Students' age fell between 19 and 25, with a mean age of 23.12 years (SD = 2.679). The study design was incidental and non-randomized. As an inclusion criteria, university degree students were accepted. As an exclusion criterion, it was requested that students with any diagnosis or treatment of personality or neurological alterations not participate. All students participated voluntarily and were taking undergraduate courses.

Instruments

Self-Regulation

The *Short Self-Regulation Questionnaire (SSRQ)* was used to measure this variable (Brown, 1998; Brown et al., 1999). Its Spanish adaptation had been previously validated in Spanish samples (Pichardo et al., 2014; Garzón Umerenkova et al., 2017). Four factors are measured using a total of 17 items. The confirmatory factor structure is consistent (Chi-square = 250.83, df = 112, CFI = 0.95, GFI = 0.94, AGFI = 0.96, RMSEA = 0.059). Validity and reliability values (Cronbach's alpha) were acceptable [total ($a = 0.86$; Omega = 0.843); goal setting-planning ($a = 0.79$; Omega = 0.784), perseverance ($a = 0.78$; Omega = 0.779), decision making ($a = 0.72$; Omega = 0.718), and learning from mistakes ($a = 0.72$; Omega = 0.722)], comparable to the English version. The scale contains statements such as: "I usually keep track of my progress toward my goals," "When it comes to deciding about a change, I feel overwhelmed by the choice," and "I learn from my mistakes."

Self- vs. External Regulation of Behavior in Health

This *SRH-ERH Questionnaire* (de la Fuente, 2022) contains six subscales with six items each. Health-regulating aspects pertaining to the individual and to their context are assessed. Each item assesses either personal (internal) or contextual (external) aspects, whether regulatory, non-regulatory or dysregulatory. Some examples of each: (1) internal regulatory: I think consciously about my health needs, (2) external regulatory: the social context that I live in (family, environment, and friends) helps me plan my health-related behavior by setting goals and objectives; (3) internal non-regulatory (it is not necessary to make decisions in order to achieve changes in my health-related behaviors); (4) external non-regulatory: the social context that I live in (family, environment, and friends) gives me the idea that you do not need to make specific decisions to make changes in your health-related behaviors; (5) internal dysregulatory (it does not make sense to change your health-related behavior, if that takes away from your enjoyment and satisfaction); (5) external dysregulatory: the social context that I live in (family, environment, and friends) helps me enjoy myself to the fullest, it does not press me to change my health-related behavior, but rather to do what I feel like, if that makes me

happy and live fully. The subscales in this instrument (de la Fuente, 2022) are: SRH (Self-Regulation health behavior), NRH (Non-Regulation or de-regulation health behavior), DRH (Dys-Regulation health behavior), ERH (External-Regulation Health behavior), ENRH (External Non-Regulation or De-regulation behavior behavior), EDRH (External Dys-Regulation Health behavior). Factor structure, as analyzed in this sample, is consistent [Chi-square = 1,348.005, df = 583, $p < 0.001$; Ch/df = 2.379; RMSR = 0.035; NFI = 0.967; RFI = 0.954; incremental fit index (IFI) = 0.902; TLI = 0.967; CFI = 0.978; RMSEA = 0.70]. Total reliability values were also acceptable (alpha total = 0.776). Subscale consistency was also acceptable: SRH = 0.847; NRH = 0.779; DRH = 0.769; ERH = 0.900; ENH = 0.761; EDH = 0.828.

Executive Function Difficulties

The Behavior Rating Inventory of Executive Function (BRIEF-A, Roth et al., 2005, 2014), adapted for university populations (de la Fuente, 2021), was used to assess EF difficulties (executive dysfunction). This questionnaire is a list of behaviors associated with EF impairment, self-reported by university students. The original version was published in order to study executive functioning in general populations, especially in pathologies such as attention deficit disorder with or without hyperactivity, learning disorders, pervasive developmental disorders, and disorders of neurological origin, such as traumatic brain injury, epilepsies (especially epilepsies with an epileptogenic focus in the temporal lobe), frontal tumors, cerebrovascular accidents, genetic syndromes, or cognitive impairment due to toxic exposure. This version contains 75 items grouped into 8 scales that measure different aspects of executive functioning difficulties: Inhibit, Shift, Emotional Control, Initiate, Working Memory, Plan/Organize, Organization of Materials, and Monitor. These scales are grouped into two general indices, Behavioral Regulation and Metacognition, and an overall score, the Global Executive Composite.

International guidelines for adaptation of psychological tests were followed for the adapting the BRIEF questionnaire to the Spanish university population (Muñiz et al., 2013). The values found for this sample were acceptable, both in construct validity (Chi-square = 81.550, df = 19, $p < 0.001$; Ch/df = 4.292; RMSR = 0.035; NFI = 0.944; RFI = 0.948; IFI = 0.957; TLI = 0.917; CFI = 0.956; RMSEA = 0.80), as well as in reliability (Cronbach's alpha = 0.956; part 1 = 0.908, part 2 = 0.930).

Emotion Regulation Difficulties

These were assessed using the *Brief Difficulties in Emotion Regulation Scale*, DERS-16 (Bjureberg et al., 2016). The original DERS-36 self-report scale (Gratz and Roemer, 2004, 2008) contains 36 items that assess the individual's typical levels of emotion dysregulation in six domains: non-acceptance of negative emotions, inability to engage in goal-directed behaviors when distressed, difficulties controlling impulsive behaviors when distressed, limited access to emotion regulation strategies perceived as effective, lack of emotional awareness, and lack of emotional clarity. The abbreviated version, DERS-16, contains 16 items that assess the following dimensions: non-acceptance of negative emotions (3 items), inability to engage in goal-directed behaviors when distressed (3 items), difficulties controlling impulsive behaviors when distressed (3 items), limited access to emotion regulation strategies perceived as effective (5 items), and lack of emotional clarity (2 items). In both versions, a Likert-type response is required, rating the degree to which each item is applicable, from 1 (almost never) to 5 (almost always). Total DERS-16 scores range from 16 to 80, where higher scores reflect greater levels of emotion dysregulation. The revalidation analyses in this sample showed adequate construct validity values (Chi-square = 26.054, df = 5, $p < 0.001$; Ch/df = 5.211; RMSR = 0. 054; NFI = 0.954; RFI = 0.916; IFI = 0.962; TLI = 0.918; CFI = 0.962; RMSEA = 0.82), and reliability (Cronbach's alpha = 0.888; part 1 = 0.803, part 2 = 0.831).

Procedure

Student participation was on a voluntary basis, beginning with their agreement and signing of the informed consent statement, followed by anonymous completion of the scales on an online platform. The R&D Project was approved by the *Research Ethics Committee* of the University of Navarra (ref. 2018.170), and compliance with the deontological norms of psychology was assured. All databases are anonymized and protected by the Data Protection Law. The data collection server is located at (NETERRA DATACENTERS EUROPE[1]); where Mapache Software Europe fulfills the required handling and all assurances pertaining thereto. The Project IP[2] is responsible for data protection and treatment.

Data Analysis

Three types of analyses were conducted, using an *ex post* facto, transversal design (Ato et al., 2013). First, the quality of the data was explored by testing for outliers and missing cases. We tested for univariate outliers by calculating the typical scores of each variable, considering cases with Z scores outside the ±3 range to be potentially atypical (Tabachnick and Fidell, 2001). Atypical combinations of variables (atypical multivariate cases) were detected using the Mahalanobis distance (D2), a statistical measure of an individual's multidimensional distance from the centroid or mean of the observations given (Lohr, 1999). In this way we detected instances with significant distance from the typical combinations of the set of variables. The literature recommends removing univariate and multivariate outliers, or reassigning them the nearest extreme score (Weston and Gore, 2006). The procedure was carried out using SPSS (v.26, IBM, Armonk, NY, United States), which provides a specific routine for missing values analysis that determines the magnitude of missing values and whether they occur in a systematic or random manner.

Assumptions related to sample size, independence of errors, univariate and multivariate normality, linearity, multicollinearity, recursion, and interval measurement level were also evaluated, and showed acceptable reliability levels. Regarding sample size, recommendations indicate including 10–20 cases per parameter, and at least 200 observations (Kline, 2005). Independence of errors means that the error term of each endogenous variable must not correlate with other variables.

[1]https://www.icdsoft.com/en/datacenters#europe

[2]www.inetas.net

In order to test for univariate normality, we examined the distribution of each observed variable, and its asymmetry and kurtosis indices. Data transformation is recommended when asymmetry values are greater than 3 and kurtosis is greater than 10 (Kline, 2005). On the other hand, Mardia multivariate index values less than 70 indicate that distance from the multivariate normal is not a critical deterrent to this analysis (Rodríguez, 2011). Although level of interval measurement is one of the assumptions, variables measured at a nominal or ordinal level were sometimes used, as long as the score distribution, particularly of the dependent variables, was not markedly asymmetric (Weston and Gore, 2006).

The multicollinearity assumptions were tested through bivariate correlations; a correlation of 0.85 or higher would indicate non-fulfillment of this assumption. The model should be recursive: causal influences must be one-directional and not have retroactive effects. Finally, it is recommended that the instruments of measure show at least moderate reliability. This aspect was also fulfilled (see section "Instruments"). A power value of 0.80 was established as acceptable. The power of a statistical test relates to: (1) sample size *n*; (2) level of alpha significance: 5% was assumed, that is, a 95% confidence level (1-alpha); (3) effect size *d* or *r*: these measures indicate the relationship between variables (correlation coefficient). Low power may indicate a small sample size, a smaller alpha, or a small effect size, while the opposites may be indicated by high power.

Normal sample distribution was checked using the Kolmogorov–Smirnoff test for dependent variables, as a preliminary analysis. We also used the Hoelter Index to test for adequate sample size (Tabachnick and Fidell, 2001). In addition, we performed analyses of linearity and atypical values, missing and influential cases, as well as critical values of multivariate normality. Recommended values for the multivariate index of kurtosis, or Mardia coefficient, are less than 0.70 (Mardia, 1970).

For Hypothesis 1, Pearson bivariate correlations were carried out. For Hypothesis 2, we used multiple regression analysis. For Hypothesis 3, we used predictive analyses of structural equations, or SEM models. We followed Hu and Bentler's (1999) recommendations, where a model shows adequate fit to the observed data if the ratio of the Chi-square to its degrees of freedom is less than five, RMSEA and SRMR values are <0.08, and NNFI (non-normed fit index), IFI and CFI are >0.95. For samples equal to or less than 250 participants, Hu and Bentler (1999) recommend using only the CFI and SRMR fit indices (not applicable in this case). The robust maximum likelihood method was used as an estimation method. This method allows the use of polychoric correlations, which are more suitable in variables with high normality indices and multivariate kurtosis, and a clearly ordinal nature [73]. Cronbach's alpha was calculated in order to test the model's total reliability, and the reliability of each of the proposed factor structures. For these analyses, we used SPSS 26 (IBM SPSS, 2019) for reliability, and AMOS v. 23 (Arbuckle, 2014) for the confirmatory factor analyses and the SEM model.

For the inferential hypothesis, Hypothesis 4, we initially calculated self-regulation and external regulation scores. In the first case, to calculate total personal regulation, we applied the summational formula of the values of self-regulation (+), non-regulation (−), and dysregulation (−), divided by three: (SR-ER-DR)/3, obtaining a weighted total score for each participant, ranging from 1 to −2.28. In the second case, to calculate external or contextual regulation, we applied the summational formula of the values of external regulation (+), external non-regulation (−), and external dysregulation (−), divided by three: (ER-ENR-EDR)/3, obtaining a continuous total score with a range between 1 and −2.17, for each participant. Subsequently, cluster analyses were performed to determine the central points and thus convert scores into low-medium-high groups for each type of regulation. The central points of the respective clusters were:

	3. HIGH	2. MEDIUM	1. LOW
SR	−0.14	−0.72	−1.33
ER	0.32	−0.44	−1.13

Based on these central points, we calculated the distance between points and divided by two in order to establish cutoff points between the intervals:

	3.0 HIGH	2.0 MEDIUM	1.0 LOW
SR	1 to −0.43	−0.044 to −1.02	−1.03 to −2.28
ER	1 to −0.06	−0.07 to −0.78	−0.079 to −2.13

With the scores now ordered on a range of 1 to 3, we calculated the average of the individual's score and the regulatory score of their context, in each case. In this way we obtained a graded progression of five levels of combined personal and contextual regulation: 1.00 =

Scores	Range						
SR	1.0	2.0	1.0	2.0	2.0	3.0	3.0
ER	1.0	1.0	2.0	2.0	3.0	2.0	3.0
AVERAGE	1.0	1.5	1.5	2.0	2.5	2.5	3.0

Based on the foregoing, this mean was taken as an IV, or heuristic on five levels, where significant between-group differences were confirmed using an ANOVA. Subsequently, ANOVAs and MANOVAs were carried out, taking EF and emotion regulation difficulties as dependent variables.

RESULTS

Preliminary Results: Descriptive Results

The preliminary descriptive results showed acceptable fit and normality parameters (see **Table 1**).

Linear Results: Association and Prediction

Self-Regulation, Executive Functions, and Emotion Regulation Difficulties

A significant negative association was found between total self-regulation and all the components of EF difficulties. The same

TABLE 1 | Normalized descriptive values of the sample.

Variable	Min.	Max.	Mean	(SD)	Error	Asymmetry	Error	Kurtosis	Error	Kolmogorov–Smirnov	Sig.
SR	2.06	4.47	3.4070	(0.02649)	0.02649	−0.089	0.142	−0.152	0.283	0.202	0.200
SRH	1.33	5.00	3.4840	(0.04142)	0.04142	−0.200	0.143	−0.213	0.284	0.169	0.200
NRH	1.00	4.67	2.3925	0.04421	0.04421	0.174	0.142	−0.592	0.284	0.213	0.200
DRH	1.00	4.50	2.4218	0.03983	0.03983	0.181	0.143	−0.184	0.285	0.248	0.177
ERH	1.00	5.00	3.4892	0.05085	0.05085	−0.230	0.142	−0.320	0.283	0.183	0.158
ENRH	1.00	4.50	2.3709	0.04572	0.04572	0.351	0.142	−0.391	0.284	0.242	0.200
EDRH	1.00	4.67	2.2144	0.04587	0.04587	0.291	0.142	−0.514	0.284	0.147	0.200
EF	1.07	3.81	2.2045	0.03317	0.03440	0.257	0.144	−0.555	0.287	0.115	0.171
ERD	1.35	4.28	2.6490	0.03440	0.03317	0.259	0.142	−0.297	0.283	0.169	0.200

SR, Self-regulation; SRH, Self-regulation in Health; NRH, Non-regulation in Health; DRH, Dys-Regulation in Health; ERH, External-regulation in Health; ENRH, External Non-regulation in Health; EDRH, External Dys-Regulation in Health; EF, Executive Functions; ERD, Emotion regulation difficulties.

TABLE 2 | Bivariate correlations between self-regulation (SR) and executive functions (EFs).

Variables	GOALS	PERSEVERANCE	DECISIONS	ERROR	SELF-REGULATION TOTAL
F1. INHIBITION	−0.259***	−0.222***	−0.153**	−0.285***	−0.339***
F2. FLEXIBILITY	−0.064	0.017	−0.332***	−0.182**	−0.187**
F3. CONTROL	−0.172**	−0.117*	−0.235**	−0.291**	−0.291**
F4. INITIATIVE	−0.388***	−0.268**	−0.263**	−0.450**	−0.450***
F5. MEMORY	−0.300***	−0.198**	−0.262**	−0.380**	−0.380**
F6. PLANNING	−0.381***	−0.274**	−0.278**	−0.442**	−0.442***
F7. ORGANIZATION	−0.111*	−0.160**	−0.169**	−0.246**	−0.246**
F8. MONITORING	−0.337***	−0.322***	−0.234**	−0.461**	−0.461***
D1. EMOTION	−0.343***	−0.136*	−0.282**	−0.452**	−0.452***
D2. COGNITIVE	−0.200**	−0.276**	−0.290***	−0.334**	−0.334***
EXECUTIVE DYSFUNCTION	−0.288**	−0.219**	−0.307***	−0.416**	−0.416***

**p < 0.05, **p < 0.01, ***p < 0.001.*

TABLE 3 | Bivariate correlations between self-regulation (SR) and emotion regulation difficulties (ERD).

Variables	GOALS	PERSEVERANCE	DECISIONS	ERROR	SELF-REGULATION TOTAL
F1. CLARITY	−0.164**	−0.063	−0.259***	−0.184	−0.232***
F2. STRATEGY	−0.149**	0.031	−0.277***	−0.218***	−0.209***
F3. ACCEPTANCE	−0.123*	0.022	−0.256***	−0.178**	−0.181*
F4. IMPULSIVITY	−0.235***	−0.118*	−0.272***	−0.238**	−0.305***
F5. GOALS	−0.075	0.054	−0.276***	−0.123*	−0.135*
EMOTION REGULATION DIFFICULTIES	−0.197**	−0.021	−0.354***	−0.247***	−0.280***

**p < 0.05, **p < 0.01, ***p < 0.001.*

was true for the components of both psychological constructs (see **Tables 2**, **3**).

Regarding bivariate association relationships between SR and ERD, significant, inverse (negative) associations were found, both at a general level and with components of emotion regulation difficulty. Note that the greatest significant negative correlation was found between total SR and the component of Difficulty with Impulse Control, one of the emotion regulation difficulties ($r = -0.305$, $p < 0.001$). As for SR components, the clearest negative relationship was seen between decision making and ERD ($r = -0.354$, $p < 0.001$).

Self- vs. External-Regulation, Executive Dysfunction, and Emotion Regulation Difficulties

The association relationships between the components of SR-ER were differentially related to EFs. While SRH (self-regulated health behavior) and ERH (externally regulated health behavior) showed a significant, positive relationship, non-regulated behavior, and context (NRH and ENRH) were shown to have a significant, moderate relationship ($r = 0.210$, $p < 0.001$; $r = 0.352$, $p < 0.001$). A positive direction was also observed in the significant positive association with dysregulatory health behavior (DRH; $r = 0.292$, $p < 0.001$) and dysregulatory health context (EDRH; $r = 0.342$, $p < 0.001$). The most consistent association observed was between the cognitive dimension and its factors, where higher association values went to subjects' lack of initiative ($r = 0.436$, $p < 0.001$) and lack of monitoring ($r = 0.436$, $p < 0.001$), respectively; and in a non-regulatory context, lack of monitoring and organization ($r = 0.388$, $p < 0.001$) and lack of inhibition ($r = 0.372$, $p < 0.001$). Also important, from the dysregulatory context, was the positive association with lack of monitoring ($r = 0.359$; $p < 0.001$) and

TABLE 4 | Bivariate correlations between self vs. external regulation (SR-ER) and difficulties inherent to executive functions (EFs).

Variables	SRH	NRH	DRH	ERH	ENRH	EDRH
F1. INHIBITION	−0.206***	0.428***	0.278**	−0.081	0.372***	0.322***
F2. FLEXIBILITY	−0.108*	0.192**	0.158*	−0.054	0.206**	0.169*
F3. CONTROL	−0.161**	0.283***	0.223**	−0.048	0.192*	0.240**
F4. INITIATIVE	−0.249***	0.436***	0.252***	−0.232**	0.341***	0.311**
F5. MEMORY	−0.244***	0.397***	0.195*	−0.156*	0.327***	0.275**
F6. PLANNING	−0.247***	0.395***	0.247***	−0.223**	0.280**	0.329**
F7. ORGANIZATION	−0.238***	0.393***	0.243***	−0.107*	0.287**	0.275**
F8. MONITORING	−0.299**	0.398***	0.325***	−0.257**	0.388***	0.359***
D1. EMOTION	−0.309***	0.477***	0.291***	−0.230**	0.371***	0.354***
D2. COGNITIVE	−0.192**	0.366***	0.268**	−0.071	0.311**	0.298**
EXECUTIVE DYSFUNCTION	−0.268***	0.447***	0.292***	−0.162**	0.352***	0.342***

SR, Self-regulation; SRH, Self-Regulation in Health; NRH, Non-Regulation in Health; DRH, Dys-Regulation in Health; ERH, External-Regulation in Health; NRH, External Non-Regulation in Health; EDRH, External Dys-Regulation in Health.
**p < 0.05, **p < 0.01, ***p < 0.001.*

TABLE 5 | Bivariate correlations between self vs. external regulation (SR-ER) and difficulties inherent to executive functions (EFs).

Variables	SRH	NRH	DRH	ERH	ENRH	EDRH
F1. CLARITY	−0.180**	0.210**	0.174*	0.044	0.132*	0.151*
F2. STRATEGY	−0.114*	0.224**	0.190*	−0.087	0.259**	0.252**
F3. ACCEPTANCE	−0.112*	0.171**	0.109*	−0.081	0.189*	0.199*
F4. IMPULSIVITY	−0.153**	0.249***	0.275**	−0.092	0.221**	0.243**
F5. GOALS	−0.045	0.062	0.051	−0.025	0.077	0.148*
EMOTION REGULATION DIFFICULTY	−0.161**	0.241***	0.210**	−0.060	0.228**	0.259**

SR, Self-regulation; SRH, Self-Regulation in Health; NRH, Non-Regulation in Health; DRH, Dys-Regulation in Health; ERH, External-Regulation in Health; NRH, External Non-Regulation in Health; EDRH, External Dys-Regulation in Health.
**p < 0.05, **p < 0.01, ***p < 0.001.*

lack of planning ($r = 0.329$; $p < 0.001$). In complementary fashion, in all NRH and DRH behaviors, the strength of association was greatest with the cognitive dimension of EF (see **Tables 4**, **5**).

The association trend was similar with Emotion regulation difficulties (ERD) and its components. Also, with less associative strength, personal, and contextual behavioral characteristics (NRH, DRH, ENRH, and EDRH) were positively associated with ERD.

Linear Prediction Results

Preliminary Analysis: Prediction of Self-Regulation From Self-Regulation–External Regulation Components

Preliminary prediction analysis showed a significant linear model [$F(6,280) = 13.144$, $p < 0.001$; adjusted $R^2 = 0.203$] where the factors "self-regulation" ($B = 0.339$, $p < 0.001$), "non-regulation" ($B = -0.0.99$, $p < 0.155$) and "dys-regulation" ($B = -0.126$, $p < 0.037$) were shown to be differential predictors of general SR. The factors ER ($B = 0.0.29$, $p < 0.649$), ENR ($B = -0.0.66$, $p < 0.353$) and EDR ($B = 0.006$, $p < 0.932$) did not present significant predictions.

Prediction of Executive Dysfunctions and Emotion Regulation Difficulties From Self-Regulation Components

The first prediction analysis showed a significant linear model [$F(4,282) = 17.976$, $p < 0.001$; adjusted $R^2 = 0.192$] where the factors of "goals" ($B = -0.115$, $p < 0.07$), "decision making" ($B = -0.230$, $p < 0.001$) and "learning from mistakes" ($B = -0.271$, $p < 0.001$) appeared as significant negative predictors of EFs. Note that the percentage of explained variance is less than in the following case.

The second prediction analysis showed a significant linear model [$F(4,293) = 16.595$, $p < 0.001$; adjusted $R^2 = 0.176$ (17% of the explained variance)] where the factors of "decision making" ($B = -0.316$, $p < 0.001$) and "learning from mistakes" ($B = -0.247$, $p < 0.001$) appeared as significant negative predictors, while "perseverance" was a significant positive predictor ($B = 0.163$, $p < 0.01$) of emotion regulation difficulties.

Prediction of Executive Dysfunctions and Emotion Regulation Difficulties From Self-Regulation–External Regulation Components

The first prediction analysis showed a significant linear model [$F(6,274) = 17.273$, $p < 0.001$; adjusted $R^2 = 0.259$ (25.9% of the explained variance)] where "self-regulation, SR" ($B = -0.114$, $p < 0.08$) was a marginally significant negative predictor, while "non-regulation, NR" ($B = 0.270$, $p < 0.001$), "external non-regulation, ENR" ($B = 0.136$, $p < 0.05$) and "external dysregulation, EDR" ($B = 0.167$, $p < 0.01$) were significant positive predictors of EFs.

The second prediction analysis showed a significant linear model [$F(6,280) = 6.122$, $p < 0.001$; adjusted $R^2 = 0.097$ (9.7% of the explained variance)] where "SR" ($B = -0.118$, $p < 0.05$) was

TABLE 6 | Statistical parameters of structural models.

Models	Type factors	Chi-square	Degrees of freedom	*p*<	CMIN/DF	TLI	RFI	IFI	TLI	CFI	RMSEA	HO0.05	HO0.01
Model 1	4 F	826,600	(299–75): 224	0.001	3,690	0.756	0.699	0.809	0.761	0.806	0.095	93	99
Model 2*	4 F	827,467	(299–73): 226	0.001	3,361	0.914	0.901	0.909	0.914	0.906	0.083	94	100

L, learning process; T, teaching process.
**Selected models.*

TABLE 7 | Total, indirect, and direct effects of the variables in this study, and 95% bootstrap confidence intervals (CI).

Predictive variable	Criterion variable	Total effect	CI (95%)	Direct effect	CI (95%)	Indirect effect	CI (95%)	Results, effects	CI (95%)
SRER→	SR	−0.476	[−0.27, −52]	−0.476	[−0.27, −52]	0.00	[−0.03, 0.02]	Direct only	[−0.27, −52]
SRER→	EF	0.649	[0.45, 0.76]	0.482	[0.56, 38]	0.166	[0.22, 0.12]	Partial mediation	[0.22, 0.12]
SRER→	ERD	0.351	[0.43, 0.27]	0.00	[−0.15, 0.18]	0.351	[0.43, 0.27]	Full mediation	[0.43, 0.27]
SR	EF	−0.350	[−31, −0.37]	−0.350	[−31, −0.37]	0.00	[−0.03, 0.04]	Direct only	[−31, −0.37]
SR	ERD	−0.189	[−0.20, −0.28]	0.00	[−0.03, 0.04]	−0.189	[−0.20, −0.28	Full mediation	[−0.20, −0.28]
EF→	ERD	0.541	[0.48, 62]	0.541	[0.48, 62]	0.00	[−0.03, 0.02]	Direct only	[−0.03, 0.02]

CI, confidence interval.
Bootstrapping sample size = 298.

shown to be a significant negative predictor, while "dysregulation, DR" ($B = 0.162$, $p < 0.05$) was a significant positive predictor of emotion regulation difficulties.

Predicting Emotion Regulation Difficulties From Components of Executive Dysfunctions

The prediction analysis showed a significant linear model [$F(2,284) = 59{,}275$, $p < 0.001$; $R^2 = 0.290$ (29% of the explained variance)] where the Emotional dimension of EFs (D1) was a significant positive predictor of Emotion regulation difficulties ($B = 0.544$, $p < 0.001$), while the Cognitive factor of EFs did not show predictive ability.

Structural Prediction

Of the models tested, the second fulfills the statistical parameters required for empirical fit (see **Table 6**).

Model 3 reflected how SR-ER factors were negative predictors of *Self-regulation* (SR), and positive predictors of Executive Function (EF) and Emotion Regulation Difficulties (ERD). Complementarily, self-regulation (SR) negatively predicted Emotion Regulation Difficulties (ERD) and Executive Function (EF). Finally, *Executive Dysfunction* (EF) difficulties were positively predictive of Emotion Regulation Difficulties (ERD) (see **Table 7** and **Figure 1**).

Figure 1 shows predictive relationships of the model. The latent variable SR-ER positively predicts EF ($B = 0.48$). The factors of non-regulation (NR), dysregulation (DR), external non-regulation (ENR), and external dys-regulation (EDR) have positive predictive weight in the configuration of the model, while self-regulation (SR) and external regulation (ER) have negative weight. The latent variable SR-ER also negatively predicts SR ($B = -0.48$), and SR negatively predicts EF ($B = -0.35$). Finally, the latent variable EF positively predicts ERD ($B = 0.54$) (see **Figure 1**).

Inferential Results

Effect of the Level of Executive Dysfunctions on Self-Regulation, and on Self-Regulation vs. External Regulation

Effect on Self-Regulation

There was a significant statistical main effect of the level of EFs on the variable self-regulation (SR) [$F(2,284) = 24.065$, $p < 0.001$; $\text{eta}^2 = 0.145$; $3 > 2 > 1$, $p < 0.001$]. Levene's test of equality of error variances, based on the mean, showed no significant between-group differences [*Levene* $(2,284) = 0.351$, $p < 0.704$] (see **Table 8**).

Effect on Self-Regulation vs. External-Regulation

Box's *M*, a preliminary test for matrix equality, showed no significant between-group differences [$F(42,159347) = 1.526$, $p < 0.716$]. There was a significant statistical main effect of the level of EFs on the variable self- vs. external regulation (SR-ER) [$F(2,284) = 7.124$, $p < 0.001$; $\text{eta}^2 = 0.145$; $3 > 2 > 1$, $p < 0.001$]. Note the greater discriminant strength in the factors NR, ENR, DR, and EDR (see **Table 9**).

Effect on Emotion Regulation Difficulties

Levene's test of equality of error variances, based on the mean, showed no significant between-group differences [$L(2,284) = 1.216$, $p < 0.298$]. There was a significant statistical main effect of the level of EFs on the variable Emotion regulation difficulties (ERD) [$F(2,278) = 35.202$, $p < 0.001$; $R^2 = 0.199$; $3 > 2 > 1$, $p < 0.001$]. This main effect was consistent both for the total score and for the factors. In this case, the effect on factor 2 (lack of emotion regulation strategies) and factor 4 (lack of impulse control) stand out as having the greatest main effect (see **Table 10**).

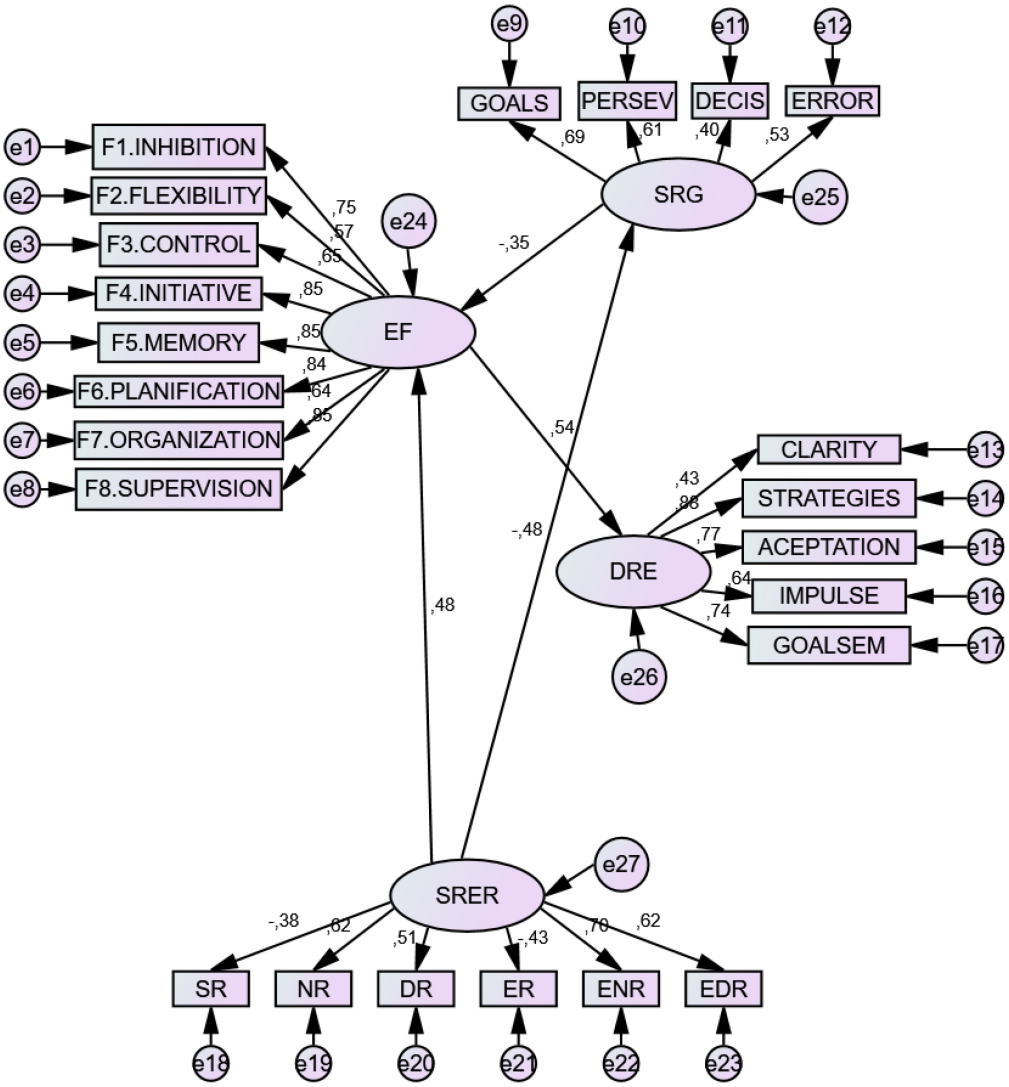

FIGURE 1 | Structural predictive model of relationships. EF, Executive Dysfunction; SRER, Self-regulation vs. External regulation; ERD, Emotion Regulation Difficulties; SR, Self-regulation; SRH, Self-Regulation in Health; NRH, Non-Regulation in Health; DRH, Dys-Regulation in Health; ERH, External-Regulation in Health; NRH, External Non-Regulation in Health; EDRH, External Dys-Regulation in Health.

TABLE 8 | Effect of low–medium–high levels of the independent variable executive functions (EF) on SR.

Level of the independent variable EF	Mean of the dependent variable SR	(SD)	*Post hoc* (Scheffé)
1 ($n = 97$) low	3.6193	(0.44024)	1 > 2, 3***
2 ($n = 121$) medium	3.3859	(0.39829)	3 > 2 > 1***
3 ($n = 69$) high	3.1630	(0.43186)	3 < 2, 1***
Total	3.4112	(0.45363)	

EF, Executive Function; SR, Self-Regulation.
****$p < 0.001$.*

Effects of the Combined Self-Regulation–External Regulation Level on Executive Functions and on ERD

Preliminary Checks for Group Adequacy

The MANOVA used to test the adequacy of the groups showed a significant main effect of the SR-ER combination on the dependent variables analyzed [$F(8,566) = 49.846$, $p < 0.001$, $R^2 = 0.413$; power = 1.0], with a greater significant effect on the variable of context regulation (ERcurve). Subsequent analyses revealed the expected significant differences between groups (see *post hoc* in the table). Box's *M* test for equality of covariance

TABLE 9 | Effect of low–medium–high levels of the independent variable executive functions (EF) on SR-ER.

Dependent variables	1. Low EF ($n = 94$)	(SD)	2. Medium EF ($n = 119$)	(SD)	3. High EF ($n = 68$)	(SD)	Mean EF ($n = 281$)	(SD)	$F(2,278)$	*Post hoc*
SR	3.702	(0.645)	3.420	(0.717)	3.269	(0.700)	3.478	(0.708)	8.481***	1 > 2, 3***
NR	2.039	(0.667)	2.392	(0.693)	2.860	(0.713)	2.387	(0.753)	27.953***	3 > 2 > 1***
DR	2.164	(0.612)	2.451	(0.644)	2.698	(0.679)	2.415	(0.679)	13.591***	3, 2 > 1***
ER	3.586	(0.834)	3.484	(0.923)	3.279	(0.763)	3.469	(0.862)	2.569*	1, 2 > 3***
ENR	2.037	(0.692)	2.375	(0.742)	2.777	(0.730)	2.359	(0.772)	20.692***	3 > 2 > 1***
EDR	1.9663	(0.784)	2.145	(0.709)	2.639	(0.728)	2.205	(0.781)	17.008***	3 > 2, 1***

SR, Self-regulation; NR, Non-Regulation; DR, Dys-regulation; ER, External-Regulation; ENR, External Non-Regulation; EDR, External Dys-Regulation.
**p < 0.05, ***p < 0.001.*

TABLE 10 | Effect of low–medium–high levels of the independent variable executive dysfunctions (EF) on emotion regulation difficulties (ERD).

Dependent variables	1. Low EF ($n = 94$)	(SD)	2. Medium EF ($n = 119$)	(SD)	3. High EF ($n = 68$)	(SD)	Mean EF ($n = 281$)	(SD)	$F(2,278)$	R^2	*Post hoc*
ERD total	2.304	(0.464)	2.756	(0.533)	2.930	(0.533)	2.645	(0.568)	35.202***	0.199	1 < 2 < 3***
F1. Clarity	2.030	(0.803)	2.324	(1.03)	2.608	(1.12)	2.419	(1.02)	11.409***	0.074	1 < 2 < 3***
F2. Strategies	1.9567	(0.629)	2.6066	(0.778)	2.994	(0.746)	2.480	(0.826)	44.631***	0.239	1 < 2 < 3***
F3. Acceptance	2.010	(0.849)	2.650	(0.954)	2.903	(0.918)	2.494	(0.977)	22.400***	0.136	1 < 2 < 3***
F4. Impulse	1.793	(0.706)	2.294	(0.872)	2.821	(0.860)	2.252	(0.901)	32.163***	0.185	1 < 2 < 3***
F5. Goals	2.611	(0.903)	3.159	(0.932)	3.125	(0.864)	2.966	(0.937)	11.258***	0.073	1 < 2 < 3***

ERD, Emotion Regulation Difficulties; F1, lack of emotional clarity; F2, emotion management strategies; F3, lack of acceptance; F4, lack of impulse control; F5, Difficulty in emotional goals.
****p < 0.001.*

TABLE 11 | Effect of the combined SR-ER levels on the continuous dependent variables SR and ER.

	Level 1.0. ($n = 19$)	Level 1.5. ($n = 70$)	Level 2.0. ($n = 107$)	Level 2.5. ($n = 80$)	Level 3.0. ($n = 9$)	TOTAL ($n = 285$)	$F(4,483)$	*Post hoc*
SRCURVE	−1.277 (0.178)	−1.001 (0.353)	−0.762 (0.493)	−0.597 (0.268)	−0.222 (0.209)	−0.798 (0.438)	23.456	3.00 < 2.50 < 2.00 < 1.50 < 1.00
ERCURVE	−1.129 (0.222)	−0.839 (0.455)	−0.344 (0.537)	0.1382 (0.447)	0.222 (0.220)	−0.373 (0.630)	57.749	3.00 < 2.50 < 2.00 < 1.50 < 1.00

TABLE 12 | Effect of the SR-ER combination levels on the dependent EF (Executive Dysfunction) variables.

	Level 1.0. ($n = 19$)	Level 1.5. ($n = 70$)	Level 2.0. ($n = 107$)	Level 2.5. ($n = 80$)	Level 3.0. ($n = 9$)	TOTAL ($n = 285$)	$F(4,280)$	R^2	*Post hoc* (Scheffé)
EF total	2.716 (0.492)	2.548 (0.591)	2.201 (0.499)	1.836 (0.428)	1.609 (0.504)	2.206 (0.584)	25.006***	0.365	1.0 > 1.5 > 2.0 > 2.5 > 3.0***
D1. COGNITIVE	2.751 (0.275)	2.577 (0.604)	2.240 (0.593)	1.733 (0.248)	1.698 (0.591)	2.197 (0.655)	28.842***	0.292	1.0 > 1.5 > 2.0 > 2.5 > 3.0***
D2. EMOTION	2.680 (0.474)	2.489 (0.624)	2.162 (0.580)	1.939 (0.515)	1.719 (0.545)	2.214 (0.594)	15.072***	0.177	1.0 > 1.5 > 2.0 > 2.5 > 3.0***
F1. INHIBITING	2.431 (0.684)	2.291 (0.791)	1.822 (0.592)	1.506 (0.493)	1.411 (0.430)	1.876 (0.702)	19.988***	0.222	1.0 > 1.5 > 2.0 > 2.5 > 3.0***
F2. FLEXIBILITY	2.940 (0.574)	2.655 (0.792)	2.475 (0.631)	2.279 (0.660)	2.347 (0.777)	2.491 (0.703)	5.092***	0.068	1.0 > 1.5 > 2.0 > 2.5 > 3.0***
F3. MONITORING	2.669 (0.616)	2.511 (0.792)	2.188 (0.742)	2.031 (0.754)	2.000 (0.787)	2.274 (0.786)	7.546***	0.097	1.0, 1.5 > 2.0 > 2.5, 3.0***
F4. INITIATING	2.684 (0.720)	2.555 (0.702)	2.160 (0.681)	1.714 (0.500)	1.680 (0.603)	2.151 (0.725)	20.724***	0.228	1.0, 1.5 > 2.0 > 2.5, 3.0***
F5. MEMORY	2.689 (0.641)	2.545 (0.674)	2.257 (0.736)	1.771 (0.603)	1.533 (0.644)	2.203 (0.746)	16.309***	0.189	1.0, 1.5 > 2.0 > 2.5, 3.0***
F6. PLANNING	2.644 (0.591)	2.509 (0.742)	2.316 (0.745)	1.87 (0.686)	1.780 (0.538)	2.270 (0.766)	19.958***	0.222	1.0, 1.5 > 2.0 > 2.5, 3.0***
F7. ORGANIZATION	3.017 (0.881)	2.611 (0.873)	2.269 (0.935)	1.600 (0.793)	1.555 (0.803)	2.193 (0.899)	17.159***	0.197	1.0 > 1.5 > 2.0 > 2.5, 3.0***
F8. MONITORING	2.727 (0.608)	2.464 (0.627)	2.199 (0.584)	1.800 (0.511)	1.652 (0.681)	2.170 (0.649)	18.784	0.212	1.0 > 1.5 > 2.0 > 2.5 > 3.0***

$^{***}p < 0.001$.

TABLE 13 | Effect of the SR-ER combination levels on the dependent ERD variables (Emotion Regulation Difficulties).

	Level 1.0. (*n* = 19)	Level 1.5. (*n* = 70)	Level 2.0. (*n* = 107)	Level 2.5. (*n* = 80)	Level 3.0. (*n* = 9)	TOTAL (*n* = 285)	*F*(4,280)	R^2	*Post hoc*
ERD	2.890 (0.561)	2.788 (0.732)	2.528 (0.680)	2.250 (0.660)	2.061 (0.870)	2.526 (0.770)	8.719***		1.0, 1.5 > 2.0 > 2.5, 3.0***
F1. CLARITY	2.809 (0.679)	2.760 (1.21)	2.394 (0.098)	2.123 (0.831)	1.833 (1.08)	2.421 (1.02)	5.505***	0.072	1.0, 1.5 > 2.0 > 2.5 > 3.0***
F2. STRATEGIES	2.961 (0.755)	2.816 (0.829)	2.418 (0.768)	2.187 (0.752)	2.177 (1.03)	2.483 (0.826)	8.512***	0.106	1.0, 1.5 > 2.0 > 2.5, 3.0***
F3. ACCEPTANCE	2.825 (0.711)	2.676 (0.944)	2.596 (1.02)	2.156 (0.899)	2.111 (1.05)	2.494 (0.976)	4.490***	0.059	1.0 > 1.5 > 2.0 > 2.5, 3.0***
F4. IMPULSE	2.841 (0.820)	2.591 (0.887)	2.204 (0.915)	1.971 (0.773)	1.703 (1.04)	2.264 (0.910)	8.812***	0.103	1.0 > 1.5 > 2.0 > 2.5, 3.0***
F5. GOALS	3.015 (0.702)	3.098 (0.929)	3.027 (0.925)	2.814 (0.961)	2.481 (1.01)	2.967 (0.969)	1.656	0.023	1.0, 1.5 > 2.0 > 2.5, 3.0***

***$p < 0.001$.

matrices also showed lack of equality between the group variances [$M = 68.234$; $F(12,6272.902) = 7.44$, $p < 0.10$] (see **Table 11**).

Effects on Executive Dysfunctions

The first ANOVA, referring to the effect of SR-ER combinations on total EF score, showed a significant main effect [$F(4,280) = 25.006$, $R^2 = 0.365$, power = 1.0]; Levene's test of equality of error variance, based on means, also showed an absence of significant between-group differences [$L(4,280) = 1.287$, $p < 0.275$]. The second MANOVA, referring to the EF dimensions, showed another significant main effect [$F(8,560) = 13.237$, $R^2 = 0.159$, power = 1.0]. The MANOVA performed with respect to the EF factors also showed a significant main effect [$F(32,1104) = 3.765$; $p < 0.001$, $R^2 = 0.098$; power = 1.0]. Box's Test of equality of covariance matrices showed a similarity of covariance matrices [Box's $M = 325.351$; $F = 1.847$; df1 = 144; df2 = 4,346.966; $p < 0.10$]. Levene's test of equality of error variances, based on means, for each factor, also showed an absence of significant between-group differences [$L(4,280)$ = between 0.280 and 1.287, $p<$, between 0.230 and 0.841]. Note that the greatest main effect was on *cognitive* EFs, that is, lack of initiative, planning and organization. The greatest effect in *emotional* EFs refers to inhibition difficulty (see **Table 12**).

Effects on Emotion Regulation Difficulties

The ANOVA referring to the effect of SR-ER combination levels on total ERD score showed a significant main effect [$F(4,286) = 8.719$, $R^2 = 0.109$, power = 0.99]; Levene's test of equality of error variances, based on means, also showed an absence of significant between-group differences [$L(4,286) = 1.085$, $p < 0.364$].

The MANOVA referring to the effect of SR-ER combination levels on ERD dimensions, showed another significant main effect [$F(20, 1140) = 3.227$, $R^2 = 0.054$, power = 1.0]. Box's test of equality of covariance matrices showed similarity among them [Box's $M = 93.740$; $F = 1,398$; df1 = 60; df2 = 4717,316; $p < 0.10$]. Levene's test of equality of error variances, based on means, for each factor, also showed an absence of significant between-group differences [$L(4,286)$ = between 0.058 and 0.090; $p <$ between 0.121 and 0.927] (see **Table 13**).

DISCUSSION

This research aimed to establish the predictive relationships between a molecular construct (SR) and a molar construct (SR-ER) with respect to a microanalytical (EF) construct and a clinical correlate (ERD), in order to provide evidence of the predictive value of these variables. The results presented here uphold the proposed relationships overall.

Regarding the association Hypothesis (1), the proposed significant relationships were found: there is an inverse relationship between SR and EF difficulties, as has been previously and sufficiently documented (Baumeister and Heatherton, 1996). SR has been shown to be widely associated with personal well-being and healthy behaviors

(Morosanovaa et al., 2021a), as well as with successful complex learning (Morosanovaa et al., 2021b).

One novel result pertains to the fact that the non-regulatory and dysregulatory contexts were positively associated with EF and ERD. This result is important because: (1) it lends support to and broadens the conceptualization of EF, as a construct associated with non-regulatory behavior (less studied) and dys-regulatory behavior (Beheshti et al., 2020); (2) of particular importance, this result documents the role of the non-regulatory and dys-regulatory context in association with the level of EFs, something that has not been addressed in classic conceptualizations (Diamond, 2013); (3) Finally, this result incorporates the specific role of a lack of regulation and of dysregulation into explanatory models of EF. Present within subjects and also in the context in which they develop, these aspects in combination help to explain the behavioral dysfunctions that are typical of executive dysfunction (Munakata and Michaelson, 2021). Correlational studies have documented reliable links between children's environments and their outcomes in multiple domains. For example, inconsistent discipline from caregivers predicts higher negative affect and behavioral problems in children (Doan and Evans, 2020), and regular family routines (such as consistent meal- and bedtimes) are associated with positive developmental outcomes (Fiese et al., 2006). Better childhood EF has been related to more positive parenting (e.g., warmth and responsiveness), less negative parenting (e.g., control and intrusiveness), and parenting that is more cognitive (e.g., autonomy support and scaffolding) (Valcan et al., 2018). When children have more unstructured time in their daily life for using engaging EFs, better self-directed executive functioning is displayed on laboratory tasks (Barker et al., 2014). By contrast, when parents and other adults in children's lives show unpredictable and unreliable behavior, this is associated with poorer executive functioning on tasks regarding delayed gratification and temporal discounting (Mauro and Harris, 2000). Household chaos is also associated with poorer executive functioning in children (Schmidt et al., 2015; Suor et al., 2017; Andrews et al., 2021). Cultures also vary in how they relate to EFs, the value they associate with them, and their tendency to engage them (Yanaoka and Saito, 2021). Finally, as expected, a positive association was found between EF and ERD, showing that executive dysfunction is associated with emotional regulatory dysfunction (Eisenberg et al., 2010).

The results above were qualified by the linear and structural prediction Hypotheses (2 and 3). Thus, the components of SR proved to be negative predictors of the total EF score (Hofmann et al., 2012). SR-ER factors were differentially predictive of EF factors; while SR and ER factors negatively predicted EF; NR-ENR and DR-EDR were positive predictors, as in other previous findings (Bernier et al., 2010; Diamond, 2016).

Also, the EF (executive dysfunction) components proved to be positive predictors of Emotion Regulation Difficulties (ERD), especially those corresponding to the behavior regulation dimension. Although this study uses a normalized sample and ADHD students did not participate, some of these results could help us understand other relationships found in previous research. A relationship has been observed between *Attention-Deficit/Hyperactivity Disorder (ADHD)*, as a case of *executive dysfunction*, and difficulties with regulating emotions, with certain conclusive results. First, emotion dysregulation in ADHD persists throughout one's lifespan and is a major factor contributing to impairment. Second, this dysregulation may be due to deficits in how one orients to, recognizes, and/or assigns attention to emotional stimuli; such deficits involve dysfunction within a striato-amygdalo-medial prefrontal cortical network. Third, while current treatments often improve emotion dysregulation, a focus on this combination of symptoms reframes clinical questions and could stimulate new therapeutic approaches. Emotion dysregulation and ADHD are correlated but are distinct dimensions. Emotion dysregulation is a core aspect of an ADHD diagnosis; the combination constitutes a nosological entity, distinct from both ADHD and emotional dysregulation alone (Shaw et al., 2014; Villemonteix et al., 2014).

Regarding the inferential Hypotheses (4), it was possible to show that the level of EFs determined the level of the remaining variables. Complementarily, the five combination levels of internal and external regulation (SR-ER) were significant negative determinants of EF and of the degree of emotion regulation difficulty (ERD), although differentially. The combination of lower SR-ER levels determined higher levels of EF and emotion regulation difficulty, and vice versa, along a gradient. These results resemble others obtained in our previous investigations (de la Fuente, 2017; de la Fuente et al., 2021a,b), but they must be revalidated by new research studies as well.

Evidence

Based on the results given, it is possible to place the EF construct in direct relationship to the SR vs. ER theoretical model. At the subject level, the SR variable is the inverse of the construct; that is, a high score in executive dysfunction leads to a low score in SRH, while NRH and DRH are high; this allows us to establish a classification continuum of university students in their individual health behavior. At the context level, ER also appears as the inverted side of the construct; that is, a high score in executive dysfunction leads to a low score in ERH, and at the same time, a high score in ENRH and EDRH, allowing us to understand a classification continuum of university students' context, to the extent that it promotes health behaviors. Finally, this research has made it possible to establish an averaged combination continuum of the above variables in a five-level combination heuristic, which accounts for the possible combinations between personal and contextual factors, and their effect on the level of emotion regulation difficulty (ERD).

Limitations and Research Prospects

Limitations due to sample size and invitation to respond may have led to a selection bias. Specifically, there is a clear limitation regarding gender: the sample contains a much higher percentage of women (63.5%) than men (36.5%). In addition, the fact that these results come from a university sample

does not allow extrapolation to other stages of education. At the same time, this may also be considered a goodness: this analysis addresses the question of EF at university level, where there has been little research on this construct. Future research should establish whether this theoretical model can explain and account for other difficulties inherent to students at this stage of education, given the importance of preventive and health promotion programs at this stage of human development.

One prospect of interest, for an adequate connection between the different levels of analysis of self-regulation behavior (microanalysis, molecular, and molar) is to complement the analysis of relationships focused exclusively on personal characteristics, by integrating the role of contextual variables. This is especially relevant when explaining delinquency or sanctionable behaviors, so as not to minimize contextual explanatory variables (Coenen et al., 2021).

Implications for the Psychology Profession

There are several professional and practical implications of this research: (1) The concept of executive dysfunction should be categorized in the proposed SR-NR-DR continuum by the SR vs. ER Theory model (2017, 2021). (2) Assessment of this construct, using the new SR-ER scale, gives us access to information from the personal and contextual regulatory domains, helping us understand that there are personal and contextual factors in protection and risk of dysregulation. (3) Psychological intervention should focus not only on moving the individual from dysregulatory to self-regulatory behavior, but also on moving from a dysregulatory to an externally regulatory context. From the standpoint of educational psychology, interventions can help toward a more regulatory design of formal, non-formal and informal education or teaching-learning contexts. In clinical and health psychology, they can contribute to increasing external regulation through contextual signals that promote health behaviors and satisfaction in the health context, and minimize dysregulatory contexts. In social psychology, progress can be made in helping organizations to avoid dys-regulatory contexts, and to promote and aid self-regulation in the organization. Such intervention can be key in enabling people with problems in EF to work and perform better, as well as in facilitating more adaptive behavior in different behavioral contexts. In short, it is time to complement the microanalysis (neurological) and molecular (clinical) models of executive dysfunction with molar (contextualized) models that allow us to analyze the role of a dysregulatory context in this behavioral problem.

CONCLUSION

The model proposed in the SRL vs. ERL Theory (2017), referring to the Self-Regulation-External Regulation construct, can be a good analysis heuristic for college students' learning and health behaviors, especially if they have any specific EF or emotion regulation difficulties. We must define what level of analysis of learning processes we want to carry out, and, based on this decision, choose the appropriate model. If one's intent is to understand the specific cognitive mechanisms involved in health behaviors, with a high degree of concreteness, it would be appropriate to work in the domain of micro-analysis: the analysis of EFs (Brown and Landgraf, 2010; Diamond and Lee, 2011; Barkley, 2012; Climent-Martínez et al., 2014). If one's objective is to understand the strategies involved in an important learning task, from a clinical perspective, a molecular level heuristic model is a better choice, i.e., general self-regulation (SR) (Liew, 2011; Miller et al., 2011; Ahmed et al., 2019). If one desires to understand difficulty, including the role of context, it seems more useful to adopt a molar level of analysis (SR vs. ER) (Doebel, 2020; Tzuriel, 2021). For all the above reasons, it is essential that we assign models to their proper scope and their object of study, understanding their strengths and limitations. Otherwise, it will be difficult for us to integrate the different existing levels in a coherent analysis of the numerous contributions regarding EF, and to train educators (family members and teachers) in these aspects (Fitzpatrick et al., 2020).

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

This study was reviewed and approved by Comité de Ética de la Universidad de Navarra, ref. 2018.170. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

JF and JM-V: rationale, design, data analysis, and writing. MP-B: review and initial data adjustment. FP-S, MV-M, and MA-R: data collection. All authors contributed to the article and approved the submitted version.

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Effects of factors of self-regulation vs. factors of external regulation of learning in self-regulated study

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Since the mid-20th century, the study of Self-Regulated Learning (SRL) has aimed to identify the distinctive characteristics that enable individuals to acquire new knowledge and skills under their control. The theory of Internal Self-Regulation vs. External-Regulation in Learning (SRL vs. ERL; 2017) has postulated that a large number of self-regulatory variables are mediated by regulated/non-regulated or dysregulated features of the context. After signing their informed consent, a total of 616 university students completed validated instruments of SRL vs. ERL, behavioral regulation (SRB), regulatory teaching (RT), and metacognitive study control strategies (SRS). Using an ex-post facto design and correlation, regression, structural equation model and mediation analyses, the present research aimed to establish multicausal predictive relationships among the analyzed variables. Results indicated positive predictive effects between the external regulation variables on the self-regulation variables in learning [regulation (SRL)/non-regulation (NRL)/dysregulation (DRL)]; as well as positive predictive effects between SRL on SRB, RT and metacognitive SRS. Additionally, external regulation (ERL) not only predicted but mediated numerous relations among the variables studied. Other findings and important considerations for future research in the field of self-regulation are discussed.

KEYWORDS

SRL vs. ERL Theory, self-regulation learning, external regulation learning, self-regulated study, metacognition

Introduction

In European countries such as for example Spain, Switzerland, France, Italy and Germany, the average adult will have been immersed in the formal education system for more than 15 years of their lives (The World Bank, 2021). Over that time, not only will their skills and difficulties associated with learning itself become apparent, but

individuals will also be exposed to a range of contexts that may or may not facilitate the acquisition of new knowledge.

Based on models from prior research, such as Biggs' 3Ps model (Biggs, 2003), the self-regulated learning model (SRL; Zimmerman et al., 2017) and the Theory of Self-Determined Behavior (Ryan and Deci, 2017) it has been posited that *effective teaching* is teaching that builds a teaching-learning environment which encourages learners to be committed to their own learning. More recently, in the framework of *SRL vs. ERL Theory* (de la Fuente, 2017), which puts forward a comprehensive vision of behavioral self-regulation and external regulation in the course of learning, important results have started to be seen in this direction (de la Fuente et al., 2017, 2019, 2020a,b; Pachón-Basallo et al., 2021; de la Fuente, 2022). In relation to SRL, the theory envisages that a student's levels of self-regulation (SRL) and contextual external regulation (ERL) are distinct but complementary variables that combine in varying proportion (high/medium/low) to predict different aspects of the behavior of university students and their academic results.

This study, seeks in particular to explain how contextual variables associated with hetero-regulatory perception (within the family, school and peers) are associated with different levels of behavioral self-regulation in learning, general behavioral self-regulation, the perception of RT and the use of metacognitive strategies before, during and after study behavior. This research seeks to provide significant empirical evidence in the field of self-regulation and external regulation in the processes of teaching and learning.

Self-regulated vs. externally regulated learning

There has been much research in Educational Psychology into SRL. However, that research has tended to focus on the subject and although some account is taken of the role of context, context has been seen as more peripheral and incidental. In fact, rather than seeing context as a 'theater' in which SRL is performed, we need to scrutinize the relationships between the subject and their context in relationship to learning 'with a magnifying glass' in a more systematic fashion. It is necessary, in addition, to carry out that scrutiny on the basis of a specific theoretical model, such as the model proposed by de la Fuente (2017) and have available instruments that are suitable to evaluate the predictions generated by the model.

Self-regulated, non-regulated, and dysregulated learning

The pattern of behaviors that characterize student's predisposition to organize their learning can be broken down as follows:

(1) Self-regulated learning: this topic has been central to research in the psychology of education and among the most investigated by researchers since the mid-20th century (Torrano and González-Torres, 2004). Its influence has extended to many disciplines and fields (Special education, personality, health, business). Interest was first sparked by the work of Banduras on self-regulation of behavior in the 1970s and 1980s. When his research started to be applied to understanding the process of learning, the term SRL was coined and became popular in the 1980s and 1990s (González-Torres and Tourón, 1992; Dinsmore et al., 2008). Starting with the Zimmerman's (1989) work titled *Self-Regulated Learning and Academic Achievement: Theory, Research, and Practice* a significant volume of important research has been conducted up until today (Popa, 2015; Roth et al., 2016; Gambo and Shakir, 2021). SRL is a broad term, such that it is not straightforward to identify and determine its boundaries and key processes. Numerous SRL models and theories developed by researchers focus on the description of the characteristics or attributes of students who self-regulate their learning processes (Roces and González-Torres, 1998; Puustinen and Pulkkinen, 2001; Panadero, 2017).

According to Zimmerman (1988), what characterizes students who self-regulate their learning is their active involvement in the regulation of three dimensions of learning: cognition, motivation and observable behavior. Other authors, such as Corno (1994), Kuhl (2000), and Pintrich (2000), add the dimensions of context and volition, respectively.

In general, those studies emphasize the following characteristics which differentiate students who self-regulate their learning from those who do not (Gonzáles-Torres and Torrano, 2008):

(a) Metacognitively and cognitively: They plan, monitor and direct their mental processes in order to achieve their aims (metacognition); they are aware of and use different cognitive strategies to acquire, develop and recover information.
(b) In terms of motivation, they are capable of generating, monitoring and modifying their motivational beliefs (for example: goals and expectations of self-efficacy) and their emotions to adapt them to the demands of a given task and a given learning situation.
(c) In terms of behavior, they are capable of creating and structuring environments that are conducive to learning (finding a suitable place to study, asking for help from teachers and classmates when they need it (help-seeking).
(d) In terms of context, whenever possible they join with the teacher in the selection and control of matters concerning tasks, the organization of classes, etc.
(e) In terms of volition, they are capable of creating and following habits that enable them to maintain their concentration, application and task persistence despite internal and external distractions.

One of the best known and accepted models, from a sociocognitive perspective, is the one proposed by Zimmerman (1989, 2015) which describes the different processes that are conducive to self-regulation of learning in three cyclical phases:

(A) Phase One, *preparation or planning*, takes place before the attempted learning starts. Its important elements are: goal setting, analysis of the tasks to be performed and the selection of the resources and strategies that will be used to achieve the goals set. In this phase, it is key to activate interest and beliefs in self-efficacy. To that end, specific, proximate and challenging goals are more effective than diffuse, delayed or easy goals to task motivation and good performance (Bandura and Schunk, 1981).
(B) Phase Two, *performance/control*, concerns performance, continuous monitoring and adjustment exercised by the subject during the task (maintenance of attention, observing, overseeing and monitoring progress (self-monitoring), self-instruction for the development of information, monitoring time and degree of application, mood, etc.).
(C) Phase Three, *final self-assessment*, comes after the performance phase and involves self-assessment of what has been achieved. Here, the subject reflects on what they have learned, on the level of performance reached in relation to the goals set, on the reasons for any successes or failures (causal attribution), evaluates their emotional reactions and degree of satisfaction, thinks about where and how to transfer what they have learned to other situations, and tries to identify errors so as to do better in future self-regulation cycles to address other tasks (Brainerd et al., 1989; Zimmerman et al., 2017).

As we can see, a student who adequately regulates their learning will demonstrate expertise in the process and the different phases described above, which are substantially the phases recognized by all models of SRL. However, we can place many students who behave in an unregulated manner or whose behavior is even dysregulated, at different points along a regulatory 'continuum'. SRL vs. ERL Theory (de la Fuente, 2017) identifies these other levels of behavioral regulation.

(2) *Non-regulated learning (NRL)*: NRL can be conceptually defined as a lack of proactivity or the absence of self-regulatory behaviors (SRB) in the process of learning. Conceptually, it is equivalent to what has been mentioned by Zimmerman and Labuhn (2012) and Cohen (2012) in relation to reactive methods during the planning and performance phases. In this case, the individual is at the mercy of the external regulatory system to determine how they should behave.
(3) *Dys-regulated learning (DRL)*: DRL is a negative level of proactivity, i.e., an approach that is active but inadequate to regulate the individual's own learning behavior. As can be seen, this dysregulation can have 'negative consequences' in terms of maintaining self-esteem, because individuals avoid the effort involved in proactive self-regulation and use self-handicapping, procrastination strategies, increased cheating in the exam hall, psychological reactance or other disruptive behaviors that ultimately do not promote learning or good psychological and moral adjustment (Valle et al., 2007; Muntada, 2013; Kapoor and Kaufman, 2020; Kapoor et al., 2021; Pachón-Basallo et al., 2021; Bakhtiar and Hadwin, 2022; Navarro-Patón et al., 2022).

External regulation, external non-regulation, and external dys-regulation of learning

General SRB and SRL are somewhat context-dependent, as underlined by Bandura. There are notable cognitive-social models that underlie research in this field, such as Zimmerman (2000, 2008). However, research has focused more on the description of the characteristics of students who self-regulate their learning. Although there are many studies as to how self-regulation can be supported, there is still a need for further studies that explore in detail the role of context in different fields (academic, social, family) and different levels (e.g., from the key elements of RT in general to instructional models of specific learning strategies). Further empirical evidence from that line of enquiry is necessary in order to explore further subject-context relationships and the different interactions that arise that are also the subject matter of SRL vs. ERL Theory.

That theory proposes that just as the subject can present three levels of self-regulation (regulation of behavior/learning; non-regulation of behavior/learning and dysregulation of behavior/learning), there are also contexts that make self-regulation more likely to occur, do not promote self-regulation or tend to lead to dysregulation of the subject. SRL vs ERL Theory therefore, categorizes external regulation in three levels (de la Fuente, 2017) that may be experienced by students in function of different patterns of signals and behaviors in the academic and other contexts that they inhabit. Those proposed levels are explained below:

(1) *Externally regulated learning*: In relation to the environment, Zimmerman and Schunk (1989) have highlighted the importance of the links between autonomous functioning and the context, specifically in the functional relationship between conduct and the environment. They emphasized the role of methods of instruction such as modeling, verbal instruction and reinforcement. According to them, external contingencies gradually promote self-regulatory responses. The presence of effective models is key to promoting a person's capacity to regulate their own learning (Zimmerman and Schunk, 1989; Nilson, 2013). The distinctive feature of this type

of regulation is that the context promotes positive or adequate proactivity. Thus, a regulatory context provides numerous stimuli that promote SRB in students, before, during and after the studying/learning processes. Those stimuli arise from background (patterns, standards, limits, expectations of successful self-regulation, value attributed to self-regulation, etc.) and from contextual consequences (positive and negative contingencies that favor self-regulation, adaptation, etc.). It has been found that a regulatory context negatively predicts psychological reactance and positively predicts self-regulation and academic confidence (de la Fuente et al., 2021b; Pachón-Basallo et al., 2021).

(2) *Externally NRL (ENL):* this level is characterized by the absence of stimuli that promote SRB in students: there are no external signs or stimuli that make self-regulated or unregulated behavior more probable at the beginning, during or at the end of the subject's behavior in a learning situation. In a non-regulatory context, which is neutral toward regulation, an individual may engage in at least a moderate level of SRB, because there are no features of the context to steer them either toward greater self-regulation or toward dysregulation of their behavior. An example of external deregulation in the classroom might be the absence of clear guidance from the teacher as to the use of mobile devices in class when it is known that indiscriminate use of such devices by students is associated with increased cyberbullying, cheating and poorer mental health (Smale et al., 2021).

(3) *Externally DRL (EDL)*: in this level, a student's context actively promotes dysregulation of learning. That is, "non-positive, inadequate, or negative proactivity" is externally promoted. There are many external signs or stimuli that make dysregulation of behavior more likely, favoring active dysregulation at the beginning, during and at the end of the behavioral episode. In this type of context, the individual has to make a great effort to attempt to self-regulate their behavior (de la Fuente, 2017). An example of this low level of external regulation might be manifested in inadequate, neglectful parenting and the influence of peers in encouraging the individual to adopt risky, dangerous behaviors that are counterproductive in terms of behaviors of academic engagement etc. (Pinho et al., 2021; Pérez Posada and Londoño-Vásquez, 2015).

Behavioral self-regulation and regulatory teaching

Self-regulatory behavior

The construct of behavioral self-regulation has been extensively researched since the end of the twentieth century in multiple scenarios. SRB is conceived as a meta-skill in which cognitive processing is under control rather than automatic, such that through self-monitoring, self-evaluation, self-reinforcement/feedback the individual is capable of planning, guiding and monitoring their behavior in a way that responds flexibly to changing circumstances (Kanfer, 1986, 1970; Miller and Brown, 1991; Brown, 1998; Miller and Rollnick, 2013).

Carver and Scheier (1998) speak of the *cybernetic cycle* of SRB characterized by four stages: *test, operate, test, and exit*. The authors explain that a subject's current behavior undergoes a process in which the subject compares it with a desired target behavior and then operates/acts to adjust their behavior until they confirm that their level of performance is at the initial target level. When the answer at the test stage is positive, the subject moves to the exit stage and the cycle starts again. In summary, SRB is behavior that seeks to reduce the discrepancy between target (desirable) behaviors and actual behaviors. That requires the person to be capable of constant feeding back to themselves concerning the narrowing or widening of any gap and adjusting their efforts and strategies to achieve the target behavior.

Self-regulated behavior and a lack of SRB have been extensively linked to sports performance, driving behavior in traffic psychology and to the general notion of people's lifestyle (Hennessy et al., 2011; Miller and Rollnick, 2013; Goffena and Horn, 2021). Many deficits of self-regulation have been linked specifically to risk behaviors such as substance abuse, impulsivity, procrastination, problem behaviors relating to food, etc. Also, from a social perspective, deficit of self-regulation has been linked to crime, teenage pregnancies, STIs, gambling addiction, domestic violence, etc. (Miller and Brown, 1991; Baumeister and Heatherton, 1996; Brown et al., 1999; Garzón-Umerenkova et al., 2018; Watson-Brown et al., 2021); Baumeister and Heatherton (1996) indicate that deficits in or lack of the capacity to self-regulate may be due to failures of self-control, of realistic goal selection, to the absence of skills compatible with the target behaviors, etc. Karniol and Miller (1983) in turn indicate that such failures of self-regulation may be preceded by changes in attention to different types of reward. Self-regulation requires the selection of long-term reward in preference to immediate reward that at any given moment could appear more attractive (Duckworth et al., 2013).

Regulatory teaching

Entwistle and Peterson (2004) suggest that effective teaching takes place when a teacher creates a classroom atmosphere in which students commit to processing content and take responsibility for their own learning. In that connection, RT (de la Fuente et al., 2012) has been defined as a contextual variable in which teaching externally promotes and favors SRL in students (Yerdelen and Sungur, 2019). Empirical research identifies high-quality teachers as those who positively influence the commitment of their students to learning activities and to their own learning performance (including social skills,

academic performance and self-regulation; Goe et al., 2008; de la Fuente et al., 2012).

Instruction is an intentional process, such that it is the educator's self-regulation of their teaching process that allows them to take effective decisions in the different phases of the educative process (Biggs, 2001, 2003). Various mediating factors in students' self-regulation of their learning and performance depend on the teacher as *adaptive expert* (Hammerness et al., 2005). The determination of clear teaching goals derived from an assessment of needs, the organization of content and planned activities carried out in the classroom to foment deep processing and evaluate it (Roehrig and Christesen, 2010). That is why the perception that students have of how their teachers teach is fundamental. Recent research has shown that variables of the learning environment perceived in the classroom are good predictors of self-regulation of learning by students and their self-perception (Biggs, 2001; Zimmerman, 2002; Pintrich, 2004; Schunk, 2005; Monereo, 2007; Schuitema et al., 2012).

The perception that students have of their educational experience is similarly a widely studied variable in multiple contexts. Regulatory learning, first, facilitates students' monitoring of their own academic performance and their satisfaction with learning. There is evidence that the gradual increase of internal and external regulation predicts increased academic confidence and decreased procrastination behaviors (de la Fuente, 2017; Putwain and Pescod, 2018; de la Fuente et al., 2021a); Baherimoghadam et al. (2021) found that even in online teaching processes there is a significant relationship moderated between perceptions of self-efficacy (i.e., the beliefs that students have about their own capacity to organize and execute the courses of action required to achieve specific outcomes (Bandura, 1986) and the level of satisfaction with the learning process.

It is important to note that educational institutions are themselves extremely interested in the perception that students have of the teaching that they receive. In fact, student satisfaction with the teaching-learning process is used as a measure of educational quality (Booth et al., 1999; Bobe and Cooper, 2019). A recent meta-analysis by Caskurlu et al. (2020) indicates that numerous studies have shown that the presence of teaching staff significantly predicts student satisfaction. Anderson et al. (2019), define RT as the design, direction and facilitation of social and cognitive processes that the teacher offers with the aim of obtaining learning outcomes that are significant to the student. Continuous feedback and direction, promotion of motivation, interest and commitment are essential components of RT.

In the aggregate, whilst student satisfaction with the teaching-learning process is generally associated with different factors such as teaching methods, course content, the learning environment, relationships with administrative departments and the learning community (Holdfor and Patkar, 2003), the research carried out by Wu et al. (2015) revealed that it is course content that best predicts that satisfaction. They placed particular emphasis on the planning of course content that matches the needs of students. In addition, those authors found that satisfaction with learning predicts the intention to continue to participate in future formal educational processes.

By way of summary, it can be assumed that adequate design and implementation by teachers of the teaching-learning process will facilitate students seeing learning as theirs, regulating it procedurally and attitudinally (knowing how, wanting to know and doing) and not just conceptually (knowing) (de la Fuente et al., 2014).

Metacognitive study control strategies

As has been said, students can regulate three important dimensions of learning: cognition, motivation/emotion and apparent behavior, as well as context factors. To do so, they use different kinds of strategies: cognitive, metacognitive and support (Dansereau, 1985; González-Torres, 1997; González-Pienda et al., 1998; Pintrich, 2004).

Cognitive strategies include study habits and different resources that assist in the process of comprehension, codification, and recall of information that Weinstein and Mayer (1986) break down in their well-known classification as: strategies of rehearsal, elaboration and organization. Those strategies and so-called *support strategies* (Dansereau, 1985), which indirectly assist cognitive processing by creating a psychological climate that is conducive to the maintenance of concentration and motivation, are not in themselves sufficient to ensure good learning. What really distinguishes students who learn well from those who learn badly is not just, as Nisbet and Shucksmith (2017) would say, the possession of a certain level of intelligence or a series of effective study methods or techniques, but the capacity to capture the demands of the task and monitor the learning situation and that is called metacognition. So-called metacognitive or secondary strategies (Dansereau, 1985) are at the heart of SRL, they are key to it. A student's learning will be poor if they do not know and they are not shown how to plan, monitor and direct their own mental and psychological processes to adjust those processes to the demands of the task (González-Torres, 1997).

Metacognition, a term introduced by Flavell (1987) includes two dimensions: (a) metacognitive knowledge which includes being aware of the personal variables of the task and the strategies that affect performance on a task and (b) metacognition as self-monitoring. Metacognition in this regulatory dimension includes three principal ingredients: planning, monitoring and evaluation of what has been achieved. A student who monitors their learning process is a student who asks themselves questions such as: what is the purpose of the task? What strategies am I going to use? Am I achieving what I set out to do? What have I achieved and how can I improve? That reflective attitude before, during and at the end

of the learning process makes students expert strategic thinkers or learners (Flavell, 1987; Ertmer and Newby, 1996; González-Torres, 1997).

There has been considerable research into the metacognitive and behavioral strategies that students use during a specific study activity (Lanza and Sánchez, 2014; Campano et al., 2017). The *Strategies for Control of Study Questionnaire* by Hernández and García (1995) assesses metacognitive strategies in three dimensions or factors: planning, oversight and review.

Planning includes behaviors in which the activities to be performed are organized in specific orders, including the time allowed for each in order to meet a study goal. This sub-category also includes, as González-Torres and Tourón (1992) mention, subdivision of tasks, the generation of questions in the face of new material, creating hypotheses, etc. *Oversight* includes review of what has been studied, including aspects that could be improved, i.e., the efforts that a student makes to observe their own behavior (Rodríguez, 2009). Finally, the *factor of review* includes the search for help from third parties when it is required and the self-evaluation of everything done over the period of study. In the *evaluation* phase, as Rodríguez (2009) indicates, the subject engages in reflection concerning the study process and their own learning, feeding back into the choice of study methods to achieve their next objectives.

It is important to note that there have been studies looking at whether there are or are not variables that could affect the use of those strategies such as might be age, academic year (Aluja-Fabregat and Blanch, 2004; Inglés et al., 2013; Campano et al., 2017). In the study conducted by Inglés et al. (2013), it was found that the use of learning strategies stagnates as students reach later academic years. The authors explain that this may because around fifteen years of age, students have already settled on strategies that they consider effective and tend to reuse them. However, in university populations it has been found that there are significant differences between different academic levels and the use of metacognitive strategies. Students who are approaching the end of their degrees are those who most use such strategies (Martínez-Fernández, 2007).

Elsewhere, a positive relationship has been observed between the use of metacognitive strategies and academic performance (Caso-Niebla and Hernández-Guzmán, 2007; Young and Fry, 2012). In the research undertaken by Caso-Niebla and Hernández-Guzmán (2007) in a population of more than 1500 students, they were able to determine that women tend to make the greatest use of study strategies and skills. In addition, the evidence also indicates (Rodríguez, 2009) that the use of control strategies in study is related to the orientation/motivation of a student toward learning. Motivational variables may influence not only performance but also the quality with which storage, processing and use of information operations that form part of the process of study are performed (González-Torres and Tourón, 1992; González-Torres, 1997). Thus, as shown by McCombs and Marzano (1990), the characteristics of students who regulate their learning are a combination of *Will* and *Skill*.

In other significant research, it has been found that pro-social behavior significantly positively predicts the use of study strategies such as the selection of the principal ideas to be studied, the search for help, self-evaluation and exam preparation, among others (Inglés et al., 2013). Finally, Lanza and Sánchez (2014) were able to conclude that no significant differences in terms of the use of learning strategies in relation to the parental support in the conducting of study tasks are found. However, the variable did impact student's organization and self-regulation.

Objectives and hypothesis

Despite the extensive evidence mentioned, there is still scant information concerning predictive and mediating variables relative to metacognitive regulatory strategies in the course of study, specifically concerning the effects of students' contexts. Consequently, the objective of this study was to determine those predictive relationships. The following hypotheses were postulated:

Hypotheses of association

(1) We expected to find a positive correlation between learning regulation variables of the subject and their context (SRL/ERL), and variables of general SRB, RT, and self-regulated study behavior (SRS). We also expected to find a negative correlation between the variables of non-regulation and dysregulation of the individual and their context (NRL/ENL and DRL/EDL) with those same variables (SRL/ERL/SRB/RT/SRS).

(2) We expected to find a positive correlation between corresponding internal and external levels of regulation of learning: (regulated) SRL with ERL; (non-regulated) NRL with ENL, and (dysregulated) DRL with EDL.

Predictive linear hypotheses

(3) It was expected that large part of the variation in the variables of SRB, RT, and SRS would be explained by variables of both subject and context (SRL/NRL/DRL-ERL/ENL/EDL). And that SRL would positively predict RT and general SRB. Together, SRL and RT would positively predict SRS. We also expected that SRB would be negatively predicted by both NRL/ENL and DRL/EDL.

(4) Each level of external regulation of learning will predict the same level of self-regulation: ERL will predict SRL; ENL will predict NRL; EDL will predict DRL. In complementary fashion, both internal and external non-regulation will positively predict internal and external dysregulation of learning, that is: ENL predicts EDL and NRL predicts DRL.

(5) We expected to find significant models of mediation in which especially SRL mediates the relationship

between contextual variables and other personal variables such as NRL and DRL.

Materials and methods

Participants

A total of 616 students from different universities voluntarily participated in this research. The sample was composed of students particularly in the fields of psychology, education and other social sciences. Of the total, 68.9% were women and 31.1% were men. The age range was 17–34 and the mean age was 22.19 years (SD = 3.19). The sample was incidental rather than probabilistic because the sample could not be randomized. The students voluntarily completed self-reports in a learning context (i.e, classes of different university subjects). Participation was anonymous and voluntary. The questionnaires were completed online.

Instruments

Self-regulation vs. external regulation of learning

That questionnaire (de la Fuente, 2020), is structured in six sub-scales, with six items each that assess behaviors related to learning, both in the person and their context: (1) SRL ("I am aware of my learning and academic performance needs."). (2) ERL ("The context in which I live (family, setting, friends) helps me to plan my behavior, through learning, study and performance goals and objectives."). (3) Internally NRL ("I don't need to make any decisions to make changes in my learning and study behaviors."). (4) Externally NRL ("In the context that I live in (family, environment, friends) we rarely talk about my behavior and what I need to do to improve my learning, study and academic performance."). (5) Internally dysregulated learning (DRL) ("I take decisions to have the most fun, even at the expense of my learning, study and performance aims."), and (6) EDL ("The context in which I live (family, environment, friends) encourages me to focus on taking decisions to enjoy the moment and to postpone learning and study decisions that are important for me."). Its confirmatory factorial structure is consistent in this sample (Chi Square = 1650,992, df = 579, $p < 0.001$; Ch/df = 2.851; RMSR = 0.05; IFI = 0.91; TLI = 0.90; CFI = 0.91; RMSEA = 0.05). The internal reliability figure for the instrument was good ($\alpha = 0.87$; $\omega = 0.84$).

Self-regulated behavior

This variable was measured using the abbreviated version of the Self-Regulation Questionnaire (SRQ; Miller and Brown, 1991). That instrument has been validated in Spanish samples (Pichardo et al., 2018) and has acceptable validity and reliability values comparable to the English version. The abbreviated SRQ is composed of four factors: (1) Goal-setting ("Once I have a goal, I can usually plan how to achieve it."). (2) Perseverance ("I am easily distracted from my plans."). (3) Decision-making ("When it comes to deciding on a change, I feel overwhelmed by the decisions."), and (4) Learning from mistakes ("Usually, once I've made a mistake once, I learn from it."). It has 17 items (all with saturation >0.40) with a consistent confirmatory factorial structure (Chi-square = 595.052, df = 113, $p < 0.001$; Ch/df = 5.26; SRMR = 0.07; CFI = 0.97, RFI = 0.96, IFI = 0.97, TLI = 0.96, GFI = 0.97, RMSEA = 0.08). Internal consistency was acceptable for the total of items in the questionnaire in this sample ($\alpha = 0.84$; $\omega = 0.84$).

Regulatory teaching

The abbreviated Interactive Evaluation of the Teaching-Learning Process Scales (EIPEA, in Spanish) (de la Fuente et al., 2012), were used to assess students' perception of how they see the provision of teaching, their SRL on their course and their satisfaction with both. The instrument has three dimensions: (1) RT, which incorporates the factors of evaluation, preparation, satisfaction with teaching ("When we are learning, the teacher helps us to set clear, realistic learning goals."), (2) SRL, which refers to factors of planning, significant learning and the use of study techniques ("Before starting a learning activity or task, I usually consider what I need to know and how long I have to give to it."). (3) Outcome, comprising two factors associated with the final product of the learning process: satisfaction with learning and significant learning ("I have learned the goals set well enough."). In this abbreviated version, 37 items were used and the confirmatory factorial structure of the scale was acceptable ($\chi^2 = 2260{,}907$, df = 492, $p < 0.001$; Ch/df = 4.59; SRMR = 0.05; CFI = 0.84, NFI = 0.85, RFI = 0.802, TLI = 0.83, NNFI = 0.80, RMSEA = 0.07) and the internal reliability value of the instrument is excellent ($\alpha = 0.94$; $\omega = 0.96$).

The regulatory strategies in study questionnaire (SRS)

This questionnaire (Hernández and García, 1995), has a structure with 17 items and three factors, which are planning, oversight and review. Completion of the questionnaire requires students to indicate the extent to which they agree with the strategies used, both at the outset ("Before starting to study, I usually think about what I need to study, what activities I have to do or how much work or time studying is going to take."), during ("If there is something I don't understand or don't know how to do, I try not to move forward until I have understood it.") and at the end of periods of study ("When I have studied a topic and it's been a while, I try to go back over it or refresh it in my memory before a test or exam."). There are five possible responses from "1. If you never usually do what the sentence says" to "5. If you normally do it a lot

or always." The confirmatory factorial structure for the scale is consistent in this sample (χ^2 = 462,242, df = 116, $p < 0.001$; Ch/df = 3.98; SRMR = 0.05; CFI = 0.90, GFI = 0.91, AGFI = 0.90, RMSEA = 0.07) and the internal validity value is good ($\alpha = 0.86$; $\omega = 0.85$).

Procedure

The participants in this research were invited to participate in the study voluntarily. After giving informed consent, they completed the scales using an online platform that ensured the anonymity of their responses. Students registered on the platform at this url: http://www.inetas.net. That tool provides assessment and intervention in a self-help system for the university students and their teachers. The R&D project was approved by the Ethics Committee of the University of Navarre (ref. 2018.170). Compliance with the ethical principles of psychology was ensured (de la Fuente et al., 2015).

Data analysis

As a preliminary step, we confirmed the normal distribution of the sample by the Kolmogorov–Smirnoff test for dependent variables (Lohr, 2010). We also used the Hoelter index to determine the adequacy of the size of the sample (Tabachnick and Fidell, 2001). Analyses of linearity and atypical values, missing cases and critical multivariate normality values were in addition performed. The values recommended for the multivariate kurtosis ratio or Mardia's coefficient were below 70 (Mardia, 1970).

For the association hypotheses (1 and 2), bivariate Pearson correlations were performed. For the prediction hypotheses (3, 4. and 5), linear regression analyses were used, and it was confirmed through remainder analysis that the data were adequately compliant with the assumptions of the linear regression model. Subsequently, predictive structural equation modeling (SEM) was performed (Weston and Gore, 2006; Kline, 2016). For that purpose, we followed the recommendations of Hu and Bentler (1999) and Hair et al. (2010), in which a model is adequately adjusted to the observed data when the ratio of chi-square to the degrees of freedom is below five, RMSEA and SRMR are <0.08 and NNFI (non-normal fit index), IFI and CFI are >0.90 for an acceptable model (Jöreskog and Sörbom, 1998). We used maximum likelihood of robust standard errors (MLR estimation) for estimation given its applicability to non-normal data. Participants with missing data were included in the estimation of the model using full information maximum likelihood (FIML) to avoid any distortion of analysis from missing values (Enders and Bandalos, 2001). Reliability of the dimensions of the model, of the overall structure and each of the factorial structures proposed was also examined by calculation of Cronbach's alpha (Quero-Virla, 2010). In addition, account was taken of the recommendations of Keith (2019) for cutoff criteria for direct and indirect effects: <0.05 deemed to be too small to be significant, above 0.05 is small but significant, effects above 0.10 are moderate and above 0.25 are large effects.

The computer programs used to conduct this analysis were SPSS 26.0 (IBM Corp, 2019) for reliability and AMOS v. 23.0 (Arbuckle, 2014) for confirmatory factorial analysis and SEM.

Results

Prior analyses

The results of the Kolmogorov–Smirnov test ($p < 0.001$) and the Shapiro–Wilk test ($p < 0.001$) were significant, such that analyses appropriate for non-parametric samples were performed. In general terms, regulatory variables (SRB; SRL; ERL; RT; RS) had means and medians higher than those for non-regulation or dysregulation, both internal and external. In addition, those variables showed negative asymmetry in which the values observed tended to be concentrated in the superior/higher segment of the relevant scales (see **Table 1**).

Linear association

The internal and external variables of regulation of learning (SRL/ERL) were significantly positively correlated with each other. In addition, the different levels of both internal and contextual non-regulation and dysregulation were significantly positively correlated (NRL/ENL, DRL/EDL). Levels of SRL and ERL were significantly negatively correlated with levels of internal and external non-regulation and dysregulation (NRL/ENL, DRL/EDL).

Following the same trend, and relative to the variables of SRB and RT, the results showed significant positive correlations between those two variables and SRL and ERL. SRB and RT were significantly negatively correlated with NRL/ENL and DRL/EDL.

Finally, SRS tended to be significantly positively correlated with RT, SRB and with SRL and ERL. Conversely, SRS was significantly negatively correlated with DRL/EDL and NRL/ENL (see **Table 2**).

Linear and structural prediction

Linear regression

Table 3 shows the linear regressions for different variables (in bold), relative to different groups of independent variables. Almost half (47%) of the variability of SRB was explained by SRL and ERL/NRL and DRL/EDL (but not ENL) [$F(8,608 = 94.088$, $p < 0.001$)]. SRL and ENL were the most significant subject variables.

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TABLE 1 Preliminary analyses.

	SRB	SRL	NRL	DRL	ERL	ENL	EDL	RT	SRS
Mean	3.333	3.874	2.654	2.409	3.670	2.604	2.353	3.781	3.852
Mean standard error	0.024	0.029	0.028	0.035	0.039	0.037	0.039	0.026	0.023
Median	3.350	4.000	2.666	2.333	3.833	2.666	2.166	3.831	3.865
IQR	0.80	1.00	1.00	1.17	1.33	1.17	1.50	0.80	0.83
Mode	3.23	4.00	2.50	2.33	5.00	3.00	1.00	3.00	5.00
Standard deviation	0.605	0.743	0.711	0.874	0.979	0.933	0.981	0.645	0.588
Asymmetry	−0.239	−0.422	0.219	0.361	−0.530	0.153	0.388	−0.651	−0.455
Standard asymmetry error	0.099	0.098	0.098	0.099	0.098	0.098	0.098	0.098	0.099
Kurtosis	0.058	−0.311	0.107	−0.227	−0.244	−0.384	−0.535	0.778	0.248
Standard kurtosis error	0.197	0.197	0.197	0.197	0.197	0.197	0.197	0.197	0.197
Range	3.53	3.33	4.00	4.50	4.17	4.17	4.17	4.00	3.50
Minimum	1.38	1.67	1.00	0.50	0.83	0.83	0.83	1.00	1.50
Maximum	4.90	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00

SRB, self-regulated behavior; SRL, self-regulated learning; NRL, non-regulated learning; DRL, dysregulated learning; ERL, externally regulated learning; ENL, externally non-regulated learning; EDL, externally dysregulated learning; RT, regulatory teaching; SRS, self-regulated study; IQR, interquartile range.

TABLE 2 Bivariate correlations between SRL vs. ERL variables and SRB, RT, and RS (n = 616).

	SRL	NRL	DRL	ERL	ENL	EDL	SRB	RT
SRL								
NRL	−0.399***							
DRL	−0.264***	0.658***						
ERL	0.513***	−0.219***	−0.159***					
ENL	−0.263***	0.512***	0.532***	−0.292***				
EDL	−0.161***	0.469***	0.638***	−0.153***	0.650***			
SRB	0.455***	−0.311***	−0.289***	0.312***	−0.203***	−0.135**		
RT	0.544***	−0.267***	−0.218***	0.351***	−0.220***	−0.181***	0.412***	
SRS	0.548***	−0.219***	−0.190***	0.378***	−0.200***	−0.156***	0.375***	0.585***

SRL, self-regulated learning; NRL, non-regulated learning; DRL, dysregulated learning; ERL, externally regulated learning; ENL, externally non-regulated learning; EDL, externally dysregulated learning; SRB, self-regulated behavior; RT, regulatory teaching; SRS, self-regulated study.
**$p < 0.05$, ***$p < 0.001$.

In relation to RT and SRS, it was observed that for both variables, approximately half of the variability (52 and 49%, respectively) was explained by the variables of SRL and ENL. With a lesser degree of significance ($p < 0.05$), the variability of SRS was partially negatively explained by EDL [$F(6, 608) = 101.257$, $p < 0.001$)]; similarly, SRB explained more than half of the variation of EDL [$F(2, 613) = 453.028$, $p < 0.001$)].

Within SRL and ERL, it was found that ERL and RT explained approximately 53% of the variability of SRL [$F(2, 613) = 354.817$, $p < 0.001$)]. In turn, around 28% of NRL was explained by ENL [$F(1, 614) = 264.047$, $p < 0.001$)]. The same pattern was found with dysregulation variables: EDL together with NRL explained more than 50% of the variability of DRL [$F(3, 600) = 214.772$, $p < 0.001$)].

Structural model

Two models of structural equations were tested: **Model 1** tested the prediction for the relationship between the external factors of ERL, ENL and EDL with the internal factors of SRL, NRL, and DRL; and for the relationship between RT and SRB, SRL and ERL and the predictive effect of SRL, RT, and EDL in relation to SRS. **Model 2** generated the closest ratios and prediction of internal variables by external variables was maintained. We tested SRL as a predictor of RT, SRS and SRB. We also assessed the predictive effects of NRL for SRB; of SRB and RT for SRS; of RT for SRS; and, ENL for SRL (see Table 4; Figure 1).

Direct and indirect effects

In relation to the direct predictive effects or internal and external self-regulation, the results showed that SRL positively predicted SRB, RT, and SRS. In turn, NRL had a significant positive direct effect on DRL and a negative predictive effect for SRB. In relation to external factors, ERL had an important predictive effect for SRL and a negative predictive effect for ENL. ENL had significant positive predictive effects for NRL and EDL; conversely, ENL was negatively predictive for SRL. EDL had a positive predictive effect for DRL. Finally, RT had

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TABLE 3 Standardized simple linear regression coefficients (n = 616).

	β	T	Significance	R^2
(1) SRB				0.476
SRL	0.544	15.666	0.000	
NRL	−0.155	−3.679	0.000	
DRL	−0.172	−3.672	0.000	
ERL	0.099	2.829	0.005	
ENL	0.033	0.767	0.443	
EDL	0.101	2.300	0.022	
(2) RT				0.523
SRL	0.597	18.012	0.000	
NRL	−0.071	−1.776	0.076	
DRL	−0.072	−1.610	0.108	
ERL	0.150	4.502	0.000	
ENL	0.015	0.375	0.707	
EDL	−0.014	−0.328	0.743	
(3) SRS				0.495
SRL	0.629	18.449	0.000	
NRL	0.011	0.275	0.784	
DRL	0.003	0.063	0.950	
ERL	0.122	3.564	0.000	
ENL	0.008	0.192	0.848	
EDL	−0.089	−2.067	0.039	
(4) SRS				0.595
SRB	0.437	14.436	0.000	
(5) SRL				0.537
ERL	0.227	7.301	0.000	
RT	0.598	19.236	0.000	
(6) NRL				0.286
ENL	0.535	15.686	0.000	
(7) DRL				0.518
ERL	−0.015	−0.511	0.610	
NRL	0.406	12.222	0.000	
EDL	0.418	12.618	0.000	

SRB, self-regulated behavior; SRL, self-regulated learning; NRL, non-regulated learning; DRL, dysregulated learning; ERL, externally regulated learning; ENL, externally non-regulated learning; EDL, externally dysregulated learning; RT, regulatory teaching; SRS, self-regulated study.

a positive predictive effect for SRB and SRS (see Table 5; Figure 1).

In relation to indirect predictive effects (see Table 5), it was found that SRL had positive indirect effects for SRB and SRS. In relation to contextual variables, ERL was the variable with the greatest number of indirect effects on other variables: it had a negative effect for NRL, DRL, EDL, SRB, RT and SRS. ENL had an indirect positive effect for DRL and conversely showed a negative indirect effect for SRB.

Mediation relationships

Taking into account the direct and indirect effects described and through an analysis of the total effects (Table 5), we found eight full simple mediations and two full multiple mediations, i.e., relationships in which the predictive effect was not direct but rather mediated by other variables. They are described below:

Self-regulated learning mediated the relationship between: (1) ERL and SRS; (2) ENL and SRS; (3) ENL and SRB; (4) ERL and SRB; (5) ERL and RT; and (6) ENL and RT. ENL mediated the relationship between: (7) ERL and EDL; and (8) ERL and NRL.

The following were characterized by multiple mediation: the relationship between ERL and DRL, which was mediated by the indirect effects of ERL and of EDL as well as NRL. The relationship between ENL and DRL was mediated by the direct effects of the relationships between ENL and NRL and EDL.

Three partial mediations were found: (1) **RT** partially mediated the relationship between SRL and SRB and (2) and between SRL and SRS. Finally, we found evidence that the predictive relationship of ERL relative to SRL was partially mediated by **ENL**.

Discussion

All students can learn to regulate their learning, because the capacity for self-regulation is not a personality type or trait that a person cannot control, but rather something modifiable and capable of change that can be improved with, among other things, the help of an appropriate teaching environment (Roces and González-Torres, 1998; Bakhtiar and Hadwin, 2022). The findings of this study are consistent with other prior studies which highlight the importance of context in predicting regulatory behavior among students; they are significant not only in the field of education but in all contexts in which students need to exercise control over their own behavior. Thus, although the SRL vs. ERL model arose in the context of SRL, it has at least in part shown itself to be a miore generally applicable model (SR vs. ER) which can be used to assess self-regulation and external regulation in other contexts, such as health (de la Fuente, 2017, 2020, 2021; Hwang et al., 2021; Pachón-Basallo et al., 2021).

TABLE 4 Models of structural linear results for the variables.

Model	χ^2	DF	CH/df	SRMR	$p<$	IFI	TLI	CFI	RMSEA	HOELT 0.05	HOELT 0.01
1	2805.967	978	2,869	0.076	0,001	0,876	0,869	0,876	0,055	231	238
2	2224.142	905	2,446	0.065	0,001	0,908	0,911	0,909	0,048	272	270

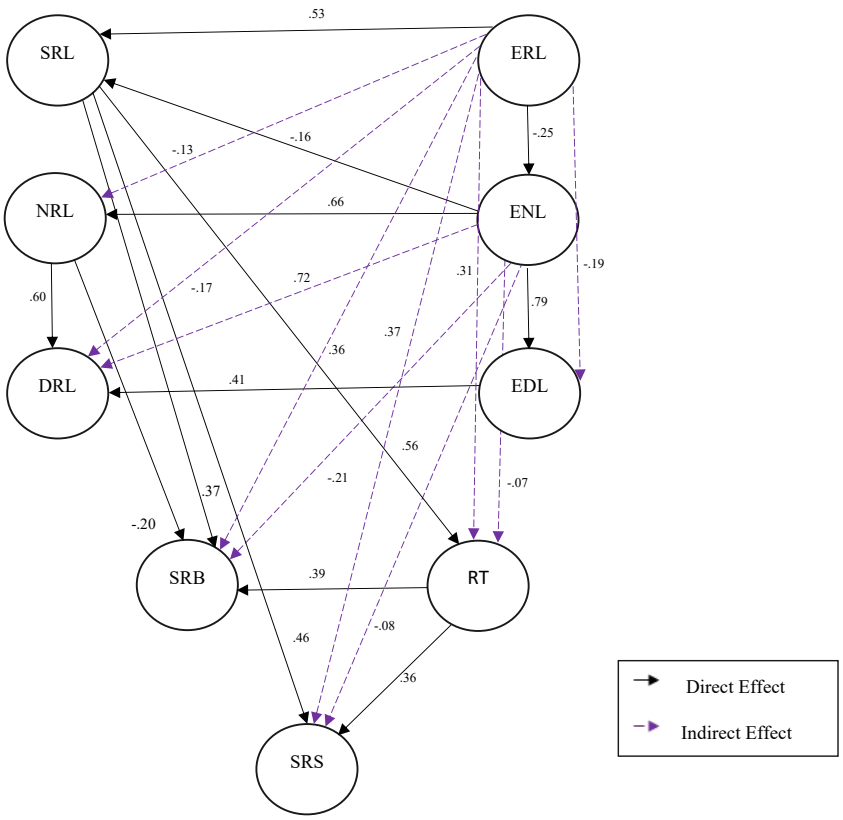

FIGURE 1
Predictive structural equation model: direct and mediational effects. SRL, self-regulated learning; NRL, non-regulated learning; DRL, dysregulated learning; ERL, externally regulated learning; ENL, externally non-regulated learning; EDL, externally dysregulated learning; SRB, self-regulated behavior; RT, regulatory teaching; SRS, self-regulated study.

Thus, in relation to hypotheses 1 and 2, the results showed that SRL and ERL were positively correlated with RT, SRB and with SRS. Those variables (RT, SRB, and SRS), were significantly negatively correlated with NRL and ENL. That is consistent with the findings of earlier research and is evidence of the external validity of the theoretical construct previously put forward by de la Fuente (2017) based on earlier theories of self-regulation of behavior (Zimmerman, 1988; Zimmerman and Schunk, 1989; Zimmerman and Labuhn, 2012; Pachón-Basallo et al., 2021).

The results described in this study prove the interdependence identified by Bandura (1986) between contextual and personal variables. As well as those mentioned and in relation to hypotheses 3–5 (prediction and mediation), the following relationships are notable:

(a) External-regulation learning was significantly positively predictive of SRL; ENL predicted NRL, and EDL predicted DRL. As an additional finding, in this study we identified that perceptions of RT positively predicted SRB.
(b) Non-regulated learning and ENL predict DRL and EDL with significant predictive weights (0.60 and 0.79, respectively). The data indicate that personal dysregulatory behaviors, such as procrastination, psychological reactance, etc. and contextual factors such as inadequate family guidance, risky group behaviors, etc., can be predicted by the absence of norms or other clear aspects of context that could steer the behavior of students before, during and after performance. The same results have also been found in the field of health, where the absence of orientating stimuli positively predicted internal and external dysregulation in relation to health adjustment behaviors in university students. In addition and in relation to executive functioning, it has been found that non-regulatory and dysregulatory contexts are positively associated with executive dysfunction and problems with emotional regulation (Pachón-Basallo et al., 2021; de la Fuente, 2022).
(c) In a direct and interactive way, EDL had a significant positive effect on DRL (0.72), which was mediated by both NRL and EDL.
(d) SRL mediated the relationship between contextual variables such as ERL and ENL relative to SRS and SRB. It can be said that a regulatory context favors SRL (directly

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TABLE 5 Total, indirect, and direct effects of the variables in this study and 95% bootstrap confidence intervals (CI).

Predictive variable	Criterion variable	Total effect	CI (95%)	Direct effect	CI 95%	Indirect effect	CI 95%	Results, effects
SRL →	SRB	0.595	(0.498, 0.660)	0.374	(0.226, 0.487)	0.217	(0.145, 0.298)	P.M.
	RT	0.562	(0.456, 0.639)	0.562	(0.456, 0.639)			D.O.
	SRS	0.663	(0.576, 0.735)	0.462	(0.333, 0.587)	0.201	(0.114, 0.281)	P.M.
NRL→	DRL	−0.596	(−0.506, 0.688)	−0.596	(0.506, 0.688)			D.O.
	SRB	−0.202	(−0.314, −0.104)	−0.202	(−0.314, −0.104)			D.O.
ERL→	SRL	0.566	(0.490, 0.640)	0.534	(0.451, 0.614)	0.032	(0.013, 0.068)	P.M.
	NRL	−0.165	(−0.257, −0.111)			−0.165	(−0.257, −0.111)	F.M.
	DRL	−0.179	(−0.265, −0.119)			−0.179	(−0.265, −0.119)	F.M.
	ENL	−0.249	(−0.361, −0.159)	−0.249	(−0.361, −0.159)			D.O.
	EDL	−0.197	(−0.278, −0.131)			−0.197	(−0.278, −0.131)	F.M.
	RT	0.318	(0.237, 0.388)			0.318	(0.237, 0.388)	F.M.
	SRB	0.368	(0.301, 0.434)			0.368	(0.301, 0.434)	F.M.
	SRS	0.375	(0.306, 0.439)			0.375	(0.306, 0.439)	F.M.
ENL→	SRL	−0.130	(−0.216, −0.058)	−0.130	(−0.216, −0.058)			D.O.
	NRL	0.664	(0.580, 0.733)	0.664	(0.580, −0.058)			D.O.
	DRL	0.720	(0.661, 0.781)			0.720	(0.661, 0.781)	F.M.
	EDL	0.791	(0.725, 0.854)	0.791	(0.725, 0.854)			D.O.
	RT	−0.073	(−0.122, −0.032)			−0.073	(−0.122, −0.032)	F.M.
	SRB	−0.211	(−0.307, −0.119)			−0.211	(−0.307, −0.119)	F.M.
	SRS	−0.086	(−0.149, −0.039)			−0.086	(−0.149, −0.039)	F.M.
EDL→	DRL	0.410	(0.313, 0.854)	0.410	(0.313, 0.503)			D.O.
RT→	SRB	0.387	(0.281, 0.505)	0.387	(0.281, 0.505)			D.O.
	SRS	0.357	(0.219, 0.487)	0.357	(0.219, 0.487)			D.O.

SRL, self-regulated learning; NRL, non-regulated learning; DRL, dysregulated learning; ERL, externally regulated learning; ENL, externally non-regulated learning; EDL, externally dysregulated learning; SRB, self-regulated behavior; RT, regulatory teaching; SRS, self-regulated study; P.M., partial mediation; F.M., full mediation; D.O., direct only; CI, confidence interval. Bootstrapping sample size = 200.

through ERL and indirectly and negatively through ENL, which in turn favors SRB, SRS and the perception of RT.

Those findings can help to answer the question why some students are not always satisfied with their own capacity for self-regulation despite recognizing the nexus between regulating themselves and improved academic results (Koenig and Guertler, 2021). In addition, the findings can complement the analysis conducted by Baumeister and Heatherton (1996) of failure in SRB, which focused mainly on personal factors (such as goal selection, self-monitoring, manifestation of inappropriate behaviors and stress/fatigue). The principal contribution of this research concerns the role of context, and the data show that context has a considerable predictive weight for student behavior. In fact, the perception that a student has of their immediate context supports or does not support certain regulatory decisions, will facilitate the use that the student will tend to make of metacognitive strategies in the study process and the specific metacognitive strategies that the student will tend to use in that process. Our results confirm what was found by Baumeister and Heatherton (1996) concerning the considerable influence that culture can have when teaching individuals about the circumstances in which loss or release of control is or is not appropriate. These findings first highlight the need for the community to act to prevent and reduce risky behaviors in young people in many contexts, beyond the merely academic. Second, they suggest that there is a need to carry out scientific research in the area of self-regulation, using instruments such as the SRL vs ERL instrument in different contexts so as to identify the strengths and areas for improvement of this new model. Results so far indicate that it is of greater utility for identifying important aspects that more traditional instruments do not take fully into account, in particular in relation to different levels of regulation and the distinction between internal and external regulation (Pintrich, 2004; de la Fuente et al., 2017, 2019, 2020b, 2022b; Goffena and Horn, 2021; Pachón-Basallo et al., 2021; Tinner et al., 2021).

In addition, in light of the results found, it is important for educational psychology to incorporate external regulation of learning behavior in its vision of effective teaching

(Entwistle and Peterson, 2004; Roehrig and Christesen, 2010), since teaching students to regulate their own learning behavior will bring advantages for them inside and outside the classroom. It is to be hoped that external regulation of learning will prompt self-regulating students in their study processes and in turn promote self-regulation in other areas of their lives (Zimmerman and Schunk, 1989; Yerdelen and Sungur, 2019). It is also probable that students who perceive that the regulation of their learning is externally facilitated will have a greater appreciation of the teaching process, which will once again impact their well-being. We hope in future research to explain how that comes about (Goe et al., 2008; de la Fuente, 2017; Putwain and Pescod, 2018; Baherimoghadam et al., 2021; Bakhtiar and Hadwin, 2022).

Limitations

This research has limitations which should be mentioned. First, there are limitations concerning the sample, which did not have enough participants to make high-level population scale inferences. Second, the initial validation of the instruments used in this research in relation to the internal and external regulation of learning was carried out in the same sample. Consequently, further revalidation studies of the specific instruments should be performed on the categorization of self-regulation vs. hetero regulation. In addition, no account was taken of possible differences arising from age, sex, or other relevant sociodemographic variables and their possible impact on the relationships among the variables considered.

Future research

Future research should continue to validate the factorial invariance of these relationships in other contexts, such as in organizations, social contexts, in teaching, in the use of ITC, etc. First, the adequacy of the categorization of dimensions of regulation (SRL/ERL-NRL/ENL, DRL/EDL), which might assist in classifying behavioral problems, should itself be confirmed. Second, cross-cultural studies should be performed to gather evidence of the intercultural validity of that categorization and the instruments developed to assess those constructs. In addition, there would be value in future research to determine the weight of each context – distinguishing family, school, and peers – in these predictive analyses so as to determine any discrepancies or similarities between the perceptions that students have. On the path toward those goals, these preliminary results provide empirical support for the proposed General SR vs. ER Theory (de la Fuente, 2021, 2022; de la Fuente et al., 2022a,b).

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The studies involving human participants were reviewed and approved by http://www.estres.investigacion-psicopedagogica.org/lib/pdf/CERTIFICADO_COMITE_DE_ETICA_UNAV.pdf. The patients/participants provided their written informed consent to participate in this study.

Author contributions

MP-B: study design, data analysis, and drafting of the initial report. JF: director of the thesis and R&D project. MG-T: supervision and revision of the writing of the article. JM-V: director of the R&D project. FP-S and MV-M: data collection. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

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Factors affecting faculty conformity in South China universities

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Based on social contagion theory, this study examines the mediating role of formalization of organizational structure between organizational identification and faculty conformity. It also analyzes the moderating role of conflict management style between organizational identification and faculty conformity, and formalization of organizational structure and faculty conformity in universities in Hunan province, China. Convenience sampling was employed to select the subjects, and 1,024 Chinese faculty members including teaching staff and administrative staff were surveyed online with the questionnaire consist of organizational identification scale, organizational formalization scale, conflict management style scale, and faculty conformity scale. 1,000 valid respondents were collected and SPSS was used to analyze the data through descriptive analysis, analysis of variance, correlation analysis, and hierarchical multiple regression. The results showed that faculty members' organizational identification had a positive effect on faculty conformity; formalization of organizational structure partially mediated the relationship between organizational identification and faculty conformity; and conflict management style positively moderated the relationship between organizational identification and faculty conformity and between formalization of organizational structure and faculty conformity. University administrators are often the initiators of conformity as they are responsible for formulating internal regulations. Therefore, they must monitor and coordinate workplace conflicts, resolve and guide faculty conformity, promote individual faculty members' self-improvement, and foster steady organizational development.

KEYWORDS

organizational identification, formalization of organizational structure, conflict management style, faculty conformity, university teachers

Introduction

Conformity improves cohesion in an organization, driving members to endorse homogenous values, and work toward shared goals (Burt, 1987; Li and Zhu, 2016). In fact, conformity is a form of social contagion that designates the dissemination of behaviors when individuals come into direct or indirect contact with others (Fenzl and Pelzmann,

2012). In educational institutions like universities, when faculty members display negative behaviors, such as arriving late or leaving early, such attitudes may spread quickly to others. Likewise, when faculty members adopt a positive attitude, such as affability or devotion to work, this behavior may quickly diffuse through the mechanisms of contagion (Jiaqi and Jianfeng, 2019). Padilla-Walker et al. (2013) explains that when the initiator is rewarded or not punished for a certain behavior, the recipient's imitation is reinforced. This behavioral contagion among faculty members is known as faculty conformity. In educational institutions, when faculty members adopt effective teaching methods, other colleagues often learn from them, especially young faculty members (Berliner, 1986). Faculty members' careers are increasingly dependent on a culture of progress and achievement (Day, 2002), prompting faculty members who are yet to receive honors to work harder and generate faculty conformity. University faculty members seem less receptive when faced with formal and informal training and learning opportunities, but their participation in training programs is relatively high (Richter et al., 2014). This phenomenon could be explained by the fact that China's official regulations on teacher training require all teachers to participate in a system of training, fulfilling at least 360 h in a 5-year cycle. Failure to meet the required hours will directly affect their titles and promotion (State Council of China, 2012).

Universities have formal written and explicitly articulated rules and regulations, which are considered as characteristics of formalization of organizational structure. These organizational policies reflect the degree of standardization of work in the organization and the extent to which employee behavior is regulated (Schminke et al., 2002). A formalized organizational structure can constrain faculty members, thereby prompting conformity (Dastmalchian and Blyton, 1998). Examples include the system to track employees' check-in and check-out when arriving or leaving the workplace and specific methods of classroom management. The theory of inhibitory contagion also implies that the core of conformity is to "ease the feeling of being constrained" (Levy and Nail, 1993). When faculty members are constrained by a formalized organizational structure, they conform to the regulations and comply with the decision of those formulating the regulations, thus reducing the likelihood of "feeling constrained" and generating a contagious mechanism of faculty conformity (Jiaqi and Jianfeng, 2019).

Ferguson (2006) explains that conformity arises due to serious conflict within an individual. Such a conflict can be divided into two types. First, the impulse is strong enough to motivate people to successfully achieve. Second, internal control is strong enough to inhibit such achievements (Jiaqi and Jianfeng, 2019). Individuals have certain tendencies or reactions when dealing with conflicts, known as "conflict management style" (Wee et al., 2021). Positive conflict management style correlates positively with employee discipline through the formalization of organizational structure and organizational behavior (Soieb et al., 2013). Formalization of organizational structure can exacerbate or mitigate conflict and influence individual behavior (Pelled et al., 1999). A compromising conflict management style is more likely to produce conformity (Petersen and Ford, 2019). University faculty members usually adopt the collaborating conflict management style when confronted with conflicts (Williams-Ilemobola et al., 2021), especially when various codes of faculty behavior are included in the formalization of organizational structure, which minimizes conflicts and produces faculty conformity with shared goals (Aditya and Setyawan, 2021). Briefly, conflict management style may have a moderating effect on the formalization of organizational structure and faculty conformity. Furthermore, Bilgicer et al. (2015) highlight that behaviors in the formalization of organizational structure are more contagious than informal behaviors in organizations. Specifically, in conflict management style, as individuals interact constantly with the group, formalization of organizational structure will more likely produce conformity. Levy and Nail (1993) emphasize that conformity is the result of group–individual interactions.

Individual factors are important in predicting conformity (Ferguson, 2006), as it entails diffusion of attitudes or behaviors and leads to social impact and transmission of information or behaviors in this process (Levy and Nail, 1993). Identification is an attitude, or an internal process that maintains relationships with the group or intervenes in an individual's attitudes (Wu et al., 2022). Thus, the higher the organizational identification, the more likely it will produce conformity (Paolella and Syakhroza, 2021). When faculty members identify with the organization they serve, they incorporate organizational values and cultural goals into their personal objectives, internalize various behavioral codes in the formalization of organizational structure, and produce behaviors of faculty conformity that are consistent with organizational goals (De Cremer and Tyler, 2005; Wu et al., 2022). Maraghoush et al. (2021) argued that organizational identification positively influences normative and consistent ethical behaviors that are constrained by the environment and cognitive perceptions. The formalization of organizational structure has a significant positive effect on normative faculty conformity (Borry et al., 2018). In other words, organizational identification may influence faculty conformity through the formalization of organizational structure. Furthermore, Burt (1987) believes that conformity is determined by interpersonal patterns, and organizational identification represents the interactions and connections in interpersonal relationships between individuals and groups (Wu et al., 2022). It is through interpersonal interactions with others that individuals contribute to the resolution of internal conflicts, which leads to conformity (Jiaqi and Jianfeng, 2019). Mello and Delise (2015) also suggest that conflict management can moderate the relationship between cognitive diversity and cohesion. Similar to organizational identification, cognitive diversity is a concept about attitudes and values (Kilduff et al., 2000), and conformity is a form of cohesion (Carron et al., 2002). Thus, conflict management styles may moderate the relationship between organizational identification and faculty conformity.

The above discussion shows that organizational identification, formalization of organizational structure, and individual conflict

management styles of university faculty members determine faculty conformity. However, the influential mechanism between them remains unclear. Clarifying how formalization of organizational structure, individual conflict management styles, organizational identification influence faculty conformity is of great significance to the deepening of conformity theory. Moreover, figuring out (Jiaqi and Jianfeng, 2019) the relationships between the variables and guiding faculty conformity is an important administrative tool to enhance organizational cohesion and accomplish organizational goals (Li and Zhu, 2016), and an effective way to promote individual faculty members' self-improvement and steady organizational development. Therefore, this study models the relationships among four variables on the basis of the theory of social contagion and uses regression analysis to validate the model to promote and enrich the application of the theory of social contagion in the field of education.

Literature review and hypothesis development

Organizational identification and faculty conformity

Organizational identification is a critical factor that binds organizational members and ensures a high level of organizational commitment (Demir, 2015). When individuals identify with an organization, they become cognitively interconnected and develop a sense of belonging with the group (Mael and Ashforth, 1992). This sense of belonging motivates people to integrate group and individual interests, thus triggering the participation of non-direct stakeholders and generating conformity (Klandermans, 2002). Studies also suggest that when a large number of organizational members identify with the organization, their expectations are consistent and they are likely to develop conformity (Paolella and Syakhroza, 2021). Abbasi et al. (2021) also suggest that organizational identification has a significant positive effect on behavior (Demir, 2015; Sharma, 2021), leading to the following hypothesis:

> *H1:* Organizational identification has a significant effect on faculty conformity.

Mediating role of formalization of organizational structure between organizational identification and faculty conformity

Schminke et al. (2002) define the formalization of organizational structure as the extent to which work is standardized in an organization and employee behavior is governed by rules and procedures, with an emphasis on accepted and explicit rules that are documented in the written form. In the setting of schools, it refers to various regulations and rules explicitly articulated in the written form. According to Dastmalchian and Blyton (1998), rules and regulations can be categorized as control rules to regulate and control the behavior of general employees, such as performance appraisal, work attendance, and leave approval; and safeguarding rules for administrators to clarify their responsibilities and prevent them from making arbitrary decisions or taking action that could harm the rights and interests of the organization or employees, such as departmental responsibilities, recruitment procedures, hazard recognition, promotion system, and research management methods. Miles (2012) explains that formalization of organizational structure places constraints on organizations, compelling those established in the same institutional domain and influenced by similar external institutional factors to become homogeneous. This process is the outcome of the impact on individual, organizational, and interorganizational levels (Miles, 2012). That is, within schools, formalization of organizational structure also creates organizational constraints for members, resulting in faculty conformity. Maraghoush et al. (2021) indicate that organizational identification impacts ethical behavior, namely normative and consistent behaviors governed by the environment and cognition. Similar to formalization of organizational structure, organizational identification constrains the behavior of members of an organization. Diminishing the perception of being constrained is a central element in generating faculty conformity (Levy and Nail, 1993). Organizational identification provides individuals with normative guidance and internalizes organizational rules and regulations (Pagliaro et al., 2018), while formalization of the organizational structure affects faculty conformity (Borry et al., 2018; Li et al., 2021). In other words, organizational identification generates faculty conformity through a formalized organizational structure. Therefore, this study proposes the following hypothesis:

> *H2:* Formalization of organizational structure has a mediating role between organizational identification and faculty conformity.

Moderating role of conflict management style

Böhm et al. (2020) propose that conflict entails a relationship between two or more social units, such as individuals, groups, and organizations. Conflicts occur within organizations at four levels: intra-individual, interpersonal, intra-group, and inter-group (Williams-Ilemobola et al., 2021). Conflict management style is an individual's tendency and reaction when dealing with disputes (Wee et al., 2021). In the developed countries of the West, people are inclined to collaborate and negotiate to resolve conflicts (Shih and Susanto, 2010; Pinto-Moreira, 2021). The avoiding and

accommodating styles of conflict resolution predict behavior, but they have a less dominant role (Trudel and Reio, 2011), and the compromising style is more likely to produce conformity (Petersen and Ford, 2019). In China, where collectivism is central to the Asian culture, people are more concerned with their image and relationships, and often adopt avoiding or collaborating styles during conflicts (Hwang, 2000). Adopting a compromising and collaborating style during conflicts can help maintain or protect mutual relationships and produce conformity with shared goals (Williams-Ilemobola et al., 2021).

Social contagion theory indicates that interpersonal patterns are a decisive factor of conformity (Burt, 1987). Organizational identification is an interpersonal pattern in individuals' interactions with others (Wu et al., 2022). The resolution of conflicts between individuals is facilitated by others (Jiaqi and Jianfeng, 2019). Conformity results from interactions that happen between individuals and groups (Levy and Nail, 1993). In universities, when individuals differ in their opinions or behaviors with their colleagues during performance assessment or teaching reform, if all fellow colleagues believe it is reasonable or unreasonable, individuals will gradually show understanding and agreement with other coworkers. Faculty conformity is generated when faculty members change their own behaviors due to their interactions with others, (Jiaqi and Jianfeng, 2019). Conflict management can moderate the relationship between cognitive diversity and cohesion (Mello and Delise, 2015). Cognitive diversity is a concept about attitudes and values (Kilduff et al., 2000), identification is the representation of attitudes (Wu et al., 2022), and conformity is a form of cohesion (Carron et al., 2002). In other words, conflict management style moderates the relationship between organizational identification and faculty conformity. In addition, Soieb et al. (2013) state that a positive conflict management style is clearly associated with employee discipline in the formalization of organizational structure and organizational behavior. Internal conflicts between recipients can predict conformity (Redl, 1949), where individuals have a strong urge for something but are meanwhile pressured not to act to satisfy that urge in the interim. This may be peer pressure from other members of the organization, and the individual is likely to adopt a collaborating style to satisfy such needs (Jiaqi and Jianfeng, 2019). The pressure may be due to organizational rules and regulations regarding formalization of organizational structure, and the individual adopts an avoidance style that suppresses demands and minimizes conflicts (Aditya and Setyawan, 2021), thereby producing conformity (Petersen and Ford, 2019). Formalization of organizational structure may exacerbate or mitigate conflicts. Conflict management style is a behavioral model for dealing with disagreements. The interaction between the two affected individuals' behavior and performance (Pelled et al., 1999). Thus, conflict management style may moderate the relationship between the formalization of organizational structure and faculty conformity. As internal behavioral codes in universities are largely developed by administrators, who are also the initiators of contagious behaviors, the contagion exerts a greater impact on general faculty members (Berliner, 1986). Bilgicer et al. (2015) found that behaviors with higher values in organizations are more contagious. Clearly, the formalization of organizational structure involves higher behavioral preferences and legitimacy (Borry et al., 2018). As behaviors on behalf of groups have greater contagion than other behaviors (Ferguson, 2006), this study proposes the following hypotheses:

> *H3:* Conflict management style has a moderating effect on organizational identification and faculty conformity.
> *H4:* Conflict management style has a moderating effect on formalization of organizational structure and faculty conformity.

Materials and methods

Research framework

Based on social contagion theory, this study examines whether organizational identification of university faculty members influences faculty conformity through the mediating role of formalization of organizational structure, and whether conflict management style has a moderating effect between organizational identification and faculty conformity, formalization of organizational structure and faculty conformity. A regression analysis was used to validate the study's theoretical model (Figure 1).

Research subjects

Convenience sampling was used to select study subjects from four universities that offer undergraduate programs with similar rankings in Hunan Province. The only criterion for inclusion for the sample was being the official faculty members in universities for more than 1 year. Thus teaching staff including professors, associate professors, lecturers and teaching assistants, along with administrative staff including department directors, college deans, and etc. were both included in the study, considering gender, age, educational background, position, salaries and teaching experience as demographic variables. After the pre-survey, questionnaires were distributed by private mails and completed online during the holiday period from October 12 to December 21, 2021. A total of 1,024 questionnaires were distributed, and 24 invalid questionnaires were excluded, with the valid response rate being 97.65%. The study purpose was explained in detail to the participants and signed informed consent was obtained online prior to completing the questionnaire. The collected data were used only for this study and will not be used for other purposes to guarantee participants' privacy. During the course of this study, we also ensured that participants had the right to withdraw their data at any stage.

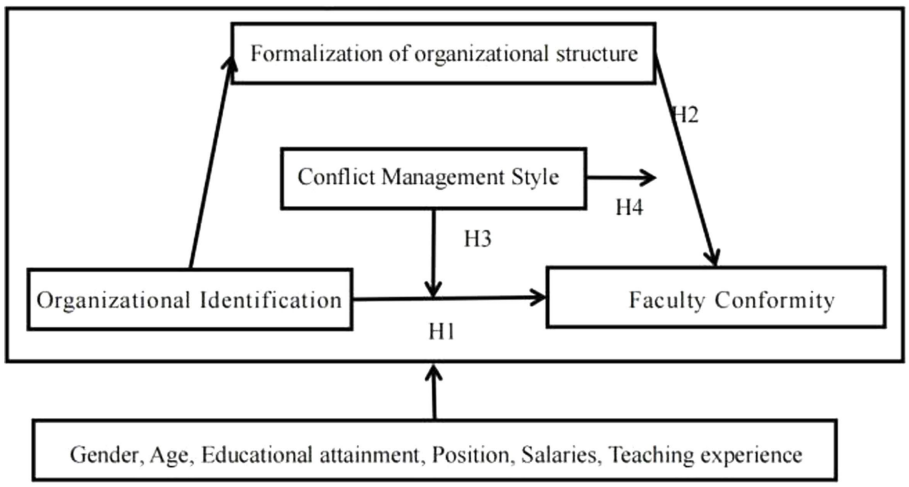

FIGURE 1
Research framework.

Research tools

Questionnaires offer an objective means of collecting information about people's knowledge, beliefs, attitudes, and behavior (Boynton and Greenhalgh, 2004). Anonymity ensures the objectivity with the respondents being not disturbed by others when completing the questionnaire. With the development of technology, the online survey with its convenience of access to unique populations, saving time and cost, was widely used in various research fields (Wright, 2005). The online survey also provided the possibility of conducting the research with the limitations of interpersonal communication in the epidemic period regulated by local government (People's Government of Hengyang, 2021). Besides, the research goal is to uncover the behavioral characteristics of individuals and groups in universities, thus survey method is more suitable.

Organizational identification was measured using the Organizational Identification Scale developed by Mael and Ashforth (1992), a uni-dimensional measurement scale with six questions. For example, "When I hear people praise my school, I feel as if they are praising me." Likert five point scale from "strongly disagree" to "strongly agree" was adopted, measuring from 1 to 5. The reliability of the original scale was 0.87. After item analysis and exploratory factor analysis, all items are suitable， and the pretest reliability was 0.891. Confirmatory factor analysis (CFA) of the formal survey showed that the factor loadings ranged from 0.79 to 0.86. The construct reliability (CR) was 0.925, higher than the assessment criterion of 0.7; the average variance extracted (AVE) was 0.673, higher than the assessment criterion of 0.5 (Fornell and Larcker, 1981).

The formalization of organizational structure was measured with the Formalization Scale developed by Schminke et al. (2002), a uni-dimensional measurement scale with five questions. For example, "My school has a large number of written rules and regulations." Likert five point scale from "strongly disagree" to "strongly agree" was adopted, measuring from 1 to 5. The reliability of the original scale was 0.73. After item analysis and exploratory factor analysis, all items are suitable, and the pretest reliability was 0.779. CFA of the formal survey showed that factor loadings ranged from 0.81 to 0.85. The CR was 0.920, higher than the assessment criterion of 0.7; the AVE was 0.696, higher than the assessment criterion of 0.5 (Fornell and Larcker, 1981).

The study subjects were faculty members in China, therefore, to ensure appropriateness of the measurement scale, we drew on studies related to conflict management style in China and the West and adopted the Conflict Management Style Scale developed by Yongmei et al. (2011), a two-dimensional measurement scale with seven questions on the collaborating style, such as "I try to negotiate with my colleagues to be able to reach a compromise, "and eight questions on the compromising style, such as "I choose to give in and not to fight with my colleagues." Likert five point scale from "strongly disagree" to "strongly agree" was adopted, measuring from 1 to 5. The total reliability of the original scale was 0.86 and the pretest reliability was 0.897. CFA of the formal survey showed that factor loading for the first question on the collaborating style, "I usually give in to my colleagues, "was below 0.7, and therefore it was removed. The remaining 14 questions had factor loadings ranging from 0.80 to 0.87. The collaborating style of CR was 0.938 and the compromising style of CR was 0.935, higher than the assessment criterion of 0.7, and the collaborating style and compromising style of AVE was 0.684 and 0.671, respectively, higher than the assessment criterion of 0.5 (Fornell and Larcker, 1981).

The measurement scale for faculty conformity was adapted from Xu and Tu (2022) conformity scale, a two-dimensional measurement scale with four questions. For example, "When all my colleagues receive a certain academic achievement or honor, I try to get it too."

Likert five point scale from "strongly disagree" to "strongly agree" was adopted, measuring from 1 to 5. The pretest reliability was 0.848. CFA of the formal survey showed that the factor loadings ranged from 0.77 to 0.83. The CR was 0.884, higher than the assessment criterion of 0.7; the AVE was 0.655, higher than the assessment criterion of 0.5 (Fornell and Larcker, 1981).

To make it more applicable and understandable for Chinese faculty members, the two original English scales were translated into Chinese. Dr. Wang, a translation major at Malaya University, and Dr. Gong, an English major at Hunan Normal University were invited to conduct a two-way translation separately on August 11, 2021, and then a pre-test was conducted after a face-to-face discussion on September 6, 2021.

Results

After the common method variance test for all items, the frequency test is used to show the situation of demographic variables, the analysis of variance (ANOVA) is used to test the difference of demographic variables on each variable. Then correlation analysis was used to test the correlation degree between two variables, and finally the regression analysis is used to test the influential relationship between variables of conflict management style, organizational identification, formalization of organizational structure, and faculty conformity.

Common method variance test

We used Harman's single factor test for assessing common method bias and conducted exploratory factor analysis for each variable. The results showed that the variance explained by the first common factor was 34.875%, which is less than the critical criterion of 40% (Harris and Mossholder, 1996). We derived five factors with eigenvalues greater than 1, which distinguished the two-dimensional conflict management style of avoiding and accommodating, along with the other variables of organizational identification, formalization of organizational structure and faculty conformity. The study data were not significantly affected by the common method bias, and the relationships between the variables found from the data were reliable.

Descriptive statistics and analysis of variance

Descriptive statistics shows that the proportion of female faculty members was 50.4%, similar to the ratio of male to female faculty members in general higher education institutions (50.17: 49.83) in the Hunan Provincial Statistical Yearbook 2020, and the number of female faculty members was increasing every year. Therefore, the sample data reflect the reality. About 53.6% of the participant faculty members were aged 26–45 years, and 6.2% did not obtain a PhD degree; 79.9% were teaching-track faculty members. The monthly salary of 38.9% of the participant faculty members varied between RMB 8,000 yuan and 10,000 yuan; 44.6% participant faculty members had more than 16 years of teaching experience.

The *t*-test showed that there were significant differences in organizational identification ($t = 1.979$, $p < 0.05$) between participant faculty members of different genders, with males having higher organizational identification than females. There were significant differences in the formalization of organizational structure ($t = 2.669$, $p < 0.01$), conflict management style ($t = 2.630$, $p < 0.01$), and faculty conformity ($t = 2.701$, $p < 0.01$) between faculty members with different levels of education. Participants who had a PhD degree scored higher than those who did not have one.

Analysis of variance showed that participant faculty members of different ages, salaries, and years of teaching experience did not qualify the assumption of homogeneity of variance in Levene's test ($p < 0.001$) for each variable. ANOVA ($p < 0.001$) showed significant differences between different groups. *Post hoc* tests using Dunnett's T3 method revealed that participant faculty members aged over 55 years scored significantly higher than faculty members of other age groups on all four variables. Those with salaries of RMB 10,000 yuan or more scored significantly higher on all four variables than those paid less than 4,000 yuan. Participant faculty members with more than 16 years of teaching experiences scored significantly higher on all four variables than those with less teaching experience.

Correlation analysis

Correlation coefficients ranging from 0.324 to 0.481. The variables moderately correlated one with another, and the correlations were positively significant ($p < 0.001$). The mean values ranged from 3.790 to 3.993, indicating a moderate to high status. Table 1 shows the Cronbach's alpha of the formal survey.

Regression analysis

The hypotheses were tested by regression analysis. Consistent with Cohen et al. (2014), we normalized organizational identification, the formalization of organizational structure, conflict management style, and the normalized scores were multiplied together to evaluate the interaction effect. In addition, we drew on the test for the mediation of a moderator effect proposed by Muller et al. (2005) and Edwards and Lambert (2007).

$$Y = \beta_{10} + \beta_{11}X + \beta_{12}Mo + \beta_{13}XMo + \varepsilon_1 \quad \text{(M4 in Table 2) (1)}$$

TABLE 1 Summary of correlation analysis.

Variables	$M \pm SD$	Organizational identification	Formalization of organizational structure	Conflict management style	Faculty conformity	Cronbach's alpha
Organizational identification	3.993 (0.906)	1				0.925
Formalization of organizational structure	3.811 (0.987)	0.324***	1			0.919
Conflict management style	3.807 (0.684)	0.480***	0.460***	1		0.897
Faculty conformity	3.790 (0.914)	0.373***	0.378***	0.481***	1	0.883

***$p < 0.001$.

$$Me = \beta_{20} + \beta_{21}X + \beta_{22}Mo + \beta_{23}XMo + \varepsilon_2 \quad \text{(M2 in Table 2) (2)}$$

$$Y = \beta_{30} + \beta_{31}X + \beta_{32}Mo + \beta_{33}XMo + \beta_{34}Me + \beta_{35}MoMe + \varepsilon_3 \quad \text{(M5 in Table 2) (3)}$$

According to Edwards and Lambert (2007), for this model, the regression equation for M is Equation 4,

$$Me = \beta_{40} + \beta_{41}X + \varepsilon_4 \quad \text{(M1 in Table 2) (4)}$$

Subscripts on regression coefficients indicate the equation in which the coefficient is estimated and the number to which the coefficient is assigned.

If β_{13} in Equation 1 is significant, then the moderation occurs in the direct effect path model (Edwards and Lambert, 2007), For Equations 2, 3, if $\beta_{21} \neq 0$ and $\beta_{35} \neq 0$ or $\beta_{23} \neq 0$ and $\beta_{34} \neq 0$ or $\beta_{23} \neq 0$ and $\beta_{35} \neq 0$, then moderated mediation model is established. The results are shown in Table 2.

After dummy coding the demographic variables, age, salary, and teaching experience were significant in predicting faculty conformity, with age having a significant positive effect on the formalization of organizational structure and teaching experience showing a negative relationship with the formalization of organizational structure, consistent with Maurizio (2014) study.

Organizational identification significantly predicted faculty conformity ($\beta = 0.255$, $p < 0.001$, M3 in Table 2), consistent with Paolella and Syakhroza (2021); thus, H1 is supported. Regression analysis of moderated mediation shows that the interaction between organizational identification and conflict management style shows faculty conformity ($\beta = 0.105$, $p < 0.01$, M5 in Table 2); thus, H2 and H3 is supported. As Norman et al. (2005) argue, the interaction between organizational identification and conflict management style is a sufficient condition for triggering contagion. The interaction between formalization of organizational structure and conflict management style indicates faculty conformity ($\beta = 0.141$, $p < 0.001$, M5 in Table 2); thus, H4 is supported.

In addition, the mediation effect of formalization of organizational structure between organizational identification and faculties' conformity behavior was tested by Sobel test, $z = 4.816$ ($P < 0.001$), which means the mediation effect was significant (Sobel, 1982).

The direction of the interaction effect is clearly plotted and shown in Figures 2, 3. When individual faculty members have a positive conflict management style, organizational identification and formalization of organizational structure are effective in enhancing faculty members' willingness to engage in conformity. Similarly, when individual faculty members have a negative conflict management style, organizational identification, and formalization of organizational structure can enhance faculty conformity; only the frequency will be reduced compared with the case of a positive conflict management style.

Discussion

Variance analysis shows that faculty members with a PhD degree, more than 55 years old, more than 16 years of teaching experiences, salaries of 10,000 RMB or more, performed better on the four variables compared with faculty members in other groups. Interestingly, in universities, a high level of education indicates better salaries, while those who are older and have more teaching experience indicates higher working age. Working age is directly linked to salaries, and people with higher salaries will show better organizational identification and willingness to stay and serve the organization (Sugirtha et al., 2020). As the years of service increase, the degree of immersion in the organizational culture is higher, which in turn increases organizational identification. In addition, they are more willing to obey the rules and regulations of the organization and complete various tasks, resulting in faculty conformity.

The regression analysis of demographic variables shows that age has positive organizational identification and faculty conformity. In this study, 53.6% of young faculty members completed their transition from being a student to becoming a teacher, but their place of study or work did not change—they

TABLE 2 Summary of regression analysis of moderated mediation.

	Formalization of organizational structure		Faculty conformity			
	M1	M2	M3	M4	M5	M5 95%CI
Gender	−0.009	−0.000	−0.006	0.004	−0.001	[−0.098, 0.093]
Age	0.120***	0.082**	0.145***	0.1103**	0.076*	[0.013, 0.085]
Educational attainment	0.0.49	0.038	0.041	0.029	0.028	[−0.046, 0.148]
Position	−0.000	0.013	−0.012	0.002	−0.000	[−0.111, 0.111]
Salaries	0.050*	0.050	0.064*	0.063*	0.052*	[0.000, 0.072]
Teaching experience	−0.317***	−0.178***	−0.249***	−0.101**	−0.044	[−0.101, 0.025]
Organizational identification	0.194***	0.191***	0.255***	0.244***	0.190***	[0.105, 0.262]
Conflict management style		0.279***		0.305***	0.295***	[0.190, 0.356]
Organizational identification x conflict management		0.154***		0.156***	0.105**	[0.024, 0.159]
Formalization of organizational structure					0.177***	[0.094, 0.237]
Formalization of organizational structure × Conflict management					0.141***	[0.062, 0.202]
R2	0.247	0.301	0.252	0.315	0.337	
△ R2	–	0.054	–	0.063	0.022	
F	46.49***	47.37***	47.79***	50.53***	45.62***	

Numbers are normalized regression coefficients.
*$p < 0.05$; **$p < 0.01$; ***$p < 0.001$.

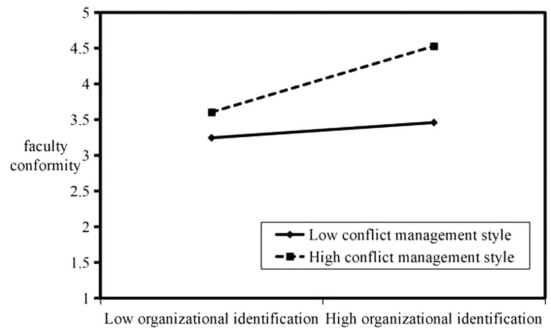

FIGURE 2
Moderating effect of conflict management style on the relationship between organizational identification and faculty conformity.

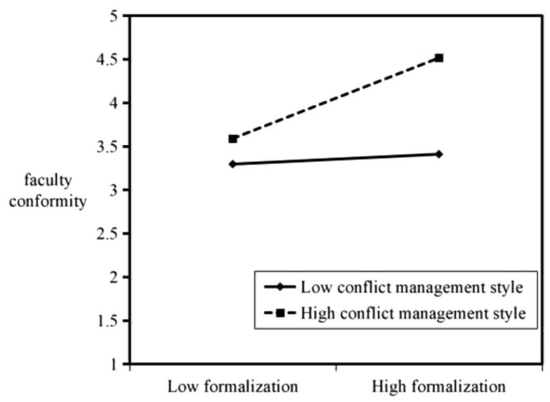

FIGURE 3
Moderating effect of conflict management style on the relationship between formalization and faculty conformity.

just moved from one university to another. They were accustomed to and internalized the behavioral constraints associated with the formalization of organizational structure as their own behavioral codes, and their pursuit of progress and achievements also contributed toward faculty conformity (Day, 2002). The number of teaching years negatively affected the formalization of organizational structure (Maurizio, 2014). In this study, 44.6% faculty members had more than 16 years of teaching experience and were less satisfied with the organization than those with less teaching experience, which is attributable to a lack of positive perception of formalization of organizational

structure among faculty members with extensive teaching experience (Ma and MacMillan, 1999). As teaching experience increases, faculty members' tolerance for assessment stipulated in the formalization of organizational structure decreases (Shi et al., 2021), thereby reducing the frequency of conformity (Day, 2002). Therefore, reducing the negative effect of the increase in teaching years is also an important issue that administrators must focus on.

The partial mediating effects showed that organizational identification has a positive impact on formalization of organizational structure (Maraghoush et al., 2021). A higher level of organizational identification is more likely to produce faculty conformity (Paolella and Syakhroza, 2021), and formalization of organizational structure can also contribute to faculty conformity (Borry et al., 2018; Li et al., 2021). This validates the social contagion theory. When faculty members are subjected to behavioral constraints resulting from the process of formalization of organizational structure, they will conform to institutional requirements and comply with the wishes of those formulating the regulations, producing faculty conformity (Levy and Nail, 1993). Improving faculty members' organizational identification is an effective way to increase faculty conformity. Extensively using the process of formalization of organizational structure can increase the frequency of faculty conformity; however, its specific effect must be considered, such as the phenomenon of high participation but low acceptance of teacher training (Richter et al., 2014).

The moderating effect shows that organizational identification and formalization of organizational structure positively enhance faculty conformity, regardless of the positive or negative conflict management style. Notably, the style of conflict management has a positive effect on faculty conformity (Petersen and Ford, 2019). Positive conflict management reduces employee turnover (De Dreu and Beersma, 2005), indicating that administrators who help faculty members deal promptly with conflicts are more effective in retaining talent. The interaction between organizational identification and conflict management shows that rational use of individual teachers' strong identification with the organization can develop a positive conflict management style and mitigate intra-individual, interpersonal, intra-group, and intergroup conflicts (Williams-Ilemobola et al., 2021), and thereby generate faculty conformity (Redl, 1949; Norman et al., 2005). It is an effective way for administrators to stimulate faculty members' compliance with the administration (Pounder, 2003). The interaction between formalization of organizational structure and conflict management shows that bureaucratic solutions can regulate teachers' behaviors by clarifying responsibilities applying various rules and regulations in the formalization of organizational structure, thereby restraining conflict within the recipients (Wheeler, 1966; Pelled et al., 1999). It is an effective way for administrators to enhance faculty conformity. In addition, Petersen and Ford (2019) emphasize that teacher training is related to personal values and conflict management styles. As opposed to "forced" participation due to institutional requirements in teacher training, administrators can enhance the effectiveness of training by increasing faculty members' organizational identification, and this is attributable to the fact that faculty members who identify with the organization are more likely to adopt consistent organizational values (De Cremer and Tyler, 2005).

Conclusion and implication

It is important for university leaders to guide faculty conformity behavior in order to condense the organizational centripetal force and achieve organizational goals (Li and Zhu, 2016). It is also an effective way to promote the individual improvement of faculty members and the steady development of the organization. This study shows that faculty members with higher with the organizational identification will have a higher frequency of conformity behavior. The ways to improve faculty members organizational identification can be started from encouraging them to improve their education, increasing their salaries, recruiting more excellent young teachers, and so on. The formalization of organizational structure can also restrict faculty members' behavior and produce conformity behavior that meets organizational goals. However, with the increase of working years, the constraints of formal rules will be weaken. Organizational identity can obviously alleviate this phenomenon.

In addition to the influence of organizational identification and formalization of organizational structure on faculty members' conformity behavior, the role of conflict management style in the variable model of this study has also been confirmed. Positive conflict management style is obviously more important when solving the intra-individual, interpersonal, intra-group, and inter-group conflict problems. Therefore, university leaders should adopt some intervention strategies on faculty members with low frequency by improving their organizational identification and promoting positive conflict management style. The positive conflict management style is more conducive to easing the sense of restraint brought by the rules and regulations in the organization, which are indispensable and necessary for administration.

In universities, education, titles, and positions are directly related to faculty members' salaries, and a higher level of education is relevant to the evaluation of titles. Distinct from their titles and positions, individuals have full control over the level of education that they can strive to obtain. Given the findings of this study, administrators can encourage faculty members to improve their educational attainment and raise their salaries for the purpose of retaining talent (Sugirtha et al., 2020). In addition, young faculty members appear to be more willing to comply with regulations in the formalization of organizational structure (Ma and MacMillan, 1999), which produces faculty conformity. Administrators responsible for human resources management can introduce more young faculty members in universities, consistent with the proportion of young faculty members, to stimulate organizational dynamics.

The success and stability of an organization depends on the ability of its managers to identify and manage workplace conflicts (Doherty and Guyler, 2008). Administrators, who are responsible for the formulation of internal regulations, should make full use of the normative nature of regulations to effectively "discipline" faculty behavior, especially at the beginning of implementing regulations (Trudel and Reio, 2011), and adopt a collaborative conflict management style to minimize internal conflicts and generate positive faculty conformity (Aditya and Setyawan, 2021). Faculty conformity must be monitored as a part of their daily routine and make complete use of the interaction between individuals, groups, and departments to effectively resolve conflicts and stimulate conformity (Williams-Ilemobola et al., 2021). In addition, administrators are also the initiators of contagious behaviors; therefore, it is important for them to promote positive energy through mechanisms of social contagion (Jiaqi and Jianfeng, 2019). This could promote self-improvement among individual faculty members and steady organizational development.

There are some limitations in this study. It is difficult to collect data when subordinates are expected to complete questionnaires about their superiors in universities that are governed or administered in a bureaucratic style. We encountered this problem during the pre-survey. This may be because subordinates are reluctant to challenge their superiors in any manner due to the fear of negative consequences such as losing their jobs (Holt and DeVore, 2005). Therefore, this study has only incorporated the assessment of formalization of organizational structure without extending the research to conformity between their superiors and subordinates (Zhang et al., 2018). We suggest that future studies may include a cohort analysis of administrators and non-administrators. In addition, the faculty conformity scale used in this study does not distinguish between faculty members' behaviors in teaching and administrative work and does not include the case of negative behaviors of conformity. Therefore, future studies may increase the dimensions of this scale or adopt a more mature scale.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Author contributions

CX conducted the study and drafted the manuscript. Y-CC participated in the design of the study and helped to revise the manuscript. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Developments in early adolescents' self-regulation: The importance of teachers' supportive vs. undermining behavior

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Research has established that the ability to self-regulate is an important factor in adolescents' learning, and cognitive and social functioning. Several theories on self-regulation and classroom studies suggest effects of the social learning environment on students' self-regulation. However, most studies investigating these relations have a cross-sectional correlational design and do not relate to adolescents, resulting in little knowledge about causal directions and adolescents. This study extends existing research by examining effects of a selection of supportive and undermining teacher behavior dimensions on early adolescents' development of self-regulation (self-regulated learning). The teacher behavior dimensions are based on ideas of the self-determination theory in which a distinction is made between dimensions that support vs. thwart three basic psychological needs (need for autonomy, competence, and relatedness) which are assumed to be important for human growth and (psychological) well-functioning. Supporting autonomy, delivering structure, and being involved with the students are assumed to be important for the fulfillment of students' basic psychological needs, while exhibiting controlling instructional behavior, having chaos, uncertainty and inconsistency in the classroom, and rejection and neglect of students, are supposed to be a treat. Questionnaires were used for measuring students' perceptions of their teachers' behavior and their own self-regulation at several points in time during their first year of secondary education. Participants in the study were 566 students belonging to 20 Mathematics/English grade-7 secondary education classes in The Netherlands. Multilevel analyses point to the importance of all three teacher need-supportive dimensions (with highest effects of structure and involvement) and indicated that teachers' need-thwarting behavior negatively affected students' self-regulation. However, when corresponding supportive and thwarting teacher behavior dimensions were included together in the same multilevel model, only the effect of the undermining dimension of controlling teacher behavior remained significant in addition to the corresponding autonomy-support dimension. Findings are in line with existing research and highlight the importance of both teachers' need-supportive and teachers' need-thwarting behavior in daily secondary-education classrooms and contribute to deepen our insight in and understanding of factors (related to external regulation by teachers) leading to

positive and negative developments of early adolescents' self-regulation, and, in particular, their self-regulated learning.

KEYWORDS

self-regulation, self-regulated learning, teacher behavior, basic psychological needs, self-determination theory, secondary education, teacher support, adolescence

Introduction

Being able to regulate oneself is a very important capacity in life and is often considered as the foundation for lifelong functioning across a wide range of domains since self-regulation plays an important role in relationships, prosocial and moral(ly relevant) behavior, well-being, learning, (academic) achievement, health, and overall success in life (Eisenberg, 2000, 2010; Moffitt et al., 2011; Carlo et al., 2012; Hofmann et al., 2014; Dent and Koenka, 2016; Hampson et al., 2016; Panadero, 2017; Chu et al., 2020). In addition, research has established that it is a predictive factor of resilience (Eisenberg and Spinrad, 2004; Artuch-Garde et al., 2017; de la Fuente-Arias, 2017), and can act as a protective factor for, in particular, youth at risk of social exclusion (Artuch-Garde et al., 2017) and maladaptive social behavior (Gardner et al., 2008). People who are able to self-regulate and manage their emotions and control their behavior are better able to act in accordance with their values, manage stress, deal with conflict, persist in difficult times, see the good in others, and achieve their goals (Eisenberg, 2000; Boekaerts, 2011; Hofmann et al., 2014; Hampson et al., 2016). However, people with poor self-regulation skills may have problems with handling frustration and stress, and may lack self-esteem and self-confidence, which might result in anxiety and anger and, in the long term, in poor well-being, poor health and poor life conditions (Moffitt et al., 2011). Furthermore, poor self-regulation is predictive of antisocial behavior (Gardner et al., 2008) and externalizing problem behavior (Eisenberg, 2000; Oldehinkel et al., 2004).

Research has established that people differ in their capacity to regulate themselves and that the ability to self-regulate is an important factor in adolescents' learning, cognitive and social functioning (Moffitt et al., 2011; Carlo et al., 2012; Hofmann et al., 2014; Dent and Koenka, 2016; Hampson et al., 2016; Panadero, 2017). It is not surprising that self-regulation (and its development) is important for adolescents' functioning at school since during adolescence, academic learning becomes more difficult, and schooling becomes increasingly complex with multiple teachers, homework, and deadlines.

Several theories and models on self-regulation recognize the role of the context or the environment in the development of self-regulation (e.g., Pintrich, 2000; Järvelä and Hadwin, 2013; Zimmerman, 2013; Murray et al., 2015; de la Fuente-Arias, 2017; Panadero, 2017; and for an overview of theories, see Newman and Newman, 2020) and classroom studies suggest that characteristics of the social learning environment (including teachers' behavior) have an impact on students' self-regulation. However, most studies investigating these relations have a cross-sectional correlational design and do not relate to adolescents. As a result, there is little knowledge about relations and causal directions between context characteristics (e.g., referring to social learning environment, teacher behavior) and adolescents' (development of) self-regulation. Since the ability to self-regulate is an important factor in adolescents' learning, cognitive and social functioning, and also in their adult life, and neuroscience has demonstrated that during adolescence rapid changes in areas of the brain relevant for the ability to self-regulate are present (Blakemore and Choudhury, 2010; Luciana, 2010; Eldreth et al., 2013), which offers particular opportunities for interventions and indicates vulnerability and developmental plasticity for environmental influences, it is important to get a better understanding of which aspects of the learning environment that teachers help to create enhance and thwart adolescent students' development of self-regulation. More in particular, longitudinal studies are needed that pay attention to characteristics of the learning environment and to teacher behavior in classes that is conducive and supportive to and not thwarting the development of adolescent students' self-regulation.

Theoretical background

Self-regulation

In the literature on self-regulation, numerous, generally overlapping, conceptualizations can be found. For example, Gillebaart (2018) defines self-regulation, in line with Carver and Scheier (2012), as "the whole system of standards, thoughts, processes and actions that guide people's behavior toward desired end states" (p. 3). These desired end states may be long-term goals, but can also be other standards or norms. It is closely related to the concept of self-control (Gillebaart, 2018), however, it involves more than controlling behavior since it provides "the entire scaffolding for successful goal pursuit" (Gillebaart, 2018, p. 3). According to Gillebaart (2018) self-regulation differs from self-control in that the ability to self-regulate "allows people to formulate goals, standards, and desired end-states, as well as to monitor any discrepancies between one's current state and these desired end-states, whereas everything that one does to steer one's

behavior toward the desired end state constitutes self-control" (p. 3). Brown (1998, p. 62) defines self-regulation as people's capacity to "plan, monitor and direct their behavior in changing situations" and stresses that people plan, monitor, assess and reflect on their own behavior on a regular basis and in periods of time. Together with Brown (1998) and de la Fuente-Arias (2017) considers self-regulation as the degree of a person's positive proactivity … in his active and adequate management of the regulation of his conduct' (p. 2). The process of self-regulation is influenced by many variables, pre-eminently control, self-efficacy, and motivation (Pintrich, 1999; Zimmerman, 2001, 2008; Pintrich and Zusho, 2002; Torrano and González-Torres, 2004; Baumeister and Vohs, 2007; Gardner et al., 2008; Bandura, 2012; Vancouver, 2018).

Self-regulation related to learning: Self-regulated learning

In addition to self-regulation as a general construct, also constructs relating to particular domains can be found in the literature on self-regulation, for example, self-regulation constructs focusing on the regulation of emotions (Eisenberg and Spinrad, 2004; Boekaerts, 2011) or related to learning (Boekaerts, 1996, 2011; Pintrich, 2000; Winne and Hadwin, 2008; Efklides, 2011; Zimmerman, 2015; de la Fuente-Arias, 2017; Panadero, 2017; Schunk and Greene, 2018). In general, the term self-regulation, when applied to learning, refers to learners' proactive process which consists of setting goals for their learning, actively monitoring their progress, and regulating their cognition, motivation, and behavior in order to achieve their learning goals (Pintrich, 2000). The term self-regulated learning is often used in this context. Although there are some variations in the definition of self-regulated learning in the literature, all definitions mention a direction towards goals and the use of self-regulation properties/strategies (de la Fuente-Arias, 2017). Furthermore, self-regulated learning is considered as a complex, dynamic, strategic, and cyclical process (Zimmerman, 2000, 2008; de la Fuente-Arias, 2017; Panadero, 2017) which consists of several phases (Pintrich, 2000; Zimmerman, 2000, 2008). As a construct, self-regulated learning is understood as a multidimensional construct referring to learners as active, goal-directed, strategic, and reflective individuals who plan, monitor, and regulate and reflect on their cognition, motivation, emotion/affect, and behavior to reach their desired goals (Pintrich, 2000; Panadero, 2017; Schunk and Greene, 2018). Numerous studies have established the importance of self-regulated learning to success in school and in further life (Zimmerman, 1990; Dent and Koenka, 2016; Artuch-Garde et al., 2017; Venitz and Perels, 2018; Jansen et al., 2019; Chu et al., 2020; Theobald, 2021).

A key component of self-regulated learning is the use of (self-regulated) learning strategies, and, in particular, the use of metacognitive strategies (Winne and Perry, 2000; Duckworth et al., 2011; Roelle et al., 2017). Learning strategies are self-initiated approaches to enhance learning (Zimmerman, 2015) and can refer to cognitive and metacognitive strategies. While cognitive strategies include students' use of basic and complex strategies for the processing of information such as rehearsal, elaboration, and organization (Garcia and Pintrich, 1994, 1995), metacognitive strategies refer to strategies that learners can use to control and to regulate their own cognition and thinking processes. They include strategies such as planning, monitoring, and regulating learning (Garcia and Pintrich, 1994). It also includes reflecting on and evaluating the effectiveness of their learning approaches (Credé and Phillips, 2011). Research indicates a positive relationship between the use of self-regulated learning strategies and a variety of school outcomes including school performance (for an overview, see for example Tuero et al., 2022) and intervention studies proved that the use of these strategies is trainable (Núñez et al., 2021; see also meta-analyses of Dignath and Büttner, 2008; Dignath et al., 2008; Jansen et al., 2019; Theobald, 2021). Moreover, the use of metacognitive strategies seems to correlate, on average, stronger with school/academic performance than cognitive strategies do (Credé and Phillips, 2011; Dent and Koenka, 2016; Chow and Chapman, 2017) and intervention studies aiming at enhancing students' self-regulated learning seem to be somewhat more effective in enhancing the use of metacognitive strategies than in enhancing the use of cognitive strategies (Theobald, 2021). Furthermore, there is evidence that older students (i.e., from secondary education on), benefit more from interventions including more metacognitive aspects (Dignath and Büttner, 2008; Panadero, 2017).

With regard to individual factors influencing students' development of self-regulated learning and use of learning strategies, theory suggests and research has established that students' emotions and beliefs about their own ability (self-efficacy, feelings of competence) play a key role (Pintrich, 1999; Pintrich and Zusho, 2002; Torrano and González-Torres, 2004; Pajares, 2008; Zimmerman and Cleary, 2009; Wigfield et al., 2011; Bandura, 2012) and that students with self-regulation learning skills are unlikely to use them proficiently if they have doubts about their learning capabilities (Duckworth et al., 2011).

Development of self-regulated learning: The importance of learning context and teacher behavior

Self-regulated learning does not take place automatically (Winne, 2005) and there are some indications that students' self-regulated learning often declines within the first year of secondary education (Van der Veen and Peetsma, 2009; Schuitema et al., 2012) and with increasing grade level (Vansteenkiste et al., 2009).

Winne (2005) stresses that students need support to become good self-regulated learners. Moreover, although self-regulated learning seems not easily be induced (Struyven et al., 2006) and it may take time to see the effectiveness of an intervention (Tuero et al., 2022; perhaps because it may take a while for students to

adapt and alter their learning behavior patterns), there is clear evidence that students' self-regulated learning is malleable and that, with adequate support and scaffolding, students can improve their self-regulated learning (Torrano and González-Torres, 2004; Dignath et al., 2008; Dignath and Büttner, 2008; Jansen et al., 2019; Theobald, 2021). This evidence suggests that students' learning environments at school and in class matter. Attention for the importance of the (learning) context or environment, and, in particular, the teaching and the behavior of teachers in that context, is not new. For example, Zimmerman (1989) already mentioned 'environment' in his triadic model of self-regulated learning and also Pintrich (2000), Hadwin et al. (2011, 2018), and Järvelä and Hadwin (2013) acknowledge in their theoretical models that contextual features in the environment can guide and constrain students' self-regulated learning. The importance of the learning environment and teachers' teaching and behavior is also recognized in the recently formulated theory of de la Fuente-Arias (2017) on self- vs. externally regulated learning. In his theory, de la Fuente-Arias stresses "that self-regulated learning is dependent on external feedback, especially during situations of sustained effort and when goals must be maintained over time" (p. 3), and he acknowledges the importance of effective/regulatory teaching including, among others, "clearly defining tasks" (p. 5), "facilitating a context of personal involvement and persistence" (p.5), the promotion of self-control and self-observation (which includes the use of metacognitive strategies), and the promotion of self-reflection by means of adjusted feedback, dialog, and affective persuasion. Other researchers refer to optimal conditions for developing self-regulation and mention learning environments in which students get the opportunity to pursue goals that they themselves find meaningful and in which students are invited to develop their skills by selecting their own activities, by taking initiative, by engaging in challenging and collaborative learning experiences, and by making their own decisions (Fredricks et al., 2004; Boekaerts and Corno, 2005). Fredricks et al. (2004) mention in their review also the importance of a combination of academic and social support from the teacher and of offering structure (i.e., being clear about expectations), which is in line with findings from research studying the influence of caregivers (parents, teachers, mentors) on children's ability to self-regulate. In this research, evidence is found for the importance of warm and responsive caregivers, the utilization of positive behavior management strategies, and the provision of a positive climate for growth and development in which caregivers provide support, coaching and modeling. Otherwise stated, these findings indicate the importance of caregivers' co-regulation (Murray et al., 2015, 2016; Housman et al., 2018) and their creation of structured environments in which students/children have opportunities to practice with guidance (Murray et al., 2016). It is less clear, however, which characteristics of the learning environment (actively) constrain or undermine students' development and engagement in self-regulated learning, and what explanatory mechanisms are involved. Knowledge of this may be important in explaining the often found decline in students' self-regulation during secondary education. In addition, it is unclear how quickly this decline in self-regulation occurs after entering secondary education.

Furthermore, in addition to the relevance of "objective" characteristics of the learning environment, several theorists and researchers point to the importance of considering students' perceptions of their learning environment and their teachers' behavior (e.g., Reeve and Deci, 1996; Boekaerts and Niemivirta, 2000; Pintrich, 2000; Ryan and Patrick, 2001; Schuitema et al., 2012; Ryan and Deci, 2020). Reference is made, among others, to the perception of classroom norms (e.g., allowance of autonomy or control, autonomy support), perceived teacher support and structure, and classroom climate (including teacher warmth), and a plea is made for more research on how different features of the context can shape, facilitate, and constrain self-regulated learning.

Self-determination theory and self-regulated learning

A theory that fits well with the concept of self-regulation and self-regulated learning as a form of optimal functioning and that addresses characteristics of the learning environment that can be useful pointers for discerning supportive vs. undermining/thwarting features of a learning environment in relation to students' (development of) self-regulated learning, is the self-determination theory. In addition, this theory recognizes the importance of how students perceive their learning environment.

According to the self-determination theory (Ryan and Deci, 2000, 2020; Deci and Ryan, 2002), and in particular the sub-theory Basic Psychological Needs Theory—BPNT (Deci et al., 1996; Vansteenkiste et al., 2020; Opdenakker, 2021), students are more likely to engage in self-regulated learning if their learning environment satisfies their fundamental basic psychological needs, namely their need to feel autonomous, competent and related. When students feel autonomous, they act in congruence with their true selves. In addition, they express their genuine preferences in order to experience a general sense of choice, volition, willingness, and ownership. They experience a sense of integrity "as when their actions, thoughts, and feelings are self-endorsed and authentic" (Vansteenkiste et al., 2020, p. 3). Frustration of this need goes along with experiencing pressure, external control, conflict, or feeling pushed in a non-wanted direction (Ryan and Deci, 2020; Vansteenkiste et al., 2020). Feeling competent entails experiencing oneself as effective in interactions with the (social) environment, having opportunities to express and extend abilities, and feeling a sense of mastery (Deci and Ryan, 2002). When this need is frustrated, students feel personal ineffective and experience failure or helplessness (Vansteenkiste and Ryan, 2013; Vansteenkiste et al., 2020). Feeling related means feeling emotionally connected to others (Skinner and Pitzer, 2012), feeling loved and cared for, experiencing warmth, and feeling a sense of belonging (Baumeister and Leary, 1995). When this need is frustrated, students feel "a sense of social alienation,

loneliness, and exclusion" (Vansteenkiste et al., 2020, p. 3). According to the self-determination theory, the social environment can support or thwart the mentioned needs leading to, respectively, growth, engagement, flourishing, and optimal functioning in case of supporting the needs (Deci and Ryan, 2002; Vansteenkiste et al., 2020) and malfunctioning when the mentioned needs are thwarted (Ryan and Deci, 2000).

Learning environments (and teachers) that are supportive to the three basic psychological needs are autonomy-supportive, deliver structure, and offer opportunities for feeling related and connected, for example, by means of an involved teacher (Opdenakker, 2021). Being an autonomy-supportive teacher entails that teachers take their students' perspectives into account, acknowledge their feelings and perceptions, provide students with meaningful choices and allow them to make their own decisions about their learning (Deci et al., 1996; Williams and Deci, 1996). In addition, autonomy-supportive teachers help students to understand the relevance of learning tasks (Assor et al., 2002), give them explanatory rationales for engaging in requested endeavors, and allow them to act upon their personal values and interests in such a way that their learning is accompanied with a sense of volition and psychological freedom (Reeve, 2009; Opdenakker, 2021). This will stimulate students to engage in self-regulated learning (Deci and Ryan, 2000; Vansteenkiste et al., 2005). However, a learning environment in which high pressure and control is present and teachers make use of controlling language, students' self-regulated learning will be thwarted (Deci and Ryan, 2000; Reeve, 2009).

Structure in the learning environment refers to offering informational and instructional support and supervision, guidance and help that meets students' wishes and tries to overcome their problems. It further entails communication of clear expectations and presentation of clear goals, consistent guidelines, and rules so that students know what it takes to do well in class, and it also includes offering constructive feedback to students (Deci et al., 1996; Reeve, 2006; Vansteenkiste et al., 2012; Opdenakker, 2021). Structure primarily supports the need for competence and helps students to feel able to effectively deal with the learning task (Skinner and Belmont, 1993). A supportive, well-structured learning environment offers students optimal challenges and gives them opportunities for growth and for achieving success (Deci et al., 1996; Opdenakker, 2021). However, a learning environment characterized by confusion, vagueness and uncertainty, inconsistent teacher behavior, lack of help and competence-thwarting feedback, will thwart students' self-regulated learning (Deci and Ryan, 2000).

Lastly, according to the self-determination theory, it is important that teachers create a caring, respectful, and supporting environment that meets students' need for relatedness (Ryan and Deci, 2020; Opdenakker, 2021). The involvement of teachers and, in particular, their availability, genuine interest in their students, and their warm and caring presence is important in this respect (Deci et al., 1996; Deci and Ryan, 2000; Ryan and Deci, 2020; Opdenakker, 2021). In contrast, when teachers reject and neglect their students, their behavior is supposed to be a treat to the fulfillment of students' basic psychological needs and can be seen as thwarting students' basic psychological needs and, therefore, also their engagement in self-regulated learning (Deci and Ryan, 2000).

There is considerable evidence for the relevance and importance of the self-determination theory in education, linking effects of learning contexts (including teacher behavior) to students' basic needs satisfaction and a variety of student/individual outcomes (for reviews, e.g., Ryan and Deci, 2000, 2020; Deci and Ryan, 2002; Vansteenkiste et al., 2020; Opdenakker, 2021; Conesa et al., 2022[1]). However, psychological need thwarting, that arises in response to perceiving that psychological needs are actively undermined, is understudied (Costa et al., 2015; Opdenakker, 2021). The few studies addressing this topic, found evidence for its relevance in relation to maladaptive functioning (see Bartholomew et al., 2018; Patall et al., 2018; Vandenkerckhove et al., 2019; Opdenakker, 2021; Conesa et al., 2022). Furthermore, there is some evidence that need-supportive teacher behavior is more important than need-thwarting teacher behavior for adaptive student behavior and optimal functioning (Skinner et al., 2008; Jang et al., 2016; Patall et al., 2018; Opdenakker, 2021) and that need-thwarting teacher behavior is more important for forms of maladaptive behavior and sub-optimal functioning (Jang et al., 2016; Patall et al., 2018; Opdenakker, 2021), although, depending on the student outcome, also unique and independent effects of both kinds of behaviors can be visible (Patall et al., 2018; Opdenakker, 2021).

Links between supportive and thwarting teacher behavior and students' self-regulated learning

Studies investigating effects of all mentioned supportive and thwarting teacher behavior dimensions on students' (development of) self-regulated learning are scarce. Moreover, most of the studies exploring the link between teacher behavior and students' self-regulated learning only address a selection of supportive teacher behavior, and studies exploring thwarting teacher behavior in combination with supportive teacher behavior are almost non-existent. A few exceptions are the study of Vansteenkiste et al. (2012), although this study strictly spoken rather focused on environments with high and low supportive teacher behavior, and the study of Opdenakker (2021). Vansteenkiste et al. (2012), explored effects of four

1 The review of Conesa et al. (2022), however, revealed that evidence of its influence (in terms of evidence for the importance of basic psychological need satisfaction) in primary education classrooms is still limited due to the lack of studies (that contain rigorous methodology). It must be said, however, that Conesa et al. (2022) excluded studies conducted in a physical education context from their review.

perceived teaching configurations on self-regulated learning of secondary school students, namely configurations characterized by (1) (moderately high) autonomy support, (2) clear expectations (part of structure), (3) vague expectations and low autonomy support, and (4) high autonomy support and clear expectations. Their cross-sectional study revealed that the teacher configuration groups differed with regard to their students' self-regulated learning: students in the teaching configuration characterized by (perceived) high autonomy support and clear expectations reported significant more self-regulated learning than students in the configuration with only autonomy support ore only clear expectations, and students in these groups had significant more self-regulated learning than students in het remaining group. Opdenakker (2021) investigated effects of perceived teachers supportive and thwarting behavior on secondary school students' procrastination behavior (which is nowadays often considered as a self-regulation failure; see Steel, 2007). She found evidence for negative associations of the three mentioned teacher behavior support dimensions (autonomy support, structure, involvement) and evidence for positive associations of the mentioned teacher behavior thwart dimensions, indicating that teachers' need-supportive behavior is associated with low procrastination behavior, while teachers' need-thwarting behavior is associated with higher levels of procrastination behavior.

Furthermore, studies focusing on the association between dimensions of supportive teacher behavior and students' (development of) self-regulated learning have demonstrated a positive relation between these dimensions and students' self-regulated behavior. For example, Sierens et al. (2009) studied the relation between perceived teachers' autonomy support, structure and self-regulated learning of secondary education students and found that structure was associated with more self-regulated learning under conditions of moderate and high autonomy support only. Also, Mouratidis et al. (2013) found evidence for the importance of structure in relation to self-regulated learning and their study revealed that this effect was partially mediated by competence need satisfaction. Schuitema et al. (2012) addressed the relationship between autonomy support, relevance (an aspect of autonomy support) and grade-7 students' development of self-regulated learning and found positive effects of autonomy support (relevance) on aspects of self-regulated learning (metacognitive strategy use, delay of gratification). Schuitema et al. (2016) investigated in their longitudinal study the direction of the effects between students' perceptions of teachers' autonomy support and involvement on students' self-regulated learning (metacognitive strategy use, delay of gratification) during their first 2 years in secondary education. They found that (only) perceived teachers' involvement predicted (both aspects of) self-regulated learning. In addition, their study revealed small reciprocal effects in both directions between delay of gratification and perceived autonomy support and they found that metacognitive strategy use predicted perceived autonomy support. Yin et al. (2009) explored the association between teacher support (including aspects of teacher involvement) and aspects of students' self-regulated learning. Their study also revealed links between teacher support and students' self-regulated learning.

Aim of the present study

In sum, it can be concluded that that teachers' supportive behavior, as defined by self-determination theory, is positively related to students' self-regulation related to learning (self-regulated learning). Furthermore, there is some indication that teacher behavior that is thwarting students' basic psychological needs is harmful for self-regulation (self-regulated learning). However, as a result of the largely lack of studies that consider both supportive and undermining teacher behaviors in relation to students' self-regulated learning, it is unclear how effects of supportive vs. undermining teacher behaviors relate to each other. Therefore, it is still unclear on which teacher behaviors interventions should focus (stimulating supportive behavior only and/or focusing on diminishing undermining behavior) to foster students' development and engagement in self-regulated learning and to avoid a decline in students' development and engagement in self-regulated learning. In addition, since most previous studies are cross-sectional, it is difficult to build knowledge on the causal directions of the relations between perceived teacher support, thwart and self-regulated learning. Furthermore, it is unclear how quickly the decline in self-regulation related to learning occurs in the first year of secondary education and if that decline is associated with students' experiences and perceptions of their teachers' supportive or thwarting behavior. The present study aims to contribute to reducing this knowledge gap and extends existing research by examining and comparing effects of a selection of perceived teacher supportive and undermining behavior (based on self-determination theory) on early adolescents' self-regulation (self-regulated learning) within a longitudinal design in which students developments are followed from start of secondary education during their first months in their first year of secondary education.

Materials and methods

Participants

In the study, which is part of a larger research project on students' motivational and self-regulated development during the first year of secondary education,[2] 566 grade-7 students (55% boys, 45% girls) participated. They belonged to 20 mathematics/English secondary education classes of three

2 The study of Opdenakker (2021) is also part of this research project.

public schools in the Netherlands which were located in a provincial city area in the northern part of the country. The schools were representative of typical public schools for middle socioeconomic status and voluntary participated in the research. Class sizes ranged from 21 to 31 students ($M = 28$, $Mdn = 29$, $SD = 2.9$), and half of the classes were English classes. The choice for Math and English classes is based on the importance and diversity of these subjects in grade 7 and because it was expected that choosing for these classes would result in heterogeneous teacher behavior. Classes of all school tracks of the regular Dutch education system were represented for both subjects: so-called transition classes (that combined several track levels in one class, 40%) were included as well as single-track classes (prevocational, general, and pre-university). Almost all students were native Duch (<1% was nonnative Dutch). The students' mean age was 12.19 years (SD = 0.55) at the start of the school year.

Procedure

Paper-and-pencil questionnaires were used to tap students' self-regulation related to learning (self-regulated learning) at the start of the school year and after about 2 months. Students' perceptions of their teachers' need-supportive and need-thwarting behavior during the first months of the school year were collected with an additional paper-and-pencil questionnaire. The questionnaires were distributed during class time and permission to distribute them was received from the school authority as well as by means of written informed consent from the students' math/English teachers and their parents/representatives. Students received an explanation of the purpose of the research before completing the questionnaires. They were assured of their confidentiality and anonymity, and in order to assure this, the administration of the questionnaires at the different time points was carried out by research assistants.

Measures

Self-regulated learning

Self-regulated learning was assessed by means of an important aspect of self-regulated learning, namely the use of metacognitive strategies. A shorted Dutch validated version (with 6 items) of the use of metacognitive strategies scale of the MSLQ of Pintrich and De Groot (1990), the most used established instrument to measure self-regulated learning (Roth et al., 2016), was used. The scale measures the use of activities such as planning and comprehension monitoring. An example of an items is: "When I'm reading, I stop once in a while and go over what I have read." Previous research has confirmed the reliability and validity of this instrument and indicates that it measures the same construct over time (Van der Veen and Peetsma, 2009; Schuitema et al., 2016). Cronbach's α values are 0.63[3] (start math/English) and 0.75/0.76 (second measurement, respectively math and English).

Need-supportive and need-thwarting teacher behavior

Students' perceptions of their teachers' need-supportive and need-thwarting behavior are assessed with The Questionnaire-on-Teacher-Support-and-Thwart (Opdenakker, 2021). The scales are based on ideas of the self-determination theory in which a distinction is made between dimensions that support vs. thwart three basic psychological needs. Supporting autonomy, delivering structure, and being involved with the students as a teacher are assumed to be important for the fulfillment of students' basic psychological needs and are measured as individual scales. Exhibiting controlling (instructional) behavior, having chaos, uncertainty, and inconsistency in the classroom, and rejecting and neglecting students, are supposed to be a treat to the fulfillment of students' basic psychological needs and are measured as individual scales as well. The questionnaire is based on the 'Teacher as a Social Context' (TASC; Belmont et al., 1992) and comprises 51 items referring support (autonomy support, structure, and teacher involvement), omission of support, and supposed opposites like controlling instructional behavior, chaos/uncertainty/inconsistency in the classroom, and teacher neglect/rejection. The items are clustered into six scales: three supporting and three thwarting scales. For convenience, we will refer to the dimensions/scales as autonomy support vs. teacher thwart—control, structure vs. teacher thwart—chaos/inconsistency, and teacher involvement vs. teacher thwart—neglect/rejection. The number of items of the six individual teacher behavior scales ranges from 5 to 12. Items were presented on a five-point Likert scale ranging from 1 = "strongly disagree" to 5 = "strongly agree." Examples of the items are: "My teacher gives me a lot of choices about how I do my schoolwork" (autonomy support), "This teacher tries to control everything I do" (teacher thwart—control), "This teacher shows how to solve problems for myself" (structure), "My teacher keeps changing how he/she acts toward me" (teacher thwart—chaos/inconsistency), "This teacher really cares about me" (teacher involvement), and "My teacher does not seem to enjoy having me in his/her class" (teacher thwart—neglect/rejection). The psychometric properties of the individual scales are sufficient to good (Cronbach's α values vary between 0.61 and 0.82).

3 According to Sijtsma (2009), Cronbach's alpha should be considered as one of the smallest lower bound estimates of reliability. In addition, its values are quite sensitive to the number of items in the scale (Nunnally, 1978). With short scales (e.g., scales with fewer than 10 items), it is common to find quite low Cronbach values (e.g., 0.5; Pallant, 2011). In this case, Briggs and Cheek (1986) suggest reporting also the mean inter-item correlation for the items and recommend an optimal range for the mean inter-item correlation between 0.2 and 0.4. In the case of the self-regulated learning measures at the start of secondary education, the mean inter-item correlation was 0.22, which is within the mentioned optimal range.

Method of analysis

In addition to descriptive statistics related to all variables and a correlation analysis related to corresponding teacher need-supportive and need-thwarting behavior, multilevel analyses (MLwiN; Rasbash et al., 2012) were performed to study the effects of the need-supportive and need-thwarting dimensions of teacher behavior on students' self-regulated learning. Two levels were distinguished in the multilevel models, namely the class level (classes) and the student level (students within classes). In addition, self-regulated learning measured at the start of the school year was controlled for. A series of hierarchical models with and without a combination of (corresponding) need-supportive and need-thwarting teacher behaviors were inspected in order to explore evidence for unique and joint effects of these teacher behavior dimensions, or otherwise stated, to explore total effects and evidence for additional effects of teacher behavior dimensions. A selection of these models, of which the results provide a comprehensive overview of the findings, will be presented in a table. In accordance with usual practice, results in the tables are presented with significance levels referring to two-sided testing. However, based on the literature/theoretical framework (and expectations derived from it), one-sided testing is allowed with regard to the effects of teaching behavior.

Results

Descriptive statistics

In Table 1, the descriptive statistics of all variables (means and standard deviations) are provided. The comparison of students' self-regulated learning (use of metacognitive strategies) at start of the school with their self-regulated learning after about 2 months indicates that students' self-regulated learning seems, in general, to decrease a little during that period (if this decreasing trend continues in a linear manner during the school year, then the decrease of self-regulated learning from start to the end of the school year is comparable to a small-to-medium effect size; Cohen, 1988; Lakens, 2013). In addition, inspection of the standard deviations of the indicator of self-regulated learning on the two occasions reveals there are clear indications of differences between students with regard to the degree they learn self-regulated, and in particular, the degree they make use of metacognitive strategies on the two measured occasions. In addition, these differences between students seem to increase during the school year.

With regard to students' perception of their teachers' need-supportive and need-thwarting behavior, grade-7 students score their teachers' behavior, on average, as more need-supportive than need-thwarting. Furthermore, they score "giving structure," on average, as highest of their teachers' supportive behaviors and score the supportive teacher behavior "being involved as a teacher" as lowest, although the score on the last-mentioned dimension is still at the middle of the rating scale. Of the need-thwarting behaviors, students score their teachers highest on "exhibiting controlling behavior" and on "having chaos, uncertainty and behaving inconsistent toward them." However, these scores are, on average, one point lower than the middle of the rating scale. In addition, the table reveals that students perceive differences in their classes with regard to their teachers' behaviors.

As mentioned, also a correlational analysis related to corresponding need-supportive and need-thwarting teacher behavior dimensions was conducted. This analysis revealed that the correlations between the support and thwart dimensions ranged from −0.39 (teacher involvement and teacher thwart—neglect/rejection) to −0.55 (structure and teacher thwart—chaos/inconsistency), with the correlation between autonomy support and teacher thwart—controlling behavior being −0.51. These correlations between corresponding dimensions indicate a rather modest covariance, and implicate that, although there is ground for common variance, there are also clear indications that these dimensions measure unique parts of teacher behavior.

TABLE 1 Means (M) and standard deviations (SD) for students' self-regulated learning and teacher support and teacher thwart dimensions.

	M	*SD*
Student self-regulation		
Self-Regulation (start)	3.23	0.59
Self-Regulation (end)	3.19	0.70
Support and thwart dimensions		
Autonomy support	3.20	0.70
Teacher thwart—Control	2.04	0.62
Structure	3.48	0.67
Teacher thwart—Chaos/inconsistency	1.95	0.58
Teacher involvement	3.02	0.64
Teacher thwart—Neglect/rejection	1.70	0.66

Main analysis

Multilevel analyses with the teacher dimensions separately included in the multilevel model revealed that both (perceived) need-supportive and need-thwarting teacher behaviors could explain differences (and changes) in students' self-regulation. The results indicated that the development of students' self-regulation was positively related to autonomy support, delivering structure, and having a teacher who is involved with students. In addition, when teachers thwarted their students' basic psychological needs, this negatively affected early adolescents' self-regulation. Furthermore, the degree to which the teacher delivered structure seemed to be the most important supportive dimension, followed by the degree of the involvement of the teacher toward their students. The degree

of autonomy support was important as well, but to a lesser extent. With regard to the need-thwarting dimensions, controlling teacher behavior as well as the creation of a chaotic learning environment with uncertainty and inconsistent teacher behavior seemed to be the most harmful teacher behaviors, with, to a clear lesser extent, also teacher behavior characterized by neglecting and rejecting students. With regard to the total effects of the teacher behavior dimensions on students' self-regulated learning, need-supportive teacher behavior dimensions explained between 9% and 15% of the variance in students' self-regulation and need-thwarting teacher dimensions between 3% and 7%.

A further inspection of the results comparing effects of supportive vs. thwarting teacher behavior revealed that teachers' supportive behaviors was stronger related to students' self-regulated learning development compared to teachers' thwarting behavior. Moreover, additional analyses in which corresponding supportive and thwarting teacher behavior dimensions are included together in the same multilevel model (see Table 2), revealed that all teacher supportive dimensions remained to have significant positive effects on students' self-regulated learning, but that of the thwarting dimensions only the effect of controlling (instructional) teacher behavior remained significant in addition to the corresponding teacher supportive dimension of autonomy support. These results indicate the supremacy of all supportive teacher behavior dimensions in relation to students' (development) of self-regulated learning compared to thwarting teacher dimensions and, in addition, deliver evidence for the harmful effects of controlling instructional teacher behavior on the development of early adolescent students' self-regulation related to learning after students' transition from primary to secondary education and during the first months of their first year in secondary education.

Conclusions and discussion

The present study aimed to contribute to the knowledge base on the effects of (perceived) need-supportive and need-thwarting teacher behavior on early adolescents' self-regulation, and in particular, on students' self-regulated learning during their first months in secondary education By addressing need-supportive teacher behavior as well as need-thwarting teacher behavior within the same study, the study was quite unique, since almost no previous study addressed all supportive and thwarting teacher behaviors based on self-determination theory within the same study (in relation to the self-regulation of students). Also, the application of a longitudinal design while investigating effects of teacher behavior in accordance with the self-determination theory is rather scarce in ecological valid environments, and, as such, the present study extends existing research as well.

Main conclusions

In this study, evidence was found for positive effects of need-supportive teacher behavior and for negative effects of need-thwarting teacher behavior on early adolescents' development in self-regulated learning during their first months in secondary education. However, the effects of need-supportive teacher behavior were stronger than the effects of need-thwarting behavior. These findings are in line with the self-determination theory, and in particular the sub-theory basic psychological needs theory (Vansteenkiste and Ryan, 2013), and with the (scarce) research literature on effects of need-supportive and need-thwarting teacher behavior on optimal functioning and adaptive student behavior (Skinner et al., 2008; Jang et al., 2016; Patall et al., 2018; Ryan and Deci, 2020; Vansteenkiste et al., 2020; Opdenakker, 2021). In addition, the findings regarding the importance of

TABLE 2 Results of multilevel models explaining students' self-regulated learning by teacher support and thwart dimensions and self-regulated learning at the start of the school year.

	Involvement—Neglect/rejection ($N=539$)		Structure—Chaos/inconsistency ($N=541$)		Autonomy—Control ($N=530$)	
	Coefficient	SE	Coefficient	SE	Coefficient	SE
Fixed effect						
Intercept	3.209**	0.041	3.208**	0.042	3.199**	0.039
Teacher support	0.284**	0.048	0.341**	0.048	0.150**	0.046
Teacher thwart	0.023	0.046	0.036	0.055	−0.096°	0.052
Self-regulated learning (start)	0.357**	0.046	0.336**	0.046	0.373**	0.048
Random effect						
Level 2 variance	0.020	0.011	0.022	0.011	0.016	0.010
Level 1 variance	0.378	0.023	0.360	0.022	0.387	0.024
Deviance	1022.535		1002.476		1019.672	

°$p<0.10$, *$p<0.05$, **$p<0.01$ (two-sided testing).

supportive teacher behavior on students' self-regulated learning are in agreement with findings regarding the influence of social environments and caregivers (e.g., parents, teachers) on children's (development of) self-regulation (Murray et al., 2015).

Furthermore, the results showed that need-thwarting teacher behavior can have unique and independent effects (in addition to joint effects with need-supporting behavior) on the development of students' self-regulated learning (which can be considered as a form of optimal functioning). More in particular, it was found that controlling teacher behavior had a unique (negative) effect on students' (development of) self-regulated learning in addition to the (positive) effect of teachers' autonomy-supportive behavior. Finding evidence for unique effects of need-thwarting teacher behavior on optimal functioning and adaptive student behavior in addition to clear effects of need-supportive teacher behavior, is in agreement with the scare literature on this topic (Patall et al., 2018; Opdenakker, 2021) and self-determination theory (Vansteenkiste and Ryan, 2013). In addition, it provides additional evidence for the importance of paying attention not only to supportive teacher behavior, but also to undermining or thwarting teacher behavior, which is also advocated by Costa et al. (2015) and Vansteenkiste et al. (2020), since it does yield, in some cases, additional functional costs (Vansteenkiste et al., 2020).

With regard to effects of supportive teacher behavior dimensions on students' (development of) self-regulated learning, all dimensions (structure, autonomy support, teacher involvement) had clear significant positive effects. However, there were also differences in the size of the effects, with structure having the largest effect, followed by teacher involvement, and autonomy support having the least strong effect. In the literature on effects of supportive teacher behavior (defined in line with the self-determination theory) on self-regulated learning, also positive effects are found for structure (Sierens et al., 2009; Vansteenkiste et al., 2012; Mouratidis et al., 2013), teacher involvement (Schuitema et al., 2016), autonomy support (Schuitema et al., 2012; Vansteenkiste et al., 2012), and teacher support (Yin et al., 2009). However, not many studies addressed effects of all three mentioned need-supportive teacher behavior dimensions together in the same research on students' self-regulated learning, which makes it difficult to compare the results of the present study regarding the importance level of the dimensions with findings in the literature. A few studies addressed autonomy support as well as structure in relation to self-regulated learning and found evidence for the importance to combine structure with autonomy support (Sierens et al., 2009; Vansteenkiste et al., 2012). In fact, Sierens et al. (2009) found only a significant (unique) effect of structure and not of autonomy support, which seems to be in line with the finding in the present study that the effect of structure is larger than that of autonomy support. Also, Schuitema et al. (2016), who also investigated effects of both dimensions but included only one teacher behavior dimension in their cross-lagged models at the same time, found no significant effect of autonomy support on self-regulated learning (use of metacognitive strategies) when the results of their final cross-lagged model are considered. Interesting was that Sierens et al. (2009) also modeled an interaction between structure and autonomy support and discovered that structure was associated with more self-regulated learning (only) when it was accompanied with moderate and high autonomy support. The importance of structure in developing students' self-regulated learning is also in line with intervention research aimed at fostering self-regulated learning of students. In this research, structured environments in which students receive strategy instruction, support, and opportunities to practice with the use of strategies seem to be fruitful and are highly advocated (Torrano and González-Torres, 2004; Dignath et al., 2008; Dignath and Büttner, 2008; Jansen et al., 2019; Theobald, 2021). In addition, the idea of scaffolding, which is one of the most utilized instructional strategies in these interventions (Torrano and González-Torres, 2004) and entails delivering support to students while they are learning (self-regulation strategies) and eliminating this support step-by-step over time as students become more competent, is quite in congruence with the findings of the present study and previous studies (investigating effects of environment dimensions in line with self-determination theory). It also underscores importance of delivering structure while helping students to become autonomous learners, and, thus, support students' autonomy. Furthermore, the finding that structure and autonomy support are both important and, that for an optimal learning environment, structure should be accompanied with medium to high levels of autonomy support (Sierens et al., 2009) could deliver an explanation (in addition to individual developmental characteristics of students) for the often-found decrease (or at most stability) in students' self-regulated learning during secondary education. In the present study, students perceived their teachers' behavior with regard to delivering structure and offering autonomy support as being at most as medium, indicating that, on average, they did not really experience very optimal teacher behaviors and a learning environment optimal for the development of (and engagement in) self-regulated learning. Furthermore, the idea of the importance of both structure and autonomy support is also in line with the recently formulated theory of de la Fuente-Arias (2017) of self- vs. externally-regulated learning™ and is congruent with recent empirical and theoretical work on motivating and demotivating teaching styles using a circumplex approach (Aelterman et al., 2019; Vermote et al., 2020; Moè et al., 2022).

A remarkable finding was the importance of teacher involvement in the present study. Teacher involvement seemed to be the second most important teacher behavior in relation to students' development of self-regulated learning. This means that students must feel cared for by their teachers, must feel that their teachers are interested in them, must experience sincere concern and responsiveness from their teacher to them in order to develop and engage in self-regulated learning. Also, Schuitema et al. (2016) found evidence for the importance of teacher involvement on students' self-regulated learning (use of metacognitive strategies, delay of gratification) in their longitudinal study and this finding is in line with research studying the influence of caregivers

(parents, teachers, mentors) on children's ability to self-regulate and to engage in academic learning pointing to the importance of warm and responsive caregivers (Stroet et al., 2013; Murray et al., 2015, 2016; Housman et al., 2018; Opdenakker, 2020, 2021). According to the self-determination theory, teachers' involvement with their students plays an important role in students' internalization process by which they 'attempt to transform socially sanctioned mores or requests into personally endorsed values and self-regulations' (Deci and Ryan, 2000, p. 235–236). Involved teachers are supportive for students' need to feel related and competent (and autonomous) and thereby facilitate the internalization of values and regulations (Deci and Ryan, 2000). By satisfying students' need for belongingness or relatedness, involved teachers nurture the motivational basis for internalization, ensuring a more effective transmission of values and regulations and a more cohesive social (class) organization (Deci and Ryan, 2000). In addition to the self-determination theory, also theories (e.g., attachment theory, teaching through interactions framework, model of interpersonal teacher behavior) and classroom studies addressing the influence of social (learning) environments on student learning and student (motivational) outcomes stress and, in case of research studies, have repeatedly demonstrated the importance of having warm teacher-students relationships (Opdenakker et al., 2012; Stroet et al., 2013, 2015; Sparks et al., 2016) and creating a warm and safe climate in classes for students' learning (for a discussion of theories and research, see Opdenakker, 2020, 2022; Opdenakker and Van Damme, 2006a,b, 2007). Teachers who are involved with their students are able to create such environments (Opdenakker and Van Damme, 2006b; Fraser, 2012; Opdenakker, 2020, 2022).

In sum, the present study was among the first to investigate the effects of three dimensions of need-supportive teacher behavior and three dimensions of need-thwarting teacher behavior in line with SDT-BPNT within the same study and to explore the effects of these teacher behavior dimensions while adopting a longitudinal design. The findings revealed that this approach is a fruitful way to gain insights into students' development of and engagement in self-regulated learning and highlighted the importance of delivering structure, being involved as a teacher and providing autonomy support to students to stimulate their engagement in and development of self-regulated learning. However, the findings also demonstrated harmful effects of teachers' controlling behavior in addition to the positive effects of teachers' autonomy supportive behavior (even within the first months of students' first year in secondary education).

Limitations and suggestions for further directions

Although the present study expanded existing research and revealed important results of teacher behavior effects on early adolescents' self-regulated learning in line with self-determination theory, the study has also a number of limitations.

The first limitation is that students' self-regulation was solely studied in relation to the domain of learning and, within that domain, limited to the use of meta-cognitive strategies. It is possible that when other aspects of self-regulated learning or self-regulation are studied (such as delay of gratification, emotion regulation or effort regulation), different findings with regard to the relative importance of the explored need-supportive and need-thwarting teacher behaviors are found. However, based on the study of Schuitema et al. (2016), in which two aspects of self-regulated learning (use of metacognitive strategies and delay of gratification) are addressed, the differences in results seem to be rather minor. It is possible, however, that when self-regulation in different domains are compared, the differences in findings are larger. Research of Murray et al. (2022) is interesting in this respect. The findings of their meta-analysis suggest not only that emotion regulation may be a critically important self-regulation mechanism during early adolescence, but also that intervention approaches focusing predominantly on emotion regulation seem to significantly improve behavioral as well as emotional outcomes. More research is needed to explore whether the hierarchy of effects found in the present study are also valid when emotion regulation is the subject of research. Moreover, it will be interesting to pay in particular attention to aspects of co-regulation between teachers and students, which is rather understudied in relation to students' emotion regulation (Murray et al., 2016).

Secondly, the reliance on student perceptions of teacher behavior and on self-reports of self-regulated learning could be seen as another limitation. Although student perceptions of their teachers' behavior are seen as very valuable and convenient in learning environment research (Opdenakker, 2021, 2022) and within the perspective of the self-determination theory (Ryan and Deci, 2020), and have high validity (Kulik, 2001), using student ratings for teacher behavior as well as for students' self-regulated learning might have inflated the observed associations between them because of shared method variance. In addition, it might be that students' ability to regulate their own learning at the start of the school year has an effect on the way they perceive their teachers' behavior during the school year. The addition of observational data and interviews with students about how they perceive their teachers' behavior could be of added value to gain more complementary and deeper insights in future research.

A third limitation of the present study is that, although a longitudinal approach was used, it was not possible to study reciprocal effects between teacher behavior and students' self-regulated learning because students' self-regulated learning was measured only twice and teacher behavior only once. Since there are some indications in the literature that students' behavior (and the way in which their behavioral is regulated, i.e., autonomous or controlled motivated) can influence (need-supportive) teacher behavior (and vice versa; see studies of Skinner and Belmont, 1993, Jang et al., 2016, Schuitema

et al., 2016, Matos et al., 2018, and Garn et al., 2019), and more in particular, that aspects of students' self-regulated learning such as delay of gratification predicts perceived autonomy support (and vice versa; Schuitema et al., 2016), it is of importance to pay attention to reciprocal effects of teacher behavior and students' self-regulated learning in future longitudinal studies. This will imply that longitudinal studies should be designed with enough/more measurement points and appropriate time intervals between them. Based on their study, Schuitema et al. (2016) suggest that these intervals should be smaller than half a school year to get more insight into how dynamic variables such as teacher behavior and students' self-regulated learning influence each other over time, which is in agreement with the recommendation of Collins and Graham (2002) to use shorter time intervals in longitudinal studies investigating influences between dynamic variables. In addition, it is relevant to focus not only on teachers' need-supportive behavior in these studies, but also to need-thwarting teacher behaviors, since there are indications in recent research that student behavior can not only effect teachers' need-supportive behavior, but also their undermining behavior (see Jang et al., 2016).

Despite the mentioned limitations, the findings of the present study contribute to our knowledge and growing understanding of the influences of learning environments and, more in particular, of facilitating and undermining factors in these environments (teacher behavior) in relation to (adolescent) students' development and engagement in self-regulated learning. The findings contribute to highlighting the importance of both teachers' need-supportive and need-thwarting behaviors in daily classrooms and indicate that, in particular, need-supportive teacher behavior (structure, teacher involvement, and autonomy support) should be fostered and controlling teacher behavior should be avoided when the development of students' self-regulated learning and students' engagement in this kind of behavior is focused on. Furthermore, the results point to the relevance of paying attention to the delivery of structure when adolescent students' development and engagement in self-regulated learning is considered. This seems, at first side, somewhat counterintuitive since students' self-regulation and autonomy is highly important in self-regulated learning. However, it is important to consider that the study was conducted with students in their first year of secondary education and started when these students had made the transition from primary school to secondary school. In addition, the findings are in line with instructional approaches such as scaffolding, that has proven to be effective in supporting students to become self-regulated learners, and are also in agreement with ideas of co-regulation and findings from research based on self-determination theory that emphasize the relevance of combining autonomy-support and delivering structure to students. The study also shows the relevance of being involved with students as a teacher. For students' development and optimal functioning, but also for the internalization of values and regulations, it is known from theory, research, and practice that it is important that students feel cared for by their teachers, that they feel that their teachers are interested in them, have sincere concern and are responsive to them. Although further research is necessary, since this teacher need-supportive dimension is rather understudied in comparison to the other need-supportive dimensions within research based on self-determination theory, and also in relation to self-regulated learning, the present study indicates that the quality of the relation teachers have with their students matters not only for students' social and emotional development and well-being (as is clearly demonstrated in much research from a developmental psychology perspective), but matters also for their learning behavior, which is important for their performance and success at school and for their success in later life.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

Ethical review and approval was not required for the study on human participants in accordance with the local legislation and institutional requirements. Written informed consent to participate in this study was provided by the participants' legal guardian/next of kin.

Author contributions

M-CO designed the study, was in charge of the data collection procedure, analyzed the data, and wrote the manuscript.

Conflict of interest

The author declares that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

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Executive function and effortful control—Similar and different evidence from big data analysis

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Introduction: The current study explored commonalities and similarities between executive function (EF) and effortful control (EC).

Methods: The major empirical studies published between 2013 and 2022 in the World of Science (WoS) was collected. The bibliographic information was systematically analyzed.

Results and discussion: (1) EC is the efficiency of executive attention that incorporates inhibitory control (IC), attentional control, activation mainly related to temperament. On the other hand, EF is the efficiency of self-directed action that encompasses IC, working memory (WM), and shifting/cognitive flexibility in particular focuses on the cognitive aspect. (2) EF research has overwhelmingly outnumbered EC research (2,000 EF studies vs. 50 EC studies per year). (3) According to a co-word analysis with keyword co-occurrences, the subject of preschool students and individual differences co-occurred in EF studies. (4) EC usually occurs with working memory and early childhood. In the more detailed analysis of the articles, the EF and EC studies used younger subject groups than older subject groups. EC studies were especially likely to use subjects in early childhood. (5) The Delis–Kaplan Tests of Executive Functioning System (D-KEFS) was the most commonly used test for EF. In contrast, the EC used self-report surveys such as the Adolescent Temperament Questionnaire (ATQ). This research illustrates and discusses key findings in the EC and EF data and provides suggestions for future study directions.

KEYWORDS

executive function (EF), effortful control (EC), big data analysis, bibliographic information, Delis–Kaplan Tests of Executive Functioning System, Adolescent Temperament Questionnaire

Introduction

Self-regulation (SR) has been an important topic in learning and education for the past 130 years since Hall (1891) mentioned a "volitional" reaction as a concept instead of an "unconscious" reaction (Post et al., 2006). SR has traditionally been described in the context of educational and settings, as the ability to comply with a request" (Kopp, 1982),

that results in initiating and ceasing activities. More recently, such ideas were expanded and specified to focus on goal-directed activities (Inzlicht et al., 2021). Given the idea, SR can be defined as activities to achieve goals in the context of human learning and socialization. These activities aims to develope both tempermantal and cognitive aspects.

The main constructs of self-regulation are executive function (EF) and effortful control (EC). EF is a self-directed action necessary in selecting and creating a goal, and it refers to implementing the goal and maintaining the behavior toward the goal (Baggetta and Alexander, 2016). Researchers note that EF is a construct composed of the following main components: (1) inhibitory control (IC), (2) working memory (WM), and (3) shifting/cognitive flexibility (Baggetta and Alexander, 2016). On the other hand, EC is "the efficiency of executive attention, including the ability to inhibit a dominant response, to activate a subdominant response, to plan, and to detect errors"(Rothbart and Bates, 2006, p. 129). Therefore, EC includes underlying constructs of (1) IC, (2) attentional control, and (3) activation. EC pertains more to emotional activities in nature and is a concept particularly focused on temperament. Given the conceptual definition, inhibition is a common notion penetrating EF and EC. In addition to structural similarity, EF and EC share a functional similarity: executive attention (Zhou et al., 2012). Due to this conceptual and functional similarity, one can often see an overlap in the use of EF and EC measurement tools. For instance, Go/No Go and Stroop testing are representative tools commonly used in EF (e.g., Belghali et al., 2022) and EC (e.g., Lengua et al., 2007). However, despite the conceptual similarities, there are differences between EF and EC studies. EF is primarily associated with self-regulating activities governed by a cognitive-psychological approach, the so-called "cool system" (Mischel et al., 2003). On the other hand, researchers have studied EC with the "hot system," i.e., more emotion-laden regulatory activities. One core construct missing in EF research but not EC research drives this difference: working memory (Zhou et al., 2012). For instance, working memory is the most crucial cerebral activity in reasoning and academic performance (Gilhooly, 2004) and is relevant to attention (Gioia et al., 2002).

More recently, Gagne (2017) used temperament-based and neural systems approaches to distinguish between EC and EF. We can easily understand EC from a temperament-based approach, whereas EF needs a more neural systems approach. When understanding those concepts from self-control perspectives, the EF IC underlies cognitive functions, but the EC IC underlies emotional temperament dimensions (Liew, 2012). Regardless of academic history and trends, educational practices in the field use both concepts interchangeably (Gagne, 2017). Some scholars even argued for synthesizing both perspectives (Liew, 2012).

As described above, the distinction between EC and EF seems complicated due to the difficulty distinguishing between cognitive–emotional development and the commonality of measures and instruments. Existing literature does not address these problems sufficiently from a systematic data-based review. Thus, the current study explores these problems from several points. First, we review EF and EC studies to understand people circumvented by drastic technological, social, and pathological changes over the past ten years (2012–2022), such as those confronting online blended learning. Advances in research have led to the development and introduction of new psychometric measurements. In addition, a systematic analysis of the relevant literature is necessary to figure out more scientifically the commonalities and/or similarities between EF and EC. The current study drives these research gaps with the following specific research questions.

In the general educational context and for typically developing human beings, what are the similarities and differences between EF and EC regarding:

1. The number of publications by year?
2. Study characteristics revealed in the keywords?
3. Definitions?
4. Instruments and subjects?

Therefore, this study clarifies the conceptual and psychometric differences between EF and EC through big data-based analysis. However, this effort does not argue against a conceptual distinction between EF and EC. Instead, the present study reveals how to explain EF and EC under the umbrella term of self-regulation. Furthermore, this clarification could function as a base to suggest how to synthesize these two concepts in the field.

Methods

Search process

I used several search parameters and steps to drive an adequate dataset for answering the research questions. First, I collected studies from the Web of Science (WoS) database with the following search parameters: published since 2013 in peer-reviewed academic journals stamped with Social Science Citation Index (SSCI), or Science Citation Index (SCI), or Art and Humanity Citation Index (A&HCI) because the indices already screen quality studies. I only used English, human learning and performance, empirical studies in nature, and behavioral or neuroimaging instruments as search terms to represent the research topics. For instance, I excluded studies using meta-analysis on the effects of EF and EC (Sung et al., 2022) to avoid redundancy in the meta-analysis and empirical studies. Second, because this review's principal goal was to find commonality and distinction between EF and EC in their concepts and operations, I created two data pools in

the keywords: one containing executive function and another containing effortful control. The initial search process resulted in a collection of 17,038 EF studies and 482 EC studies. I downloaded the data on May 4, 2022.

Due to the many retrieved articles, the next step was to narrow the initial data pools to manageable levels. Thus, I filtered the EF studies based on their inclusion in the "HIGH H INDEX" category offered by the WoS database. This second step resulted in 85 EF articles for generating thematic maps. Finally, I further narrowed the datasets for more analyses (keyword co-occurrences, concepts, subjects, and instruments). **Figure 1** summarizes the data filtering steps.

Analysis

I obtained the number of publications by year from the initial search data from the WoS, which included 17,038 EF and 482 EC studies. To figure out study characteristics in the keywords, I considered 85 articles with high ranks according to the WoS search index for the EF and EC pools, respectively. First, I analyzed these pools' keywords and obtained thematic maps. Next, I extracted keyword co-occurrences for the EF and EC pools with 30 top high-ranked articles. Finally, I used the Bibliometrix package in R (Aria and Cuccurullo, 2017) to map the themes and co-occurrences with keywords from the pools.

In addition, to address differences in the concepts/operations, subjects, and instruments, I analyzed 15 highly-referenced articles from each of the EF and EC collections. Then, I extracted conceptual similarities and differences by reviewing the collected papers. Finally, after the physical screening, I examined the EF and EC measurements and population groups.

Results and discussion

Annual publication

Figure 2 illustrates the initial search process, where bar charts represent the number of publications by year, and the line charts are the percentage of publications within that year out of the total published articles over the recent decade. As displayed in the left chart, the number of EF study publications steadily increased from approximately 1,400 to 2,200. On the other hand, the annual EC publications remained similar from 2013 to 2016 (about 40), then almost doubled from about 40 in 2016 to 80 in 2019. The increment was again steady afterward. Regardless of the trend in the annual publication rates, the number of total publications over the decade contrasts between EF and EC. While EC studies are about 50 per year, EF studies are approximately 2,000 per year, i.e., 400 times more than EC studies.

Study characteristics revealed in keywords

Thematic maps using keywords

I mapped clusters of keywords on a two-dimensional diagram covering density and centrality to enable an understanding of significant research trends (**Figures 3**, **4**). Centrality refers to the degree of interaction a cluster has with other parts of the network. Density means the degree to which a particular keyword appears in the content several times (Hu et al., 2013). The thematic map is an intuitive plot that locates the themes according to the quadrant: (1) the upper right quadrant refers to the motor theme, (2) the lower right presents the basic theme, (3) the lower left quadrant means emerging and declining themes, and (4) the top left quadrant is the specialized/niche theme.

Figure 3 shows the thematic map for the discourse in executive function studies. The motor themes of the EF studies (quadrant 1) conveyed school-readiness interventions for children. In addition, I observed a prevalence of basic (quadrant 2) and niche themes (quadrant 4). The basic themes covered three chunks: the first chunk regards older adults' cognitive impairment (e.g., Alzheimer's, dementia), the second chunk pertains to children's deficits (e.g., neuropsychological performance and schizophrenia), and the third chunk concerns memory (short-term and long-term). Overall, the basic themes retrieved from the EF studies were relevant to age-specific cognitive malfunctioning. Niche themes (quadrant 4) were pertinent to selective attention, Asperger syndrome, and executive dysfunction.

Figure 4 shows a thematic map highlighting the discourse in effortful control studies. The hot topics of the EC studies, presented in motor themes (quadrant 1), conveyed personality and emotional regulation in early childhood. The "hot" system weighing temperament and emotion seemed closely related to the EC studies, as noted by Mischel et al. (2003). As opposed to older adults as focal research subjects in EF studies, the basic themes for EC studies (quadrant 2) comprised three clusters mainly dealing with young children. The first keyword cluster was young children's temperament, the second cluster regarded children's EF and attention, and the third covered petrophysical functioning (e.g., prefrontal cortex and anterior cingulate cortex) concerning attention and delay. Developing mechanisms, randomized control, and cognitive deficits were niche themes (quadrant 4) in the EC studies, i.e., themes for specific fields.

In addition, I located three chunks of themes in the center of the chart regarding the relevance degree of EF studies. The first chunk pertained to expertise and decision-making. The second included school readiness for preschool and elementary school students. The last chunk was about adolescents' inhibitory control and performance, which showed sparse density compared to the first two chunks. Finally, confirmatory

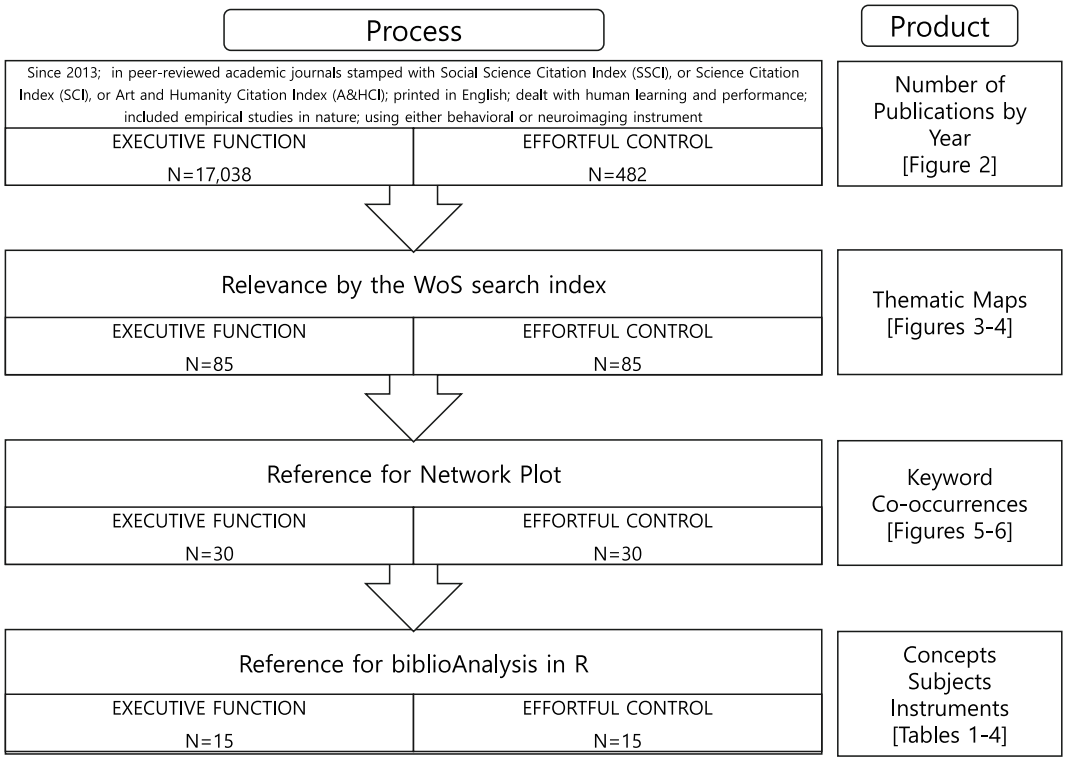

FIGURE 1
Data filtering process and the products using the data pool for executive function and effortful control studies.

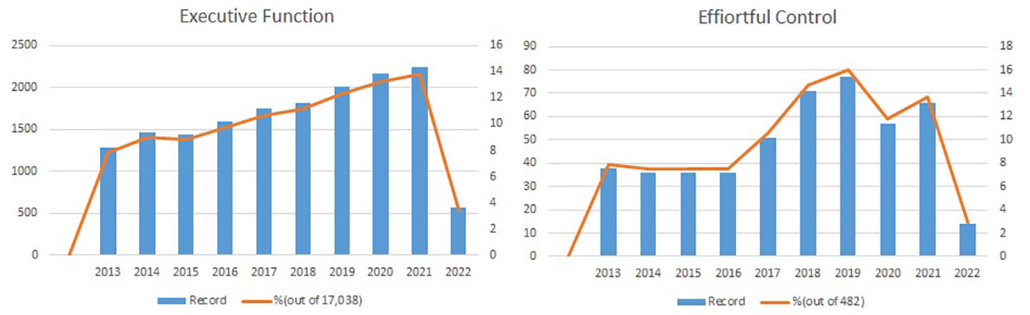

FIGURE 2
Amount of publications for executive function studies **(left)** versus effortful control studies **(right)** by year (2013–2022).

factor analysis for the EC behavior rating inventory resulted in emerging or declining themes (quadrant 3).

Co-word analysis with keyword co-occurrences

A program generated a visual word map of co-word networks to uncover links between concepts through term co-occurrences. As one can observe from Figure 5, four major chunks of keywords emerged from the 30 most cited EF studies according to the degree to which the keywords were likely to occur together. Individual differences in preschool children appeared, and performance co-occurred with inhibition, brain, and attention in childhood. Schizophrenia and school readiness also strongly co-occurred with executive function. Finally, the older adult presented together with dementia and memory impairment.

Likewise, Figure 6 shows three co-occurring chunks of keywords. Effortful control arose with working memory, early childhood, and preschool children. Self-regulation also comprised a big keyword chunk with achievement and temperament in this study pool. Finally, individual differences, IC, and personality co-occurred and were strongly related to EF.

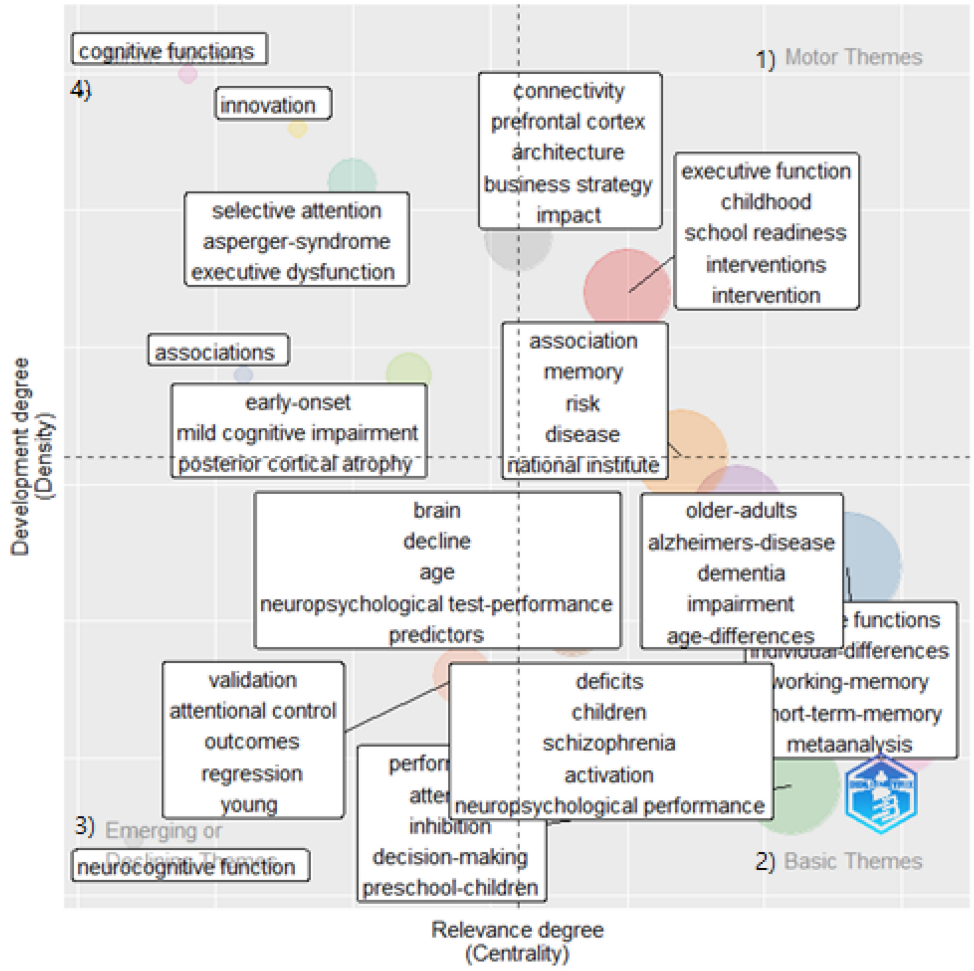

FIGURE 3
Thematic map of 85 executive function studies (2013–2022). Each quadrant refers to (1) a motor theme, (2) a basic theme, (3) an emerging/declining theme, and (4) a specialized/niche theme.

These trends were similar to what I found in the thematic maps (**Figures 3**, **4**).

Concepts of executive function and effortful control

In addition to the above structural analysis for recent EF and EC studies, I performed a semantic analysis to comprehend academic definitions of these two constructs. I retrieved 15 top-cited articles from each study pool. The explicit descriptions in the articles are as follows (**Tables 1**, **2**). According to these references, the most common use of adjectives defining EF included "goal-directed" (e.g., Benson et al., 2013), "domain-general" (e.g., Lucas et al., 2013), and "task-related" (Gijselaers et al., 2017). The components or processes for defining EF were "self-regulation," "control," "working memory," "inhibition," "planning," "attention," and "shifting" (e.g., Rhodes et al., 2016). EF is a multifaceted construct comprising higher-order and lower-order functions. For instance, Gijselaers et al. (2017) viewed EF as a hierarchical construct of common EF and EF-specific variation. In addition, "cognitive" processes (e.g., Niermeyer et al., 2019) were salient for attributes. This overall trend is consistent with Zhou, Chen, and Main's study Zhou et al. (2012). However, other studies also mentioned "emotional" and "social" processes (e.g., Lima et al., 2014). The most cited articles defined EF as a cognitive process underlying goal-directed and task-related behavior and a multifaceted construct, including self-regulation, working memory, inhibition, planning, attention, and shifting. The EF can also encompass emotional and social regulatory processes.

While EF regarded more "what to do," EC highlighted "what not to do." The most cited articles often mentioned "inhibit a dominant response," "suppress impulsive or premature responses," and "self-regulation" in their definition. In addition to these highlights on IC over premature and unnecessary

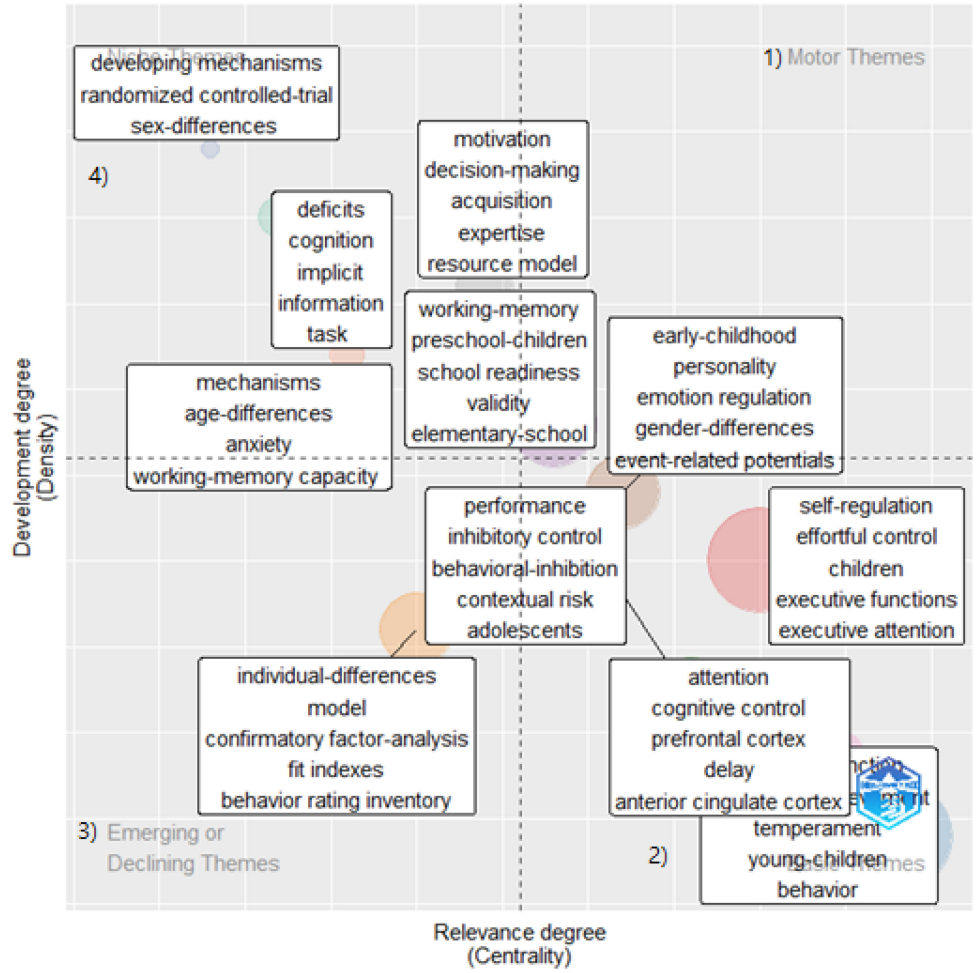

FIGURE 4
Thematic map on 85 effortful control studies (2013–2022). Each quadrant refers to (1) a motor theme, (2) a basic theme, (3) an emerging/declining theme, and (4) a specialized/niche theme.

responses, studies included "activation of a subdominant response" and "reactivity" as core components of EC. Following Zhou et al.'s (2012)' study, definitions and operations indicated that EF and EC's commonality often included inhibition as a core construct. In addition, researchers discriminated EC from EF because EC is more of a "temperament" (Lipsey et al., 2017). I also found this trend in the current analysis.

Instruments and subjects

The common test for EF is the Delis–Kaplan Tests of Executive Functioning System (D-KEFS), which includes Wisconsin Card Sorting (to measure shifting), Trail Making (to measure IC), and the verbal fluency test (to measure working memory) (see **Table 3**). Otherwise, researchers used similar tasks to measure the underlying constructs of shifting, inhibitory control, and working memory. For instance, Benson et al. (2013) examined children's shifting ability with the "Bear/Dragon" game, similar to the "Simon Says" game. Other studies often measured shifting ability with a card sorting test (e.g., Lucas et al., 2013).

When it comes to EC, the major research instrument is the self-report survey. For instance, six out of 15 EC studies used the Adolescent Temperament Questionnaire (ATQ) (e.g., Lin et al., 2013; Zeytinoglu et al., 2017) or the Early Adolescent Temperament Questionnaire (EATQ). Evans and Rothbart (2007) developed the original ATQ in 35 items capturing (1) attention control (12 items), (2) activation control (12 items), and (3) IC (11 items). Each item asks the respondent to indicate their agreement with a statement (e.g., "Although the assignment is hard, I can finish it on time"). Later, researchers revised and published a shorter version with 17 items for adolescents. The next instrument researchers frequently used was the Delay-of-Gratification, applied in three studies (e.g., Duckworth et al., 2013; Kim et al., 2013; Lin et al., 2019).

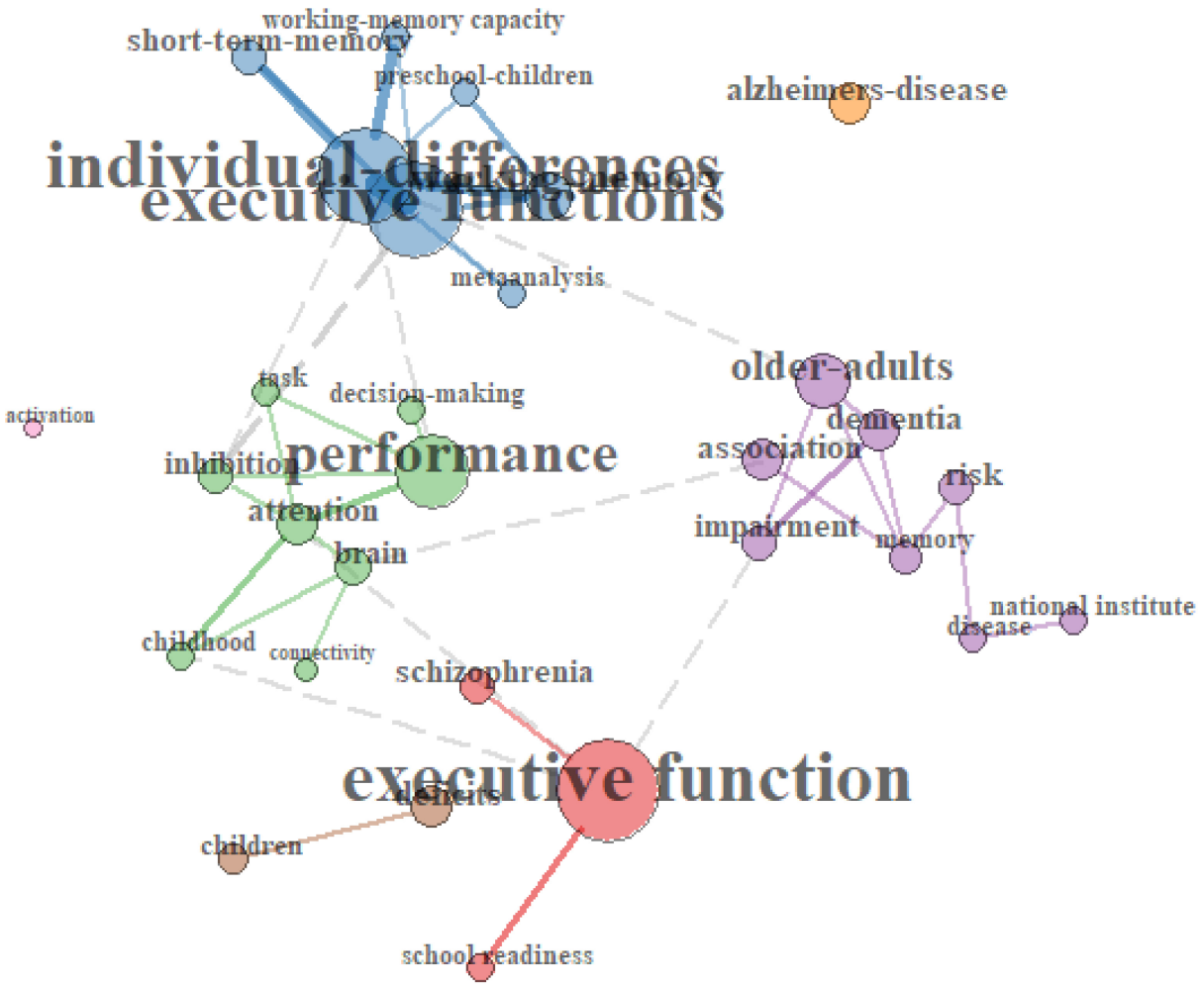

FIGURE 5
Keyword co-occurrence plots on 30 most cited executive function studies (2013–2022).

In terms of subject groups, EC studies (**Table 4**) involved very young subjects such as infants (Kim et al., 2013) or toddlers (Sulik et al., 2015; Lin et al., 2019). In contrast, EF studies (seven out of 15) used children (Benson et al., 2013) as a subject group. This phenomenon seems to pertain to the cognitive development process of humans. In childhood, corresponding to the early stage of development, the brain is less myelinated and thus shows very distracted brain activity (Brydges et al., 2013). As a result, children's IC for minimizing and simplifying unnecessary tasks to achieve goals is weaker than adolescents' (Atherton et al., 2020). In addition, effortful control develops around two years of age and rapidly in infancy (Kim et al., 2013).

In addition, there is a shared belief in establishing EC early as possible for satisfactory human socialization and schooling (Eisenberg et al., 2003). For instance, psychologists have chosen infant EC as their research topic following the EC's critical period and its ripple effect on infants' lives (e.g., Duckworth et al., 2013; Kim et al., 2013; Lipsey et al., 2017). In contrast to the research gap between EC and EF in using infants as study subjects, researchers used adolescents with a similar frequency (5 out of 15) between EF (e.g., Rhodes et al., 2016) and EC studies (e.g., Bao et al., 2015). Researchers were less likely to use adult subject groups for EC and EF studies; however, I found one more article in the EF study pool than in the EC study pool. In sum, the EF and EC studies used younger subjects more often than older subjects. In addition, EC studies were especially likely to use subjects in early childhood.

Key findings

This study explored the common attributes and differences between EF and EC based on the results of major empirical studies published between 2013 and 2022. As a result of big data analysis using bibliographic information published in the World of Science (WoS), major published papers found a slight

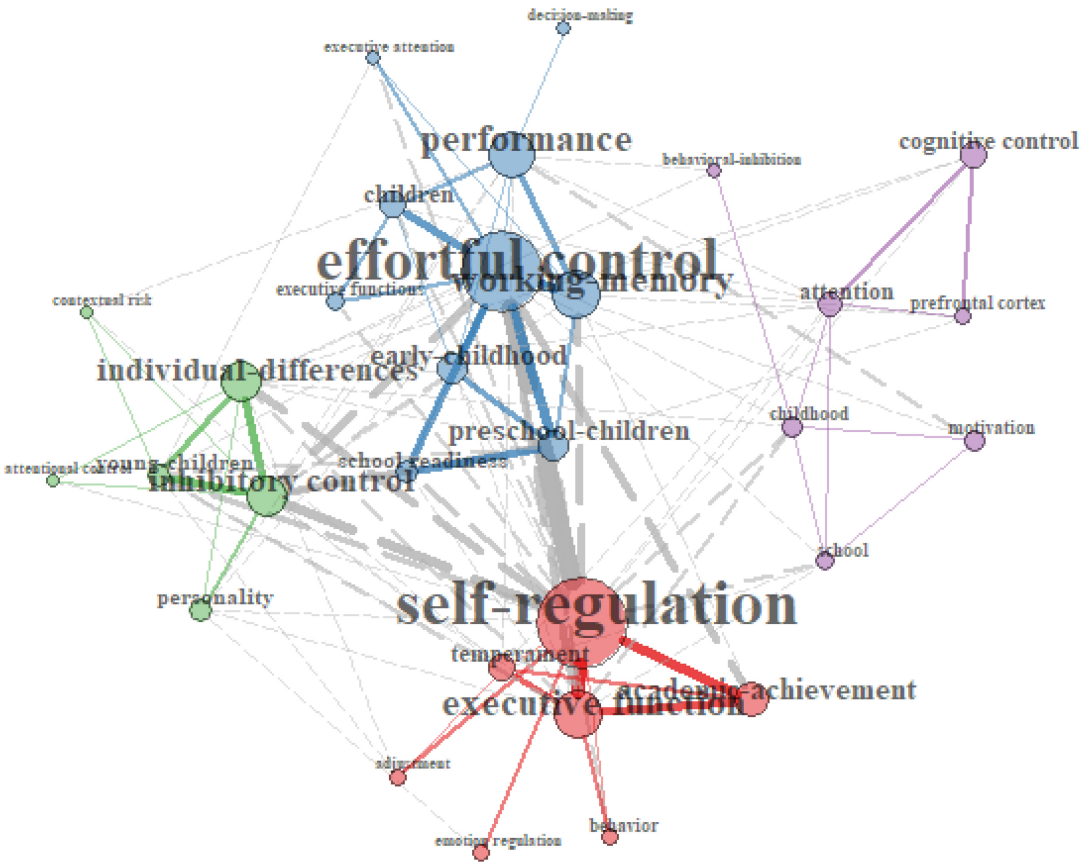

FIGURE 6
Keyword co-occurrence plots on 30 most cited effortful control studies (2013–2022).

difference between EC and EF in terms of concepts, measures, instruments, and subjects of use.

Hot effortful control and cool executive function

As per the definition, the efficiency of executive attention that incorporates inhibitory control (IC), attentional control, activation mainly related to temperament. On the other hand, most EF studies focused on the cognitive rather than the affective aspect. The keyword analysis also showed a slightly more pronounced difference between the two research streams. According to the keyword thematic topic analysis, in the EF studies, cognitive keywords such as "working memory" and "short-term memory" appeared as base themes. On the other hand, the EC studies include temperament as the base theme leading the basic flow of the study.

Metcalfe and Mischel's (1999) hot versus cool framework explains the given conceptual differences well through a hot/cool system; humans have a two-fold interactive processing system. The hot system is the "go" system because it follows an emotional process and responds immediately and simply. It decreases under stress and is necessary for the control of external stimuli. On the other hand, the cool system follows a cognitive process, develops slowly and late, and has the nickname "know" system. When stressed, the cool system becomes a stimulus rather than an activation and is necessary for voluntary control. The EF functions based on a cool system, whereas the EC is based on a hot system.

Regarding measures and instruments, the EF–EC distinction needs further discussion. Indeed, the present analysis of the measures showed overlaps between the two concepts. For example, major EF studies used such comprehensive batteries as D-KEFS, which highly rely on cognitive interaction activity time, such as the Sorting Test and Tower Test. At the same time, there was considerable use of performance tests (e.g., Go/No Go, Trail-Making) that measure immediate response in EF studies. EC researchers also switched between instruments based on hot and cool systems. For instance, Kim et al. (2013) used a representative hot system-based measure called "Delay of Gratification" to measure EC and a cool system-based measure such as "Go/No Go." The Adolescent Temperament Questionnaire (ATQ) (Evans and Rothbart, 2007), which

TABLE 1 Explicit definitions of the executive function retrieved from 15 most cited articles.

No.	First author	Year	Definition
1	Benson	2013	• The processes that underlie *goal-directed behavior* including self-regulation, planning, working memory, response inhibition, and resistance to interference (Carlson et al., 2013)
2	Lucas	2013	• *Domain general skills* that enable the planning and control of their behavior • These skills involve cognitive flexibility, inhibitory control (IC), and working memory
3	Semrud-Clikeman	2014	• A heterogeneous term frequently incorporates working memory, cognitive flexibility, planning, and organization (Nigg et al., 2002) • These skills refer to how a person understands situations rather than what the person knows
4	Rhodes	2016	• A broad term used to describe essential organizational processes that go beyond working memory to include a range of other strategic processes: Anticipation and deployment of *attention, impulse control and self-regulation, initiation of activity, working memory, mental flexibility, and utilization of feedback, planning ability, and organization, and selection of efficient problem-solving strategies* (Anderson, 2008)
5	Rhodes	2014	• A compendium of constructs comprising three core, dissociable components: *inhibition, working memory, and set-shifting* (Miyake et al., 2000; Lehto et al., 2003; Diamond, 2013), and several higher-level functions such as planning and problem solving (Diamond, 2013)
6	Niermeyer	2019	• A complex, multifaceted construct that consists of a set of higher-order cognitive abilities that allow an individual to engage in successful *goal-directed behavior* that is adaptive and socially informed (Stuss et al., 2001; Cummings and Miller, 2007; Lezak et al., 2012; Suchy, 2015)
7	Lundervold	2019	• *General-purpose control mechanisms* (Miyake et al., 2000) that serve to regulate cognitive processing, especially in complex and/or novel settings
8	Boschiloo	2014	• The functions necessary for *goal-directed behavior* (e.g., Best and Miller, 2010) • The literature describes a wide range of executive functions, such as inhibition, updating working memory, shifting, planning, organization skills, attentional control, and self-control (Alvarez and Emory, 2006; Best and Miller, 2010; Hofmann et al., 2012)
9	Martin-Perpina	2019	• The capacities for *formulating goals, planning, and carrying out plans* effectively; essential for independent, creative, and socially constructive behavior
10	Lima	2014	• A set of cognitive skills that enable the individual performance of voluntary *actions to orient goals*, encompassing control processes in cognitive, emotional, and social areas
11	Gijselaers	2017	• *Common EF* is the ability to *manage the tasks at hand and the task-related information* and use this information to guide and steer lower-level processing • EF-specific variation is the variation that remains after controlling for common EF variation • When controlling for common EF variation, there is only a specific variation for updating and shifting (Miyake and Friedman, 2012) • This finding means that the common EF ability is a basic need for all three EFs and is especially important for inhibition, as no EF-specific variation remains after controlling for common EF (Miyake and Friedman, 2012)
12	Rosas	2017	• These are psychological processes involved in the *conscious control of thought and action* (Zelazo and Müller, 2011). • This group is a family of functions we use when we need to concentrate, and following our initial impulses is inappropriate (Diamond, 2012) • The main components of EF are IC, working memory (WM), and cognitive flexibility (CF) (Diamond, 2013)
13	Ljubin Golub	2016	• A set of correlated but separable control processes that *regulate* lower-level cognitive processes in support of *goal-directed* behavior (Friedman et al., 2008): inhibition of automatic or prepotent response and updating working memory representations, and shifting/switching between tasks or mental sets (Friedman et al., 2008) • It also includes sustained and selective attention (Alvarez and Emory, 2006), and dual-tasking (Logie et al., 2004)
14	Kavanaugh	2016	• A collection of "top-down" *control* and self-regulatory processes required to *obtain goals and objectives* (Barkley, 2012; Diamond, 2013)
15	Taha	2017	• An umbrella term for the *management, regulation, and control* of cognitive processing (Lezak, 2004, p. 611)

frequently appears in EC research, is based on effortful control, consisting of three sub-constructs: activation control, attention control, and IC. Attention control is close to cerebral activity, and IC is an item measuring temperamental activity. It is challenging to differentiate between these two constructs due to the ambiguity of the hot–cool systems in the EC and EF measurement tools and their use. Nevertheless, we can understand this commonality in the same context as what was argued by the existent literature (e.g., Liew, 2012; Gagne, 2017).

Younger subjects used in effortful control studies than in executive function studies

A more noticeable difference was captured between the EC and EF studies concerning the study subjects. Statistically, participants' ages in EC studies were lower than in EF studies. Researchers argue that EC of self-regulation abilities critically develops at 22–33 months of age (Bernier et al., 2010); some

TABLE 2 Explicit definitions of effortful control retrieved from 15 most cited articles.

No.	First author	Year	Definition
1	Kim	2013	• The capacity to *suppress* deliberately and voluntarily *a dominant or prepotent response and perform a subdominant response* is a key aspect of children's *temperament* (Derryberry and Rothbart, 1997; Rothbart and Bates, 2006) and personality (Caspi and Shiner, 2006)
2	Duckworth	2013	• The ability to *inhibit a dominant response to perform a subdominant response* (Rothbart and Bates, 1998, p. 137)
3	Lipsey	2017	• Involves volitional behavioral regulation related to aspects of *temperament* (Kochanska et al., 2000); *suppression of impulsive or premature responses* when required by a task
4	Bao	2015	• The efficiency of executive attention, including the ability to *inhibit a dominant response and/or activate a subdominant response* and plan and detect errors (Rothbart and Bates, 2006, p. 129)
5	Studer-Luethi	2016	• A *temperament* factor in childhood represents the developmental process underlying conscientiousness, naming it effortful control (cf. Ahadi and Rothbart, 1994; Blair and Razza, 2007) • Together, neuroticism and effortful control represent the two temperament categories: reactivity and self-regulation (Rothbart et al., 1994)
6	Wang	2018	• A group of abilities concerning how well an individual could *inhibit a dominant response, activate a subordinate response*, plan, and detect errors (Rothbart and Bates, 2006)
7	Zeytinoglu	2017	• The regulatory component of *temperament* involves attentional processes that enable individuals to voluntarily *shift and focus their attention and inhibit or activate their responses* (Evans and Rothbart, 2007)
8	Di Norcia	2015	• *Delaying, slowing down motor activity, suppressing or initiating an activity* when required, lowering voice, and effortful attention
9	Lin	2019	• The ability to *inhibit a dominant* (motor, vocal, emotional, or cognitive) response and *activate a subdominant response* (Rothbart et al., 2003; Rueda, 2012): IC, effortful attention, conflict resolution, and the ability to identify and correct errors and plan actions (Kochanska et al., 2000)
10	Lin	2013	• A set of regulatory processes to *inhibit dominant* (but inappropriate) *responses*, perform subdominant (but avoidant) behaviors and *control attention* (Evans and Rothbart, 2007)
11	Sulik	2015	• The self-regulatory aspect of *temperament that supports volitional control* of attention, emotion, and behavior
12	Tiego	2020	• The efficiency of executive attention includes the ability to *inhibit a dominant response and/or activate a subdominant response* and plan and detect errors (Rothbart and Bates, 2006, p. 129)
13	Omura	2015	• The ability to *inhibit a dominant response to perform a subdominant response* and/or facilitate efficient executive attention: attentional, inhibitory, and activation control (Rothbart et al., 2000, 2001)
14	Zorza	2013	• A basic dimension of *temperament* that mediates between voluntary control of behavior and regulation of emotional reactivity (Derryberry and Rothbart, 1997)
15	Cerda	2014	• Involves the abilities to enjoy activities of *minimal intensity, to shift and focus attention deliberately, and inhibit or initiate a response* as required by particular circumstances (Putnam et al., 2006; Gartstein et al., 2012)

even claim 12–18 months as a critical period in EC development (Kochanska and Knaack, 2003). Thus, there seems to be an age difference between EC and EF development. Moreover, EC researchers predominantly used infants or toddlers in their studies. In contrast, EF studies used children older than the EC's major study participants but still young. The EF and EC studies with this interest in children support existing studies (Montroy et al., 2016) that early stages of human development result in differentiated self-regulation.

There is a link between the age difference of study subjects and the main topics covered in EF and EC studies. For example, research topics that form a significant trend regarding EF were school readiness and interventions related to school adjustment. This finding is of interest to researchers considering that the subjects of EF studies are mainly children. In addition, the main keywords such as "emotion regulation," "personality," and "event-related" confirm the flow of EC research. One can infer emotion regulation and personality to accompany EC studies, considering the operational definition of EC frequently includes temperament. However, more direct measures such as the event-related instrument would be useful when researchers pay attention to babies before language development because the subjects' self-report is unavailable, and their behaviors are not easy to interpret.

Future directions

In this study, I explored the similarities and differences between EC and EF through big data analysis of major studies over the past decade. Still, undoubtedly, we need more work. Therefore, I derived several important future research topics in summarizing this study's key findings.

In terms of publication numbers over the past decade, EF research has overwhelmingly outnumbered EC research (2,000 EF studies vs. 50 EC studies per year). Few researchers are studying self-regulation or IC from an emotional perspective, as few invoke EC. Most come from the EF perspective. The difference in publication number relates to the analysis results in which the academic and operational definition

TABLE 3 Instruments and subject of executive function retrieved from 15 most cited articles (Supplementary Appendix).

No.	First author	Year	Subject	Age or grade	*N*	Instrument
1	Benson	2013	Child	3.5 years	24	• Response Conflict-Executive Functioning scale = Bear/Dragon + Grass/Snow + Dimensional Change Card Sort
2	Lucas	2013	Child	Preschool	144	• Dimensional Change Card Sort (set-shifting) • Day/Night (IC) • Eight Boxes (working memory)
3	Semrud-Clikeman	2014	Child	8.5–17.5 years	108 = 38 Control + 36 Autism + 31 Non-verbal learning disabilities	• Delis-Kaplan Tests of Executive Functioning System *(D-KEFS)* (Delis et al., 2001) = Card Sorting + Trail making + Verbal Fluency
4	Rhodes	2016	Adolescent	12–13 years	63	• Cambridge Neuropsychological Test Automated Battery (CANTAB) (Morris et al., 1987) = SWM (Spatial Working Memory) + Stockings of Cambridge (planning) + Stop-Signal (inhibition) + ID/ED (attention set-shifting).
5	Rhodes	2014	Adolescent	12–13 years	56	• Spatial Working Memory (SWM; working memory) + Stockings of Cambridge (SOC; planning) + Stop-Signal (inhibition) + ID/ED (attention set-shifting)
6	Niermeyer	2019	Older Adult	69.19 years	110	• Delis–Kaplan Executive Functioning System battery (*D-KEFS*; Delis et al., 2001)
7	Lundervold	2019	Adult	30 years	63 ADHD + 73 Control	• PASAT (Working Memory), Color-Word Interference Test (Response Inhibition)
8	Boschiloo	2014	Adolescent	12–18 years	173	• Objective: Sorting Test and the Tower Test from the Delis-Kaplan Executive Functioning System (*D-KEFS*) (Delis et al., 2001) • Subjective: Behavior Rating Inventory of Executive Function—Self Report Version (BRIEF-SR) (Guy et al., 2004)
9	Martin-Perpina	2019	Adolescent	11–18 years	977	• Dysexecutive Questionnaire (DEX-SP) (Wilson et al., 1996)
10	Lima	2014	Child, Adolescent	6–16 years	31 Epilepsy + 35 Controls	• Wisconsin Card Sorting Test (*WCST*)
11	Gijselaers	2017	College student	18–80 years	4,945	• Trail Making Test (TMT; Army Individual Test Battery, 1944) • Substitution Test (ST) (symbol digit modalities test by Smith, 1991) • N-back task (NBT; Lezak et al., 2004)
12	Rosas	2017	Child	5.5 years	109	• Hearts & flowers (General EF measures) • Stroop animal (Cognitive inhibition) • Bzz! (Behavioral inhibition) • Torpo (Visual working memory) • Geometric figures (Cognitive flexibility)
13	Ljubin Golub	2016	College student	20 years	87	• Verbal fluency task • Stroop task
14	Kavanaugh	2016	Child	6–12 years	76 No-Neuropsychology + 75 Neuropsychology	• COWAT-FAS • Trail Making Test-B • Stroop Color • Word Test-Children's Version • Wisconsin Card-Sorting Test • Rey Complex Figure Test-Copy Condition
15	Taha	2017	Child/w asthma	12.46 years	27 Asthmatic + 30 Normal	• Wisconsin Card Sorting Test (*WCST*)

of EF often already includes the academic and operational definition of EC. Researchers know less about self-regulation in the hot system (EC). Furthermore, researchers have usually paid attention to EC as a way to solve emotional problems such as violence and delinquency in *children and adolescents* (Eisenberg et al., 2003). However, we must advance studies

TABLE 4 Instruments and subject of effortful control retrieved from 15 most cited articles (Supplementary Appendix).

No.	First Author	Year	Subject	Age or grade	N	Instruments	
1	Kim	2013	Infant in a two-parent family	①T1 38 month ②T2 52 month	100	• ①Assessments of EC "Hot" Function: Delay-of-*Gratification* Tasks	• ②EC "Cool" Functions: Motor Inhibition, Go-No Go, Effortful Attention Tasks
2	Duckworth	2013	①Youth ②Early child	①5th grade ②4 year	56	• ①Reward-related impulses/CBQ attention focusing	• ②Delay of *gratification*
3	Lipsey	2017	Early child	pre-K	608	• Whisper and Turtle-Rabbit tasks	• Teacher Ratings of Cognitive Self-Regulation
4	Bao	2015	Adolescent	7th–9th grade M = 13.53 year	2,758	• Adolescent Temperament Questionnaire-Revised (*ATQ*-R, Ellis and Rothbart, 2001)	
5	Studer-Luethi	2016	Child	2nd grade M = 8year. 3 month	99	• Child's Working Memory (WM) task	• Teachers' ratings (EC) • Parents' ratings (EC, neuroticism)
6	Wang	2018	Adolescent	6th–8th grade	850	• Early Adolescent Temperament Questionnaire-Revised (*EATQ*-R, Capaldi and Rothbart, 1992)	
7	Zeytinoglu	2017	Mother	19–58 year	278	• Adult Temperament Questionnaire Short Form (*ATQ*; Evans and Rothbart, 2007)	
8	Di Norcia	2015	Early child	25–41 month	74	• Reverse categorization • Musical box • Slowing down • Motor activity • Lowering voice • Clean-up	
9	Lin	2019	Early child	4–6 year	244	• EC(Hot): Snack *Delay task*,Toy Delay task (Kochanska et al., 2000)	• EF(Cool): Stroop, K-CPT
10	Lin	2013	Undergraduate (adolescent)	19.45 year	320	• Adolescent Temperament Questionnaire (*ATQ*) (Evans and Rothbart, 2007) = activation control (12 items) + attention control (12 items) + IC (11 items)	
11	Sulik	2015	Early child	4.49 year	106	• Bird and Dragon • Knock-Tap • Gift Wrap • Continuous Performance Task	
12	Tiego	2020	Early adolescent	11 year	136	• Early Adolescent Temperament Questionnaire-Revised (*EATQ*-R) = self-report + parent-report	
13	Omura	2015	Adult	20.42 year	27	• AX-CPT during EEG (similar to the Go/No Go task)	
14	Zorza	2013	Adolescent	12–14 year	359	• Early Adolescence Temperament Questionnaire–Revised Self Report (*EATQ*-R self-report; Ellis and Rothbart, 2001)	
15	Cerda	2014	Child	1st grade	744	• Walk-a-Line • Star Telephone Poles • Circle • (IC, task accuracy)	

on the EC development of *older subjects* such as adults and the elderly.

It seems necessary to make EC and EF typography a broad spectrum. In other words, when and how we differentiate the EC and EF sub-constructs, it is essential to map them according to the stage of human development. One can start the discussion with the example of studies on inhibition, a key and basic construct of EF and EC. IC appeared to show

individual differences around the age of one to two at the onset of toddlerhood (e.g., Montroy et al., 2016). If so, when will the remaining sub-constructs (working memory, shifting, planning, organization, and attentional control) become noticeably differentiated? The answer to this question will provide the basic idea needed to grow and develop EF and EC, a psychological construct that directly impacts academic performance. The answer depends on devising a program for children's cognitive development or providing an educational environment.

Furthermore, it is necessary to broaden the understanding of determinants and outcome variables related to the development of EC and EF. For instance, one can ask how a person's EC and EF develop or change before and after school age. How can EC and EF change when the person is situated in public education or home-schooling becuase these two environments involve different levels of temperament and cognitive engagement. This elaboration of the research questions may expand the existing EF and EC studies.

In addition, research on constructs of the agents also seems to need specification. For instance, the IC appeared to be a common core construct across EF and EC. At the same time, research has shown that the IC develops drastically during childhood. Thus, the systematic analysis of the IC studies targeting childhood would elaborate on the EF and EC differences and commonalities.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Author contributions

The author confirms being the sole contributor of this work and has approved it for publication.

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Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpsyg.2022.1004403/full#supplementary-material

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Temporal learning analytics to explore traces of self-regulated learning behaviors and their associations with learning performance, cognitive load, and student engagement in an asynchronous online course

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Self-regulated learning (SRL) plays a critical role in asynchronous online courses. In recent years, attention has been focused on identifying student subgroups with different patterns of online SRL behaviors and comparing their learning performance. However, there is limited research leveraging traces of SRL behaviors to detect student subgroups and examine the subgroup differences in cognitive load and student engagement. The current study tracked the engagement of 101 graduate students with SRL-enabling tools integrated into an asynchronous online course. According to the recorded SRL behaviors, this study identified two distinct student subgroups, using sequence analysis and cluster analysis: high SRL (H-SRL) and low SRL (L-SRL) groups. The H-SRL group showed lower extraneous cognitive load and higher learning performance, germane cognitive load, and cognitive engagement than the L-SRL group did. Additionally, this study articulated and compared temporal patterns of online SRL behaviors between the student subgroups combining lag sequential analysis and epistemic network analysis. The results revealed that both groups followed three phases of self-regulation but performed off-task behaviors. Additionally, the H-SRL group preferred activating mastery learning goals to improve ethical knowledge, whereas the L-SRL group preferred choosing performance-avoidance learning goals to pass the unit tests. The H-SRL group invested more in time management and notetaking, whereas the L-SRL group engaged more in surface learning approaches. This study offers researchers both theoretical and methodological insights. Additionally, our research findings help inform practitioners about how to design and deploy personalized SRL interventions in asynchronous online courses.

KEYWORDS

temporal learning analytics, educational data mining, asynchronous online course, self-regulated learning, cognitive load, student engagement

1. Introduction

As the COVID-19 pandemic continues, there is a recent trend shifting from technology-assisted or blended learning toward totally online learning among universities worldwide (Hew et al., 2020). Online courses are usually provided in two modes: synchronous and asynchronous. Compared with the former, asynchronous online learning (AOL) can hold larger numbers of students, afford greater flexibility in time and space, and encompass greater student autonomy (Yoon et al., 2021). For example, asynchronous online courses (AOCs) enable students to learn anytime and anywhere. This is particularly beneficial to students who face practical challenges managing time zone differences and unstable internet access during the pandemic. Moreover, students can proceed through the course at their own pace, resulting in learner-centered learning processes (Kim et al., 2021). Despite this, students are often confronted with difficulties sustaining commitment in AOCs (Alhazbi and Hasan, 2021). For example, due to the lack of real-time learning support from instructors and peers, online learners struggle to organize and manage their learning tasks by themselves, causing negative learning experiences and outcomes (Seufert, 2020). Therefore, this time-independent delivery mode requires learners to enact self-regulated learning (SRL) strategies to plan and manage their learning processes independently. A review article by Wong et al. (2019a) reveals that considerable efforts have been made to integrate SRL-enabling tools into AOCs to support SRL strategy use. Unfortunately, even when presented with opportunities to facilitate self-regulation in AOL environments, not all students adopted optimal SRL behaviors to achieve expected learning outcomes (Fincham et al., 2018; Wong et al., 2019a). Therefore, it is necessary to (1) identify subgroups of students with different patterns of SRL behaviors and (2) examine subgroup differences regarding learning outcomes.

The person-centered approach is considered suitable because it can identify homogeneous clusters of individuals who exhibit similar features within their cluster but function in a different way compared with those from other clusters (Hong et al., 2020). Previous studies (e.g., Zheng et al., 2019) utilize various person-centered approaches (e.g., cluster analysis) to classify students according to SRL behaviors. However, many of them rely strongly on self-report measures of SRL behaviors, which suffer from issues including response bias and generate limited information about actual SRL strategy use (Baker et al., 2020). Moreover, even in those studies that remove the aforementioned restrictions of self-reports by using behavioral data (e.g., clickstreams), students are profiled based on the cumulative frequencies of SRL behaviors, which ignores the dynamic and contextual nature of SRL (Azevedo, 2014; Siadaty et al., 2016). In other words, the aggregate, nontemporal representations of SRL behaviors fail to retain any information about how students perform SRL over time and how their learning activities are adapted to meet specific task and environmental demands (Baker et al., 2020). Therefore, whether and how chronological representations of SRL behaviors can be used to identify student subgroups warrants investigation.

In recent years, there have been increasing numbers of attempts to compare learning performance across students' SRL profiles in online learning environments (e.g., Cicchinelli et al., 2018; Lan et al., 2019). However, little is known about the differences in cognitive load (CL) and student engagement (SE) between SRL profiles, especially in the context of AOL. When studying in AOCs, in addition to dealing with the learning task at hand, students have to handle decisions that instructors are often responsible for, including planning how to proceed and reflecting on what they already learned (Seufert, 2018, 2020). Such additional demands require students to exert effective self-regulation, which otherwise might cause "mental fatigue" or cognitive overload that impedes learning (Seufert, 2018). Moreover, recent review studies building bridges between SRL and CL make theoretical arguments that self-regulation of learning processes relates to cognitive load (Seufert, 2018, 2020; de Bruin et al., 2020). Nevertheless, little empirical evidence to date has been found to verify this argument in AOL settings. Additionally, SE is another crucial determinant of online learners' academic success (Wong and Liem, 2021). When switching to "emergency remote learning" during COVID-19, students found themselves fighting "digital burnout" or "online learning fatigue" and thus disengaged from course activities (Martin et al., 2022). Prior research suggests that students' SRL strategies, as well as SRL profiles, have associations with their engagement in AOCs (e.g., Anthonysamy et al., 2020; Pérez-Álvarez et al., 2020). However, to our knowledge, no study exists to investigate how actual behavioral processes of SRL relate to SE in AOL environments. Therefore, whether and how subgroups of students with distinct patterns of SRL behavioral trajectories differ in CL and SE warrants investigation.

The emergence of temporal learning analytics allows researchers to explore whether student subgroups can be identified based on temporal SRL behaviors, compare how SRL behaviors of student subgroups act dynamically over time, and interpret why student subgroups differ in learning outcomes (Knight et al., 2017; Chen et al., 2018; Saint et al., 2022). In temporal learning analytics, two common types of temporal features are considered: the passage of time (e.g., how much time learners spend on learning tasks) and the temporal order (e.g., how events or states are sequentially organized; Chen et al., 2018). The current study focused on analyzing the temporal order of SRL behaviors. Although increasing studies have taken the temporality of SRL into account, SRL researchers (e.g., Saint et al., 2020a,b) point out that most temporal analyses of SRL lack sound theoretical underpinning or use a single analytical method, raising the concerns of ontologically flat explanations of learning as proposed by Reimann et al. (2014). This study captured students' SRL behaviors as they interacted with SRL-enabling tools embedded in an AOC designed based on Zimmerman (2000) three-phase model and Barnard et al. (2009) online SRL strategies. Then,

we combined lag sequential analysis and epistemic network analysis to articulate and compare patterns of how students' SRL behaviors unfold throughout the course. Such a combination can significantly enhance our understanding of the temporal nature of the SRL processes.

1.1. Temporal learning analytics for SRL in AOL environments

SRL refers to "an active, constructive process whereby learners set goals for their learning and then attempt to monitor, regulate, and control their cognition, motivation, and behavior, guided and constrained by their goals and the contextual features of the environment" (Pintrich, 2000, p: 453). In developing various SRL models, researchers have reached a consensus that SRL is a cyclical and dynamic process (Panadero, 2017). Zimmerman (2000) divides SRL processes into three cyclical phases: forethought, performance, and self-reflection, each containing specific SRL strategies that learners are expected to execute. Furthermore, researchers increasingly emphasize SRL as highly context-specific due to continuous innovation in learning formats (Kim et al., 2018). To capture and measure the essence of online SRL, Barnard et al. (2009) operationalized the three-phase model by conceptualizing six constructs: goal setting, environmental structuring, task strategies, time management, help seeking, and self-evaluation. Based on these online SRL constructs, many studies have captured actual online SRL behaviors (e.g., Ye and Pennisi, 2022) and perceived online SRL strategies (e.g., Sun et al., 2017) and have developed interventions for promoting online SRL (e.g., Lai et al., 2018). However, these studies have paid little attention to the temporal dynamics of these online SRL behaviors.

Advances in SRL theory, learning technology, and analytic method have motivated the emergence of temporal learning analytics for SRL (Knight et al., 2017; Chen et al., 2018). First, modern SRL research conceptualizes SRL as a series of temporal events that learners perform during actual learning situations rather than as stable and decontextualized traits or aptitudes (Winne, 2010; Azevedo, 2014). Second, advanced learning technologies (e.g., intelligent tutoring systems) have been developed for tracing temporal characteristics of SRL by recording fine-grained behavioral data on the fly (Azevedo et al., 2018; Azevedo and Gašević, 2019). Third, recent developments in temporal analysis methods have further spurred researchers to undertake temporal analyses of SRL (see review by Saint et al., 2022).

By reviewing existing empirical studies employing behavioral data to explore the temporal dynamics of self-regulation in AOL, we found that very few studies (e.g., Cicchinelli et al., 2018; Fincham et al., 2018; Srivastava et al., 2022) have attempted to identify student subgroups by comparing SRL traces across individual students. For example, based on traces of SRL activities codified from log files captured by learning management systems (LMSs), Cicchinelli et al. (2018) divided learners into four subgroups (i.e., continuously active, inactive, procrastinators, and probers) utilizing sequence analysis and agglomerative hierarchical clustering. Additionally, the majority of relevant studies reveal and compare processes or patterns in online SRL by student subgroups using various temporal analytical techniques including, but not limited to: lag sequential analysis (LSA), epistemic network analysis (ENA), process mining (PM), and sequential pattern mining (SPM; e.g., Saint et al., 2020a; Hwang et al., 2021; Zheng et al., 2021; Sun et al., 2023). For example, Wong et al. (2019b) leveraged SPM to explore 103 Massive Open Online Course (MOOC) learners' interactive sequences with course activities related to SRL and compared the differences in sequential patterns between students who viewed the SRL-prompt videos and those who did not.

In sum, researchers have illustrated heterogeneity in student SRL behaviors in AOL environments. However, most of them established student subgroups based on (quasi-) experimental designs or through comparisons of cumulative counts of SRL behaviors across students. The use of temporal SRL behaviors for detecting student subgroups is still an underexplored area of research but is one that can extend our current knowledge on the complex nature of temporally unfolding SRL processes. Additionally, although many temporal analyses were undertaken using the same data source in similar learning contexts, their research findings are not entirely consistent and may even be contradictory. One reason for this is that these researchers generally adopt a single analytical approach per study, and different analytical approaches between studies may lead to inconsistent research results (Saint et al., 2020a). As Reimann (2009) pointed out, analyses using a single analytical approach may suffer from ontological flatness. Therefore, multiple analytical approaches should be consolidated to confirm and complement each other in examinations of temporal dynamics of SRL.

1.2. SRL processes, cognitive load, and student engagement

Cognitive load theory assumes that (1) for learning to take place, information must be encoded into long-term memory by working memory (WM) and (2) human WM is limited in both capacity and duration (Sweller et al., 1998, 2019). When performing complex or novel learning tasks, learners must process large amounts of information and interactions simultaneously, which may overload their finite WM and thus impair academic performance (Sweller, 2010). Sweller et al. (1998) defined cognitive load (CL) as the amount of WM resources required to process complex or novel information. They recognize three types of cognitive load: intrinsic, extraneous, and germane. Intrinsic cognitive load (ICL) refers to the processing resources associated with the inherent properties of the task and is determined by task complexity and learner expertise (Sweller et al., 1998). Extraneous cognitive

load (ECL) arises from unnecessary and irrelevant information imposing processing demands due to suboptimal instructional design (Sweller et al., 1998). ECL could distract learners from the task at hand and hamper learning (Stiller and Bachmaier, 2018). Germane cognitive load (GCL) refers to the WM resources that learners devote to dealing with ICL (Sweller et al., 1998). Unlike the other two loads, GCL helps with schema construction and automation and thus benefits learning (Miller et al., 2021). Appropriate instructional design can manage ICL, reduce ECL, and encourage GCL while still preventing overload (Van Merriënboer and Sweller, 2010).

Researchers have recently extended previous research on CL by unraveling the intricate relationship between SRL and CL (de Bruin et al., 2020; Seufert, 2020). Eitel et al. (2020) propose that (1) CL results not only from how instruction is designed but also from how learners process this instruction and (2) how instruction is processed by learners depends on their ability and willingness to exert self-control. According to Baumeister et al. (2007), self-control is portrayed as a conscious, deliberate, and effortful subset of self-regulation. Eitel et al. (2020) further demonstrated that offering learners proper guidance about cognitive and metacognitive strategies can improve their self-control of cognitive processing to reduce ECL and foster GCL. Additionally, Seufert (2018) argued that in different phases of self-regulation, learners need to invest cognitive and metacognitive resources in addition to dealing with the original learning task. The affordances of self-regulation impose cognitive load and might even cause cognitive overload (Seufert, 2018). Seufert (2018) analyzed the affordances of Zimmerman (2000) three phases of SRL in terms of ICL, ECL, and GCL. Meanwhile, external learning supports (e.g., prompts) have the potential to promote effective self-regulation processes, which can elicit the optimal amount of CL (Seufert, 2018). A handful of empirical studies (e.g., Liu and Sun, 2021; Sun and Liu, 2022) also illuminate how the employment of SRL-enabling tools for supporting SRL strategies can optimize cognitive load in AOCs.

In sum, researchers have established theoretical connections between SRL and CL and suggested how to optimize CL by externally supporting learners' self-regulation. However, since this is an emerging research topic, limited studies have empirically investigated the underlying mechanisms through which temporally unfolding SRL processes have associations with ICL, ECL, and GCL. Additionally, to our knowledge, no studies have examined the relationship between SRL and CL in a specific course, especially in the context of AOL.

Student engagement (SE) refers to a student's active participation and involvement in learning tasks and activities and consists of three different but related dimensions: behavioral, emotional, and cognitive (Fredricks et al., 2004). Behavioral engagement (BE) describes students' observable behaviors while participating in academic activities that are crucial for attaining desired academic outcomes and preventing dropouts (Fredricks et al., 2004). This includes attention, concentration, effort, persistence, positive conduct, absence of disruptive behaviors, and involvement in curricular and extracurricular activities (Fredricks et al., 2004; Appleton et al., 2008). Emotional engagement (EE) describes students' affective reactions (e.g., anger, anxiety, boredom, happiness, and interest) to teachers, peers, courses, and schools, their willingness to do the coursework, their sense of belonging in school, and their evaluation of school-related outcomes (Fredricks et al., 2004). Cognitive engagement (CE) describes thoughtfulness and willingness to exert effort to comprehend complex ideas and master difficult skills (Fredricks et al., 2004). It reflects students' psychological investment in learning and strategic emphases on active self-regulation of skills and usage of deep learning strategies (Fredricks et al., 2004; Greene, 2015).

Prior research has adopted variable-centered approaches (e.g., correlation and regression) to associate SRL with SE in AOL (e.g., Pellas, 2014). For example, Sun and Rueda (2012) analyzed 203 college students' self-reports of self-regulation and engagement after watching video recordings of lectures in a distance course. They found that self-regulation was significantly positively correlated with BE, EE, and CE, implying that students with higher levels of self-regulation demonstrated higher levels of engagement. The positive relationship between SRL and SE has been well established in variable-centered studies (Anthonysamy et al., 2020). Going beyond analyzing SRL behaviors from a variable-centered perspective, which assumes the same relations and average means for an entire population, recent studies (e.g., Pérez-Álvarez et al., 2020) increasingly concentrate on person-centered approaches to detect divergent SRL profiles and how those profiles differ regarding SE. These approaches are especially apt for studies conducted in AOL contexts where SRL behaviors vary greatly across individual students. For example, mapping SRL behavioral indicators with the clickstreams of 5,014 learners enrolled in an MOOC, Lan et al. (2019) employed K-means to find two types of learners (i.e., auditors and attentive) who shared similar patterns of SRL behaviors. They concluded that the attentive learners who followed the learning pathway intended by the instructors showed higher course engagement and completion rates than the auditors who accessed course content selectively and irregularly.

In sum, existing studies have illuminated the impacts of students' SRL profiles on their engagement in AOCs, but most are limited to examining BE. Whether and how SRL profiles are associated with EE and CE remains unclear. Moreover, these studies distinguished SRL profiles according to frequency-based measures of SRL behaviors. To date, no studies have related divergent profiles of temporally unfolding SRL processes to the three types of SE.

The purpose of the current study is therefore threefold: (1) identifying student subgroups according to traces of online SRL behaviors; (2) examining the student subgroup differences in learning performance, CL, and SE; and (3) articulating and comparing behavior patterns of online SRL between the student subgroups. This study offers researchers

both theoretical and methodological insights. Additionally, our research findings inform practitioners about how to design and deploy personalized SRL interventions in the context of AOL. Accordingly, the research questions are as follows:

RQ1. Can student subgroups be identified by the traces of SRL behaviors collected from the use of SRL-enabling tools to complete an AOC? If so, what are their characteristics?

RQ2. Do the identified student subgroups significantly differ in learning performance, cognitive load, and student engagement?

RQ3. How does this study differentiate the identified student subgroups according to their behavior patterns of online SRL?

2. Materials and methods

2.1. Participants and settings

We recruited 113 graduate students who had never attended research ethics courses before from universities in northern Taiwan. These participants were asked to complete an asynchronous online research ethics course. The course consisted of four learning units, each of which took participants approximately 40 min to complete. Twelve students were excluded because of data limitations, such as incomplete traces of SRL behaviors and insufficient learning time, leaving a final sample size of 101 students (M_{age} = 24.21 years, SD_{age} = 3.37, 53.5% female).

Sun and Liu (2022) designed the learning units according to Zimmerman (2000) three-phase SRL model and integrated Barnard et al. (2009) online SRL strategies in the form of tools into the three phases of SRL. In the forethought phase, learners selected a learning unit with reference to their personal interests and prior-knowledge test scores on the course list (Figure 1). Then, they were required to set a learning goal and a learning duration referring to previous learners' averages on unit test scores and time-on-unit (Figure 2). Based on Elliot and Church (1997) achievement goal theory, we recommended that learners choose among three different learning goals: mastery, performance-approach, and performance-avoidance goals (Figure 2). According to the learning duration data collected by Sun et al. (2018, 2019), we provided four options: 20, 30, 45, and 60 min. If learners want to change the learning unit, they can click the "Course List," which takes them back to the course list. From there, they can reselect a learning unit.

After plan making, learners proceeded to the performance phase in which they could implement SRL strategies *via* these tools to study multimedia learning materials (Figure 3). Students could watch and control learning materials with flash animation and switch between content sections freely by leveraging a navigation menu. Meanwhile, the top of the course interface displays a toolbar with three tools, namely, "Countdown," "Expected Time," and "Notes." Learners can check how much time is left by clicking on "Countdown." The information about the remaining time is masked in the absence of click actions for 5 s. When only 5 min are left, the "Countdown" icon will flash to remind learners to adjust their learning pace, such as resetting learning duration *via* "Expected Time." When studying the materials, learners can use "Notes" to type in, delete, and save notes. While learning, if learners want to change the learning unit and learning goal, they can return to the course list by clicking the "Course List" to recreate their study plan.

After studying the learning materials, learners evaluate their performance by attending a unit test. Once finishing the test, learners received a performance feedback report including their test performance and the items they missed (Figure 4). Based on the feedback, learners determined whether to retake the unit test, review the learning materials, or start another learning unit. After finishing all the learning units, learners were asked to fill out cognitive load and student engagement questionnaires.

Considering the prevalence of digital multitasking and distraction in AOL settings, this study defines and identifies learners' off-task behaviors in terms of Sun et al. (2018) study carried out in the same course. Specifically, off-task behaviors appear if there are 20 min of gap time between two consecutive keystrokes or clicks. It should be noted that we exclude the environmental structuring dimension since it is hard to measure based on action logs. Additionally, students were asked to pass the course independently. Thus, help-seeking strategies were not provided in the course. Nevertheless, when encountering technical problems, learners could contact instructors *via* email.

2.2. Data collection

We collected the participants' SRL behaviors according to the coding scheme (Table 1) developed based on Zimmerman (2000) three-phase model and Barnard et al. (2009) online SRL strategies. This study developed 10 SRL behavior codes and embedded coding rules into the learning system. Once learners used the SRL-enabling tools or were off-task, the corresponding behaviors were detected and recorded automatically. For descriptions of each coded behavior, please see "Participants and settings."

Online unit tests were administered to evaluate the participants' research ethics knowledge acquired in the course. Specifically, the four tests contained 25, 13, 17, and 16 multiple-choice items, and the maximum score of each test was 100 points. We averaged the four test scores for each participant as his or her learning performance score. All the items were developed and applied by Sun et al. (2018, 2019).

The cognitive load questionnaire by Leppink et al. (2013) was adapted to measure the participants' ICL (three items), ECL (three items), and GCL (four items). All the items were assessed on an 11-point Likert scale (0 = *strongly disagree*, 10 = *strongly agree*). The Cronbach's α was.92, 0.90, and.92 for ICL, ECL, and GCL, respectively.

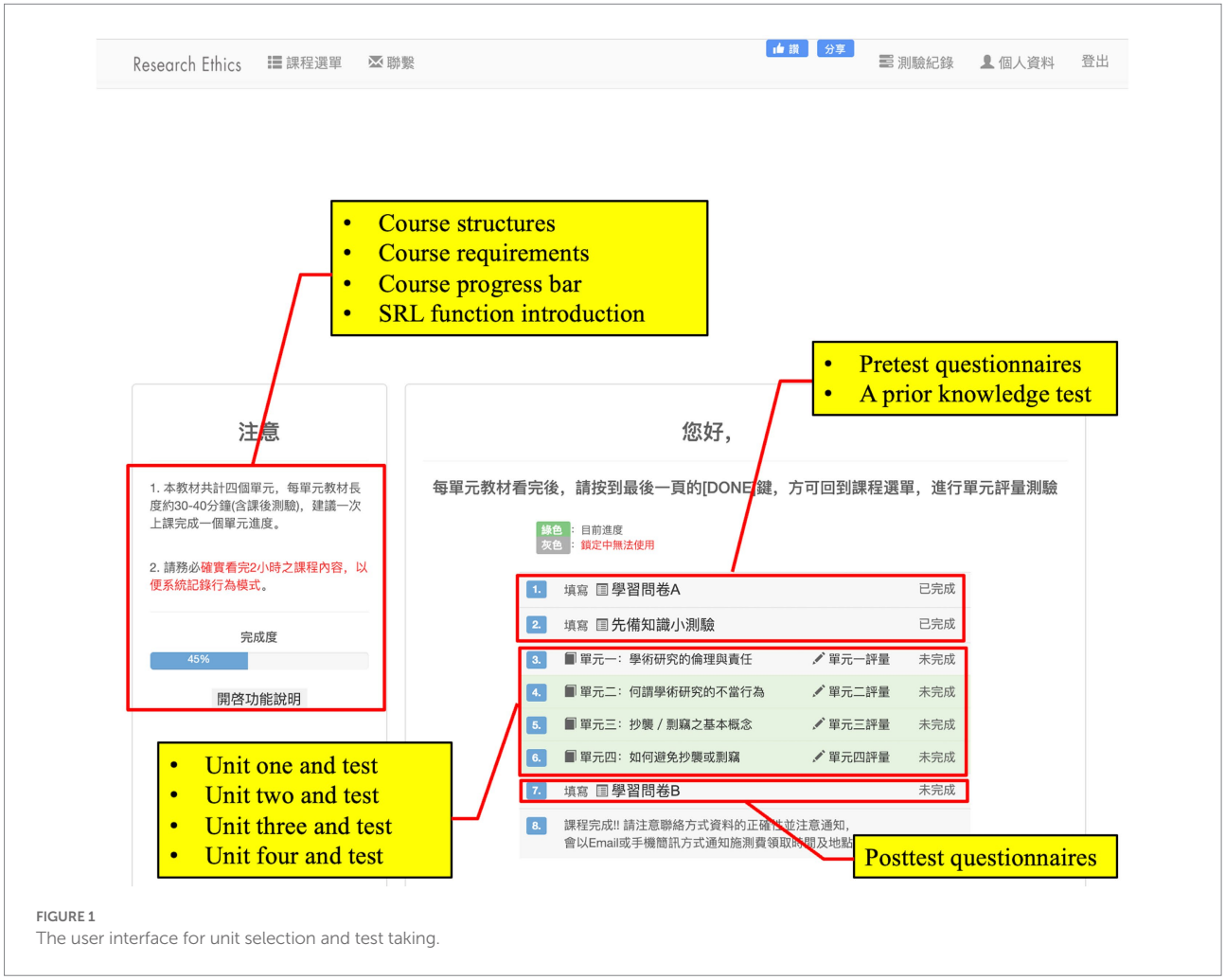

FIGURE 1
The user interface for unit selection and test taking.

The student engagement questionnaire by Fredricks et al. (2005) was adapted to measure the participants' BE (five items), EE (six items), and CE (eight items). All the items were assessed on a 5-point Likert scale (1 = *strongly disagree*; 5 = *strongly agree*). The Cronbach's α was.71, 0.92, and.87 for BE, EE, and CE, respectively.

2.3. Data analysis

A sequence analysis with the R package *TraMineR* (Gabadinho et al., 2011) was undertaken to visualize and compare the sequences of behaviors captured based on our coding scheme. The first step of implementing between-sequence comparisons was obtaining edit distances for pairs of sequences as the minimal cost, in terms of inserting, deleting, and substituting sequence behaviors to transform one sequence into another. Specifically, a dissimilarity matrix was established using the optimal matching algorithm with an insertion/deletion cost of 1 and a substitution cost matrix based on observed transition rates between behaviors. Based on the dissimilarity matrix, we employed K-medoids with the R package *fpc* (Henning, 2020) to organize these behavior sequences into homogeneous clusters. Meanwhile, the average silhouette method was used *via* the R package *factoextra* (Kassambara and Mundt, 2020) to find the optimal number of clusters. To label the identified clusters, we used *TraMineR* to plot the behavior distribution and representative sequences for each cluster. Additionally, Welch's independent *t* tests were performed to quantify the differences between the clusters regarding learning performance, cognitive load, and student engagement.

This study ran an LSA (Bakeman and Quera, 2011) using GSEQ 5.1 software to identify, visualize, and compare significant transition patterns among the SRL behavior codes demonstrated by the clusters. First, the SRL behaviors were coded into two-behavior sequences according to the chronological order. Second, to tally transitions among these behavior codes, the LSA produced a transitional frequency matrix in which each cell represents the number of times that one particular "given" code transitions immediately to another "target" code. Third, after generating the transitional frequency matrix, it proceeded to compute a transitional probability matrix. Specifically, a transitional probability represents the ratio of the frequency of a cell to the frequency for that row. Fourth, it computed an adjusted residual (i.e., *z* score) for each transition to determine whether the transitional probability showed

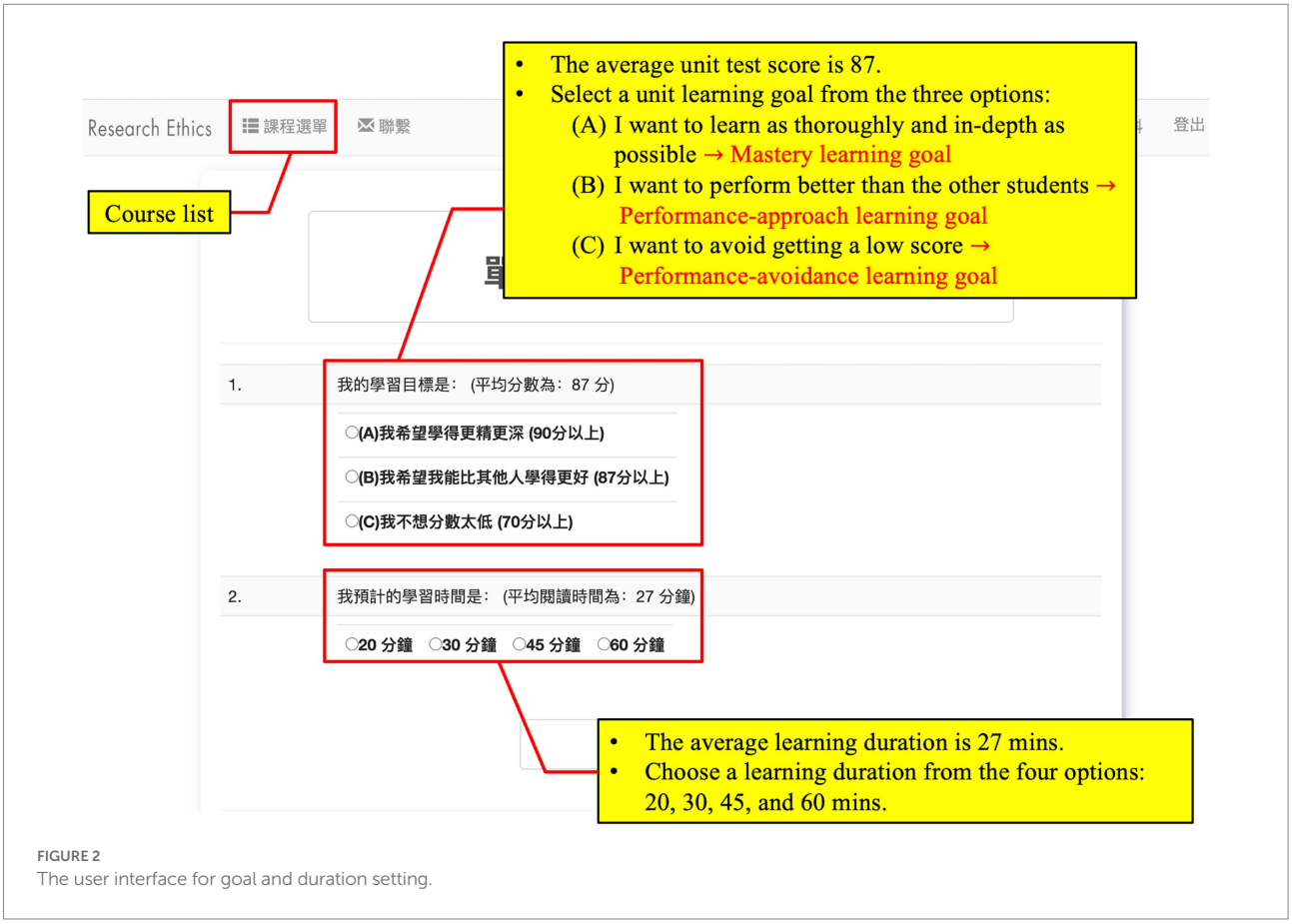

FIGURE 2
The user interface for goal and duration setting.

significant deviation from its expected value. A z score above 1.96 implies that the transition from one code to another successor code reaches statistical significance ($p < 0.05$). Last, the behavioral transition diagram for each cluster was created according to the significant transition sequences.

An ENA (Shaffer, 2017) was implemented *via* the ENA Web Tool (version 1.7.0; Marquart et al., 2018) to model, visualize, and compare the cooccurrences of the codes for the two groups. First, this study defined the SRL behavior codes as the ENA codes, the participants as the units of analysis, and two consecutive SRL behaviors as the moving stanza. Second, based on the temporal behaviors, it created an adjacency matrix per stanza per participant, summed the adjacency matrices across all stanzas into a cumulative adjacency matrix for each participant, and then converted each resulting cumulative adjacency matrix into a normalized adjacency vector in a high-dimensional space. Third, it constructed a projected ENA space by performing dimensional reduction on the vectors *via* means rotation (MR) and/or singular value decomposition (SVD). MR is performed to position group means along a common axis to obtain the largest differences between the groups, whereas SVD is utilized to generate orthogonal dimensions that represent the most variance explained by each dimension. Fourth, it produced each participant's epistemic network graphs in this space employing two coordinated representations: (1) a projected point graph, which showed the location of his or her network in the two-dimensional ENA space, and (2) a weighted network graph where nodes represent the codes and edges correspond to the relative frequency of links between any pair of nodes. The node positions are fixed across all networks and determined through an optimization routine minimizing the distance between the projected points and the centroids of their corresponding network graphs. Last, to compare the network graphs between the groups, we created ENA subtraction graphs by subtracting the weight of each connection in one group network from the corresponding connections in the other. In addition, the distributions of the projected points for the groups were compared using two-sample t tests.

3. Results

3.1. RQ1: Identifying student subgroups based on the SRL behavior sequences

We collected a total of 4,546 SRL behaviors generated by the whole sample. Figure 5 displays the behavior frequencies. Moreover, this study visualized behavior sequences for each

FIGURE 3
The user interface for "Countdown," "Expected Time," and "Notes."

participant in Figure 6. Each point on the x-axis of the figure represents a corresponding position of a behavior sequence, and each value on the y-axis represents a single participant. Each line shows a series of SRL behaviors, as distinguished by different colors, that an individual learner executed during the course. Figure 6 reveals that for the learning of each unit, almost all participants start with selecting a learning unit, then setting a learning goal and duration, and end up taking a unit test. It also shows that the vast majority exhibited unique and personalized SRL behavior sequences, especially in the forethought and performance phases. For example, some students are more inclined to set performance-avoidance goals. Moreover, the sequence length widely varies from 16 to 193, indicating that some students performed longer sequences of behaviors. Such differences suggest that learner heterogeneity in temporal SRL behaviors may exist.

According to Figure 7, $K=2$ was chosen as the ideal number of clusters. Subsequently, the partitioning around medoids (PAM) algorithm was used on the dissimilarity matrix obtained from sequence analysis, classifying participants into two clusters: Cluster 1 ($n=36$) and Cluster 2 ($n=65$). Figures 8–10 illustrate that between-cluster heterogeneity and within-cluster homogeneity became readily apparent in the two-cluster SRL behaviors. Although Cluster 1 had a smaller number of participants than Cluster 2, the former exhibited more frequent behaviors and longer sequence lengths (Figure 8). Both clusters' state distributions of SRL behaviors from the beginning to the end of the course are depicted in Figure 9. Figures 5, 9 show that students from Cluster 1 devoted more effort to the performance phase, especially in time management, whereas those from Cluster 2 focused more on the regulatory activities of the forethought and reflection phases. Moreover, learners from Cluster 2 preferred setting performance-avoidance learning goals.

To further explore the differences in how learners from different clusters regulated their learning, we extracted the medoid, or most central sequences, from the two clusters as their representative sequences (Figure 10). Cluster 1 was represented by eight representative sequences, which were long and covered 36.1% of the sequences. In Cluster 2, we identified only one representative sequence, which was relatively short in length but gave 69.2% coverage. The sequences mined from Cluster 1 showed that the learners adaptively went through the three phases of SRL and demonstrated sophisticated behavior transitions. For example, when facing different learning units, learners modified learning goals by self-evaluating their performance at that time. When studying unit materials, they executed strategies of notetaking and time management

FIGURE 4
The user interface for test feedback.

depending on their learning needs. After off-task behaviors occurred, the learners usually checked the remaining learning time to adjust the subsequent learning pace. In contrast, the representative sequence identified in Cluster 2 indicated that although three-phase SRL was triggered, the participants predictably repeated the same set of SRL behaviors without any modification of strategies across the four learning units. Interestingly, they oriented themselves toward performance-avoidance learning goals. Given the findings above, we labeled Cluster 1 and Cluster 2 as the high online self-regulated learning group (H-SRL) and the low online self-regulated learning group (L-SRL), respectively.

3.2. RQ2: Comparing the subgroups' learning performance, cognitive load, and student engagement

Table 2 shows that the H-SRL ($M = 87.31$, $SD = 5.43$) had significantly better learning performance than the L-SRL ($M = 83.49$, $SD = 10.32$). Moreover, the H-SRL ($M = 7.42$, $SD = 5.59$) exhibited significantly lower ECL than the L-SRL ($M = 10.88$, $SD = 7.15$). The H-SRL ($M = 33.11$, $SD = 5.26$) experienced significantly greater GCL than the L-SRL ($M = 30.26$, $SD = 5.35$). However, the t test results on ICL revealed nonsignificant differences between the groups. For the SE, the CE of the H-SRL ($M = 29.28$, $SD = 4.37$) was significantly higher than that of the L-SRL ($M = 26.83$, $SD = 5.16$), but no significant differences were found in BE and EE. According to Cohen (1988), the effect size was small for learning performance and medium for ECL, GCL, and CE.

3.3. RQ3: Examining the subgroups' behavior patterns of SRL

Supplementary Appendix A presents the LSA results. The significant behavior patterns are portrayed in Figure 11, where the behavior codes are signified with round rectangles and the significant transitions are signified with arrows. Both groups shared some common transition sequences. In the forethought phase, the participants started by choosing a learning unit, then settled on a learning goal, and ended up with setting a learning duration (SU → G1, G1 → SD, SU → G2, G2 → SD, SU → G3, and G3 → SD), indicating that they usually acted in compliance with the tools supporting goal setting. In the performance phase, they repeatedly took notes (TN ⇄ TN)

TABLE 1 The coding scheme of online SRL behaviors.

SRL phase	Online SRL strategy	Online SRL behavior	Code
Forethought	Goal setting	Selecting a learning unit	SU
		Choosing a mastery learning goal	G1
		Choosing a performance-approach learning goal	G2
		Choosing a performance-avoidance learning goal	G3
		Setting a learning duration	SD
Performance	Task strategies	Taking notes	TN
	Time management	Checking remaining learning time	CT
		Resetting a learning duration	RD
Reflection	Self-evaluation	Taking a unit test	TT
		Performing off-task behaviors	OT

and usually performed time management-related behavior transitions such as repeatedly checking remaining learning time (CT $\rightleftarrows$ CT), checking remaining learning time before attempting a test (CT $\rightarrow$ TT) and switching between checking remaining time and resetting learning durations (CT $\rightleftarrows$ RD). These sequences illustrate that students are required to invest much effort in organization and time management in AOL contexts. Additionally, it should be noted that both groups exhibited off-task behaviors after setting a learning duration (SD $\rightarrow$ OT) or before checking remaining learning time (OT $\rightarrow$ CT). This kind of behavior transition indicates that off-task behaviors are difficult to prevent in AOL environments, but SRL-enabling tools can offer remedy support, such as displaying the remaining learning time. In the self-reflection phase, after completing a unit test and receiving system feedback, the learners either attended the same unit test again (TT $\rightleftarrows$ TT) or started another learning unit (TT $\rightarrow$ SU), indicating that learners evaluated their learning according to the unit test and system feedback and then made learning adjustments. However, some different behavioral transfers were found between the two groups. The H-SRL usually went off-task after selecting a learning unit (SU $\rightarrow$ OT), indicating that learners disengaged from the forethought phase, possibly because they struggled to determine an appropriate learning goal and learning duration by themselves. In contrast, the L-SRL directly attempted a test after setting a learning duration (SD $\rightarrow$ TT) or undertaking off-task activities (OT $\rightarrow$ TT), indicating that the L-SRL gravitated more toward unit tests to pass exams through minimal engagement.

The results of ENA showed that the x-axis corresponding to MR explained 23.4% of the variance in the network, while the y-axis corresponding to SVD explained 28.9% of the variance in the network. Moreover, two-sample *t* tests were applied to examine whether the network centroids (colored squares surrounded by dashed-border rectangles representing 95% confidence intervals) for the two groups differed along both the x-axis and the y-axis. We found a significant difference between the H-SRL ($M = -1.34$, $SD = 0.93$) and the L-SRL ($M = 0.74$, $SD = 1.16$) on the x-axis ($t = -9.86$, $df = 86.81$, $p < 0.001$) but a nonsignificant difference between the H-SRL ($M = 0.00$, $SD = 1.34$) and the L-SRL ($M = 0.00$, $SD = 1.79$) on the y-axis ($t = 0.00$, $df = 90.26$, $p = 1.00$). These findings indicate that the H-SRL made stronger connections to G1, TN, CT, and RD, whereas the L-SRL made stronger connections to G3 and TT.

The ENA subtraction graph (Figure 12) was used to compare the mean networks of these two groups. Specifically, the H-SRL displayed stronger connections of SU and SD with G1 and weaker connections of SU and SD with G3 than the L-SRL, indicating that the H-SRL tended to choose mastery learning goals, while the L-SRL tended to set performance-avoidance learning goals. Moreover, the H-SRL showed more associations related to TN, CT, and RD and fewer associations related to TT than the L-SRL, indicating that the H-SRL preferred enacting organization and time management strategies to master the course content, while the L-SRL focused more on the unit tests than on the course materials. The H-SRL exhibited stronger links between OT and SU and CT and weaker links between OT and TT than the L-SRL. These links indicate that the H-SRL was more likely to exhibit off-task behaviors while planning for the learning units and usually checked the remaining learning time when off-task behaviors occurred. In contrast, when continuing learning was impeded due to off-task activities, the L-SRL was more inclined to start taking the unit tests rather than shifting back to reading the unit materials.

4. Discussion

This study found heterogeneity in students' behavioral processes for online SRL. Specifically, we classified the participants into two clusters (i.e., H-SRL and L-SRL) according to their traces of SRL behaviors derived from an AOC with SRL-enabling tools. We found that the H-SRL obtained higher learning performance than the L-SRL. This finding is partially consistent with Cicchinelli et al. (2018), who leveraged behavioral trajectories of SRL codified from trace data derived from an LMS to detect student subgroups. They found the highest test scores in the group who performed

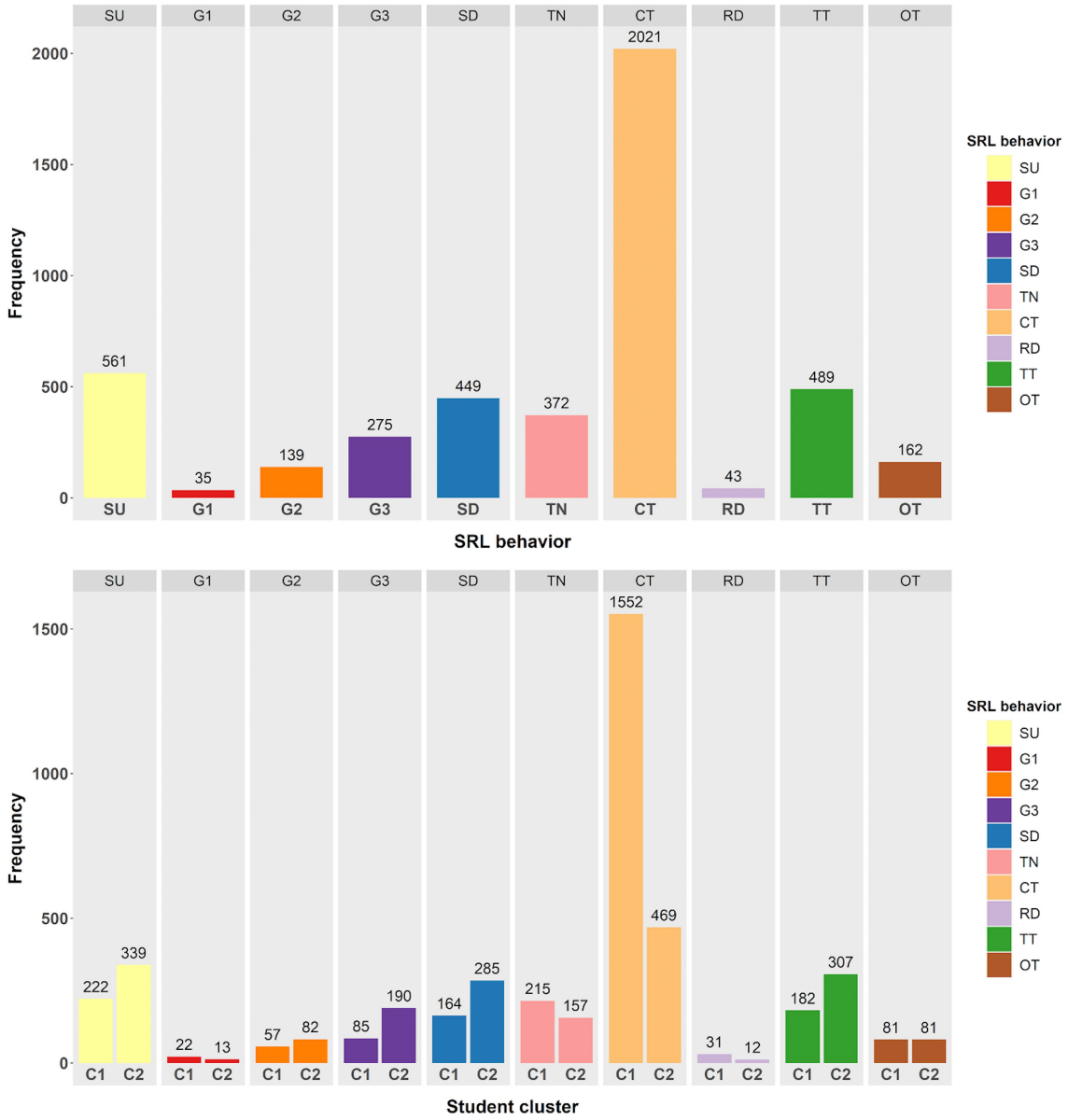

FIGURE 5
The frequencies of SRL behaviors for the overall sample (top) and the two clusters (bottom). C1=Cluster 1; C2=Cluster 2.

SRL behaviors in regular and structured ways rather than in others who rarely or irregularly engaged in SRL activities.

Additionally, the H-SRL experienced lower ECL and higher GCL than the L-SRL, which verifies the theoretical assumption that learners' self-regulation of learning processes has associations with their cognitive loads (Seufert, 2018). Moreover, these findings support the view that how learners process instruction relates to ECL and depends on learners' abilities and willingness to exert self-control (Eitel et al., 2020). In this study, compared to the L-SRL, the H-SRL who exerted more self-control of their cognitive processing (e.g., checking learning time frequently) showed lower ECL. Additionally, the findings substantiate another assertion that the use of learning strategies and external learning supports is associated with GCL (Klepsch and Seufert, 2020). In this study, the H-SRL who engaged more with SRL strategies *via* the SRL tools, particularly time management and notetaking, experienced higher GCL than the L-SRL. Another possible reason for this result is that in contrast with the L-SRL, the H-SRL bore lower ECL, freeing up more mental resources for germane processes to maximize learning. Additionally, the H-SRL showed more CE than the L-SRL, which aligns with the findings of Kim et al. (2021), who demonstrated the relationship between SRL strategy use and CE in AOCs. They found that students who more frequently performed resource management strategies (e.g., time management) showed higher CE.

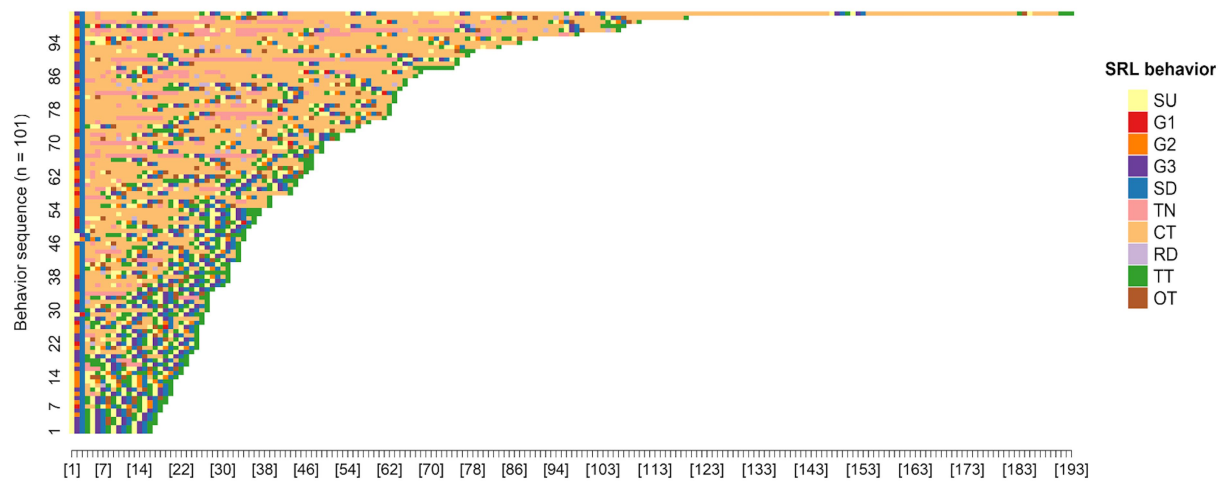

FIGURE 6
Plot of SRL behavior sequences for the whole sample.

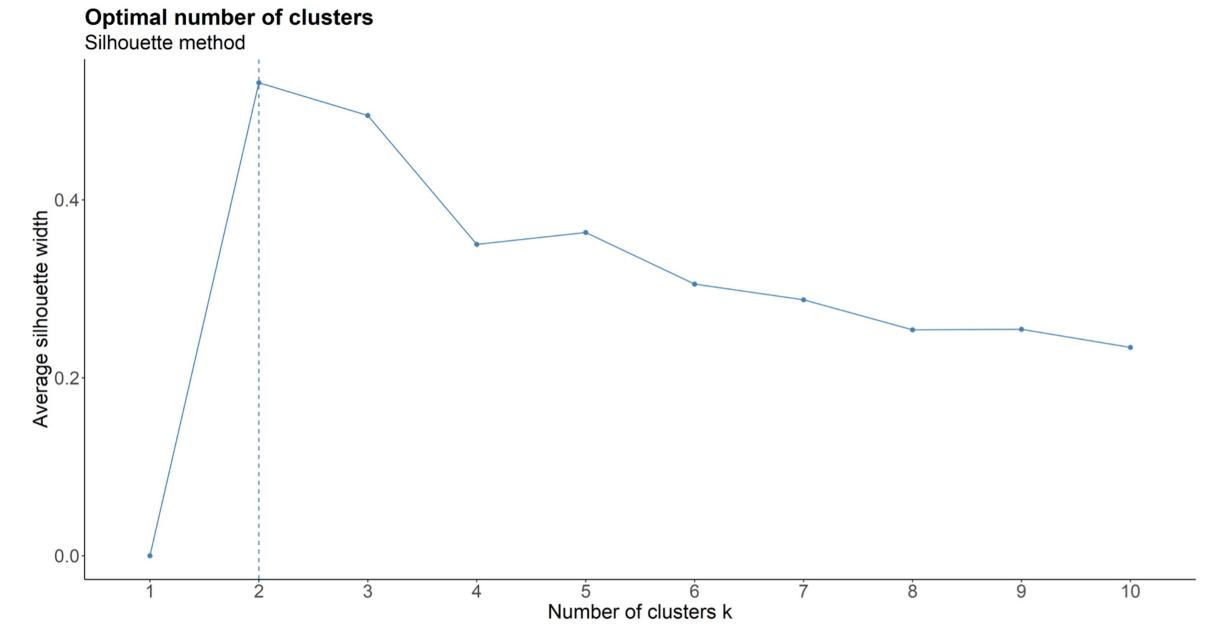

FIGURE 7
Average silhouette method for the selection of optimal clusters.

The above findings suggest that although the SRL-enabling tools were provided to support SRL strategies in AOL environments, not every learner will take advantage or glean the benefits of such tools to regulate their learning processes well. It is highly possible that some learners ignore or do not comply with the provided SRL support (Bannert et al., 2015). Due to poor compliance with support, learners' regulation was not well aligned with the learning processes, or they failed to engage in deeper learning processes (Seufert, 2018).

The LSA results showed that both groups went through three-phase SRL cycles and executed many identical behavior transitions among SRL behaviors, which implies that the SRL-enabling tools, to some extent, can facilitate students' implementation of SRL strategies in AOL. However, we also noticed that both groups performed off-task behaviors in the performance phase. This is not surprising, as opportunity costs for studying are relatively high when students are in AOCs (Eitel et al., 2020). Opportunity costs reflect events or activities that one must delay or sacrifice to achieve an academic goal (Wolters and Brady, 2021). For example, it is challenging to persist in engaging with an AOC when the mobile phone is in reach or when friends are present. To address this issue, as suggested by Kim et al. (2021), educators should design AOCs

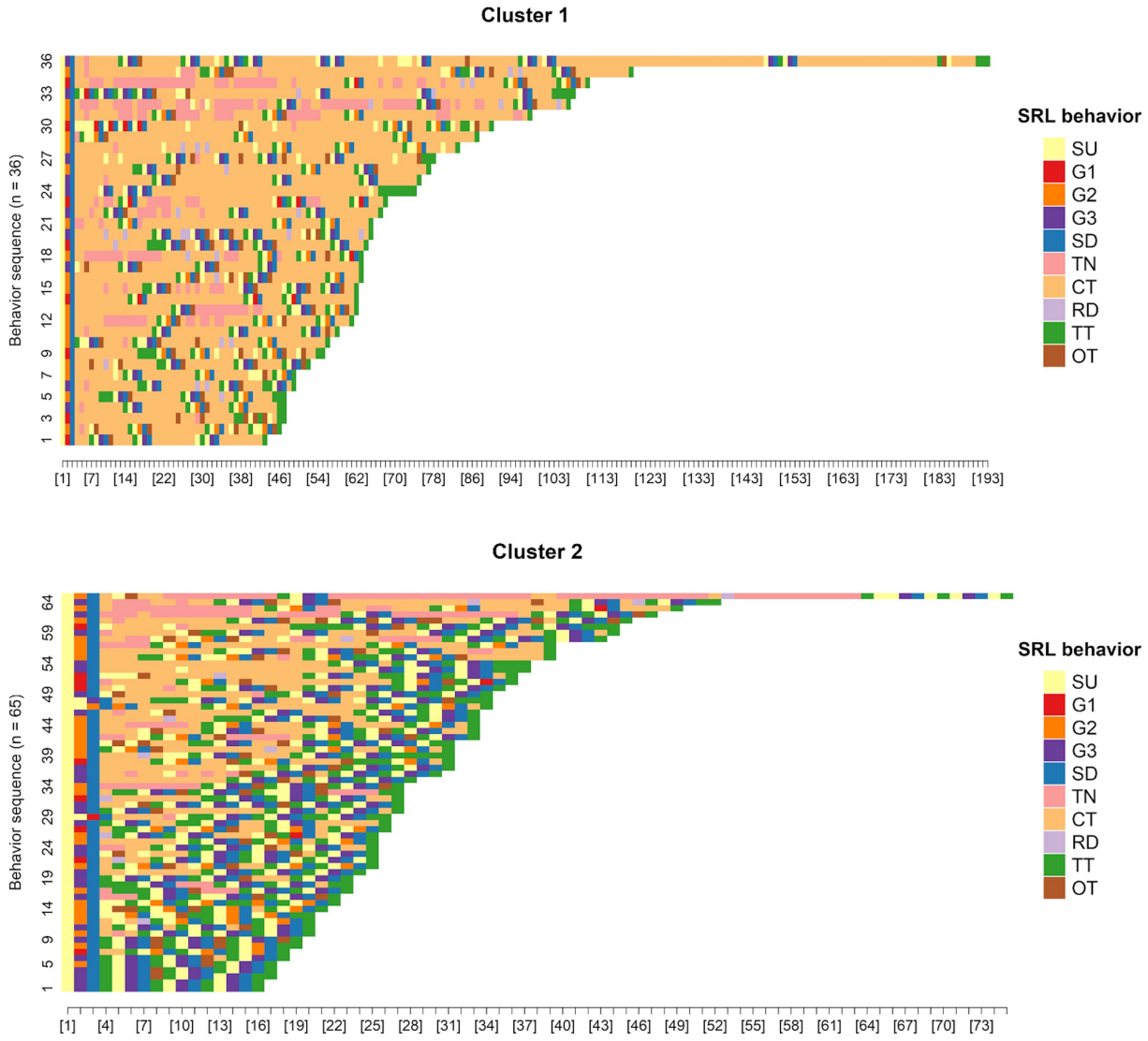

FIGURE 8
Plots of SRL behavior sequences by clusters.

in a way that is helpful to sustain students' engagement throughout the course. Additionally, the LSA results also reveal the differences in behavior transitions between the groups. For the H-SRL, off-task situations were detected in the forethought phase. One possible explanation is that insufficient reference information provided in the forethought phase made learners struggle to accurately judge the difficulty of course content and thus hesitate to set learning goals and learning durations. This explanation is underpinned by Hwang et al. (2021), who report that students who referred to peers' suggestions for self-regulation were more likely to set appropriate learning goals in an AOC with SRL support. In contrast, the L-SRL displayed more transition sequences related to taking tests. Specifically, when encountering some challenges, such as distraction or managing learning processes independently, the L-SRL tended to avoid such challenges by attempting unit tests directly, suggesting that the L-SRL had a strong tendency to follow surface learning approaches. Surface learning approaches are characterized by weak learner commitment toward studying, low engagement with learning content, and high concentration on assessment and are negatively associated with learning performance (Matcha et al., 2019; Taub et al., 2022). Similarly, many prior studies on SRL also demonstrated the adoption of surface learning approaches in AOL (Loeffler et al., 2019). For example, based on the use of study tactics extracted from trace data that an LMS captured, Saint et al. (2020b) identified four learner strategy groups (i.e., active agile, summative gamblers, active cohesive, and semiengaged groups) and reported that the summative gamblers group tended to use surface learning approaches and underperformed on course exams compared with other groups. Specifically, this group mostly focused on summative assessments and exhibited suboptimal learning behaviors such as jumping straight to a summative test after goal setting.

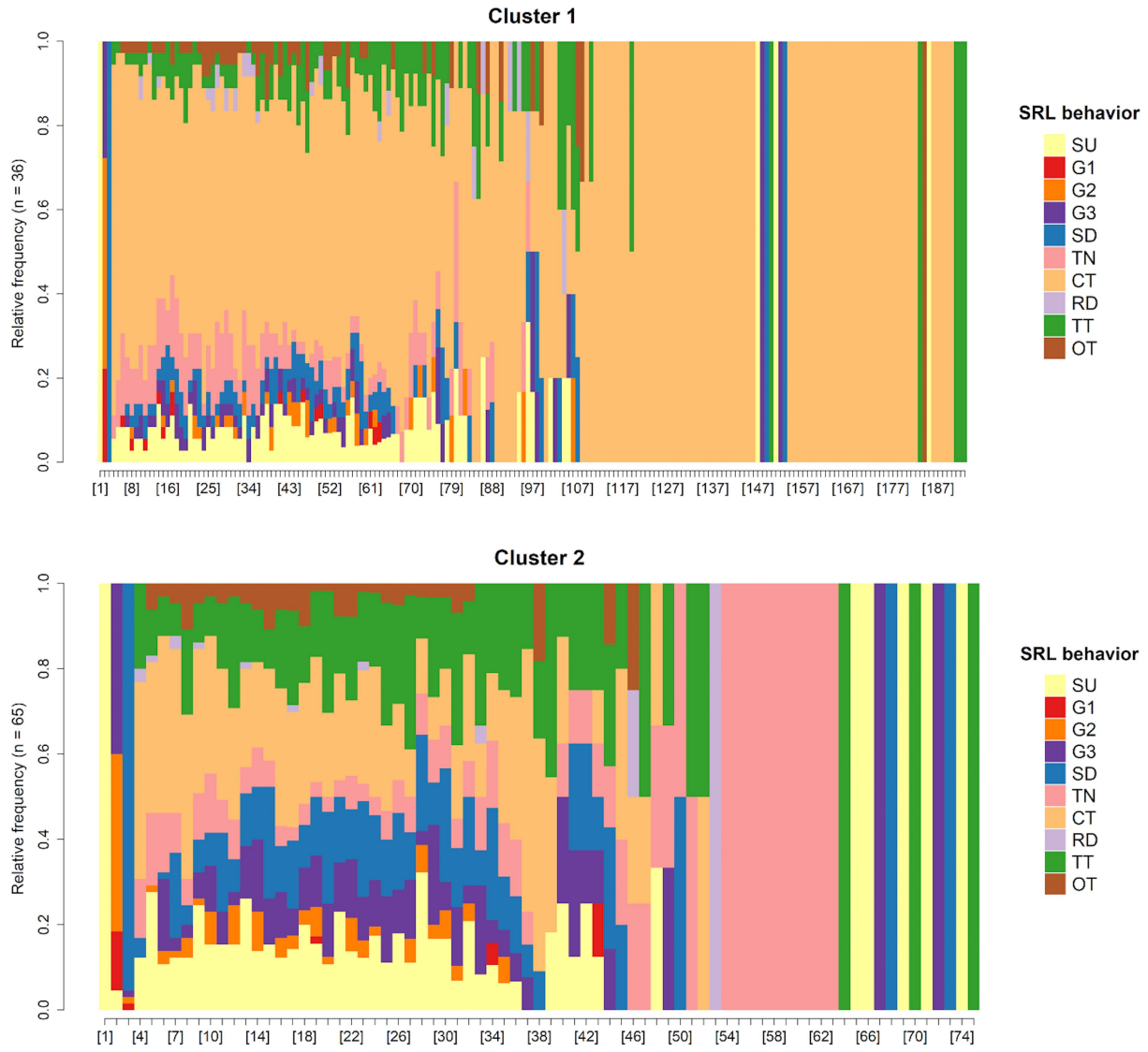

FIGURE 9
SRL behavior distribution plots by clusters.

We conducted an ENA to confirm and complement the LSA findings. Unlike the LSA, which generated directional transition sequences, the ENA quantitatively compared the two groups' networks of co-occurrences between behaviors and uncovered the group differences in specific network connections in more detail. Specifically, a significant difference was found in the co-occurrence networks between the two groups. Moreover, the ENA subtraction graph showed that the H-SRL had stronger associations between selecting learning units and performing off-task behaviors, whereas the L-SRL had stronger associations between taking unit tests with setting learning durations and performing off-task behaviors, which confirmed the LSA findings. More interestingly, in contrast to the LSA results that both groups shared some common behavior patterns, the ENA subtraction graph unveiled the group differences in these behavior patterns. Specifically, the H-SRL made more connections to setting mastery learning goals and managing learning time, which echoes prior review research by Wolters and Brady (2021), who reported positive correlations between college students' use of time management strategies and the adoption of mastery learning goals. In contrast, the L-SRL made more connections to setting performance-avoidance learning goals and taking unit tests, which verified the LSA finding that the L-SRL preferred surface learning approaches. Similar findings were also reported by Jovanović et al. (2017), who mined five student groups (i.e., intensive, strategic, highly strategic, selective, and highly selective groups) according to students' learning sequences representing their interactions with an LMS and revealed that the intensive and strategic groups outperformed the highly selective group in exam performance. They found that the intensive and strategic

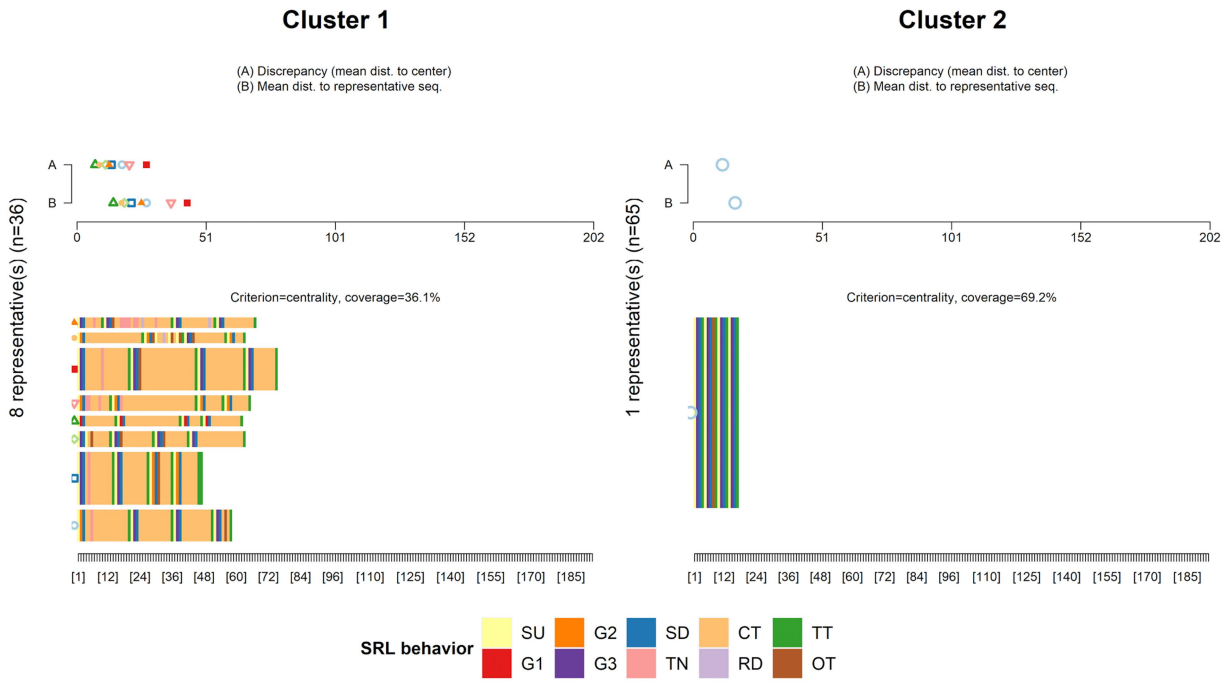

FIGURE 10
Representative sequence plots by clusters.

TABLE 2 The results of Welch's independent *t* tests on learning performance, cognitive load, and student engagement between the two groups.

Variables	H-SRL (*n*=36)		L-SRL (*n*=65)		*t* (*df*)	*p*	Cohen's *d*
	M	*SD*	*M*	*SD*			
Learning performance	87.31	5.43	83.49	10.32	2.43 (98.82)*	0.017	0.46
Intrinsic cognitive load	13.22	5.91	14.74	7.64	−1.11 (88.35)	0.271	−0.22
Extrinsic cognitive load	7.42	5.59	10.88	7.15	−2.69 (87.72)**	0.009	−0.54
Germane cognitive load	33.11	5.26	30.26	5.35	2.59 (73.46)*	0.012	0.54
Behavioral engagement	19.39	3.04	18.46	2.72	1.52 (65.96)	0.132	0.32
Emotional engagement	19.83	4.75	18.09	4.73	1.77 (72.17)	0.081	0.37
Cognitive engagement	29.28	4.37	26.83	5.16	2.52 (82.97)*	0.013	0.51

*$p < 0.05$, **$p < 0.01$, ***$p < 0.001$

groups displayed mastery-goal orientation and actively practiced different learning strategies to adapt to the course requirements, whereas the highly selective group exhibited performance-goal orientation and typically employed surface learning approaches.

5. Conclusion

The present study contributes to research in the field of SRL in several ways. First, we examined the temporal dynamics of students' SRL behaviors in the context of AOL by identifying and visualizing potential student subgroups (i.e., H-SRL and L-SRL) based on students' trajectories of online SRL behaviors. Second, we investigated whether and how the differences in SRL behavioral trajectories are associated with AOL success by (1) testing the student subgroups for differences regarding learning performance, cognitive load, and student engagement and (2) uncovering the SRL behavior patterns of the subgroups. Third, this study provided empirical evidence for the association of the self-regulation of learning processes with cognitive load and student engagement. We found that the H-SRL had lower ECL and higher GCL and CE than the L-SRL. Last, this study is the first attempt to combine LSA and ENA to articulate and compare behavior patterns of SRL. It not only offers more holistic and in-depth insights into the temporal characteristics of SRL but also addresses, to some extent, the concerns of ontological flatness proposed by Reimann et al. (2014).

The current findings have important implications for the research and practice around SRL in the context of AOL. First,

considering that the L-SRL preferred performance-avoidance goals and ignored time management and notetaking, instructors should encourage students to pursue mastery learning goals and actively engage in time management and notetaking, especially in AOCs. Additionally, this study informs the design of adaptive SRL interventions. Since not all learners were able to equally benefit from fixed SRL support, SRL interventions should be tailored to meet the needs of students with different patterns of SRL behaviors. We highly recommend that educators develop adaptive SRL interventions that can track and evaluate SRL behavior changes on the fly and provide immediate and personalized suggestions on SRL strategy use. Additionally, the temporal analyses of learners' interactions with SRL support can evaluate how an SRL intervention relates to learning outcomes. Indeed, Damgaard and Nielsen (2018) highlighted the importance of examining the mechanisms that behavioral interventions affect, as interventions may fall short of intended positive effects if the understanding of the likely affected behavioral pathways is insufficient. Finally, the visualization of temporal SRL behaviors conveys quantitative information in a more digestible and actionable way, which enables instructors to (1) pinpoint how SRL processes unfold over time and differ across different SRL groups and (2) determine when and how to intervene as warranted.

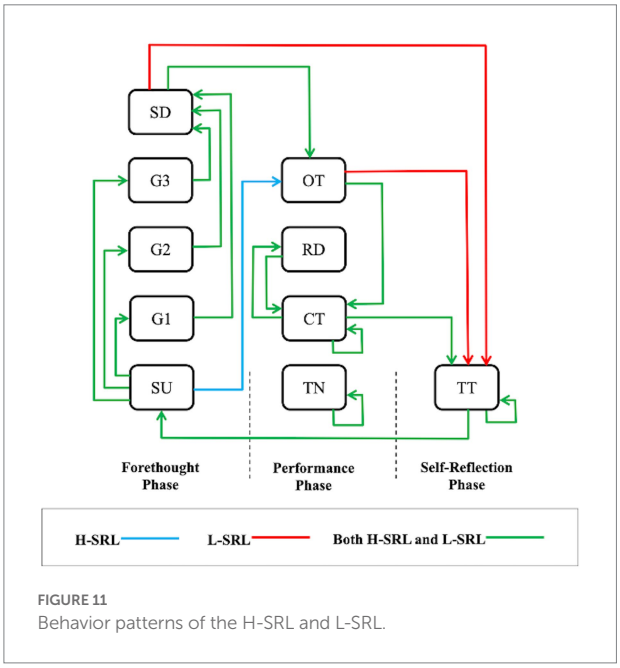

FIGURE 11
Behavior patterns of the H-SRL and L-SRL.

The current study has some limitations that should be addressed in future research. First, all the participants were

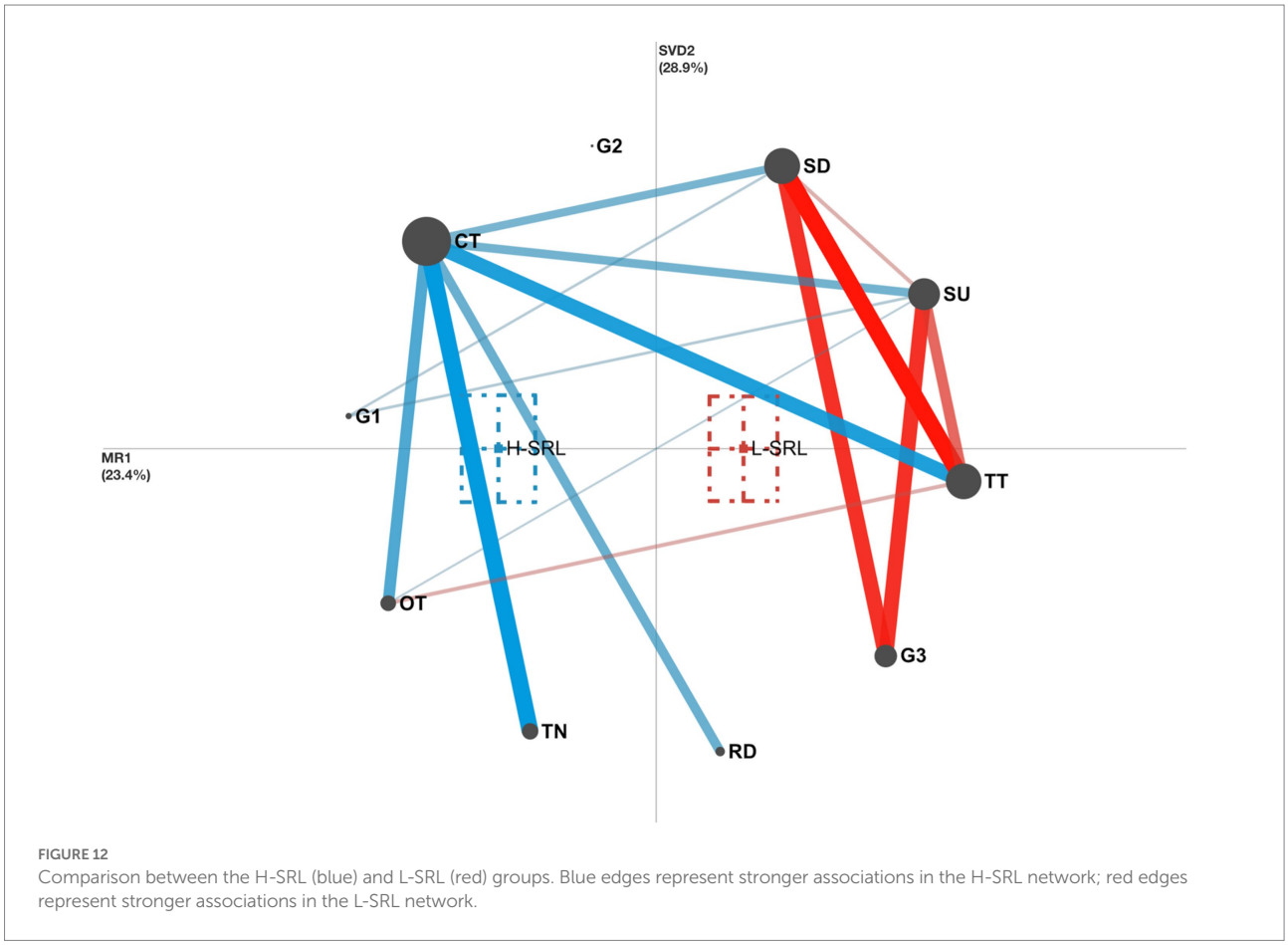

FIGURE 12
Comparison between the H-SRL (blue) and L-SRL (red) groups. Blue edges represent stronger associations in the H-SRL network; red edges represent stronger associations in the L-SRL network.

graduate students from universities located in northern Taiwan, which may limit the generalizability of our findings. Future studies should include a larger sample of students at other educational levels and from different countries/regions. Secondly, as with most SRL research, this study conducted a postanalysis of students' SRL behaviors. Future studies could integrate this postanalysis into AOCs to offer students immediate learning analytics-based feedback to support their calibration for SRL. Thirdly, this study did not collect students' scores of prior knowledge tests regarding research ethics, which limits the examination of the relationship between students' prior knowledge and their SRL behavioral traces. In the future, researchers could investigate whether student groups with distinct SRL processes differ in prior knowledge and how students with different levels of prior knowledge perform their SRL behavioral trajectories. Fourthly, the participants' SRL behaviors were dominated by time management due to the time restrictions imposed in the course, which may make our study not represent most behavioral data-based SRL studies, especially in authentic learning settings in which time management is usually in the background. Thus, we encourage researchers to examine further the association of time management with learning outcomes in AOL settings. For example, future studies could explore how students' learning outcomes are related to the frequency of time management behaviors or SRL behavioral sequences involving time management. Moreover, it remains unclear whether our findings about distinct SRL behavioral patterns can be generalized to large-scale open AOL environments, such as MOOCs. Finally, because SRL is a multidimensional construct that includes (meta) cognitive, emotional, motivational, and behavioral components, it is difficult to use a single data source to capture the full range of SRL processes. Hence, future researchers could utilize multimodal multichannel data (e.g., physiological measures) to create a more comprehensive picture of SRL processes.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

Ethical approval was not provided for this study on human participants because all of the research data were stored on the first author's and the corresponding author's personal computers that are password-protected, and can be accessed by only the first author and corresponding author of this paper for research purposes. All of the participants in the sample voluntarily participated in the study. Individual responses were confidential. No identifying information linked responses to individuals, and thus students' private information was fully protected in the study. There are no conflicts of interest to declare. Written informed consent for participation was not required for this study in accordance with the national legislation and the institutional requirements.

Author contributions

JS contributed to course development, data collection, research idea, and manuscript writing and editing. YL contributed to research idea, data analysis, and manuscript writing and revision. XL contributed to manuscript writing and editing. XH contributed to manuscript review and editing. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

Supplementary material

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Ice Cream: new virtual reality tool for the assessment of executive functions in children and adolescents: a normative study

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This study focuses on the obtention of normative data for participants between 8 and 16 years old who were administered the Ice Cream test, a virtual reality tool designed to evaluate executive functions. The normative sample comprised *n* = 821 participants (49% female), with an age range of 8 to 16 years old, recruited across nine different testing sites in Spain. Experienced evaluators in psychological assessment, recruited and trained by the developer of the test, administered the test to the recruited sample. An empirical analysis of Ice Cream identified three factors, namely planning, learning and flexibility. Descriptive normative groups by age and gender were initially provided. A homoscedasticity analysis by gender showed no statistically significant differences between male and female participants. Cluster analysis by age suggested the creation of different age groups, respectively, 8 to 11 and 12 to 16 in Planning and Flexibility, and 8 to 9 and 10 to 16 in Learning, and subsequently, descriptive data for the established age groups per factor are shown. A confirmatory factor analysis showed the suitability of the 3 factors established as measured of three differentiated executive functions. Complementary data on the validity and reliability, and internal consistency of the scales are provided. Obtained normative data are relevant for evaluating executive functions in children and adolescents in a more ecological way. Further studies are needed to determine sensitivity and specificity of Ice Cream VR test to measure executive functions in different clinical populations.

KEYWORDS

neuropsychological assessment, virtual reality, executive functions, ecological validity, normative data

1. Introduction

Executive functions are the set of processes that regulate self-control capacity of our conscious and unconscious systems when it comes to establishing response patterns, organization, planning, time management and, in general, achievement of goals and objectives (Best and Miller, 2010; Bausela-Herreras, 2014; Josman and Meyer, 2018; Ruiz-Gutiérrez et al., 2020). In general, terms like executive functioning or control refer to essential mental abilities to deploy an efficient, creative and socially accepted behavior. In addition, executive functions include a series of cognitive processes, such as anticipation, goal selection, planning, behavior selection, self-regulation, self-control, and feedback (Díaz-Orueta et al., 2014). As accurately described by Diamond (2013, p. 135), they are a series of "top-down

mental processes needed when you have to concentrate and pay attention, when going on automatic or relying on instinct or intuition would be ill-advised, insufficient, or impossible" and she refers to the three core EFs as inhibition, working memory, and cognitive flexibility, with all potential name variations associated to these. Previously, Miyake et al. (2000b) acknowledged the relevance of recognizing both the unity and diversity of executive functions, and with their study, they shed some light on the uniqueness of three target executive functions (namely, "shifting", "updating" and "inhibition") while recognizing their moderate correlation with one another.

Executive functions (EF) are essential for an adequate neurological development through different life stages (Best and Miller, 2010). Given their role as regulators of multiple processes, both at a cognitive and an emotional level, their correct development is crucial for achieving milestones associated with age in the areas of learning, behavior and emotional management (Bausela-Herreras, 2014). A suboptimal performance of executive functions can condition maturational changes, global performance and the course of a normative or neurotypical development. More specifically, a dysfunction in executive functions may be linked with symptoms associated with developmental disorders such as attention deficit disorder with/without hyperactivity (ADHD) or autism spectrum disorders, among others (Bausela-Herreras et al., 2019).

When it comes to understanding Executive functions (EF) in children, according to Reilly et al. (2022), EF are key predictors of long-term success that develop rapidly in early childhood, but EF's developmental trajectories from preschool are not fully understood, and how these trajectories differ based on characteristics of children and their families (based on income, ethnicity, urban versus rural environment, etc.) remains to be characterized. These authors found high individual variability in EF trajectories in children depending on their baseline EF performance, such that children with higher EF at preschool (2 to 4 years-old) entry showed relatively steeper growth during preschool compared to low-EF peers, but those differences attenuated by the end of kindergarten (4 to 6 years-old), which makes it necessary to examine these different trajectories in detail in future studies, to better understand the status and potential trajectories of EF in later stages of childhood and early adolescence. Separately, Davidson et al. (2006) found that cognitive flexibility (switching between rules), even with memory demands minimized, showed a longer developmental progression, with 13-year-olds still not at adult levels. Moreover, Duncan (2006) emphasizes the role of socioeconomic status as a differential factor for the development of EF in children at this age. Probably, the best account of developmental trajectories of EF in later childhood was done by Best and Miller (2010), who talk about (1) rapid changes in inhibition from 3 to 5, less rapid from 6 to 8, and more stable since that age (despite the continuation of brain maturation); (2) a linear increase in working memory from ages 4 to 14 and a leveling off between ages 14 and 15 across nearly all tasks examined, and (3) a protracted development of the ability to successfully shift between task sets through adolescence, from preschool-aged children who can handle shifts between simple task sets and older children who later can handle unexpected shifts between increasingly complex task sets. Both behavioral and physiological measures indicate that during adolescence, monitoring of one's errors is evident, and by middle adolescence, task switching on these complex shift paradigms typically reaches adult-like levels.

In this context, one of the most significant problems in understanding executive functions is the breadth and diversity of criteria used to define them. For example, Zelazo and Müller (2002) distinguished between (1) the 'cold' executive function component, more purely cognitive, associated with the dorsolateral prefrontal cortex and, according to Hongwanishkul et al. (2005, p. 618), more likely to me measured by "abstract decontextualized problems" like the task presented in the Wisconsin Card Sorting Test; and (2) the 'hot' executive function component, in charge of regulating aspects that are associated with a relevant emotional component (Mehsen et al., 2021), associated with the ventromedial-prefrontal cortex areas, and more likely to be measured by tasks that involve the regulation of affect and motivation. Since the existence of pure processes is rare, the usual understanding is that EF display a joint and synchronized job between both systems in order to achieve the most efficient result in each situation (Best and Miller, 2010).

When it comes to their assessment, EF share the same problems and challenges as other cognitive functions. Rabbitt (1997) drew attention to the low test–retest reliability and uncertain construct validity of executive function tests; the difficulties to relate functions to specific neuroanatomical areas or neurophysiological systems; the problem of identifying what ultimately are just tasks demands (such as inhibition, planning, monitoring or control) with different system architectures when in fact could be produced by the same system architecture; or the identification of task performance indices and system performance characteristics as equivalent to statistical constructs such as the general intelligence factor. Separately, Díaz-Orueta et al. (2014) pointed out that classical neuropsychological assessment does not reproduce the wide range of stimuli an individual may encounter in their daily life. More specifically, the classical evaluation environment (e.g., a health care center, an office) is closer to a "lab environment," does not offer any contextual cues to the patient (as real-life environments do), distractors are minimized or erased, sensory modalities are assessed separately, and environmental noise and temperature are set as stable conditions for everyone. Moreover, classical evaluation tests are conditioned by a floor or ceiling effect, tend to evaluate the information storage in a relatively brief period of time, and demand learning of information that does not have any personal relevance for the patient.

Despite the wide availability of traditional paper-and-pencil tools for the purported assessment of executive functions (Lalonde et al., 2013), these tools may show some patients showing a test performance better than expected (or within normal limits) and yet displaying difficulties with activities of daily living, which makes the prediction of patient's future behavior on the basis of these assessment tools highly questionable. Bombín et al. (2014) stated that the strategy traditionally followed for the evaluation of executive functions has been its atomization in different cognitive threads, as shown in previous studies by Miyake et al. (2000a,b). However, in clinical practice, the disintegration of a global and complex cognitive process like this into countless related subcomponents is often problematic to grasp performance in executive functions in its entirety (Lezak, 1982; Chan et al., 2008) due to problems associated to measurement of functionality, ecological validity and task-impurity (or the inability of traditional EF tasks to measure EF only and measure EF to its maximum extent -Snyder et al., 2015). Miyake et al. (2000a) recognized that the assessment of executive functions needs to overcome serious problems of conceptualization, measurement, lack

of correspondence between anatomical structures and functions (i.e., there is no direct correspondence between "frontal lobes" and EF), task impurity, low reliability of classical tests and construct validity. Subsequently, the tests designed according to this paradigm are often of limited value for clinical procedures (such as diagnosis or rehabilitation plans) due to the poor correspondence with the clinical reality of the patient.

These discrepancies suggest that classical neuropsychological tests may not adequately reproduce the complexity and dynamic nature of real-life situations. To overcome these limitations, latest technological developments such as virtual reality (VR) based neuropsychological assessment tools, may achieve greater accuracy and validity for the assessment of a wide range of cognitive functions, including executive functions (Climent et al., 2014; Kim et al., 2021; Borgnis et al., 2022).

Virtual reality reproduces three-dimensional environments with which the patient interacts dynamically, with a feeling of immersion in the environment similar to the presence and exposure to a real environment. In addition, the presentation of target stimuli, as well as distractors or other variables, can be systematically controlled. Likewise, more consistent and precise answers can be obtained, as well as a detailed analysis of them (Camacho-Conde and Climent, 2022; Kusi-Mensah et al., 2022; Silva et al., 2022). Kim et al. (2021) describes that fully immersive virtual reality (VR) as a promising resource, not only necessary to overcome the existing limitation of neuropsychological tests, but also for the development of tailored treatments for EF within activities of daily living (ADLs) due to its high ecological validity, which is in line with recent reviews on the topic (Borgnis et al., 2022).

Subsequently, in order to overcome the existing limitations and develop on the potential provided by the latest Virtual Reality based technologies, the aim of this study was to obtain normative data for a new developed VR based neuropsychological test, the Ice Cream VR test, on a population of children between 8 and 16 years old. Ice Cream is a VR test designed to evaluate executive functions including Processing speed, Working memory, Planning, Learning, Cognitive flexibility, interference and Perseverations, and help clinicians complement the information included in the diagnosis and subsequent follow-up of any disorder that affects these parameters. Prior to the Ice-Cream test, one of the best examples of VR based tests for EF is the Jansari assessment of Executive Functions for Children (JEF-C) by Gilboa et al. (2019), a non-immersive computerized assessment of executive functions, which presented promising results for children and adolescents with acquired brain injury with a complex task that appeared to be both playful as well as sensitive and ecologically valid. Similarly, Ice Cream [like other VR Tests such as AULA (Iriarte et al., 2016) or AQUARIUM (Climent et al., 2021)] shows the advantage of being presented as a VR "game," thus facilitating the initial predisposal of children and adolescents to the evaluation. In previous studies, Iriarte et al. (2016) found that the game-like scenario provided by AULA VR-based neuropsychological test was reported as a motivational asset for children and adolescents when faced with the cognitive testing. According to Lumsden et al. (2016), careful application of gamification can provide a way to develop engaging and yet scientifically valid cognitive assessments. More recently, Ferreira-Brito et al. (2019) found that narrative context was the main used gamification feature used in video games used for cognitive assessment, as it has no association with player's performance, but instead helps contextualize and add meaning to the test's main activity, inspiring motivation and long-term willingness toward tasks that may be perceived as boring and repetitive in its non-gamified version. In this context, hence, it is important to highlight that although, *a priori*, the Ice Cream VR test may seem like a playful activity, it is a really intense cognitive exercise but initially, much better perceived and more stimulating for the subjects than the classic paper and pencil tests.

The following Method section will present a description of the normative sample and the Ice-Cream VR test variables and measures. Due to the complexity of the test, for the Results section we have moved beyond the mere description of normative data. Consequently, the Results section will provide a detailed statistical rationale of the results for the total sample, separate distributions by sex and age with associated normality and homoscedasticity analyses, a cluster analysis by age, an in-depth analysis of the validity and reliability of the scales, a confirmatory factor analysis that evidences the main variables measured by the Ice-Cream VR test and a detailed analysis of the test reliability and internal consistency. With this structure, the current study aims to both present normative groups for the general population for the Ice-Cream VR test as well as provide further understanding on the construct validity and scales contained in the test.

2. Methods

2.1. Participants

The normative sample comprised a total number of $n = 821$ participants (49% female), with an age range of 8 to 16 years old, recruited across nine different testing sites in Spain. Inclusion criteria required no neurological pathology, sensory alterations or other type of condition that may limit the use of the virtual reality devices necessary for the evaluation, and being native in Spanish as it was the main language for the assessment tool in this normative study. Table 1 shows the distribution by sex and age for the normative sample.

The target number of participants to be included in the study in order to ensure representativeness of the general population in Spain was done according to three criteria: age, gender and educational level. The target numbers were estimated according to the ratios obtained for these three criteria from the data of the census from the National Institute of Statistics in Spain for the year 2016 (the latest available up to date).

The sample size estimation was performed with the assistance of two psychometricians, according to practical feasibility criteria and considering the cost–benefit balance (Prieto-Valiente and Herranz, 2004). A minimum of 400 people whose sociodemographic characteristics were representative of the general Spanish population was recommended. Following a procedure recommended by the psychometricians involved in the study, as it was done previously in other normative studies (Iriarte et al., 2016, for example), no specific evaluations were previously performed to exclude children with potential psychiatric disorders or other neurodevelopmental disorders. The rationale for this was that, in order to ensure a recruitment from the general population as representative as possible, no disorder-specific exclusion criteria would be set; so that any potential prevalence of psychiatric or neurodevelopmental disorders in the normative sample would be a fair representation of that same prevalence in the general population.

TABLE 1 Sample distribution by age and sex.

Age	Sex	Total	Percentage
8	Female	34	2.74
8	Male	32	2.58
9	Female	56	4.52
9	Male	70	5.65
10	Female	63	5.08
10	Male	65	5.24
11	Female	45	3.63
11	Male	58	4.68
12	Female	48	3.87
12	Male	38	3.06
13	Female	37	2.98
13	Male	39	3.15
14	Female	53	4.27
14	Male	57	4.60
15	Female	49	3.95
15	Male	39	3.15
16	Female	15	1.21
16	Male	23	1.85

The sample size is 821.

The administration of the test was carried out by evaluators recruited by the company Giunti-Nesplora, developer of the test, trained for the use of the VR equipment and the administration of the Ice Cream VR test. Data collection was conducted in nine different cities across Spain in order to ensure geographical representativeness of the sample. Moreover, a questionnaire collecting socio-demographic data from participants (e.g., educational level, occupation, languages spoken, etc.) was administered.

Prior to the study, and in order to comply with ethical guidelines, signed informed consent forms were obtained from participants (only for those who were already 16 years old, according to the Spanish legislation) and from their parents or guardians (for the majority of participants under 16). The Ethical Committee approved the study and the data collection protocol for Research with Human Beings. The study was carried out in accordance with the Code of Ethics of the World Medical Association (Declaration of Helsinki) for experiments involving humans.

2.2. Measure

Nesplora Ice Cream is a test oriented to assess executive functions by simultaneously measuring learning, planning, attention, working memory, cognitive flexibility, processing speed, interference and perseverations. It was designed as a test to support the diagnosis and a measure of efficacy and follow up for treatments targeting learning and other cognitive problems. As the name suggests, the test takes place in a virtual ice cream shop where the testee must attend to a series of customers, while observing a number of rules or criteria, and serve them the ice creams they ask for.

The task is performed in an environment that simulates an ice cream shop. The testee is given a set of VR glasses with movement sensors that allow them to see and hear what happens in that VR environment, thus immersing the individual in the virtual ice cream shop environment. All task instructions are presented on an auditory basis. The perspective places the subject within the counter, oriented to the customers. Head movements are captured by the headset and the software updates the scene, giving the subject the impression of actually being in the virtual environment. The subject then begins by performing a usability task that will help them get familiarized with the environment and the task. It is understood that the cashier is the one telling the individual what to do (i.e., the testee listens to an audio speech with instructions). Here, they must complete the task by pressing a button when pointing to certain objects indicated by the cashier (i.e., the ice cream making machine, a paper basket, the recipe book, a phone and a clock).

Once the usability task is done, the voice of the cashier appears again saying that the boss will call to provide a series of rules or criteria that the testee must strictly adhere to when it comes to serving the customers, as follows: "*You'll be working at the ice cream shop for a while. Customers come in groups of four and you must serve them following your boss's orders. Call your boss and he'll tell you his priorities to serve customers. Click on the phone to call him.*" Then, the individual must point to the phone and push the button to make a call. The boss will explain the instructions "*First you have to serve the surf students. They come with a neoprene surf suit, and they leave the floor soaking wet. Then, the people in suits, who are from a nearby company and usually in a hurry. They carry an identification badge on their chests. Third, serve the volunteers who are cleaning the beach. They're wearing reflective vests. And within this order, always serve those who have a ticket first, as they have already paid for their ice cream. For example, if there are two people wearing suits, serve the one with the ticket first. If you do not remember your boss's priorities, you can call him on the phone whenever there aren't any customers in the shop.*"

After this, there will be a trial to test the different instructions set, the assignment of shifts according to what clothes clients wear and the different ice cream recipes. The training makes the participant fail in order to show them how to throw the wrong ice cream in the bin. The test registers every click as well as every response time and inter-click latencies between different events (i.e., every click made over the avatars of the customers, the buttons on the ice cream making machine, or other incorrect objects during this training trial). During the training the book is shown 4 times for the same amount of time so that all participants are exposed in the same way to be able to learn the recipes equally (see Figure 1).

Then, the actual test will start with the first group of four customers. With each group of customers (14 in total during the test), the test taker must:

(1) click on the individual customers in the right order (according to the instructions given by the boss) in order to set their order
(2) turn on the ice cream making machine.
(3) click on the individual customer who must be the first according to the established order,
(4) prepare the ice cream requested by each customer (ice cream #1, 2, 3 or 4 from the recipe book), if possible, without looking at the recipe book,
(5) give each ice cream to the right customer.

Overall, the performance in the Ice Cream Seller Test can be divided into three general tasks: (1) Planning: give the customers their turn according to previously specified rules or

FIGURE 1
Screenshot of Nesplora Ice Cream test, from the test taker perspective. Reproduced with permission from Giunti-Nesplora SL.

criteria, (2) Learning, part A (working memory): serve the ice creams to the customers while consulting the recipe book as little as possible, (3) Learning, part B (cognitive flexibility): serve the ice creams to the customers while consulting a new modified version of the recipe book as little as possible. In both parts A and B the test works with the same structure, environment and task. However, when the individual is halfway doing the test, the initially learnt series of ice creams changes, and a new set of ice cream variants need to be learnt to perform correctly in the second half of the test, thus intending to demand some cognitive flexibility from the subject. The planning and the preferences set to attend the customers are thus maintained, while the ice cream variant change implies to unlearn some cues and relearn a new different set of cues.

In terms of variables measured, the test captures different performance measures across the tasks. In the Planning task, the test collects information on processing speed and rule learning (correct customer order designation, correct ice cream delivery). In the second task (learning, part A, working memory), there are measures of processing speed and learning potential. In the third task (learning, part B, cognitive flexibility) measures on processing speed, interference, perseverations and switching are collected. Overall composite indices of planning, working memory and cognitive flexibility are provided at the end.

Thus, the indices provided in the report for planning include:

- Planning: the number of assignments of customers performed in the right order.
- Assignment time: time required to perform the assignment, regardless of being a correct or incorrect assignment.
- Cognitive load: a measure of how the increasing difficulty of the test affects planning. It is calculated by comparing errors of the first half versus the second half of the test.
- Fatigue: It is measured by comparing time to complete the second half of the test versus time to complete the first half.
- Prospective planning: ability to remember to turn on the ice cream making machine. The subject must do this at the beginning of each of the 14 rounds with customers.
- Coherence indicator: the subject performs the task as planned, even if it was planned wrong according to the given instructions.
- Impulsivity: when the subject clicks on the phone while there are customers in the shop.
- Incorrect assignments: the subject makes the right ice cream but gives it to the wrong customer. It is associated with poor attention or immediate memory.

Second, the indices provided in the report for working memory will include:

- Correct services: number of ice creams correctly sold.
- Consultations: number of times the subject had to consult the recipe book or call the boss.
- Net correct answers: Number of clients correctly assigned and served without any consultations. It indicates the subject's ability to process, encode and keep the information.
- Time of service: time required by the subject to perform each particular action.

Finally, the indices provided in the report for cognitive flexibility are:

- Interference: it measures to what extent the learning and practice with the first recipe books interferes with the learning of the new set of ice cream variants (i.e., the new recipe book). Here, the clinician must judge whether an outstanding performance in the second half of the test, with the new recipe book, reflects either

TABLE 2 Description of variable results for the total sample (n = 821).

	Mean	SD	Q1	Median	Q3	Max	Skew	Kurtosis
Number of shifts correctly assigned in Part 1	4.68	2.26	3	6	7	7	−0.51	−1.13
Number of shifts correctly assigned in Part 2	4.63	2.56	2	6	7	7	−0.64	−1.18
Learning potential to identify whether the customer wears a neoprene suit	132.01	98.56	18	146	242	242	−0.14	−1.63
Learning potential when it comes to assign the right order to the customers	160.82	137.27	0	189	288	341	0.04	−1.66
Number of total correct ice creams delivered correctly without looking at the recipe book on Part 1 rounds	24.01	5.74	23	26	28	28	−2.27	5.39
Number of correct #1 ice creams delivered without looking at the recipe book in Part 1 rounds.	10.58	2.45	10	12	12	12	−2.46	6.46
Number of correct #1 ice creams delivered without looking at the recipe book in Part 2.	8.27	2.24	7	9	10	10	−1.64	2.43
Number of correct #1 ice creams delivered without looking at the recipe book in Part 2.	21.09	6.23	18	23	26	28	−1.23	1.09
Learning potential in relation to making ice cream #1 correctly	114.50	59.86	74	138	164	164	−0.79	−0.89
Learning potential in terms of flexibility when making ice cream #4 in Part 2 (which was ice cream #1 in Part 1)	69.75	55.52	9	74	121	147	0.08	−1.48
Number of perseverations when making the ice creams in Part 2	1.32	1.82	0	1	2	16	2.22	8.00
Learning potential in terms of flexibility when making ice cream #1 in Part 2 (which is different from ice cream #1 in Part 1)	59.40	51.24	4	58	125	125	0.18	−1.62

The sample size is 821 and the minimum for each variable is 0.

cognitive flexibility or, on the contrary, reflects a new learning (if the performance in the first half with the first recipe book was poor).
- Switching: it refers to the ability to perform with the new recipe book. It takes into account the performance in the two last trials with the first recipe book, and the two first trials with the new recipe book.
- Perseverations: it indicates the number of wrong items of the second half of the test that would be correct in the first half (with the initial recipe book).

It is important to mention that the Ice Cream VR test produces more than 1867 variables with the information generated in the evaluation. Of all these variables, a total of 1,055 were selected for what will constitute the clinical report of the test to be used in the future with clinical samples. This selection has been based on clinical criteria and ease of interpretation. The rest of the variables may be used in the future either to prepare other types of reports or to complement the existing clinical report. Therefore, the results shown in this section correspond to the main variables that appear in the report, which were selected based on their expected clinical utility. Supplementary Tables 1, 2 show the main final variables used in the clinical report and their corresponding abbreviations.

3. Results

In this section we present the results of the test administration carried out in Spain on people aged between 8 and 16 years old for the obtention of normative data for the Ice Cream VR Test.

The variables taken for each of the subtests to determine the scales were as follows. These variables have been selected from the set of variables under psychological criteria and according to what is to be measured in each subtest, and these criteria were on the basis of the statistical procedures (i.e., cluster analyses and confirmatory factor analysis) presented, respectively, in subsections 3.3 and 3.6 of this Results section. The scales and variables they comprise are presented below.

Planning:

- Number of shifts correctly assigned in Part 1.
- Number of shifts correctly assigned in Part 2.
- Learning potential to identify whether the customer wears a neoprene suit or not, (measured at Round 13).
- Learning potential when it comes to assign the right order to the customers.

Learning:

- Number of total correct ice creams delivered correctly without looking at the recipe book on Part 1 rounds.
- Number of correct #1 ice creams delivered without looking at the recipe book in Part 1 rounds.
- Learning potential in relation to making ice cream #1 correctly.

Flexibility:

- Number of total correct ice creams delivered correctly without looking at the recipe book on Part 2 rounds.
- Number of correct #1 ice creams delivered without looking at the recipe book in Part 2.
- Number of perseverations when making the ice creams in Part 2.
- Learning potential in terms of flexibility when making ice cream #4 in Part 2 (which was ice cream #1 in Part 1).
- Learning potential in terms of flexibility when making ice cream #1 in Part 2 (which is different from ice cream #1 in Part 1).

3.1. Results for the total sample

Next, we describe the variables for the total sample. Secondly, the differences according to sex and age found in the normative sample are shown. Third, the normative groups obtained, and the homoscedasticity and normality analysis are described. Finally, the reliability of the Nesplora Ice Cream test scales, a confirmatory factor analysis, and test reliability and internal consistency will be presented.

Table 2 presents the overall results for the total sample.

TABLE 3 Descriptive data for each variable with respect to sex: male.

Variable	Mean	Std. dev	Median	Max	25th	75th	Skew	Kurtosis
Number of shifts correctly assigned in Part 1	4.74	2.27	6	7	3	7	−0.54	−1.12
Number of shifts correctly assigned in Part 2	4.73	2.52	6	7	2	7	−0.72	−1.04
Learning potential to identify whether the customer wears a neoprene suit	130.88	97.35	146	242	18	242	−0.13	−1.60
Learning potential when it comes to assign the right order to the customers	159.03	136.66	153	341	10	288	0.06	−1.66
Number of total correct ice creams delivered correctly without looking at the recipe book on Part 1 rounds	24.00	5.82	26	28	23	28	−2.14	4.63
Number of correct #1 ice creams delivered without looking at the recipe book in Part 1 rounds.	10.56	2.49	12	12	10	12	−2.38	5.81
Number of correct #1 ice creams delivered without looking at the recipe book in Part 2.	114.13	60.00	138	164	74	164	−0.78	−0.91
Number of correct #1 ice creams delivered without looking at the recipe book in Part 2.	21.19	5.96	23	28	18	26	−1.18	1.05
Learning potential in relation to making ice cream #1 correctly	8.36	2.11	9	10	7	10	−1.58	2.39
Learning potential in terms of flexibility when making ice cream #4 in Part 2 (which was ice cream #1 in Part 1)	1.42	1.98	1.	16	0	2	2.36	9.00
Number of perseverations when making the ice creams in Part 2	69.71	55.70	74	147	9	121	0.07	−1.50
Learning potential in terms of flexibility when making ice cream #1 in Part 2 (which is different from ice cream #1 in Part 1)	58.78	50.96	58	125	4	125	0.19	−1.61

The sample size is 421 and the minimum for each variable is 0.

As can be observed after studying the frequencies of the values obtained from the sample, most of the variables are distributed asymmetrically. Since the analysis of samples that do not have a normal distribution becomes a problem in common statistical parametric tests that assume normality in the data, specific procedures-methods that assume *de facto* that type of distribution have been used (Brown and Forsythe, 1974a), instead of attempting one of the following transformations: logarithmic, square root, or inverse. To test the normality of the sample according to sex, we tested whether or not the data set fits a normal distribution. For this purpose, a data Energy test was performed (Székely and Rizzo, 2017). Data energy is the value of a real function of distances between data in metric spaces. The name energy is derived from Newton's gravitational potential energy, which is also a function of distances between physical objects. One of the advantages of working with energy functions (energy statistics) is that even if the data are complex objects, such as functions or graphs, we can use their real-valued distances for inference. This type of test has been used in studies on multivariate normality obtaining high accuracy in the results. The direct connection between energy and mind/observations/data is a counterpart of the equivalence of energy and matter/mass in the equation: Albert Einstein's $E = mc^2$.

For this reason of asymmetry, the following section will show different results for gender and age groups, each of them followed by an analysis of normality and homoscedasticity.

3.2. Distribution by sex with associated normality and homoscedasticity analyses

Table 3 shows the descriptive results for the male participants of the normative sample ($n = 421$).

In order to verify normality for each variable considering sex, the non-parametric Anderson-Darling test was used (Marsaglia and Marsaglia, 2004). This test is a modification of the Kolmogorov–Smirnov test (Shapiro et al., 1968) where more weight is given to the tails. It uses a specific distribution to calculate the critical values. This has the advantage of allowing a more sensitive test and the disadvantage that critical values must be calculated for each distribution. The starting hypotheses are:

> *H0*: the data are from a normal distribution.
>
> *H1*: data are not from a normal distribution.

Applying an Anderson–Darling Test on the subset of data pertaining to the male sex for the selected variables (listed in Table 3) non-normality was obtained with a p-value under 0.00 (df = 12.19).

Separately, Table 4 shows the descriptive results for female participants of the normative sample ($n = 400$).

Similarly, an Anderson-Darling Test was applied on the subset of data belonging to the female sex for the selected variables (see Table 4) and non-normality was obtained with a p-value below 0.00 (df = 11.83).

The assumption of homogeneity of variances (homoscedasticity) considers that the variance does not vary for the different values of a variable belonging to different groups. That is, as a null hypothesis, it considers that the variance is equal between groups and as an alternative hypothesis that it is not.

As many of the variables follow an asymmetric distribution, we have chosen to use the Brown–Forsythe test (Brown and Forsythe, 1974b) whose centrality statistic is the median, which offers good robustness to many types of non-normal data while retaining good statistical power. This test makes it possible to test for equality of variance in 2 or more populations without the need for the size of the groups to always be the same. Table 5 shows the homoscedasticity results with respect to sex.

As can be seen in Table 5, the null hypothesis is accepted for all the variables presented, hence, the variance of all the variables is equal for male and female participants. As the null hypothesis is accepted for the variables of the planning, learning and flexibility subtests, the cluster analysis will not differentiate between women and men, implying that there is no need to present separate normative data groups based on gender.

TABLE 4 Descriptive data for each variable with respect to sex: female.

Variable	Mean	Std. Dev	Median	Max	25th	75th	Skew	Kurtosis
Number of shifts correctly assigned in Part 1	4.61	2.25	5	7	3	7	−0.47	−1.14
Number of shifts correctly assigned in Part 2	4.53	2.62	6	7	2	7	−0.56	−1.31
Learning potential to identify whether the customer wears a neoprene suit	133.21	99.92	146	242	32.25	242	−0.15	−1.67
Learning potential when it comes to assign the right order to the customers	162.71	138.07	189	341	0	288	0.02	−1.66
Number of total correct ice creams delivered correctly without looking at the recipe book on Part 1 rounds	24.01	5.66	26	28	23	28	−2.40	6.21
Number of correct #1 ice creams delivered without looking at the recipe book in Part 1 rounds.	10.60	2.40	12	12	10	12	−2.56	7.17
Number of correct #1 ice creams delivered without looking at the recipe book in Part 2.	114.88	59.77	151	164	74	164	−0.81	−0.87
Number of correct #1 ice creams delivered without looking at the recipe book in Part 2.	20.98	6.51	23	28	18	26	−1.24	1.03
Learning potential in relation to making ice cream #1 correctly	8.18	2.36	9	10	7	10	−1.65	2.25
Learning potential in terms of flexibility when making ice cream #4 in Part 2 (which was ice cream #1 in Part 1)	1.20	1.62	1	9	0	2	1.79	3.66
Number of perseverations when making the ice creams in Part 2	69.81	55.40	74	147	9	121	0.10	−1.47
Learning potential in terms of flexibility when making ice cream #1 in Part 2 (which is different from ice cream #1 in Part 1)	60.04	51.58	58	125	4	125	0.16	−1.64

The sample size is 400 and the minimum for each variable is 0.

TABLE 5 Homoscedasticity with respect to sex.

Variable	Brown–Forsythe Statistic	Denom *df*	*p*-value
Number of shifts correctly assigned in Part 1	0.743	817.305	0.389
Number of shifts correctly assigned in Part 2	1.264	812.422	0.261
Learning potential to identify whether the customer wears a neoprene suit	0.114	814.136	0.736
Learning potential when it comes to assign the right order to the customers	0.147	815.914	0.701
Number of total correct ice creams delivered correctly without looking at the recipe book on Part 1 rounds	0	818.511	0.985
Number of correct #1 ice creams delivered without looking at the recipe book in Part 1 rounds.	0.06	818.882	0.806
Learning potential in relation to making ice cream #1 correctly	0.033	817.163	0.857
Number of total correct ice creams delivered correctly without looking at the recipe book on Part 2 rounds	0.254	803.446	0.615
Number of correct #1 ice creams delivered without looking at the recipe book in Part 2	1.377	797.386	0.241
Number of perseverations when making the ice creams in Part 2	2.917	801.455	0.088
Learning potential in terms of flexibility when making ice cream #4 in Part 2 (which was ice cream #1 in Part 1)	0.001	817.276	0.98
Learning potential in terms of flexibility when making ice cream #1 in Part 2 (which is different from ice cream #1 in Part 1)	0.123	815.718	0.726

All variables have a "num df" = 1.

3.3. Cluster analysis by age

To determine the scales according to age, different clustering techniques were used ("hierarchical," "kmeans," "diana," "model," "pam," "clara," "agnes"). Testing with different techniques allows us to work with the technique that presents greater robustness and greater clarification of the groups according to the data we are working with. Between the ages of 8 and 16, three groups have been established for the scales according to age for the three subtests: planning (8–11 and 12–16), learning (8–9 and 10–16), and flexibility (8–11 and 12–16), as shown in Figures 2–4 (and associated Table 6). For planning, the division of 11 years old showed a high proximity of values (47 vs. 56), hence, it was decided to build a cluster between 8 and 11 years old and thus match the groups obtained for flexibility in a more consistent way. It can be seen that the two main dimensions generated explain more than 85% of the subjects in the sample.

3.4. Distribution by age with associated normality and homoscedasticity analyses

Data from 821 subjects were initially analyzed and 3 age groups were identified to obtain the scales (8–9, 10–11, 12–16). Table 7 shows the sample distribution according to these clustered age groups.

To check the normality for the normative groups, the same test has been used, an Energy Test, used in the contrast of the normality of the sample according to sex. Also in this case we will test whether or not the data set conforms to a normal distribution.

3.4.1. Planning

Normality for Planning subtest for the under 17 age scale is shown below. Table 8 shows the data for the 8 to 11 years old Planning cluster. No variable shows a normal distribution.

Table 9 shows the data for the 12 to 16 years old Planning cluster. No variable shows a normal distribution.

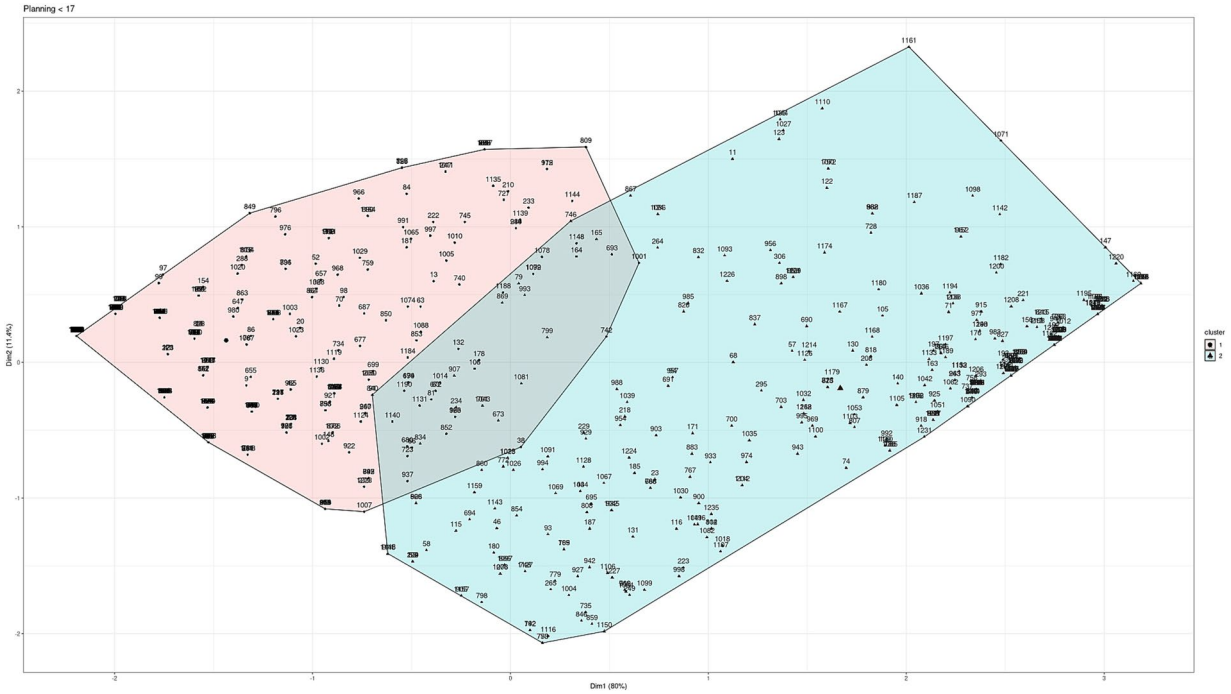

FIGURE 2
Cluster analysis for planning.

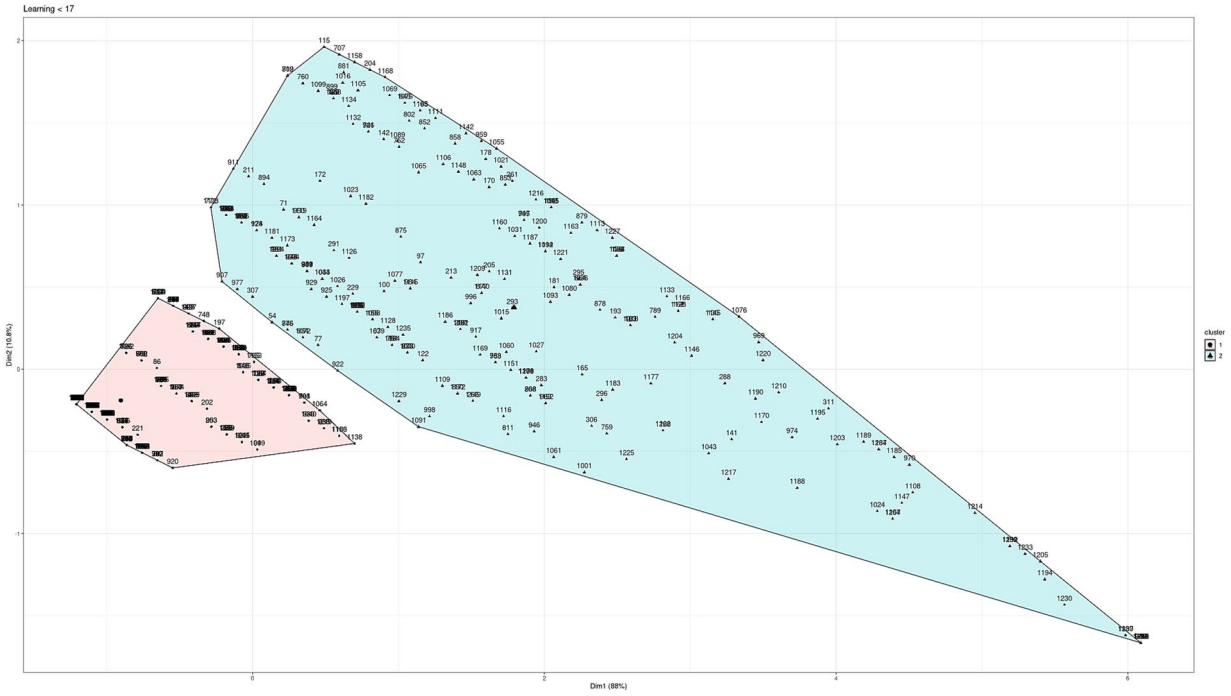

FIGURE 3
Cluster analysis for learning.

3.4.2. Learning

Normality for Learning subtest for the under 17 age scale is shown below. Table 10 shows the data for the 8 to 9 years old Learning cluster. No variable shows a normal distribution.

Table 11 shows the data for the 10 to 16 years old Learning cluster. No variable shows a normal distribution.

3.4.3. Flexibility

Finally, normality for Flexibility subtest for the under 17 age scale is shown below. Table 12 shows the data for the 8 to 11 years old cluster. No variable shows a normal distribution.

Table 13 shows the data for the 12 to 16 years old Planning cluster. No variable shows a normal distribution.

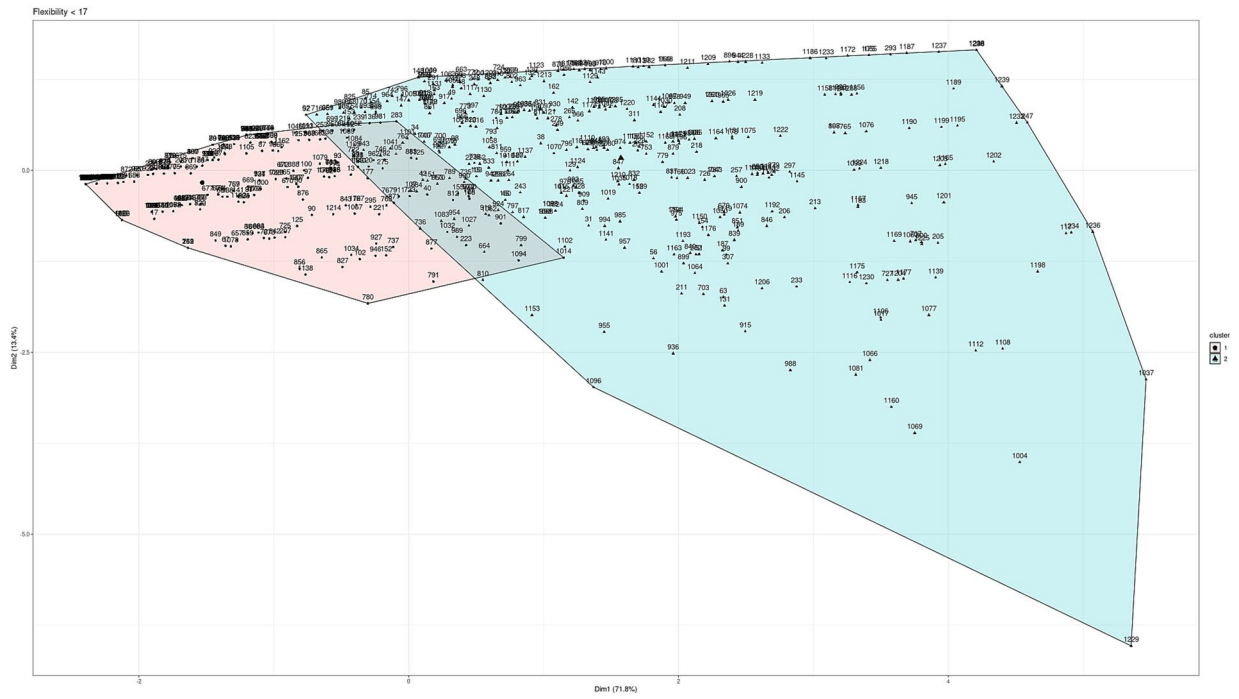

FIGURE 4
Cluster analysis for cognitive flexibility.

TABLE 6 Clustering with respect to age (<17) and subtest: planning, learning, and cognitive flexibility.

Scale	Age									
Planning	Age	8	9	10	11	12	13	14	15	16
		10	37	47	**56**	**52**	**52**	**87**	**70**	**30**
		56	**89**	**81**	47	34	24	23	18	8
Learning	Age	8	9	10	11	12	13	14	15	16
		21	51	**71**	**68**	**62**	**56**	**100**	**80**	**37**
		45	**75**	57	35	24	20	10	8	1
Cognitive flexibility	Age	8	9	10	11	12	13	14	15	16
		9	35	50	44	**52**	**55**	**81**	**63**	**27**
		57	**91**	**78**	**59**	34	21	29	25	11

Bold values show the highest value.

TABLE 7 Sample distribution by clustered age groups.

Years	Sex	Total	Percentage per age cluster
08–09	Female	90	46.88
08–09	Male	102	53.12
10–11	Female	108	46.75
10–11	Male	123	53.25
12–16	Female	202	50.75
12–16	Male	196	49.25

The sample size is 821.

3.5. Validity and reliability of the scales

Validity is the result of a process of gathering empirical evidence based on theoretical assumptions that, in sum, allow us to make an evaluative judgment that affirms the relevance and sufficiency of the interpretations based on the results of a test. This judgment depends not only on the items of the test, but also on the sample on which the test is carried out, and on the context of application.

Construct validity is the unifying concept that integrates content and criterion validity considerations into a common framework for testing hypotheses about theoretically relevant relationships (Messick, 1980). The ultimate goal of validation is explanation and understanding, and therefore, this leads us to consider that all validation is construct validation (Cronbach, 1951). The most widely used methodological procedures for obtaining data on the validity of psychological constructs have been factor analysis and the multitrait-multimethod matrix. Both systems are respective indicators of the so-called "factorial validity" and "convergent-discriminant validity."

For this study, convergent-discriminant validity will not be addressed because all the variables are part of one of the constructs and there is also a relationship between them. The basic underlying

TABLE 8 Planning variable with respect to age 8–11: descriptives and normality tests (Anderson-Darling test and multivariate normality *E*-statistic test).

Variable	Mean	Std. Dev	Median	Max	25th	75th	Skew	Kurtosis	df (A–D test)	df (*E*-test)
Number of shifts correctly assigned in Part 1	3.78	2.27	3	7	2	6	0.05	−1.29	11.5270*	13.75*
Number of shifts correctly assigned in Part 2	3.72	2.61	4	7	1	6	−0.07	−1.56	19.0935*	
Learning potential to identify whether the customer wears a neoprene suit	96.73	94.31	65	242	5	192	0.43	−1.40	26.5873*	
Learning potential when it comes to assign the right order to the customers	105.65	124.36	24	341	0	236	0.71	−1.13	38.4602*	

The sample size is 423 and the minimum of each variable is 0.
*All variables show "NOT normality" with a $p < 0.001$.

TABLE 9 Planning variable with respect to age 12–16: descriptives and normality tests (Anderson-Darling test and multivariate normality *E*-statistic test).

Variable	Mean	Std. dev	Median	Max	25th	75th	Skew	Kurtosis	df (A–D test)	df (*E*-test)
Number of shifts correctly assigned in Part 1	5.62	1.83	6	7	5	7	−1.25	0.42	38.7009*	39.31*
Number of shifts correctly assigned in Part 2	5.60	2.12	7	7	5	7	−1.51	0.91	52.4739*	
Learning potential to identify whether the customer wears a neoprene suit	169.52	88.72	242	242	102	242	−0.79	−0.91	38.3730*	
Learning potential when it comes to assign the right order to the customers	219.46	125.67	288	341	120	341	−0.65	−1.07	24.5681*	

The sample size is 398 and the minimum of each variable is 0.
*All variables show "NOT normality" with a $p < 0.001$.

TABLE 10 Learning variable with respect to age 8–9: descriptives and normality tests (Anderson-Darling test and multivariate normality *E*-statistic test).

Variable	Mean	Std. dev	Median	Max	25th	75th	Skew	Kurtosis	df (A–D test)	df (*E*-test)
Number of total correct ice creams delivered correctly without looking at the recipe book on Part 1 rounds	19.29	7.88	22	28	16	25	−1.09	0.24	8.0861*	7.15*
Number of correct #1 ice creams delivered without looking at the recipe book in Part 1 rounds	8.64	3.47	10	12	7	11	−1.19	0.45	10.4668*	
Learning potential in relation to making ice cream #1 correctly	71.95	61.42	74	164	9	114	0.25	−1.41	8.1849*	

The sample size is 192 and the minimum of each variable is 0.
*All variables show "NOT normality" with a $p < 0.001$.

TABLE 11 Learning variable with respect to age 10–16: descriptives and normality tests (Anderson-Darling test and multivariate normality *E*-statistic test).

Variable	Mean	Std. dev	Median	Max	25th	75th	Skew	Kurtosis	df (A–D test)	df (*E*-test)
Number of total correct ice creams delivered correctly without looking at the recipe book on Part 1 rounds	25.45	3.91	27	28	25	28	−2.80	10.30	63.3906*	107.51*
Number of correct #1 ice creams delivered without looking at the recipe book in Part 1 rounds	11.17	1.62	12	12	11	12	−3.08	12.69	96.7260*	
Learning potential in relation to making ice cream #1 correctly	127.48	53.00	164	164	114	164	−1.22	0.12	77.8759*	

The sample size is 629 and the minimum of each variable is 0.
*All variables show "NOT normality" with a $p < 0.001$.

assumptions of factor analysis are more conceptual than statistical. From this point of view, the assumptions of normality and homoscedasticity can be ignored, being aware that their non-compliance produces a decrease in the observed correlations. In reality, normality is only necessary when a statistical test is applied to the significance of the factors; however, such tests are rarely used. In fact, some degree of multicollinearity is desirable. If visual inspection reveals that there is not a substantial number of correlations greater than 0.30 then the factor analysis is probably inappropriate (Cronbach, 1988). The following Figure 5 shows that this is not the case.

The presence of multicollinearity can be identified by evaluating the determinant of the correlation matrix of the variables entered into the study: A low determinant, i.e., close to 0, indicates high multicollinearity between the variables. Barlett's test of sphericity is obtained by a transformation of the determinant of the correlation matrix and compares, under the hypothesis of multivariate normality, whether the correlation matrix of the p variables observed is the identity. If a correlation matrix is the identity, it means that the intercorrelations between the variables are zero. If the null hypothesis is confirmed, the variables are not intercorrelated. Conversely, if the test statistic shows large values (or a determinant close to zero) the null hypothesis is rejected with some degree of significance. If the null hypothesis is accepted, the variables are not intercorrelated and the application of a factor analysis should be reconsidered. These results (Barlett Statistic = 1147.46, df = 66, $p < 0.000$) implied the existence of correlated variables and, therefore, indicate a factor analysis can be applied.

TABLE 12 Flexibility variable with respect to age 8–11: descriptives and normality tests (Anderson-Darling test and multivariate normality *E*-statistic test).

Variable	Mean	Std. dev	Median	Max	25th	75th	Skew	Kurtosis	df (A–D test)	df (*E*-test)
Number of total correct ice creams delivered correctly without looking at the recipe book on Part 2 rounds	18.70	6.58	20	28	15	23.50	−0.84	0.11	7.6019*	12.71*
Number of correct #1 ice creams delivered without looking at the recipe book in Part 2	7.58	2.49	8	10	6	10	−1.20	0.90	18.9877*	
Number of perseverations when making the ice creams in Part 2	1.77	2.10	1	16	0	3	1.99	6.43	23.5434*	
Learning potential in terms of flexibility when making ice cream #4 in Part 2 (which was ice cream #1 in Part 1)	47.69	50.46	36	147	0	97	0.71	−0.87	24.7935*	
Learning potential in terms of flexibility when making ice cream #1 in Part 2 (which is different from ice cream #1 in Part 1)	40.74	46.50	19	125	0	77	0.83	−0.83	34.4003*	

The sample size is 423 and the minimum of each variable is 0.
*All variables show "NOT normality" with a $p < 0.001$.

TABLE 13 Flexibility variable with respect to age 12–16: descriptives and normality tests (Anderson-Darling test and multivariate normality *E*-statistic test).

Variable	Mean	Std. dev	Median	Max	25th	75th	Skew	Kurtosis	df (A–D test)	df (*E*-test)
Number of total correct ice creams delivered correctly without looking at the recipe book on Part 2 rounds	23.62	4.65	25	28	22	27	−1.93	4.67	20.9735*	38.97*
Number of correct #1 ice creams delivered without looking at the recipe book in Part 2.	9.01	1.64	10	10	9	10	−2.37	6.59	47.2729*	
Number of perseverations when making the ice creams in Part 2	0.83	1.30	0	6	0	1	1.89	3.44	47.2739*	
Learning potential in terms of flexibility when making ice cream #4 in Part 2 (which was ice cream #1 in Part 1)	93.20	50.90	97	147	54	147	−0.55	−1.00	18.7337*	
Learning potential in terms of flexibility when making ice cream #1 in Part 2 (which is different from ice cream #1 in Part 1)	79.23	48.57	98	125	31	125	−0.45	−1.40	30.7827*	

The sample size is 398 and the minimum of each variable is 0.
*All variables show "NOT normality" with a $p < 0.001$.

3.6. Factor analysis

As a next step to confirm the feasibility of performing a factor analysis, a sample adequacy analysis was performed. Sample adequacy measures whether the variables share common factors. In short, if there are a large number of non-zero partial correlation coefficients, it is interpreted that the hypotheses of the factor model are not compatible with the data (Shrestha, 2021). One way to quantify this fact is with Kaiser–Meyer–Olkin's KMO Sample Mean of Adequacy. A KMO value of less than 0.5 indicates that it is not acceptable to carry out a factor analysis with the data provided. In this case, as shown in Table 14, all values obtained were higher than 0.75 (KMO = 0.82).

Therefore, it is acceptable to perform a factor analysis. The results of the factor analysis were as shown below in Table 15.

The factor loadings matrix plays an important role in interpreting the meaning of the factors. When the factors are orthogonal they quantify the degree and type of the relationship between the factors and the original variables. In practice, factor extraction methods may not provide adequate factor loading matrices for interpretation. In order to tackle this problem, there are factor rotation procedures which, starting from the initial solution, search for factors whose factor loadings matrix makes them more easily interpretable. Of the three procedures used: orthogonal, varimax and promax, it is the promax rotation procedure that has allowed a better interpretation of the loading of the variables in the factors. The promax procedure alters the results of an orthogonal rotation to create a solution with factor loadings as close as possible to the ideal structure. The ideal structure is obtained by raising to a power (between 2 and 4) the factorial loadings obtained in an orthogonal rotation. The higher the power, the more oblique the solution obtained.

The Factorial Analysis carried out explains 72.4% of the variance. Separately, the percentage of variance that has not been explained by the three factors ('planning', 'learning', 'flexibility') is shown in Supplementary Table 3.

3.7. Test reliability and internal consistency

The Ice Cream test presents certain special characteristics that, in some respects, bring it closer to an "adaptive" type of test, since the time of presentation between stimuli, the appearance of distractors, their frequency, etc. depend on the sequence of responses given by the person. In many respects it could be said that each subject may actually be responding to a "different" test. This, which considerably improves the ecological validity of the test and its real efficacy, makes it difficult, however, to estimate the reliability of all the measures scaled, at least in what is traditionally understood as the reliability coefficient of a test. This is the reason why it is only possible to estimate the classical reliability of scales. Nevertheless, if these are reliable, in turn, they also guarantee the reliability of the rest of the aspects scaled. It should also be clarified that aspects such as standard deviations,

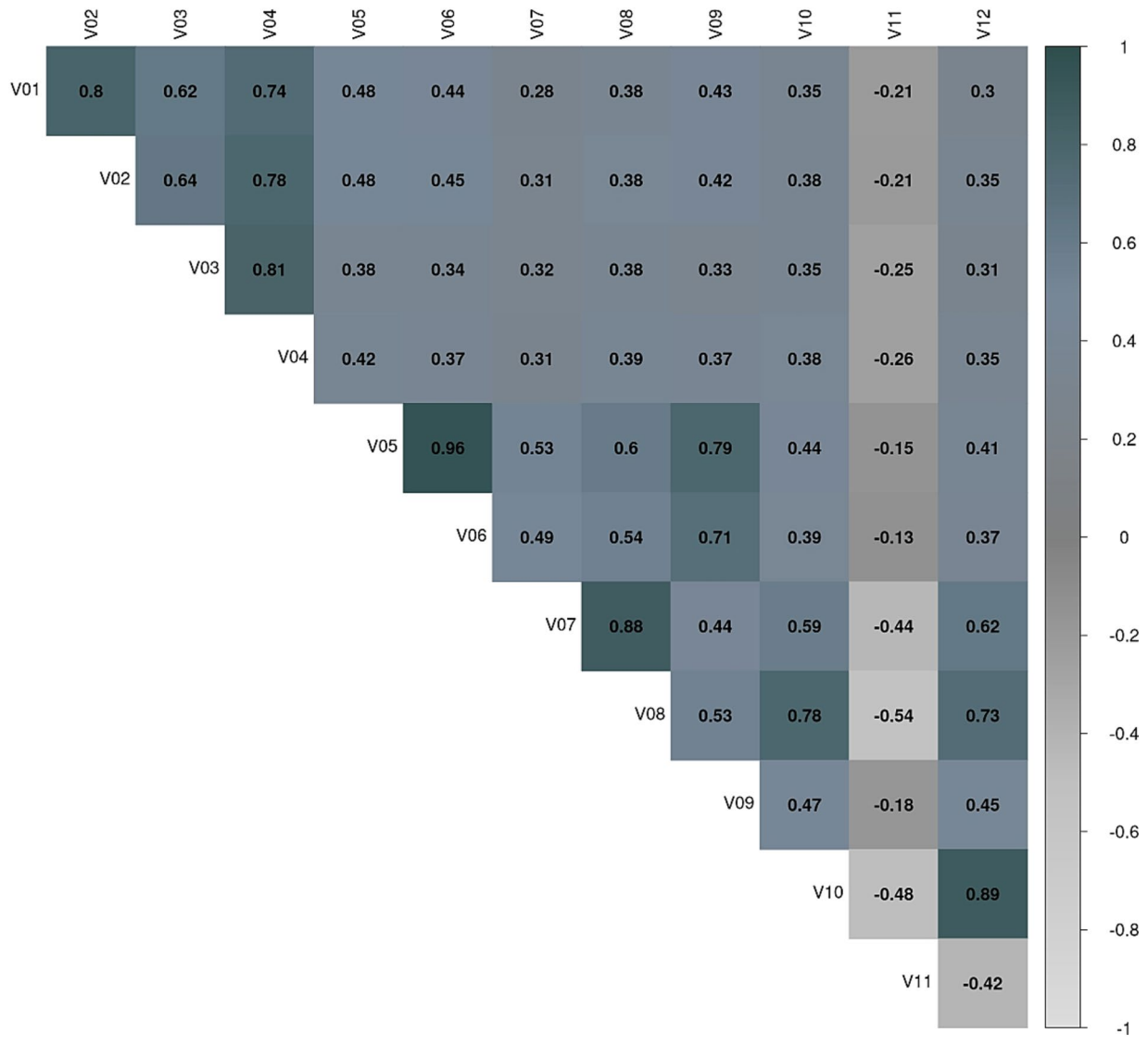

FIGURE 5
Ice Cream VR test. Variable correlation matrix. V01: Number of shifts correctly assigned in Part 1. V02: Number of shifts correctly assigned in Part 2. V03: Learning potential to identify whether the customer wears a neoprene suit or not, (measured at Round 13). V04: Learning potential when it comes to assign the right order to the customers. V05: s1.h.score.n. V06: Number of correct #1 ice creams delivered without looking at the recipe book in Part 1 rounds. V07: Number of correct #1 ice creams delivered without looking at the recipe book in Part 2. V08: Number of total correct ice creams delivered correctly without looking at the recipe book on Part 2 rounds. V09: Learning potential in relation to making ice cream #1 correctly. V10: Learning potential in terms of flexibility when making ice cream #4 in Part 2 (which was ice cream #1 in Part 1). V11: Number of perseverations when making the ice creams in Part 2. V12: Learning potential in terms of flexibility when making ice cream #1 in Part 2 (which is different from ice cream #1 in Part 1).

reaction times, etc., which can be very useful for the diagnosis and classification of adults, do not support, strictly speaking, the concept of reliability coefficient.

To determine the absence of errors in the measurement of a test, or the precision of its measurement, that is, its reliability, Cronbach's alpha will be used. This is the degree to which all test items co-vary with each other. Cronbach's alpha is not a usual statistic, so it is not accompanied by any *p*-value that allows us to reject the hypothesis of reliability in the scale, but the alpha is accompanied by its corresponding 95% confidence interval. However, the closer it is to its maximum value, 1, the greater the reliability of the scale. Furthermore, in certain contexts and by tacit agreement, it is considered that alpha values greater than 0.7 or 0.8 (depending on the source) are sufficient to guarantee the reliability of the scale. An alternative method for reliability estimation is McDonald's omega which works with factor loadings that are the weighted sum of the standardized variables, a transformation that makes the calculations more stable (Ventura Leon and Caycho-Rodríguez, 2017) and assumes that the variance between items can be different. The difficulty index and discrimination index have also been calculated. These indices become indicators of the quality of a test to the extent that they are within acceptable ranges. The difficulty index measures the difficulty of an item, and the discrimination index is the power of an item to distinguish between subjects who perform the task well and those who do not. Note that it is common to find in the

TABLE 14 Sample adequacy means.

Variable	KMO
Number of shifts correctly assigned in Part 1	0.89
Number of shifts correctly assigned in Part 2	0.88
Learning potential to identify whether the customer wears a neoprene suit	0.85
Learning potential when it comes to assign the right order to the customers	0.83
Number of total correct ice creams delivered correctly without looking at the recipe book on Part 1 rounds	0.75
Number of correct #1 ice creams delivered without looking at the recipe book in Part 1 rounds.	0.77
Number of correct #1 ice creams delivered without looking at the recipe book in Part 2.	0.76
Number of total correct ice creams delivered correctly without looking at the recipe book on Part 2 rounds	0.78
Learning potential in relation to making ice cream #1 correctly	0.90
Learning potential in terms of flexibility when making ice cream #4 in Part 2 (which was ice cream #1 in Part 1)	0.75
Number of perseverations when making the ice creams in Part 2	0.91
Learning potential in terms of flexibility when making ice cream #1 in Part 2 (which is different from ice cream #1 in Part 1)	0.80

Kaiser–Meyer–Olkin.

TABLE 15 Factor analysis results.

Variable	Planning	Learning	Flexibility
Number of shifts correctly assigned in Part 1	**0.787**	0.108	−0.051
Number of shifts correctly assigned in Part 2	**0.823**	0.094	−0.051
Learning potential to identify whether the customer wears a neoprene suit	**0.846**	−0.066	0.022
Learning potential when it comes to assign the right order to the customers	**0.993**	−0.072	−0.029
Number of total correct ice creams delivered correctly without looking at the recipe book on Part 1 rounds	0.004	**0.958**	0.073
Number of correct #1 ice creams delivered without looking at the recipe book in Part 1 rounds.	−0.02	**0.955**	0.026
Number of correct #1 ice creams delivered without looking at the recipe book in Part 2.	−0.112	0.112	**0.871**
Number of total correct ice creams delivered correctly without looking at the recipe book on Part 2 rounds	−0.059	0.104	**0.968**
Learning potential in relation to making ice cream #1 correctly	0.048	**0.689**	0.137
Learning potential in terms of flexibility when making ice cream #4 in Part 2 (which was ice cream #1 in Part 1)	0.082	−0.016	**0.761**
Number of perseverations when making the ice creams in Part 2	−0.092	0.24	**−0.638**
Learning potential in terms of flexibility when making ice cream #1 in Part 2 (which is different from ice cream #1 in Part 1)	0.053	−0.006	**0.724**

Bold values show the highest weight for each variable.

literature the "difficulty index" or "degree of difficulty" as the ratio between the number of correct answers and the maximum possible score. According to this definition, the higher the index, the higher the number of correct answers and therefore the easier the question, which is the opposite of difficulty. From a purely semantic point of view, it is more accurate to call the ratio between the number of correct answers and the total number of examinees an ease index, as explained by García-Cueto and Fidalgo (2005). Data for Test Reliability and Internal Consistency are provided in Supplementary Table 4.

4. Discussion

The present study has presented the first data that were obtained for Nesplora Ice Cream as a new ecological, virtual reality-based test for the obtention of a comprehensive profile of executive functions. More specifically, the data presented here are the first set of normative data collected for children between 8 and 16 years old, thus becoming, to our knowledge, in the first tool of its kind (a VR-based neuropsychological test for executive functions) in providing normative data of this magnitude for this age range (i.e., children and adolescents).

Among the extensive number of variables potentially produced by the test, the current normative study has tried to show the main core variables measured by the test. As a consequence, the statistical procedures leading to a confirmatory factor analysis have reduced the existing measures into 12 main core measures that divide precisely into 3 factors, namely Planning (4 measures), Learning (3 measures) and Cognitive Flexibility (5 measures). These three factors explain more than 72% of the variance. Cluster analyses carried out have also shown that the recommendation for the establishment of two differentiated age groups for Planning and Cognitive Flexibility (Group 1: 8 to 11 years-old; group 2: 12 to 16 years-old), and for Learning (Group 1: 8 to 9 years-old; group 2: 10 to 16 years-old) give clues on the milestones for development of executive functions in these stages of development.

Additionally, cluster analyses by gender have shown no statistically significant differences between boys and girls, which makes it unnecessary to establish separate normative groups by gender. Moreover, reliability and internal consistency data are presented, and specific ceiling and floor effects detected per each scale x age-group combination have been reported.

Despite the limitations of the current normative study (focused on population from Spain, and thus requiring as a priority for immediate future research a cross-cultural validation that allows its administration and clinical use in different international settings), the Nesplora Ice Cream VR test implies a clear hamper of ecological

validity as described by Marcotte et al. (2010). As pointed out by Diaz-Orueta et al. (2022), VR-based tests like this (1) overcome the limitations of traditional sterile, distractor-free testing environments that do not capture real-life environmental demands, allowing a more accurate prediction of an individual's level of function in real-life settings; (2) allow the monitoring of testee's behavior in a more continuous way, increasing the sample of behavior usually captured by traditional standardized neuropsychological tests; and (3) provide more clarity to the nature of specific cognitive constructs measured, which *per se* is an innovation in the area of executive functions tests, by properly delineating the boundaries between planning, learning and cognitive flexibility measures. Separately, since the focus on the 8 to 16 years old group cannot provide a full picture on the trajectories of EF development, additional studies would be required with a more detailed focus on the use of the test to uncover the developmental trajectories of EF across the lifespan, which would require a comparison between different cohorts that falls beyond the scope of the current study. Moreover, the statistical procedures followed in the study (i.e., cluster analysis and confirmatory factor analysis) mainly focus on a construct validity approach, and further convergent validity studies -as well as studies with specific clinical populations -would be desirable to prove further the added value of this test versus traditional EF measures.

In relation to previous attempts to improve ecological validity, the most reliable example of an executive function test aiming for accurately predict behavior based on its results is the Behavioral Assessment of the Dysexecutive Syndrome (BADS; Wilson et al., 1996) for evaluation of executive functions, and the Naturalistic Action Test (NAT; Giovannetti et al., 2002) for the assessment of level of independent functioning. However, developments in the area of VR, subject to adequate quality, allow both clinicians and researchers to administer ecologically relevant stimuli placed in a meaningful and familiar context and, as a result, they can measure responses and behaviors in a more comprehensive way (provided visual and physical characteristics of items, avatars and characters are of high quality and realistic). Additionally, as previously pointed out by Diaz-Orueta et al. (2022), VR technology allows tester-control over stimuli, distractors and other variables, and any or all of these factors can be adjusted depending on the response features of the individual undergoing assessment – thereby allowing more personalized assessment.

In summary, this study, despite the constraints and the need for cross-cultural validation with additional, international community-based and clinical samples, constitutes, to our best knowledge, the first Virtual Reality based neuropsychological test that provides normative data for the age group of 8 to 16 years old that measures and distinguishes in a meaningful, ecological way between planning, learning and cognitive flexibility processes. Future additional research is needed to ensure that these measures allow reliable and accurate predictions that extend the application of these types of tools to early detection of executive syndromes and subsequent appropriate treatment planning and accurate prediction of behavioral outcomes in different clinical settings with different conditions affecting executive functioning.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The studies involving humans were approved by Ethics Committee related to Research with Human Beings from the University of the Basque Country (UPV-EHU), Spain. The studies were conducted in accordance with the local legislation and institutional requirements. Written informed consent for participation in this study was provided by the participants' legal guardians/next of kin.

Author contributions

MF, GC, and UD-O conceptualized the study and wrote the first draft. MF conducted the first literature review, and UD-O completed it. UD-O described the measure used and MS-C completed it. MS-C worked on the recruitment, data collection and ethical issues of the study. FR-O produced all the statistical analysis, with collaboration from MF, GC, and UD-O. MF and UD-O wrote the discussion and refined the final draft. All authors contributed to the article and approved the submitted version.

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Conflict of interest

FR-O, MS-C, and GC work in the R+D+i Department of Giunti-Nesplora, developers and editors of the commercial version of the Ice Cream test. MF and UD-O are collaborators in the development of validation studies of the tests developed by Giunti-Nesplora, but have neither any commercial relationship nor receive any economic contribution as a result of this collaboration.

Publisher's note

Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpsyg.2023.1196964/full#supplementary-material

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Brief report: noise reduction in preschool from a self-regulated learning perspective—implementation of a game-based voice regulation training program

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An 8-week voice regulation training program (VRTP) incorporating everyday activities was implemented in an experimental preschool classroom (EG; $n = 34$), which was compared with a control preschool classroom (CG; $n = 31$). The VRTP includes songs, games, and conversations aiming to raise children's awareness of noise levels and teach voice modulation skills. Grounded in the theoretical framework of self-regulated learning, the study's objectives were to evaluate the impact of the VRTP on noise levels, children's self-regulation, and pre-literacy skills. Noise levels were assessed weekly using an electronic noise meter before and during the program. The EG preschoolers demonstrated modest but significant improvements over their pre-VRTP levels of voice modulation, behavioral and emotional self-regulated learning, and pre-literacy skills, in contrast with the CG children. The findings provide evidence that young children's self-regulation may be enhanced in preschool, challenging the field of developmental–educational psychology to consider self-regulated learning during early childhood.

KEYWORDS

psychological processes, self-regulated learning (SRL), preschool, behavior regulation, experiment, voice modulation, game-based intervention, language skills

1. Introduction

Vygotsky (1978) theory of learning presents a social and language-based approach to learning aimed at enhancing students' experiences as active speakers and listeners. Furthermore, Vygotsky emphasized that in order to internalize processes, young children express their self-talk out loud (Vygotsky, 1978). However, although children's learning relies on verbal communication, multiple children speaking simultaneously in the environment can cause an increase in speech volume in response to background noise (e.g., the Lombard effect; McKellin et al., 2011). Although we may expect a constant buzz in early-years classrooms when children are engaged in deep and meaningful learning, even through play, when this noise exceeds certain levels, it can hamper learning (Persson Waye and Karlberg, 2021). Within preschool settings, noise levels may exceed

the recommended 50 dB (Heft, 2013), ranging from 58 to 72 dB (Shield and Dockrell, 2004), causing highly impaired hearing. Excessive noise levels interfere with auditory processing, memory, and attention, creating annoyance and motivational deficits (Maxwell and Evans, 2000). Very loud noise can disrupt children's learning, particularly given their limited linguistic resources, as the speech of conversational partners may become noise for unintended secondary audiences (McKellin et al., 2011; Hotchkin and Parks, 2013). Under a developmentally realistic perspective on the issue of noise in preschool classrooms, investment in decreasing noise levels should be considered, as these children (ages 3–6 years) are at a critical stage in acquiring the linguistic and social–emotional development required for formal schooling (Education Ministry, 2010; Office of Head Start, 2010). For example, children's vocabulary knowledge and phonological awareness may be mastered during the preschool years and serve as the foundation for reading comprehension in school and self-regulation (Anglin et al., 1993; Vallotton and Ayoub, 2011; Sala et al., 2014). *Vocabulary* refers to knowledge of words and their definitions. *Phonological awareness* is a term used to refer to the ability to identify and compare sounds; for example, to select a word that starts with a certain sound from among several words or to compare the sound with other sounds or different words (Education Ministry, 2007). Vocabulary and phonological awareness comprise pre-literacy skills.

Given that speaking is a behavior, high noise levels constitute a behavioral issue. Therefore, behavioral regulation—the ability to control and produce situationally appropriate actions and behaviors—is needed to reduce noise (Barbosa et al., 2022). Voice modulation interventions may be applied to control and modify inappropriate speech, speech frequency and duration, and voice intensity (Bronson, 2000; Fonagy and Target, 2002; Lee, 2005). Modifying noise levels becomes critical when the acoustic features of the classroom structure are ineffective in reducing noise (Christidou et al., 2015). Previous research investigating methods to reduce noise in the classroom have explored how the classroom's physical structure can affect noise levels. These interventions typically involve actions such as fitting sound absorbers, modifying floor carpets, and equipping chairs with noise-reducing covers (Evans, 2006; Persson Waye and Karlberg, 2021). For example, in their intervention study, Persson Waye and Karlberg (2021) changed the physical structure of seven preschools in Sweden (e.g., by changing floor mats to plastic mats). Using an electronic device that measures sound, they found slightly decreased sound levels in meal/craft- and playrooms. In investigating the voice regulation training program (VRTP), we were interested in identifying a noise reduction method targeting children's behavior rather than modifications to the classroom infrastructure.

The VRTP was designed to enhance psychological processes of the self-regulated learning (SRL) components of monitoring and controlling noise using age-appropriate game-like activities and circle games (Diamond et al., 2007; Barnett et al., 2008; Tominey and McClelland, 2011; Wijns et al., 2021). Given that SRL emerged from work on cognitive engagement in young adults (Corno and Mandinach, 1983; Winne and Hadwin, 1998; Panadero, 2017), applying SRL with young children from a developmental and educational perspective constitutes an innovation (Perry, 2019). SRL occurs in flexible and recursive stages as loosely sequenced cyclical feedback loops between monitoring and adjusting of emotions, behaviors, and cognitions as learners acquire knowledge or skills directed at achieving learning goals during studying or educational games (Zimmerman, 2000; Pintrich, 2004; Ben-Eliyahu, 2019; Compagnoni et al., 2019). *Cognitive SRL* (CSRL) refers to processes and strategies for monitoring and changing cognitions related to learning (e.g., information and memory processing). For example, a teacher who repeats letter names is applying and modeling rehearsal strategies. In preschool children, current work suggests that such learning strategies can be improved through interventions (Dörr and Perels, 2019; Wijns et al., 2021).

Emotional SRL (ESRL) refers to one's experiences, expression, and adjustment of emotions during learning (Ben-Eliyahu and Linnenbrink-Garcia, 2013). The most prominently studied forms of emotion regulation include *reappraisal* (thinking about the situation from another perspective) and *suppression* (not expressing emotion; Gross and John, 2003). These forms of ESRL have been found to shape emotions and the use of learning strategies (Ben-Eliyahu and Linnenbrink-Garcia, 2013, 2015). By age 5, children can recognize emotions, with marked improvements as they grow (Widen and Russell, 2013) and use autonomous strategies such as reappraisal; however, until age 5, preschoolers develop and regulate emotions with adult help (Sala et al., 2014).

Behavioral SRL (BSRL) refers to monitoring and changing of behaviors to achieve learning goals such as writing and talking. Regulation is maintained through self-management, environmental structuring, and knowledge about performing actions and behaviors (Zimmerman, 2000). BSRL is the first requirement when children enter school. They need to restrain or modulate many behaviors and their intensity, such as lowering their voices when working in groups or controlling impulsive behaviors (Lee, 2005; Savina, 2021). BSRL may manifest in several ways depending on age appropriateness: by planning where and what to learn; by initiating or stopping behavior (e.g., sitting still); by changing the intensity, frequency, and duration of actions; or by behaving appropriately in the absence of external monitoring (Thompson, 1991; Bronson, 2000; Zimmerman, 2000; Fonagy and Target, 2002; Berger et al., 2008).

Most SRL processes (e.g., working memory and attention) develop more or less in parallel, reaching maturity during adolescence (Pintrich and Zusho, 2002; Bryce et al., 2011). Despite their immature brain development, which leads to decreased abilities, preschoolers in most countries are expected to regulate their learning and engage in academic-type activities, such as identifying and naming colors, shapes, numbers, and letters, and dividing words into syllables (Education Ministry, 2010; McLean, 2010; Department for Education, 2017). To further confirm the validity of using the SRL framework to investigate preschool children's learning, we asked 45 preschool teachers to classify 47 activities their pupils engaged in as academic or non-academic (for a full description, see Supplementary material). The findings showed that academic learning occurs in preschool, ensuring the relevance of SRL for preschoolers.

As novice regulators, preschool children require scaffolding from others in order to regulate themselves successfully. Through teacher–student interactions, regulation in learning can be trained

(Bronson, 2000; Diamond et al., 2007; Schmitt et al., 2015; Li et al., 2020). Thus, the preschool years are critical for developing regulation (Blair, 2002; Diamond et al., 2007; McClelland and Cameron, 2012; Barbareev, 2016).

Previous work has shown that regulation in specific domains can be trained, focusing on specific skills and examining their improvement (Diamond et al., 2007; Barnett et al., 2008; Tominey and McClelland, 2011). The innovation of the current study is that we investigated the efficacy of the VRTP (Research Question 1-RQ1) by comparing voice modulation in two groups: a preschool class that underwent the VRTP (experimental group [EG]) and a control preschool class [control group (CG)]. Furthermore, we sought to answer a basic scientific question (Research Question 2-RQ2): Does transfer occur from the behaviorally concrete operation of voice modulation to other SRL domains (e.g., CSRL) and pre-literacy skills? We hypothesized that EG participants would adjust their voices in different areas of the classroom more than the CG participants (RQ1). Second, we reasoned that if basic monitoring and control strategies are improved during the VRTP, then transfer might occur; thus, we hypothesized that improvements would occur in all SRL domains and pre-literacy skills (RQ2). Using an experimental design, we implemented a VRTP as an antidote for noise levels in early childhood formal education, merging developmental science and educational psychology by applying an SRL framework. Our primary goal was to discern how learning through play may lower noise levels in preschool and whether noise reduction can contribute to the development of children's self-regulation and language skills.

2. Methods

2.1. Participants

Two separate preschool classrooms serving children from a lower-middle socioeconomic demographic background in Israel, established in the past 5 years[1], were recruited for the study and randomly assigned to one of the conditions. In Israel, educational institutions are neighborhood-based. In this way, preschools are allocated based on pupils' home addresses, resulting in a socioeconomically homogeneous group of families that can be characterized according to their community. The two preschool classrooms were chosen after consulting with the city's Department of Education to ensure their common features and a similar socioeconomic background. This decision was also supported by the socioeconomic classification system of the national Central Bureau of Statistics. This geography-based assignment facilitated the recruitment of preschools. The groups were comparable in age, with children of ages ranging from 2.9 to 3.5 years, $t(63) = -0.58$, $p = 0.564$. The EG preschool classroom ($n = 34$, mean age = 38.35 months, $SD = 3.21$, 47% girls) underwent the VRTP, whereas the other preschool classroom (CG; $n = 31$, mean age = 38.84 months, $SD = 3.55$, 48% girls) was unaware of the intervention and implemented their routine education program. Each preschool classroom was taught by a different teacher. Among the 4-person team of teaching staff in the EG, the head teacher had 15 years of teaching practice, while among the 3-person team of teaching staff in the CG, the head teacher had 22 years of experience. The staff members at both preschools were all women, ranging in age from 23 to 56 years ($n = 7$, mean age = 40.29, $SD = 12.07$), and had teaching experience ranging from 3 to 22 years (mean = 12.71, $SD = 7$). Parental consent and child assent were obtained, and the university's ethics committee approved the study, enabling all preschool children to participate.

2.2. Instruments

The study utilized a combination of collectively and individually administrated measures. Participants' SRL and pre-literacy skills were assessed individually, while noise intensity measurements were taken collectively (see Appendices A, B).

2.2.1. Voice regulation training program

The VRTP included games, activities, and visual aids (see Appendix A) to enhance children's awareness of their personal and collective voices, as well as training and imparting voice regulation strategies (Christidou et al., 2015). After 3 h of training, the EG teacher implemented 11 weeks of VRTP sessions. First, the teacher discussed voice intensity with students using the visual aids of a voice meter and signs depicting noise levels considered appropriate for different areas in the classroom (Appendix A). For example, children were attuned to the relative quiet characterizing the reading area, whereas outside, children could talk loudly. Children were then introduced to the "volume button," an imaginary button that controls one's voice volume. One can turn an imaginary "knob" to adjust one's voice to match different spaces and situations, subject to classroom conventions, as presented in pictures. The children were informed that they could request that another person (a teacher or child) adjust their volume button. Another form of training included games and songs, such as repeating rhythms in a whisper or aloud, depending on what the teacher signaled. The games were implemented 2–3 times weekly, while the songs were incorporated daily. Additionally, hand gestures were practiced during the activities as a signal to diminish or augment voice volume. Throughout the 11 weeks, the teacher provided constructive feedback and encouragement to motivate children to regulate their voices.

2.2.2. Noise intensity measures

Sound level was measured in both classrooms using the same electronic noise meter (type: GM1356 Digital LCD Sound Level Meter 30–130 dB) with the standard scale of decibels, a logarithmic scale (Evans, 2006). Noise readings provided accurate minimum and maximum decibels within seconds, depending on the ambient noise level. We used an average noise level measurement reflecting the actual noise in the classroom, as maximum voice readings may be impacted by momentary extraneous noises, such as a falling object, and minimum voice readings may be impacted by the number of children in the space.

1 Both preschool classrooms had similar acoustical features aimed at reducing noise levels such as blackboards on the walls, tile floors, and white acoustical tiles on the ceilings.

2.2.3. SRL questionnaires

SRL measures included 19 items adapted from the Ben-Eliyahu and Linnenbrink-Garcia (2015) SRL scales. These items were modified in line with comments on the original items from three preschool teachers who were not involved in the study. This adapted questionnaire was used for teacher reports on each child's CSRL (Cronbach's α for T1, T2 = 0.94), ESRL (reappraisal: Cronbach's α for T1 = 0.91, T2 = 0.89; suppression: Cronbach's α for T1 = 0.73, T2 = 0.77), and BSRL (Cronbach's α for T1 = 0.96, T2 = 0.98). Items were presented on a 5-point Likert-type scale, ranging from 1 (*never*) to 5 (*always*) (see Appendix B). Teachers' reports were used because teachers spend extensive periods interacting with and observing their students and can provide reliable reports on their SRL (Hutchinson et al., 2021). Teachers can even identify shifts in the children's emotional states by observing behaviors such as deep breathing, self-talk, or changes in facial expression, body language, and vocal tone.

2.2.4. Pre-literacy assessments

These included vocabulary and phonological awareness evaluations specifically created for preschoolers, with children's responses categorized as either demonstrating knowledge or not, with a maximum of 36 points awarded (Aram and Levin, 2002; Tavor, 2008). Each accurate answer was worth one point. The outcomes of both assessments were merged to create a single measure of pre-literacy skills for parsimony. The reason to aggregate pre-literacy skill data was to reduce the risk of type I errors and to provide a clear interpretation of the research findings.

2.3. Procedure

The study was conducted during the school year. It consisted of three phases: 2 months at the beginning of the year for pre-training (T1), then 2 months of VRTP in the EG (T2), and a post-training evaluation at the end of training (T3). Figure 1 illustrates the study design and measurement timeline, showcasing the sequence of measures and intervals between evaluation points.

Noise intensity measures were carried out weekly in both preschool classrooms at T1 and T2. Measurements were taken in four classroom spaces in which varying noise levels were anticipated: the library, breakfast area, socio–dramatic play area, and all-purpose space (open space at the center of the classroom with tables for activities and didactic games). Data on noise intensity were collected seven times before implementation of the VRTP (T1) and eight times during its implementation (T2). To directly compare T1 and T2 measurements, we used mean substitution for the eighth T1 measurement (Tsikriktsis, 2005). To ensure standardization for both classrooms, noise intensity was recorded on Thursdays, when all staff members were present in both preschool classrooms. The sound level was recorded at the same time and in equivalent spaces (such as breakfast or free play spaces) in both classrooms (Keller-Bell and Short, 2019). Due to various school holidays during which fewer children were present, noise measures were not taken during T3, as some children were on extended trips with their families. These factors created fluctuations in the preschoolers' attendance and daily routines, making it difficult to obtain consistent and representative noise measurements at that particular time point. The unstable environment of the holidays and end–the-year atmosphere extended beyond the typical controllable factors and potentially would have brought bias into the results. The children's SRL measures and pre-literacy skills measures were collected at T1 and T3. Pre-literacy skill assessments were conducted by the first author in two 20-min sessions with each child separately.

Teachers were blind to the study design, questions, and to the regulation component. Teachers did not know how many other preschools were involved in the study or whether the training was part of the intervention. The teachers focused only on voice measurement.

2.4. Data analysis plan

The analyses addressed the effects of the VRTP on voice regulation (RQ1) and on SRL and pre-literacy achievement (RQ2). To evaluate noise levels, we compared the decibel levels in the EG and the CG at T2 using nonparametric tests for small sample sizes (Rosner and Glynn, 2009). Nonparametric tests were further justified as the assumption of homogeneity of variance was not met [Box's M: $F(36) = 4.60$, $p < 0.001$]. The Mann–Whitney (MW) U-test, an alternative to the two-sample t-test, was used to assess the differences (median-based) between and within groups for significance. Effect sizes were calculated using an online calculator that transforms the test statistic Z into effect sizes (Lenhard and Lenhard, 2016), and the G*Power program was used to estimate power. To examine interactions, we calculated a difference score for each group (e.g., T1 ESRL was subtracted from T3 ESRL), reflecting the degree of change in SRL and pre-literacy achievement across time and enabling investigation of the differences between the groups' respective progress. A positive score reflects an increase in capacity, whereas a negative score reflects a decrease.

3. Results

3.1. Voice intensity

MW tests were used to investigate differences in noise decibel levels between the EG and CG in all areas (based on a total score) and separately in each space (see Table 1). To establish baseline group differences and account for these, we examined noise decibel levels prior to the VRTP intervention (T1). At T1, the EG was characterized by lower noise levels ($EG_{median} = 64.64$, $CG_{median} = 70.18$). Examining the differences between the EG and CG for each space, EG noise levels were significantly lower than the CG noise levels in the library and the socio–dramatic play area. During implementation of the VRTP (T2), significant noise level differences were found in the all-purpose space, in addition to the differences in the library and socio–dramatic play area. The "all-purpose space," the classroom's central area where children engage in play activities at set periods throughout the day, typically operates parallel to the library space but its use does not overlap with breakfast time. In the all-purpose space, the EG maintained

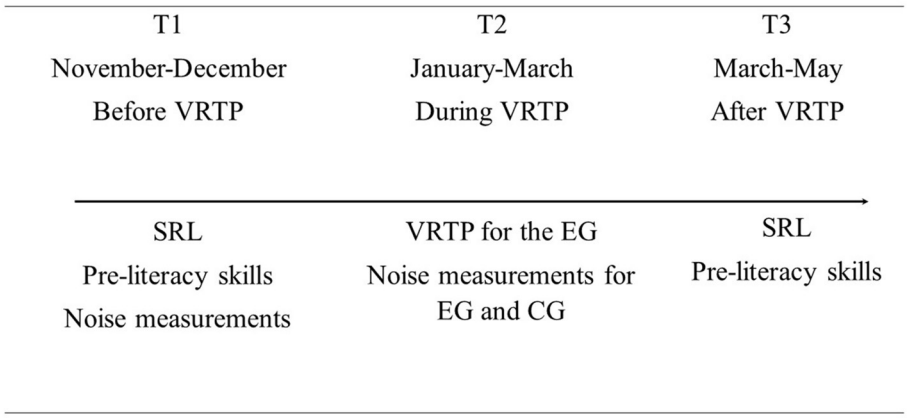

FIGURE 1
Timeline of study implementation and measurement design. EG, experimental group; CG, control group; SRL, self-regulated learning; VRTP, voice regulation training program.

lower noise levels over time and decreased noise levels during the VRTP.

Examining each group for within-group differences at T1 vs. T2, the Wilcoxon signed-rank test yielded a significant difference between time points in the all-purpose space for the EG but not for the CG (Table 1). Considering minimum noise measurements, reflecting the lower-end potential for noise regulation and a baseline from which noise fluctuates in the classroom, a separate Wilcoxon signed-rank test exclusively on minimum intensities revealed no significant differences in the average noise level medians. Specifically, the EG showed a reduction in overall noise levels ($Z = -1.960$, $p = 0.050$. $r_{effectsize} = 0.71$) and a reduction in noise levels in the all-purpose space ($Z = -2.100$, $p = 0.036$. $r_{effectsize} = 0.77$). These findings suggest that the VRTP intervention was associated with decreased noise levels, at least in the noisiest areas of the preschool classroom.

3.2. Transfer effects: SRL and pre-literacy measure

Between-group and within-group differences were investigated (see Table 2). MW tests were conducted to compare the two groups on all measures prior to the VRTP intervention (T1), indicating that the EG had poorer BSRL and lower levels of reappraisal. After the VRTP (T3), the median suppression score in the CG was unchanged; however, significant differences indicated that the EG suppressed their emotions more than the CG after the VRTP but not before. Upon examining the overall SRL median scores, there was a significant difference between the groups before the VRTP (T1), with the EG having a lower median; however, after the VRTP (T3), no differences were observed between the groups, indicating that the overall SRL of the EG increased, closing the gap with the CG.

A sign test was used to examine within-group differences for each group, comparing T1 with T3. Among the EG children, changes in all parameters, aside from CSRL, which remained stable, were found to be highly significant ($p < 0.001$); in contrast, among the CG, only pre-literacy skills demonstrated growth, along with a decline in CSRL.

Considering differences before and after the intervention in each group (time × group interaction), we compared the difference scores for the raw data (T1 vs. T3) between the groups. In this way, for each measure, the gap between T1 and T3 was calculated (e.g., T1 ESRL was subtracted from T3 ESRL), meaning that a positive score indicated an increase over time and a negative score reflected a decrease. The raw score reflected the groups' respective progress, as measured by the change in SRL and pre-literacy skills across time. These difference scores were entered into the MW test. Significant differences were found between the groups (see Table 3) in BSRL, ESRL-reappraisal, ESRL-suppression, and pre-literacy achievement. These findings support the utility of the VRTP for enhancing BSRL, ESRL (reappraisal and suppression), and pre-literacy skills in the EG relative to the CG, providing support for the hypotheses.

4. Discussion

The present study provides evidence that SRL could be integrated into the preschool curriculum. Thus, rather than older students' teachers having to undo maladaptive learning strategies or teach them how to learn, these strategies may be taught already in early childhood. Overall, the VRTP was found to be effective in reducing noise and in transferring to SRL and pre-literacy skills, providing partial support for the study's hypotheses. Voice regulation comprises habits linked to specific contexts, such as time, place, and the presence of people; to modify behavior, it is essential to focus on manipulating stable context cues rather than relying solely on willpower (Fiorella, 2020), facilitated by the VRTP. During preschool, as the entry point for children in learning how to behave in a school environment, learning social skills and voice regulation is crucial.

In addition to modest improvements in voice regulation, EG children demonstrated concurrent improvements in BSRL

TABLE 1 Differences in noise level (decibel) between experimental group (EG) and control group (CG) and within differences by activity area and for all areas together.

	Between-groups tests[a]												Test of within groups[b]							
	Pre-training (T1)		Sig.	U	*r*	Power	During training (T2)		Sig.	U	*r*	Power	EG				CG			
	EG	CG					EG	CG					Sig.	Z	*r*	Power	Sig.	Z	*r*	Power
Library			0.002	2.00	2.56	0.84			0.001	0.00	3.10	0.93	0.674	−0.42	0.21	0.70	0.208	−1.26	0.66	0.51
Median	62.19	72.32					61.05	70.65												
Range	14.70	10.10					26.80	8.25												
Breakfast			0.753	29.00	0.16	0.76			0.916	31.00	0.05	0.92	0.208	−1.26	0.66	0.51	1.00	0.00	–	–
Median	60.03	60.74					63.82	64.72												
Range	15.75	14.00					14.10	17.90												
Socio-dramatic play			0.018	9.50	1.46	0.57			0.002	2.00	2.56	0.84	0.123	−1.54	0.84	0.51	0.263	−1.12	0.58	0.51
Median	67.91	74.10					60.05	75.50												
Range	13.35	10.80					15.35	16.30												
All-purpose space			0.074	15.00	1.00	0.52			0.009	7.00	1.74	0.64	0.025	−2.24	1.35	0.56	0.161	−1.40	0.75	0.50
Median	69.55	74.00					68.07	75.42												
Range	19.75	10.80					15.20	16.30												
All areas together			0.006	6.00	1.87	0.65			0.001	0.00	3.10	0.93	0.069	−1.82	1.02	0.52	0.889	−0.14	0.07	0.89
Median	64.64	70.18					63.56	71.22												
Range	6.23	10.55					9.53	8.17												

[a]*p*-value for Mann-Whitney test. [b]Test statistic (T) for Wilcoxon signed-ranks test. *r*, nonparametric Cohen's d based on an online calculator (Lenhard and Lenhard, 2016).

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TABLE 2 Differences in SRL and academic achievement between the experimental group (EG) and control group (CG) and within differences for each group.

	Between-groups tests[a]												Test of within groups[b]							
	Pre-training (T1)		Sig.	U	*r*	Power	Post-training (T3)		Sig.	U	*r*	Power	EG				CG			
	EG ($n = 34$)	CG ($n = 31$)					EG ($n = 34$)	CG ($n = 31$)					Sig.	Z	*r*	Power	Sig.	Z	*r*	Power
BSRL			<0.001	95.50	2.00	1.00			<0.001	205.00	1.23	0.91	0.047	−2.12	0.55	0.55	0.152	−1.44	0.36	0.50
Median	1.00	3.00					1.00	2.40												
Range	0.60	4.00					4.00	4.00												
CSRL			0.358	457.50	0.23	0.52			0.301	448.50	0.26	0.51	0.061	−1.88	0.48	0.49	0.004	−2.79	0.74	0.47
Median	2.67	3.33					2.17	2.67												
Range	4.00	4.00					3.83	4.00												
ESRL; Reappraisal			<0.001	184.50	1.35	0.96			0.003	302.00	0.79	0.51	<0.001	−3.78	1.06	0.76	0.294	−1.07	0.27	0.52
Median	1.67	3.00					1.67	2.50												
Range	1.00	4.00					3.67	4.00												
ESRL; Suppression			0.298	457.00	0.23	0.47			<0.001	263.50	0.95	0.61	<0.001	−4.34	1.28	0.93	0.795	-.26	0.07	0.80
Median	1.00	1.00					3.00	1.00												
Range	3.67	4.00					4.00	4.00												
Overall SRL			<0.001	190.00	1.31	0.95			0.102	402.50	0.41	0.49	<0.001	−4.23	1.23	0.91	0.103	−1.63	0.41	0.49
Median	1.54	2.92					2.04	2.44												
Range	1.92	3.25					2.71	3.13												
Pre-literacy			0.249	439.50	0.29	0.50			0.457	470.50	0.19	0.56	<0.001	−4.64	1.41	0.98	0.012	−2.48	0.65	0.49
Median	16.50	18.00					19.50	19.00												
Range	21.00	19.00					22.00	19.00												

[a]*p*-value for Mann-Whitney U-test. [b]Test statistic (T) for Wilcoxon signed-rank test. *r*, nonparametric Cohen's d based on an online calculator (Lenhard and Lenhard, 2016). BSRL, behavioral SRL; CSRL, cognitive SRL; ESRL, emotional SRL.

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TABLE 3 MW test results for between-groups T1–T3 difference scores.

	EG	CG	Sig.	U	*r*	Power
	Median (range)					
BSRL	0.00 (4.20)	0.00 (4.00)	0.005	341.50	0.63	0.35
CSRL	−0.25 (4.17)	−0.50 (4.17)	0.468	472.00	0.18	0.57
ESRL-reappraisal	0.42 (3.33)	0.00 (4.50)	0.008	324.50	0.70	0.51
ESRL-suppression	1.67 (4.33)	000 (5.67)	<0.001	233.00	1.09	0.79
Pre-literacy	4.00 (15.00)	1.00 (13.00)	0.001	285.50	0.86	0.48

[a]*p*-value for Mann-Whitney test. [b]Test statistic (T) for Wilcoxon signed-ranks test. *r*, non-parametric Cohen's d based on an online calculator (Lenhard and Lenhard, 2016). BSRL, behavioral SRL; CSRL, cognitive SRL; ESRL, emotional SRL.

(planning) and ESRL after the intervention. An intervention of this nature may yield a form of transfer or strengthening of the SRL contingency (monitoring and controlling), so that once change was realized in relation to voice, the children appeared to apply this to other forms of BSRL (i.e., planning) and ESRL. As with BSRL, ESRL has a concrete outcome—the experience and expression of emotion—that preschoolers can feel and observe in themselves and others. EG preschoolers' teachers reported greater use of the reappraisal and suppression facets of emotion regulation after the intervention. These findings suggest that the EG preschoolers may have learned to be more flexible and choose between regulatory strategies to align with their desired emotions; this critical adaptation has been reported by most current research in adult samples (Sheppes, 2020). Our findings provide hope that the building blocks of SRL, namely monitoring and control, may be improved intentionally, as revealed in prior work with different age groups (Tominey and McClelland, 2011; Sezgin and Demiriz, 2019; Bernacki et al., 2020).

Although language achievements occur naturally over time, our findings demonstrate that the children participating in the VRTP showed more improvements in their pre-literacy achievements than the CG preschoolers (as reflected in the T1 and T3 difference scores). The EG's improved pre-literacy achievement coincides with their modest decrease in noise. The voice regulation internalization process may have facilitated general language development and communication (De Bruin and van Gog, 2012; Blair and Raver, 2015; Lonigan et al., 2017). During the VRTP, the preschoolers were exposed to games and structured interactions using accurate and nuanced language, voice intonation, and phonology, perhaps enhancing their attunement to their surroundings and social interactions.[2] More work should be conducted to unpack and explore the source of the observed differences. In addition to the VRTP, other environmental and psychophysiological factors, such as parental involvement, language exposure, and neurological factors, may have been at play. In addition to considering such contextual and personal characteristics, future work should employ a more robust design with larger samples and longitudinal follow-up to obtain a deeper understanding of the dynamics associated with implementing the VRTP.

5. Conclusion and impact

Implementing a VRTP to reduce preschool noise levels coincided with ESRL, BSRL, and improvements in pre-literacy skills, suggesting benefits for developmental trajectories beyond reducing noise levels. Future studies should aim to obtain additional measurements documenting each child's voice and longitudinal data on the quality of their school transition. However, the current study provides evidence for a transfer of SRL across domains at young ages, an important contribution to developmental–educational psychology. As part of the recent surge of interest in preschool SRL (Erdmann and Hertel, 2019; Perry, 2019), the present study suggests that SRL development in young children may be supported with everyday activities easily incorporated into the current curriculum without necessitating additional funds. Educators and parents may incorporate voice modulation games or fun and simple exchanges to encourage children's awareness of their personal and collective voices.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The studies involving humans were approved by the University of Haifa—Ethics Committee. The studies were conducted in accordance with the local legislation and institutional requirements. Written informed consent for participation in

2 For example, in the "guard dog" game, a child sits in the middle of the circle and needs to guard an object with their eyes closed. They focus on sounds and verbal exchanges in order to guard the object from their peers in the circle, who are the "thieves." In doing so, children learn to be more aware of their environment in the guard dog role and also learn to identify their peers' intentions as part of the group trying to steal the object, as they need to communicate without making noise.

this study was provided by the participants' legal guardians/next of kin.

Author contributions

All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpsyg.2023.1213348/full#supplementary-material

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The combined value of executive functions and self-regulated learning to predict differences in study success among higher education students

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Introduction: Self-regulated learning (SRL) has traditionally been associated with study success in higher education. In contrast, study success is still rarely associated with executive functions (EF), while it is known from neuropsychological practice that EF can influence overall functioning and performance. However some studies have shown relationships between EF and study success, but this has mainly been investigated in school children and adolescents. EF refer to higher-order cognitive processes to regulate cognition, behavior, and emotion in service of adaptive and goal-directed behaviors. SRL is a dynamic process in which learners activate and maintain cognitions, affects, and behaviors to achieve personal learning goals. This study explores the added value of including EF and SRL to predict study success (i.e., the obtained credits).

Methods: In this study, we collected data from 315 first-year psychology students of a University of Applied Sciences in the Netherlands who completed questionnaires related to both EF (BRIEF) and SRL (MSLQ) two months after the start of the academic year. Credit points were obtained at the end of that first academic year. We used Structural Equation Modeling to test whether EF and SRL together explain more variance in study success than either concept alone.

Results: EF explains 19.8% of the variance, SRL 22.9%, and in line with our hypothesis, EF and SRL combined explain 39.8% of the variance in obtained credits.

Discussion: These results indicate that focusing on EF and SRL could lead to a better understanding of how higher education students learn successfully. This might be the objective of further investigation.

KEYWORDS

executive functions, self-regulated learning, study success, academic success, higher education, student, structural equation modeling

1 Introduction

Executive functions (EFs) strategies, i.e., strategies that help students learn new content or solve problems are vital in developing lifelong learning skills. However, up to now, most educational research has focused on self-regulated learning (SRL) to explain successful learning and study success (e.g., Hayat et al., 2020; Moghadari-Koosha et al., 2020; Sun et al., 2023). In contrast, EF is mainly approached from a neuropsychological and clinical perspective, focusing on EF dysfunction and related educational problems (e.g., Meltzer et al., 2018, pp. 109–141; Dijkhuis et al., 2020), and it is hardly studied in ecological settings (i.e., standard learning settings). The studies conducted on EF in the educational context have primarily focused on children and adolescents (e.g., Diamond and Ling, 2016; Pascual et al., 2019; Zelazo and Carlson, 2020), not on young adults in higher education. To our best knowledge, EF and SRL have yet to be examined in combination within the context of higher education. Therefore, this study explores the relationship between EF and SRL and the extent to which they impact students' study success in higher education.

Executive function and SRL originate from two paradigms, respectively founded in neuropsychology and based on educational research. Both have their methods, tests, and language. Researchers generally base their research on one of two perspectives. Nonetheless, both concepts have been associated with successful studying and study success in young adults (e.g., Garner, 2009; Musso et al., 2019; Pinochet-Quiroz et al., 2022) and are essential to a broader understanding of student's ability to learn. The following section describes the definitions, similarities and differences between EF and SRL.

Self-regulated learning is about students becoming masters of their learning process which implies being able to adopt the most appropriate strategy for a learning task to be developed (Zimmerman, 2015; Dent and Koenka, 2016). SRL is generally considered a dynamic, cyclical process consisting of different phases and sub-processes of learning (Panadero, 2017). One of the most used and well-operationalized SRL models states that the cyclical process contains the following phases: (1) forethought, planning, and activation; (2) monitoring; (3) control; and (4) reaction and reflection (Pintrich, 2004). Each phase has four different areas for regulation: cognition, motivation/affect, behavior, and context.

Executive functions can be defined as a set of cognitive processes, partially independent and involved in top-down control of behavior, emotion, and cognition (Baggetta and Alexander, 2016; Nigg, 2017). EF refer to the most basic level of behavioral analyses or the neuropsychological level (De la Fuente et al., 2022). EF are effortful and invoked when automatic responses and routines do not work. This mainly happens in novel, complex, or otherwise challenging situations (Miller and Cohen, 2001; Barkley, 2012; Diamond, 2013). Therefore, EF are critical in learning, study success, and flexible behavior (Denckla and Mahone, 2018, p. 6).

Executive functions are a multidimensional concept; the literature describes several classifications of EF. Baggetta and Alexander (2016) found 39 different components or processes of EF in their review, with three core EF being the most commonly mentioned in the 106 studies they examined, i.e., inhibition (68%), working memory (35%), and cognitive flexibility (31%):

1. Inhibition (inhibitory control, including self-control or behavioral inhibition; or interference control, including selective attention and cognitive inhibition). This is the ability to control one's attention or inhibit dominant or automatic behavior, responses, thoughts, and emotions (e.g., Baggetta and Alexander, 2016). For example, being able to study for a more extended time without being distracted.
2. Working memory. This ability is described as keeping the information in mind and working with it (e.g., Baddeley, 2010; Diamond, 2013). For example, reading a textbook, remembering what you read, and coming up with examples from your own experience that relate to what is described in the learning materials.
3. Cognitive (or mental) flexibility (or set-shifting). This refers to the ability to literally and figuratively change perspective, remove irrelevant information and retrieve new information, think differently, or change your behavior (e.g., Diamond, 2013; Nigg, 2017). Essentially, it is about adapting to a changed situation. For instance, while working on a group assignment in an (interdisciplinary) team, being able to put yourself in someone else's perspective.

Combining these core "lower-order" processes creates "higher-order" or complex processes such as planning, reasoning, and problem-solving (Diamond, 2013).

One of the classifications that describes both the core and complex EF and is often used in research (in both academic and clinical contexts) is that of Gioia et al. (2000). We chose this classification because of its well-operationalized EF components and its emphasis on assessing behavioral manifestations of EF in an individual's daily life (Baggetta and Alexander, 2016). Additionally, based on this classification Gioia et al. (2000) developed the Behavioral Rating Inventory Executive Functions (BRIEF), a self-reported questionnaire that has been translated into Dutch and standardized for children (Huizinga and Schmidts, 2012) and adults (Scholte and Noens, 2011).

This classification – based on factor analyses of EF behavioral descriptions – comprises nine EF, including the three core EF described before, next to the more complex or higher-order EF "self-monitor," "emotional control," "initiate," "task monitor," "plan/organize," and "organization of materials."

Executive function can be conceptualized on two levels: the core EF on a cognitive level (i.e., how the brain thinks) and the core EF and complex EF on a behavioral level (i.e., how the brain thinks expressed in behavior). Both levels refer to EF; however, in studies, they are operationalized and measured differently and refer to different underlying mechanisms of EF (e.g., Barkley and Fischer, 2011; Toplak et al., 2013). Researchers hypothesize that this is why directly or task-based measured core EF hardly overlap with the indirectly or self-reported measured EF (e.g., Barkley and Fischer, 2011; Toplak et al., 2013).

An advantage of directly assessing EF is that these task-based tests better test the actual performance of a specific EF. However, these results provide information about how well the student functions in an optimal and highly structured environment and, therefore, are not easily generalized across settings (Naglieri and Otero, 2014, pp. 191–208). The advantage of a self-reported EF is its higher ecological validity because it provides information about

how well the student functions in a less structured environment, such as a school or home setting (Barkley and Fischer, 2011). An assumption with self-reports is that they measure behaviors related to the cognitive processes measured by task-based measures of EF. Because we are interested in how students experience their EF in their daily settings, we use self-report questionnaires in this study to assess EF.

The same reason applies to SRL; we are interested in the students' perceptions of their SRL in general. SRL self-reports fall under the category of "offline measures," referring to the timing of the measurements, in this case, that the self-reports are taken before or after the task and not during the task (i.e., "online measures," such as think-aloud protocols or systematic observations) (Veenman, 2005; Schellings, 2011). When taking an SRL self-report, the student reflects on how they usually approach the learning task, so it provides more general information than specific information about a task at that moment. Thus, it depends on the research question of which measurement instrument is most appropriate (Rovers et al., 2019).

Self-reports also have drawbacks. Paradoxically, being able to complete the self-reports requires EF of the student to reflect on past and future behaviors (Garner, 2009), suggesting that a student with weak EF will be less able to self-report.

Another issue might be that students over- or underestimate themselves and whether there is a discrepancy between their intentional behavior and what they actually demonstrate [as demonstrated for SRL by Broadbent and Poon (2015)]. Students who overstated their performance on EF performance measures also achieved significantly higher scores on self-reports (Follmer, 2021).

Rovers et al. (2019) showed that students can report – via questionnaires – relatively accurately what their general self-regulatory functioning is, while at a detailed level, they have difficulty pinpointing exact SRL strategies. They argue that the level of granularity is of influence and that different types of measurement are valuable, depending on the research question. The same kind of reasoning could apply to the practical use of these measurements. For example, the benefit of self-reporting is that students become aware of their SRL strategies, which is an intervention in itself (Panadero et al., 2016). So, if self-monitoring is the objective, self-reports are an excellent option.

Conceptually, both EF and SRL refer to higher-order (top-down) cognitive processes. However, they differ in the context in which they are applied. EF are essential for navigating everyday life and engaging in social interactions (Barkley, 2012). EF become active when a student faces new, complex, or challenging daily life problems, including but not limited to problems encountered in the learning environment. In those moments, the student must make decisions, resolve issues, learn from mistakes, mentally play with ideas (be creative), think before acting, resist temptations, and stay focused (Diamond, 2013). In contrast, SRL occurs specifically and exclusively in the learning context and focuses on acquiring knowledge, automating skills, and achieving learning results. SRL involves both conscious and unconscious deep processing of information, or the repetition of facts, to eventually consolidate this information in long-term memory (Wirth et al., 2020).

Another difference is that SRL strongly emphasizes motivation or the "why" someone does something and the willingness to put effort into it (Schunk and Greene, 2018), in contrast to EF, which focus more on the "how," i.e., "how do I solve this problem or adapt to the situation?"

Studies on the *relationship between EF and SRL* suggest a partial overlap between the constructs (e.g., Garner, 2009; Effeney et al., 2013; Follmer and Sperling, 2016). In these studies, EF and SRL are – indirectly – measured via self-reports demonstrating that EF expressed on a *behavioral* level overlap partially with SRL, also expressed on a behavioral level. Moreover, it seems that, in particular, the metacognitive dimensions of SRL are associated with or coincide with EF, for instance, planning (Effeney et al., 2013; Pinochet-Quiroz et al., 2022). The ability to plan allows a student to set and achieve goals in everyday life (context of EF) and focus explicitly on prioritizing learning tasks (context of SRL). However, self-reported EF and SRL are not the same in learning environments, and when overlapping, EF appear to contribute to variability in SRL processes, and the other way around, SRL processes implicate EFs (Garner, 2009).

However, in contrast, EF appear to be more unidirectionally related to SRL when measured directly through neuropsychological tasks, i.e., meaning task-based EF mediate through SRL on academic achievement and not the other way around (e.g., Rutherford et al., 2018; Musso et al., 2019). Only the core EF (i.e., working memory, inhibition, or cognitive flexibility) are task-based measured in these cases. In other words, SRL strategies seem to employ *core* EF – on a cognitive level – to achieve learning results, which makes sense because to sustain a learning strategy, the student must focus, keep information online, avoid distractions, and be cognitively flexible in disregarding old information in favor of new information.

In summary, EF can be conceptualized and measured at a cognitive and behavioral level (typically task-based and self-reported). Self-reported EF are most likely to have a partially overlapping relationship with self-reported SRL. In contrast, task-based EF are more likely to support self-reported SRL in achieving study success, thus showing a mediating role.

Studies about *EF, SRL, and study success* are scarce, particularly in young adult students. In this population, we identified only the study by Musso et al. (2019), who investigated the coherence between EF, SRL, and study success in a group of first-year university students. They found mediating effects of EF via SRL on math performance. Musso et al. (2019) measured EF directly (i.e., measured with neuropsychological tasks) and focused solely on working memory and executive attention.

To our knowledge, no study has focused on self-reported EF and SRL together as predictors of study success in higher education. There are a few studies that have investigated the relationship between self-reported EF and study success in the context of higher education. These studies indicate that self-reported EF problems negatively affect study success (e.g., Knouse et al., 2014; Baars et al., 2015; Ramos-Galarza et al., 2020). On the other hand, numerous studies have shown a positive relationship between SRL and study success in higher education (e.g., Honicke and Broadbent, 2016; Virtanen et al., 2017; Sun et al., 2018). The added value of EF in conjunction with SRL and their explanatory value for study success still needs to be determined to investigate if the concepts combined have the potential power to improve study success. Therefore, this study investigates the following research question:

Do self-reported EF and SRL combined explain variations in study success among higher education students better than either

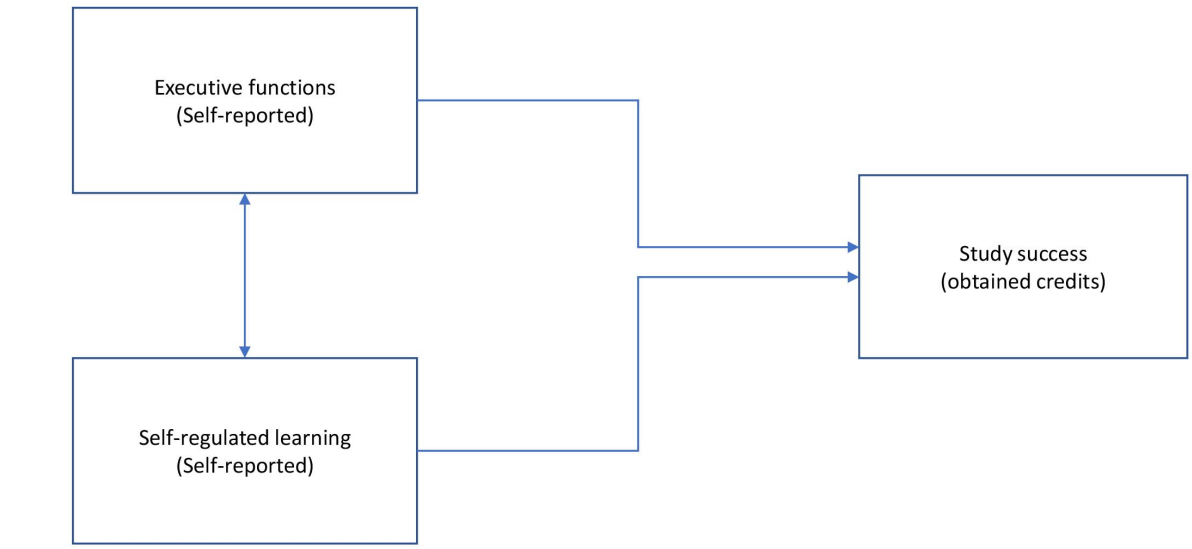

FIGURE 1
Research model of the relationship EF and SRL, and study success.

TABLE 1 Overview of the selection process of the final sample size for the structural equation modeling analyses.

Number of students that completed one or both questionnaires (n = 484)	Number of removed respondents	Sample size
Students who did *not* sign the informed consent	40	444
Students of age (<18 and >25 years; or unknown)	99	345
Students (18 years and older) who filled out the wrong version of the BRIEF*	3	342
Students who filled out the BRIEF improbably, inconsistently and negatively**	0	342
Students who did *not* fill out the BRIEF *and* MSLQ	27	315
Final sample		315

*We provided the BRIEF-2 version for students 16 and 17 years old. However, some of the 18 years and older, who should fill out the adult-version of the BRIEF, clicked on the wrong link and completed the wrong BRIEF. We analyzed the data of the 16 and 17-year-old students in a different study.
**These are three validity scales of the BRIEF to evaluate whether the student's answer pattern is not overly negative, inconsistent, or atypical.

TABLE 2 Descriptive analyses.

Variables	Mean	SD	%	n
Age (years)	19.80	1.73		315
Gender				
Male			31.7%	100
Female			67.3%	212
Different			1.0%	3
Education before applied university (in the Netherlands)				
Havo			54.9%	173
Vwo			7.9%	25
Mbo			30.5%	96
Hbo			5.7%	18
Other			1.0%	3

Havo and VWO are comparable to high school; Mbo compares to regular secondary vocational education; Hbo refers to higher education.

separately? Notably, since there appears to be a reciprocal non-mediating relationship between self-reported EF and self-reported SRL, we assume two independent variables that can directly or combined affect study success.

Following the research model depicted in Figure 1, we will investigate (1) the relationships between EF and SRL (measured 2 months after the start of the academic year), and study success (measured at the end of the academic year, and (2) the combined effect of EF and SRL on study success.

We hypothesize that EF and SRL combined explain statistically significantly more variance in the number of credits obtained at the end of the academic year than each construct separately.

In addition, the aim is not to examine the different dimensions of EF and SRL and their relationships. Given the inter- and intra-individual differences due to the developmental trajectory of both EF and SRL, we expect these specific dimensions to have little expressive power when looking at individual students. We expect the results to provide insight into the group. However, this picture may differ if students have been developing for 6 months or if a different group of students is involved. Therefore, we explore the concepts of EF and SRL without identifying the specific dimensions.

The COVID-19 pandemic made studying and life more challenging for students due to lockdowns and regulations (e.g., Copeland et al., 2021; Ihm et al., 2021). During this time, students may have faced a constant stream of new and complex issues, which

could have impacted their EF. While not the main focus of our research, we also wanted to understand how these circumstances affected students' self-reported EF and SRL. As such, we asked students if the lockdowns and regulations influenced how they completed our questionnaire.

2 Materials and methods

2.1 Procedures

This study was conducted following a retrospective cohort design (Ato et al., 2013). EF and SRL data for this longitudinal survey study were collected from the last week of November 2020 through the first week of December 2020 during the first-year module "Diagnostic Research Part 1 (DR1)." At the end of the academic year in July 2021, we collected the obtained credits. One of the main objectives of module DR1, is learning to conduct research. In that context, the students fill out various questionnaires to experience what participating in research entails.

The study measurements were integrated into the educational program so students could complete the online questionnaires during a lesson. All the students received their results and feedback regarding their test performances. As a follow-up, students were offered to discuss their results with the researcher, lecturer, or mentor.

In the *first week of the module*, the students were informed about the study aim and procedure during an online lecture. They were told that completing the questionnaires would take approximately 45–60 min, that participation was voluntary and confidential, and that no credits were involved. According to institutional ethical advice committee (SEAC) guidelines, informed consent was drawn and provided for signature at the start of the procedure. All students were invited to participate, but we only used the results of students who signed the informed consent for analyses.

During class in the *second week of the module*, students completed the questionnaires on first EF (Behavior Rating Inventory of Executive Function – Adult version) then SRL (Motivated Strategies for Learning Questionnaire), then descriptive questions, such as the COVID-19 control question. The completion of the questionnaires would take students approximately 30–60 min.

The credits earned at the end of the school year were retrieved from the school's database and could be up to 60 credits.

2.2 Participants

This study included all first-year students of the program Applied Psychology of the University of Applied Sciences in the Netherlands. The inclusion criteria were *first-year higher education students* between *18 and 25 years*, assuming that around 25, the prefrontal cortex is mature, and the EF are optimally developed (Giedd and Rapoport, 2010). We are particularly interested in first-year students because the transition from high school to higher education impacts this group because they must learn new ways of learning and personal changes, such as living independently (Lowe and Cook, 2003; Carragher and McCaughey, 2022). We excluded student younger or older than 25 years.

A total of 484 first-year students participated in module DR1 and completed the questionnaires. Of them, 444 signed the informed consent. We excluded 129 students for various reasons (**Table 1**). The final sample contained 315 first-year higher education students. **Table 2** includes the descriptive data.

2.3 Measures

2.3.1 Study success

Study success was measured by retrieving the number of credits earned after the first school year (including two semesters) from the university's database.

In addition, we used two self-report measures, namely for EF and SRL, which we discuss further below.

2.3.2 Behavior Rating Inventory of Executive Function – Adult version

The BRIEF-A is a self-report questionnaire to describe EF based on behaviors of adults (18–90 years) (Roth et al., 2005, 2013). This instrument has been standardized for the executive functioning of adults in everyday environments, and specifically in the Netherlands for adults aged 18–65 years (Scholte and Noens, 2011).

The BRIEF-A includes nine non-overlapping and empirical-based scales (**Table 3**). The nine scales are measured by 75 items about perceived EF deficits over the past month on a three-point scale (1 = never; 2 = sometimes; 3 = often). The higher the score on specific behaviors, the higher the level of perceived EF deficits.

The total raw scores of the subscales can be transformed into *T*-scores, making it possible to compare them with a representative norm group. A *T*-score of 65 or greater indicates "clinical" problems with a specific EF or a cluster of EF (the total or index scores) (Roth et al., 2005; Scholte and Noens, 2011). However, Schwartz et al. (2020) and Abeare et al. (2021) demonstrated that in some cases, particularly in clinical samples, a cut-off *T*-score of $\geq$80 or $\geq$90 demonstrates higher specificity and is a more realistic representation.

There is always a percentage of the participants unwilling or unable to complete the questionnaires credibly. Therefore, we should be aware of the symptom validity, i.e., the extent to which scores on self-reports reflect true levels of emotional distress (Larrabee, 2012). In particular, young adults (i.e., students) cannot always realistically assess their EF deficits (Toplak et al., 2013), which is demonstrated by the lack of relationship between both subjectively and objectively measured cognitive abilities, with other psychological factors believed to play a role, such as depressive symptoms (Toplak et al., 2013). Therefore, it is recommended to control for this through symptom validity testing. The BRIEF-A contains three validity scales to measure three aspects of non-credible responding (negativity, inconsistency, and infrequency) (Roth et al., 2005; Scholte and Noens, 2011).

We calculated the internal consistency of the BRIEF-A and its component subscales. The analysis yielded acceptable internal consistency reliability (**Table 3**).

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TABLE 3 Reliability subscales BRIEF-A and example items.

Index (total of subscales) Subscale	Cronbach's α	Number of items	Example item
Behavioral regulation			
Inhibition	0.68	8	I am impulsive
Shift	0.72	6	I am bad at change
Emotional control	0.89	10	I overreact to minor problems
Self-monitor	0.66	6	I say things without thinking
Metacognition			
Initiate	0.75	8	I find it challenging to start working independently
Working memory	0.77	8	I can only concentrate for a short time
Plan	0.78	10	I don't plan tasks ahead
Task monitor	0.69	6	I make sloppy mistakes
Organization of materials	0.81	8	I don't clean up my mess

TABLE 4 Reliability subscales MSLQ and example items.

Index (total of subscales) Subscale	Cronbach's α	Number of items	Example item
Motivational beliefs			
Intrinsic goal orientation	0.69	4	The most satisfying thing for me in this course is trying to understand the content as thoroughly as possible
Extrinsic goal orientation	0.69	4	If I can, I want to get better grades in this class than most of the other students
Task value	0.87	6	I like the subject matter of this course
Control of learning beliefs	0.67	4	If I try hard enough, then I will understand the course material
Self-efficacy for learning and performance	0.93	8	I expect to do well in this class
Test anxiety	0.86	5	When I take tests I think of the consequences of failing
Learning strategies			
Rehearsal	0.77	4	I memorize keywords to remind me of important concepts in this class
Elaboration	0.74	6	When reading for this class, I try to relate the material to what I already know
Organization	0.79	4	I make simple charts, diagrams, or tables to help me organize course material
Critical thinking	0.74	5	I try to play around with ideas of my own related to what I am learning in this course
Metacognitive self-regulation	0.77	11	I try to think through a topic and decide what I am supposed to learn from it rather than just reading it over when studying
Time and study environment	0.76	8	I make good use of my study time for this course
Effort regulation	0.72	4	I work hard to do well in this class even if I don't like what we are doing
Peer learning	0.50	3	I try to work with other students from this class to complete the course assignments
Help-seeking	0.73	4	I ask the instructor to clarify concepts I don't understand well

2.3.3 Motivated Strategies for Learning Questionnaire

The MSLQ assesses SRL (Duncan and McKeachie, 2015). It is a self-report questionnaire designed to assess students' motivational orientations and the use of different learning strategies. Self-reports have proven reliable and valid instruments for gaining general insight into students' SRL (Rovers et al., 2019).

The questionnaire consists of a motivational and a learning strategies scale, consisting of respectively six and nine subscales (**Table 4**).

The subscales of the MSLQ demonstrate moderate to good internal consistency reliability, except for Peer learning, which was poor (**Table 4**). This may be because this scale contains the least number of items, namely three items, or that it is a different population than the one with which the MSLQ was validated.

2.3.4 Impact of COVID-19

To gain insights into the impact of the COVID-19 pandemic, we asked the students if the lockdowns and regulations influenced how they filled out the questionnaire. Response options were as follows*: 1 = I am more negative/I experience more problems; 2 = I do not act differently than before COVID-19; 3 = I am more optimistic/I notice challenges.*

2.4 Statistical analyses

Pearson's correlation coefficients are calculated to explore the relationships between the BRIEF-A and MSLQ subscale scores. According to Cohen (1992), <0.3 means a weak correlation, 0.3–0.5 is a moderate correlation, and 0.5 or higher is a strong correlation effect.

To test our hypothesis, structural equation modeling (SEM) was conducted. SEM is a statistical method that uses various models to test hypothesized relationships among observed variables (Schumacker and Lomax, 2015). The following standard model fit indices were used: Chi-square-test (χ^2), standardized root mean residual (SRMR) confirmatory fit index (CFI), and root mean square error of approximation (RMSEA).

A non-significant χ^2 test is considered as good. In contrast, a large and significant χ^2 test indicates a big discrepancy and, thus, a poor fit between the model and original data (Hu and Bentler, 1999). Because the χ^2 becomes increasingly unreliable when the sample size is more significant than 250 (Byrne, 2006), the statistic χ^2 divided by its degrees of freedom (df) is used (Bollen, 1989), where a ratio >2.00 represents an inadequate fit (Byrne, 2006).

A value less than 0.08 is considered a good fit for the SRMR, an absolute measure indicating zero as a perfect fit. The SRMR has no penalty for model complexity (Hu and Bentler, 1999). CFI values >0.90 and 0.95 indicate acceptable and excellent fit, respectively, and RMSEA values <0.06 and <0.08 indicate a good to acceptable fit (Hu and Bentler, 1999).

A rule of thumb of confirmatory factor analyses (CFA)/SEM is often a ratio of cases to free parameters, or N:p, namely at least 10:1 to 20:1 (e.g., Schumacker and Lomax, 2015; Kline, 2016). In our study, we sufficiently achieve the minimum ratio of 10:1 with our sample of 315 cases and 27 variables.

The first step of SEM involves specifying a set of latent variables and their relations. We tested the constructs (EF and SRL) with CFA, using maximum likelihood (ML) estimation, with AMOS 26.0, to identify the measurement model for study success. This resulted in a model with low CFI (0.64) and high multicollinearity.

Therefore, we conducted an exploratory factor analysis (EFA) per theoretical construct. As a result, the latent variables were established, and the construct –"Peer learning"- was removed due to low reliability ($\alpha = 0.50$), inadequate convergent validity (factor loadings were 0.27, 0.44, and 0.87) and the fact that the construct loads with Help-Seeking (for an overview of the included items, see **Supplementary Tables 1**, **3**, **4**). Also before and after the EFA some of the other constructs had a suboptimal reliability (e.g., Self-Monitor and Anger Outbursts). Although a Cronbach's alpha of minimally 0.7 is preferable, a value of 0.6 is acceptable (Hajjar, 2018). The observable measures for the latent variables were partially adjusted (for an overview of the removed items, see **Supplementary Tables 2**–**4**).

Again, a CFA was conducted, showing a reasonable amount of multicollinearity, but the model fit measures are between acceptable margins (χ^2/df = 1.55; SRMR = 0.06; RMSEA = 0.04; CFI = 0.85).

The second step comprises creating a SEM, including all the defined latent variables to test our hypothesis. This Model 1 combined all the variables to test how EF and SRL would explain the total variance in study success. Again, we expected that not all variables would be (equally) significantly correlated and contribute to the variance of study success.

Additionally, two models were created and tested to establish the contribution of SRL and EF separately to gain insights into the differences between the concepts separately and combined. Model 2 comprised all the SRL latent variables, and Model 3 the EF latent variables. A Chi-square difference test statistic was used to measure the differences between the models (where $p < 0.05$ means a significant difference).

3 Results

The study was conducted as planned with no significant details in implementation. The results will answer the research question of the combined value of EF added to SRL to better understand the differences in study success. We hypothesize that EF and SRL combined explain statistically significantly more variance in the number of credits obtained at the end of the academic year than each construct separately.

First, we provide descriptive data, then discuss the correlations between the different constructs (EF and SS, SRL and SS, and EF and SRL) and finally, test the hypothesis.

3.1 Descriptive statistics

The students' total BRIEF-A *raw* scores ranged between 75 and 178. The average was 118.01 (SD = 19.10). Their average *normative* scores fell in the range of "normal or average" level of perceived EF deficits (*T*-score between 30 and 59) to "clinical (*T*-scores 65 and higher)." Approximately 17% of the student population was in the subclinical range (defined as a *T*-score of 60–64), whereas 20% of the students perceived EF deficits in the clinical range (*T*-score ≥65). It is expected that for some EF scales a cut-off score of

$T \geq 80$ may be more valid, for instance, "working memory" (Abeare et al., 2021). So, the percentage of students that realistically report "clinical" EF deficits, might be lower than 20%.

The MSLQ has no specific cut-off scores. The average total score of motivated strategies of students was 5.06 (SD = 0.57) on a scale of 1–7. The average total score of learning strategies was 4.49 (SD = 0.65) on a scale of 1–7.

Finally, the obtained credits after one school year ranged from 0 to 60, with 60 points being the maximum possible. The average was 49.03 (SD = 15.54).

3.2 The correlations between executive functions, self-regulated learning, and study success

We conducted correlation analyses to examine the relationships between EF-SRL, EF-study success, and SRL-study success. Table 5 shows the relationships between EF and SRL. We found weak correlations (range $r = -0.23$ to $r = -0.26$) among the composite scores of the self-reported measures: between EF behavioral and metacognitive indices and SRL motivational beliefs index, and the EF indices and SRL learning strategies index.

At the level of subscales, there are many weak to strong negative correlations between SRL subscales and EF subscales. The directions of the significant correlations indicate that students who report more EF problems also report using fewer SRL strategies.

Table 6 describes the correlations between EF and study success. We found weak but significant correlations between study success and six EF subscales (range $r = -0.12$ to $r = -0.24$). These (weak) correlations suggest that an increase in EF problems is associated with less study success.

Table 7 describes the correlations between SRL and study success. The correlation analysis between SRL and study success resulted in weak significant correlations between study success and six SRL subscales (range $r = -0.11$ to $r = 0.21$). Overall, these findings suggest that an increase in applying SRL is associated with more study success.

To sum up, we found significant correlations between all the constructs.

3.3 Hypothesis test of the explanatory model of variances in study success

To test our hypothesis, we evaluated the model fit through SEM after performing confirmatory and exploratory analyses. The model shown in Figure 2 was tested.

The total model without restrictions fit the data well according the Hu and Bentler (1999) thresholds (χ^2/df = 1.53; SRMR = 0.06; RMSEA = 0.04; CFI = 0.84), except for the CFI.

The CFI does not reach the preferred threshold of a minimal 0.90, meaning that the hypothesized model may not fit the observed data as well as is preferred (Van Laar and Braeken, 2021). Nevertheless, a model with a CFI value below 0.90 can be interpreted if the other measures meet the stated requirements – which is the case (Marsh et al., 2004). Another consideration is that the CFI might have dropped because our model is large and complex (Pat-El et al., 2013), and Hu and Bentler's cut-off values may be too stringent in these cases (Marsh et al., 2004, 2005). Specifically, Marsh (2007, p. 785) states that "It is almost impossible to get an acceptable fit (e.g., CFI, TLI > 0.9; RMSEA < 0.05) for even 'good' multifactor rating instruments when analyses are done at the item level and there are multiple factors (e.g., 5–10), each measured with a reasonable number of items (e.g., at least 5–10/per scale) so that there are at least 50 items overall" which is the case in our study. Therefore, we continued testing the model, demonstrating that the total model explains 40.1% of the variance in obtained credits (Table 8).

To explore if the combination of EF and SRL explains the variance in the number of credits better than EF and SRL separately, Models 2 and 3 were tested (respectively, Figures 3, 4). The model with the EF variables provided a good fit to the data (χ^2/df = 1.47; SRMR = 0.06; RMSEA = 0.04; CFI = 0.93), explaining 19.8% of the variance in obtained credits. The model with the SRL variables explained 22.9% of the variance in obtained credits and had a worse fit than the model of the EF, but can be considered a sufficient fit to the data (χ^2/df = 1.88; SRMR = 0.07; RMSEA = 0.05; CFI = 0.85), again except the CFI threshold. Chi-square difference tests showed that both the EF and SRL models differ significantly from the total model (respectively EF model: χ^2diff = 5,439.29; df = 3,535; $p < 0.001$ and SRL model: χ^2diff = 3,965.71; df = 2,643; $p < 0.001$), indicating that the combination of EF and SRL better explains the variance in obtained credits than EF and SRL separately.

In conclusion, the total model explains the most variance (39.8%) in the obtained credits.

3.4 Impact of the COVID-19 pandemic on executive functions and self-regulated learning

We used Pearson's correlation method to calculate the mean score on the question assessing the impact of the COVID-19 pandemic ($M = 1.74$; SD = 0.78) with the index scores of the BRIEF-A (EF) and MSLQ (SRL). The data showed weak, significant correlations between the answer to this question and EF metacognition ($r = -0.21$; $p < 0.001$), SRL motivational strategies ($r = 0.18$; $p = 0.001$), and SRL learning strategies ($r = 0.15$; $p = 0.007$). These results imply that the more the COVID period has led students to have a more pessimistic attitude toward their study process, the more EF metacognition problems were reported, and the fewer SRL strategies were used.

4 Discussion

This study sought to investigate the added value of including EFs and SRL in predicting study success after one academic year among higher education students. We explored (1) the relationship between EF and SRL the relationship between EF and study success and SRL and study success, and we hypothesized that (2) the combination of self-reported EF and SRL would explain differences in study success better than separately. First, Regarding the relationships between the constructs our findings show that EF and SRL are correlated. This is consistent with previous studies

TABLE 5 Pearson product-moment-correlations between self-regulated learning and executive functions.

EF indices and subscales SRL indices and subscales	Behavioral index	Metacognitio index	Inhibit	Shift	Emotional control	Self-monitor	Initiate	Working memory	Plan/ organize	Task monitor	Organizing materials
Motivational beliefs	−0.23**	−0.26**									
2. Intrinsic goal orientation			−0.11*	−0.03	−0.06	0.01	0.00	−0.16**	−0.09	−0.06	−0.06
3. Extrinsic goal orientation			−0.15**	−0.10	0.12*	−0.19**	0.03	−0.23**	−0.12*	−0.15**	−0.13*
4. Task value			−0.09	−0.06	−0.13*	−0.08	−0.04	−0.18**	−0.08	−0.08	−0.09
5. Control beliefs			−0.00	0.03	−0.18**	−0.12*	−0.03	0.00	−0.01	0.00	−0.18**
6. Self-efficacy			−0.19**	−0.04	−0.23**	−0.12	−0.12	−0.30**	−0.22*	−0.28**	0.00
7. Test anxiety[1]			0.23**	0.04	0.35**	0.41**	0.04	−0.22**	0.21*	0.23**	0.16*
Learning strategies	−0.09	−0.24**									
8. Rehearsal			−0.12*	−0.06	0.06	0.12*	0.06	−0.17**	−0.11	−0.14*	−0.12*
9. Elaboration			−0.14*	−0.07	−0.08	0.05	−0.05	0.23**	−0.18**	−0.20*	−0.17**
10. Organization			−0.13*	−0.07	0.07	0.15**	0.00	−0.25**	−0.09	−0.22**	−0.16**
11. Critical thinking			0.05	0.10	−0.07	−0.00	0.01	0.09	0.05	0.05	0.05
12. Metacognitive self-regulation			−0.14**	−0.16**	−0.12*	−0.02	−0.12*	−0.24**	−0.20**	−0.23**	−0.19**
13. Time and study environment			−0.37**	−0.34**	−0.11*	−0.09	−0.24**	−0.51**	−0.34**	−0.51**	−0.41**
14. Effort regulation			−0.36**	−0.35**	−0.11*	−0.09	−0.24**	−0.52**	−0.34**	−0.50**	−0.40**
15. Peer learning			−0.08	−0.01	−0.10	0.01	0.04	−0.07	−0.03	−0.12*	0.10
16. Help-seeking			−0.11*	−0.08	−0.08	−0.01	−0.02	−0.16**	−0.10	−0.21**	−0.14*

The behavioral index score includes inhibit, shift, emotional control, and self-monitor. The metacognitive index score includes the initiate, working memory, plan/organize, task monitor, and organization of materials. Motivation scales refer to the total of the subscales below. The same is true for learning strategies. [1]Test anxiety is reversed; a higher score refers to more test anxiety which implies more problems with studying.

*Correlation is significant at 0.05 level (two-tailed).

**Correlation is significant at 0.01 level (two-tailed).

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TABLE 6 Pearson product-moment-correlations between executive functions and executive functions and study success (obtained credits).

Variable	Mean	SD	Range	1	2	3	4	5	6	7	8	9	10	11	12
1. Study success	49.03	15.54	0–60	–											
2. Executive functions total	116.51	19.00	69–207	−0.21**	–										
3. Behavioral index	47.93	8.61	30–90	−0.02	0.70**	–									
4. Metacognition index	68.58	14.35	39–117	−0.27**	0.90**	0.33**	–								
5. Inhibit	13.63	2.88	8–24	−0.18**	0.53**	0.62**	0.33**	–							
6. Shift	9.78	2.52	6–18	0.07	0.51**	0.71**	0.25**	0.21**	–						
7. Emotional control	15.89	4.67	10–30	0.08	0.50**	0.82**	0.17**	0.18**	0.56**	–					
8. Self-monitor	8.63	1.97	6–18	−0.09	0.45**	0.61**	0.23**	0.56**	0.22**	0.23**	–				
9. Initiate	14.5	3.36	8–24	−0.24**	0.66**	0.43**	0.62**	0.40**	0.36**	0.24**	0.24**	–			
10. Working memory	14.22	3.32	8–24	−0.12**	0.61**	0.54**	0.49**	0.54**	0.41**	0.28**	0.37**	0.55**	–		
11. Plan/organize	16.46	3.75	9–27	−0.20**	0.61**	0.45**	0.53**	0.48**	0.33**	0.21**	0.34**	0.69**	0.66**	–	
12. Task monitor	10.91	2.14	6–18	−0.19**	0.59**	0.48**	0.49**	0.58**	0.26**	0.20**	0.45**	0.60**	0.60**	0.68**	–
13. Organization of materials	13.99	3.57	8–24	−0.16**	0.44**	0.30**	0.41**	0.37**	0.12*	0.18**	0.21**	0.48**	0.40**	0.51**	0.55**

A higher BRIEF score refers to more self-reported problems with executive functions. The "Executive functions total" is the total score of all executive functions (5–13). The behavioral index score includes inhibit, shift, emotional control, and self-monitor. The metacognitive index score includes initiate, working memory, plan/organize, task monitor, and organization of materials.

*Correlation is significant at 0.05 level (two-tailed).

**Correlation is significant at 0.01 level (two-tailed).

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TABLE 7 Pearson product-moment-correlations between self-regulated learning, and self-regulated learning and study success (obtained credits).

Variable	Mean	SD	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1. Study success	49.03	15.54	–														
Motivation scales	5.06	0.57															
2. Intrinsic goal orientation	5.03	0.90	0.10	–													
3. Extrinsic goal orientation	4.82	1.09	0.17**	0.22**	–												
4. Task value	5.05	0.95	0.00	0.59**	0.30**	–											
5. Control beliefs	5.46	0.81	−0.05	0.27**	0.09	0.36*	–										
6. Self-efficacy	5.53	0.77	0.11	0.44**	0.26**	0.40**	0.52**	–									
7. Test anxiety[1]	3.50	1.41	−0.06	−0.07	0.30*	0.01	−0.19**	−0.30**	–								
Learning strategies	4.49	0.65															
8. Rehearsal	4.38	1.25	−0.04	0.29**	0.27**	0.36**	−0.02	0.10	0.16**	–							
9. Elaboration	4.94	0.88	0.13*	0.46**	0.30**	0.48**	0.22**	0.36**	0.08	0.58**	–						
10. Organization	4.36	1.24	0.03	0.28**	0.36**	0.32**	0.00	0.14*	0.23**	0.70**	0.65**	–					
11. Critical thinking	3.97	0.98	−0.18*	0.30**	0.10	0.21**	0.06	0.11	0.08	0.15**	0.27**	0.21**	–				
12. Metacognitive self-regulation	4.42	0.76	0.06	0.46**	0.25**	0.42**	0.19**	0.30**	0.02	0.52**	0.67**	0.56**	0.39**	–			
13. Time and study environment	5.19	0.80	0.20**	0.26**	0.20**	0.30**	0.01	0.39**	−0.15*	0.21**	0.31**	0.26**	−0.13*	0.31**	–		
14. Effort regulation	5.03	0.96	0.21**	0.29**	0.23**	0.27**	−0.05	0.33**	−0.07	0.21**	0.31**	0.28**	−0.12*	0.31**	0.76**	–	
15. Peer learning	3.89	1.18	−0.04	0.23**	0.12*	0.18**	0.00	0.15**	0.02	0.20**	0.37**	0.29**	0.31*	0.39*	0.10	0.06	–
16. Help-seeking	4.21	1.22	0.11*	0.18*	0.10	0.04	−0.10	0.08	−0.02	0.24**	0.39**	0.29**	0.07	0.34**	0.26**	0.20**	0.53**

[1]Test anxiety is reversed; a higher score refers to more test anxiety which implies more problems with studying.

*Correlation is significant at 0.05 level (two-tailed).

**Correlation is significant at 0.01 level (two-tailed).

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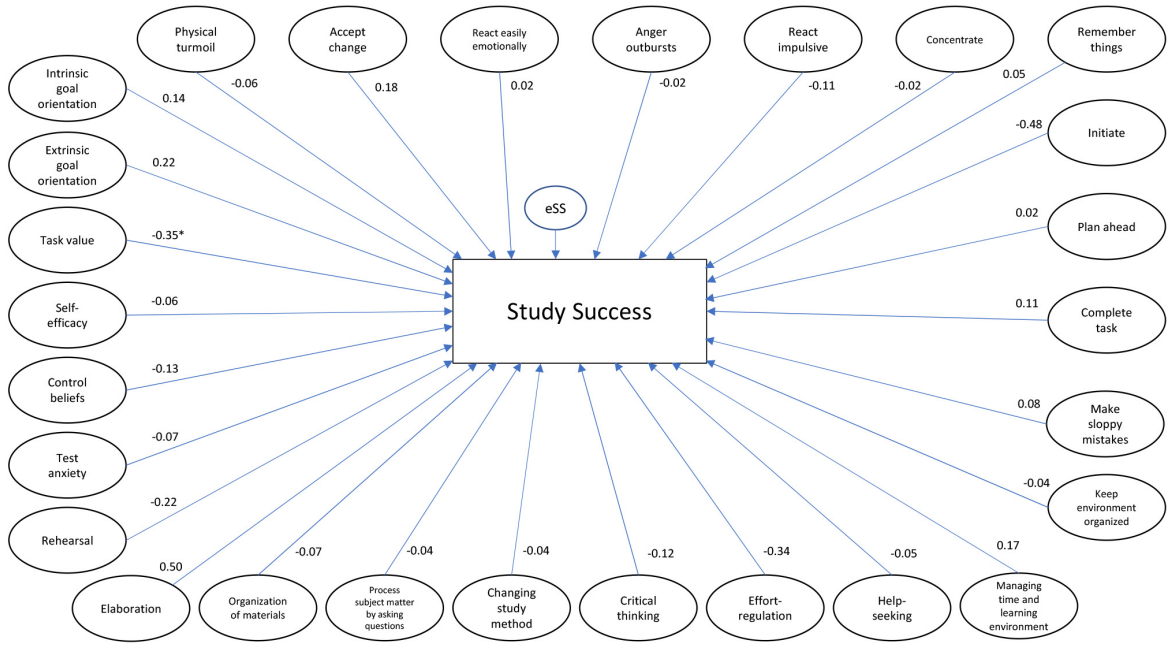

FIGURE 2
Total model, including all the latent variables of EF (starting above left "physical turmoil to keep environment organized") and SRL variables, standardized betas, and *p*-values. $*p < 0.05$.

demonstrating associations between EF and SRL among high school students (Effeney et al., 2013; Rutherford et al., 2018) and university students (Garner, 2009; Follmer and Sperling, 2016). The weak to moderate correlations between EF and SRL makes it clear that these concepts partially overlap but are not the same (Garner, 2009). In addition, EF and SRL both correlate – partially and weakly – with study success, indicating a trend of more EF problems or less SRL comes with fewer credits earned after one school year, in line with studies such as those by Baars et al. (2015) and Ramos-Galarza et al. (2020) for EF, and Li et al. (2018) and Moghadari-Koosha et al. (2020) for SRL.

Second, to better understand the influence of EF and SRL combined on the differences in study success, we compared the imposed models separately and combined. In line with our hypothesis, EF and SRL combined explained the variance in study success after one academic year better than EF and SRL separately. This indicates that a student who performs poorly on EF will likely demonstrate less effective SRL and likely have less study success. Similar results were found by Musso et al. (2019), although they used task-based EF measurements, whereas we used self-reported EF. Even though more research is needed, Musso's and our findings indicate that combining EF and SRL is vital for the learning processes. A student with more developed EF strategies can reflect on, choose from, or integrate rules where appropriate (Moran and Gardner, 2018, pp. 29–56) and thus be better able to self-regulate their learning and achieve more success.

The current study has some important strengths, such as the empirical confirmation of the need for integration of two theoretical models relevant to education and study success, with the use of proven valid and reliable instruments and the use of SEM to test the models while better accounting for measurement error (Tomarken and Waller, 2005).

On the other hand, this study has a few limitations. First, a non-probabilistic sample was used, namely students of Applied Psychology, which limits the generalization of the results to other groups of students or young adults. Future research could include students from different studies and levels as a more representative sample of young adult learners.

Second, self-reporting measurements were used, which have apparent advantages, such as surveying a large population without much effort and high ecological validity (Barkley and Fischer, 2011). However, a known pitfall with self-reporting is that students may (un)consciously fill out the questionnaires differently than they would show in observed behavior (e.g., McDonald, 2008; Demetriou et al., 2015).

Particularly, self-reports of cognitive abilities are sensitive to response bias and psychological factors, such as depression, anxiety, or chronic pain. For instance, Schwartz et al. (2020) found that self-reporting EF with the BRIEF-A probably measured emotional distress over executive dysfunction. However, they argued that this could be the case in specific samples such as theirs, namely middle-aged veterans who all showed intact EF and experienced heightened psychiatric distress. Abeare et al. (2021) demonstrated inconsistent results to the conclusion of Schwartz et al. (2020), suggesting a more plausible explanation that "non-credible presentation manifests as extreme levels of symptoms on the BRIEF-A-SR- and self-report inventories in general" (Abeare et al., 2021, p. 9). Additionally, a reasonable number of studies have shown that the BRIEF-A can validly measure EF in various target groups such as deaf and hearing students (Hauser et al., 2013), students and procrastination (Rabin et al., 2011), and depression within students (Mohammadnia et al., 2022).

Nevertheless, both Schwartz et al. (2020) and Abeare et al. (2021) suggest that on the validity scale "negativity" a cut-off

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TABLE 8 Structural equation model (SEM) of EF and SRL, and EF separately to SRL.

	χ^2	df	χ^2/df	SRMR	RMSEA [CI]	CFI	AIC	Model comparison	df	Δ CMIN	*p*
Model 1: total	6530.209**	4278	1.53	0.06	0.04 [0.04, 0.04]	0.84	7676.209				
Model 2: EF	2564.50**	1365	1.88	0.06	0.04 [0.03, 0.04]	0.93	1410.922	2 vs. 1	3535	5439.29	<0.001
Model 3: SRL	2,738.75**	1,420	1.93	0.07	0.065 [0.05, 0.06]	0.85	3026.496	3 vs. 1	2643	3965.71	<0.001

** $p < 0.001$.

score of 4 (instead of ≥6) is more representative (i.e., essentially a frequency count of the extreme self-ratings on 10 items of the BRIEF-A). In our study, this would imply that 10 more students should have been disregarded as outliers. However, considering this small number of students, we do not expect different outcomes. To gain insight into the impact of assessment mode on outcomes, research is needed that includes both self-report measures of EF and SRL and objective measures, such as neuropsychological tests for EF or learning analytics for SRL (Yamada et al., 2017). Additionally, measurement instruments that can support screening for non-credible symptom reports can be used (Abeare et al., 2021), such as the MMPI-2 (Schwartz et al., 2020).

Subsequently, a CFI (just) below 0.9 indicates a reasonable but not good fit of the model with the dependent variable. That is, as argued, if the CFI scale is considered as a continuum and not, as is often incorrect, as a dichotomous scale. If our model had had a higher CFI, it would be easier to make statements about the relationship between the variables in the model and the outcome measure. However, this does not alter the fact that the correlations between the various SRL scales and the EF scales with study success have been reliably established. The lower CFI mainly concerns correlations between these (sub)scales, making it more difficult to see what their unique contribution is to study success. Further research will be required to investigate this further.

A final limitation might have been that this study was conducted during the COVID-19 pandemic. Research demonstrates that the lockdowns and other restrictive regulations impacted students' lives considerably (e.g., Copeland et al., 2021; Ihm et al., 2021), and therefore we investigated the self-reported impact of COVID on how students completed the questionnaires. We found that this period negatively related to how students experience their EF and SRL. This was especially true for students reporting severe EF problems, which implies that the results might be colored because assessments were conducted during the pandemic. Appelhans et al. (2021) found a similar result: young adults with preexisting EF deficits have shown increased unhealthy behavior since COVID-19. We think this period especially challenged students' EF because of the constant flow of new and complex issues they encountered. Nevertheless, although students' response patterns might have deviated a bit due to COVID-19, we think that, in light of previous research, patterns would have been the same when assessed in regular times. However, it might be valuable to repeat the study in non-pandemic times.

Future research could further explore how EF and SRL impact study success in theory and practice. One aspect is that a large part of the variance in study success is still unaccounted for, and future research could focus on finding additional answers, for example, in personal and contextual regulatory factors, such as studied by De la Fuente et al. (2022) and Pachón-Basallo et al. (2022).

Another aspect is that EF and SRL have different yet complementary conceptual lenses on how students learn and achieve success [such as Dinsmore et al. (2008) suggest for metacognition and SRL]. Although our study is not about the conceptual lens of EF and SRL, further research into how we can learn from both ways of looking at things to understand student study behavior is desirable since the results confirm that, taken together, they better predict study success even though they do not measure the same thing. The findings of this study can be used to motivate improving learning environments in higher education.

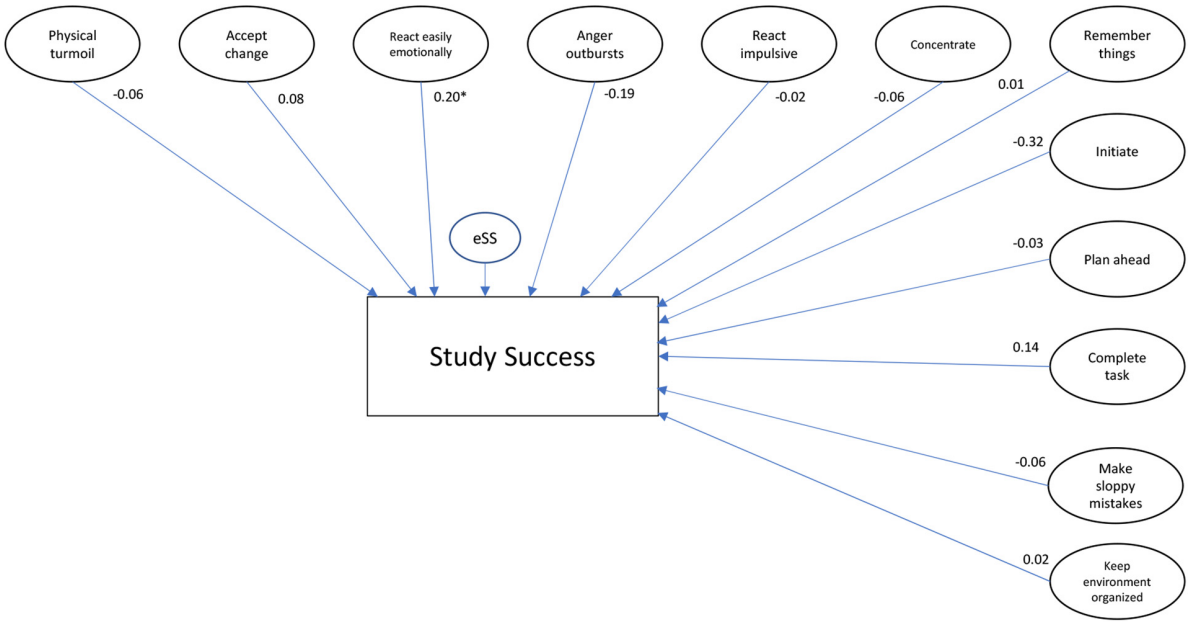

FIGURE 3
(Self-reported) EF model, including all the latent variables of EF, standardized betas, and *p*-values. *$p < 0.05$.

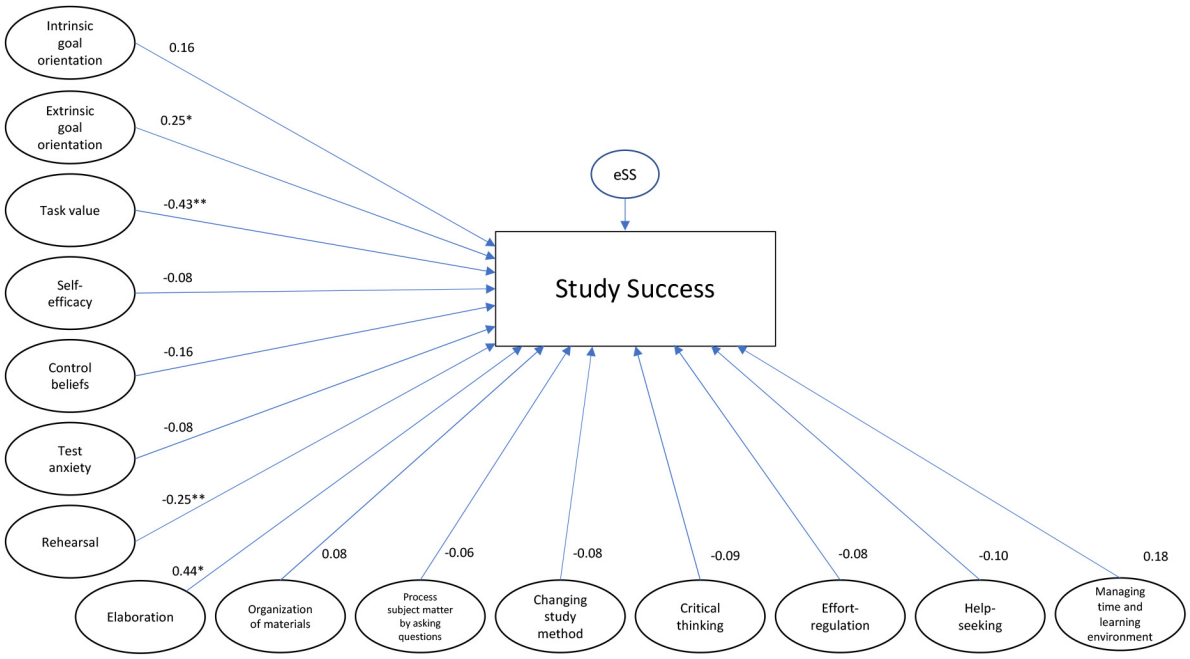

FIGURE 4
(Self-reported) SRL model, including all the latent variables of SRL, standardized betas, and *p*-values. *$p < 0.05$; **$p < 0.01$.

Since EF and SRL combined better explain the differences in study success, it makes sense to look at the available EF tools to expand the educational professional's toolbox beyond the already available SRL tools (e.g., Theobald, 2021). Providing education of EF in addition to SRL probably increases the levels of success in students. Furthermore, metacognitive knowledge about SRL and EF leads to more motivation to use the learned strategies correctly (e.g., Veenman, 2011; Follmer, 2021). Additionally, in the design of (blended) learning environments, educational professionals can build a certain degree of adaptivity when considering different levels of students' EF, knowing that individual differences are significant. For example, regarding problems with task initiation, one can think of a lesson structure with more intermediate moments during which a student can ask a supervisor for help, more formative tests, or additional (warm-up) assignments in a module that support and encourage the start-up. This way

of working is not new and also falls under the intersection of educational science, psychology, and neuroscience, also called neuroeducation (e.g., Jolles and Jolles, 2021; Willingham, 2023).

5 Conclusion

In conclusion, this study highlights that while EF and SRL cohere and are related to study success, they do not measure the same. This is also reflected in that each separately explains less variance in study success than taken together. Nonetheless, combined they provide more information about how student achieve study success. Generally, a student reporting EF deficits will likely report less effective SRL and achieve less study success in the long-term. This suggests that attention to EF alongside SRL in education is justified and valuable. Future theoretical research on both the working mechanisms of EF and SRL is needed, as well as the more practical application of the knowledge associated with EF and SRL.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The studies involving humans were approved by Ellis van Dooren-Wissebom, chairperson of the LLM Saxion Ethical Advice Committee (SEAC). The studies were conducted in accordance with the local legislation and institutional requirements. Written informed consent for participation in this study was provided by the participants.

Author contributions

DM secured funding for the study, conceptualized the study, oversaw, and conducted the data collection, analyzed the data, and led the writing of the manuscript. MS-D managed the data collection in SPSS and contributed to drafting the method and result sections of the manuscript. JD supervised the design, data collection and analyses, and manuscript writing. JF supervised the writing of the manuscript. AJ provided feedback on the latest versions of the article. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpsyg.2023.1229518/full#supplementary-material

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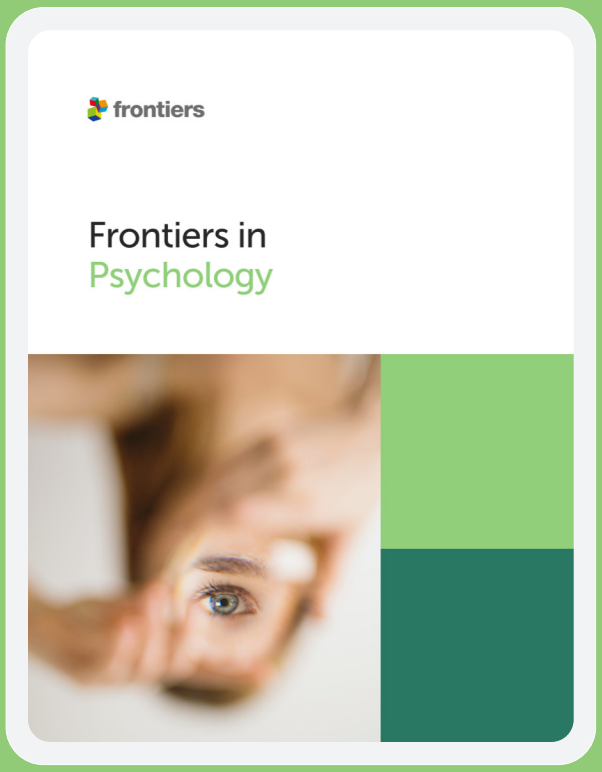

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