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Behavior and self-similarity between nano and human scales: From T-pattern and T-string analysis (TPA) with THEME to T-societies

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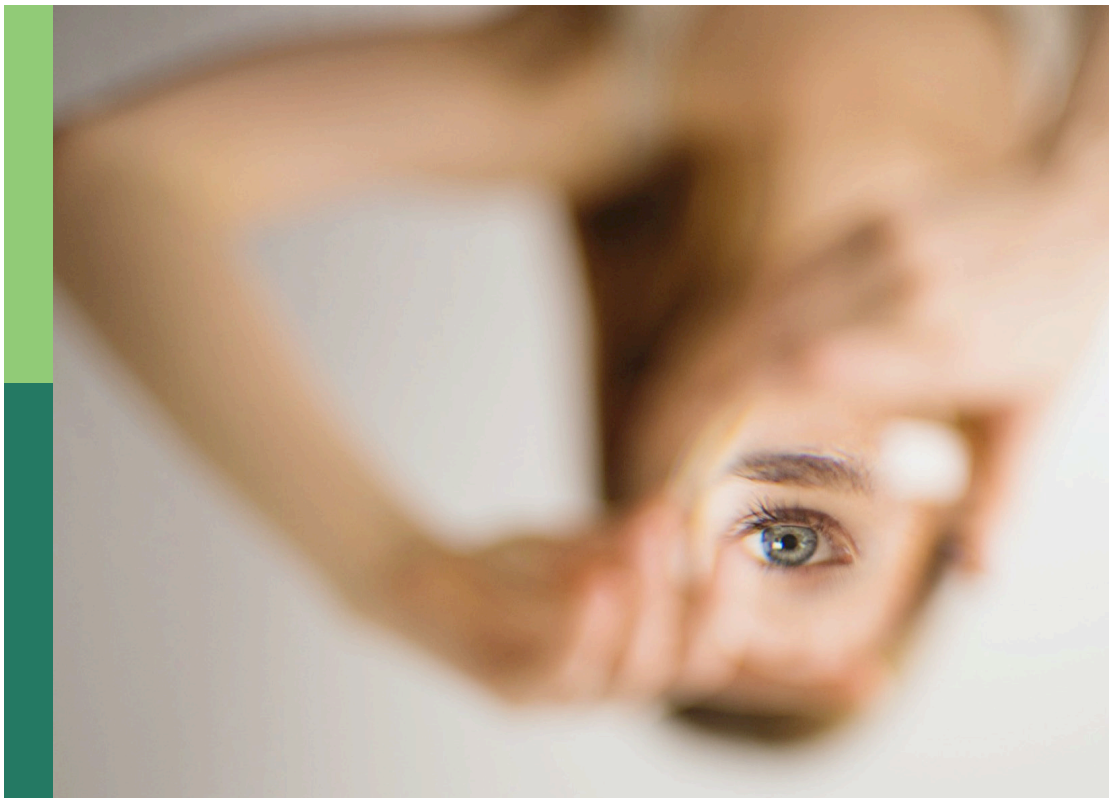

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Editorial: Behavior and self-similarity between nano and human scales: from T-pattern and T-string analysis (TPA) with THEME to T-societies

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Editorial on the Research Topic
Behavior and self-similarity between nano and human scales: from T-pattern and T-string analysis (TPA) with THEME to T-societies

This project was inspired in the sixties by primatologist Morris's (1967) "The Naked Ape," Tinbergen (1963), Von Frisch (1967), and Lorenz (1974) ethological research, rewarded in 1973 by a shared Nobel Prize in Medicine or Physiology, and Wilson's (1975) opus "Sociobiology". Other important inspirations were Skinner (1969) work on probabilistic real-time contingencies, Chomsky (1957) on syntactic structure and creativity, Montagner (1971) on interactions in social insects and in children (Montagner, 2012), Duncan (1977) on turn-taking in human dyadic interactions, and Dawkins (1976) on behavioral hierarchy and detection algorithms.

Structured animal mass-societies ($>10^4$ individuals) are only found in insects and modern humans and understanding their similarities and differences became a major aim through a search for hidden interaction patterns. Existing multivariate and artificial neural network methods and models lacked adequate description and detection of complex real-time patterns requiring new mathematical time structure (1-D) models, now the T-system, with detection algorithms and software (THEME^{TM}).

The first was the T-pattern concept, a statistical hierarchical self-similar (pseudo-fractal) pattern recurring with significant translation symmetry since detected in human, animal, and brain network behavior (Magnusson, 1996, 2000, 2005; Casarrubea et al., 2015, 2018; Magnusson et al., 2016; Casarrubea and Di Giovanni, 2020). Gradually, more structural concepts i.e., T-meme, T-composition, T-associate, T-packet, T-music, T-string, T-religion, T-money, and T-society have been added constituting the T-system (Magnusson, 2020).

Spatial string T-patterns, called T-strings, characterize the extra-individual voluminous purely informational (inert) texts essential for the formation of specialized individuals in human mass-societies and the giant extra-individual DNA molecules essential for the formation of citizens in protein mass-societies. Such mass-societies based on Giant Extra-Individual Purely Informational T-strings or GEIPITS, and thus called T-Societies, are only found in proteins and humans and T-Societies of T-Societies only in humans, a unique self-similarity.

T-societies are notably not found in earlier Homo Sapiens nor in social insects that use very different mechanisms, more like those in bodies as societies of cells.

With the invention of writing, powerful precise cumulative extra-individual (external) memory, in a biological eye-blink human T-Societies appeared with this unique self-similarity across some nine orders of magnitude in years and size, coinciding with explosive growth in human knowledge, laws, science, and technology. While humans descend from earlier primates, human mass-societies descend from the far earlier mass-societies of proteins existing on the same bio-mathematical continuum unifying culture and biology.

Presenting a new view of human modern mass social life, we aim to give the reader the most up-to-date perspective on how T-pattern detection and analysis (TPA) with Theme has led to new insight into the structure of behavior, interaction, communication and social organization in both human and non-human subjects. Contributions in this Research Topic (RT) range from different areas such as behavioral and brain sciences, health sciences, sport science, education, and communication thus suggesting the remarkable affordability and versatility of TPA in the study of the most multifaceted aspects of human and non-human behavior.

The diversity of disciplines utilizing TPA does not place a preferential order in the fruition of the contents, with the sole exception of the contribution that the Reader of this RT should take into consideration first, i.e. that of Magnusson, creator of the T-system and TPA. In his elegant work, in fact, the Author presents important propaedeutic aspects of theoretical and conceptual order concerning the model and method at the basis of the detection algorithm. He then continues with the definition of his new and striking addition to the T-system, the concept of T-societies the basis for his definition of the biomathematical self-similarity and uniqueness of human mass-societies at the heart of this RT. The RT continues with a contribution by Fioretti and Neumann in which the Authors summarize and rationalize current typologies of organizational forms, arranging available classifications in a hierarchy of increasing generality; in a second step, they discuss various communication structures pointing to the presence of several sources endowed with global connections as the most efficient diffusion mode. Sáiz-Manzanares et al. present a systematic review of the use of TPA during the last half decade with a special focus on mixed methods and data mining techniques; the contribution offers a detailed overview of the use of the approach in the study of human and non-human behavior. Alonso-Vega et al. discuss the role of verbal interaction pattern analysis in Clinical Psychology, analyze the patterns of verbal interactions, and compare the results using TPA and GSEQ, i.e., a software tool sequential analysis. Simon and Blanchet focus on three adult-child relationships: those with a foster carer, a father, and a mother; interestingly, very different interactive processes were identified: for instance, with the foster carer the interaction patterns were mainly focused on play objects, whereas they involved more collaborative activity with the father and distraction/avoidance behaviors with the mother. Santos et al. discuss the use of TPA in Sport Science, by analyzing offensive and defensive actions of football goalkeepers; the authors argue that the study could contribute to a better knowledge of the goalkeeper's behaviors in the competition. Pennill and Timmers propose an original application of TPA in describing patterns of verbal interaction in newly formed music ensembles; the Authors suggest that such a novel use of TPA could contribute to the understanding of human group behavior and interaction patterns leading to expert team performance. Casarrubea et al. present a review of the use of different approaches, such as transition matrices based analyses and TPA, in the study of the behavior from rodents to non-human primates; the Authors discuss the advantages and drawbacks of each approach and suggest that their work could represent a useful background for all scientists who intend to study quantitative and structural aspects of behavior. Anguera et al. present an elegant review of the use of TPA in the modern scientific literature; following PRISMA guidelines, searches were carried out by means of different and widely known scientific databases such as Scopus, PsycINFO, Web of Science; the Authors conclude that TPA shows a remarkable affordability and applicability and that a noticeable presence TPA in studies using observational methodology is evident. Chacón-Moscoso et al. the so-called "Methodological Quality Scale" (MQS), i.e., a tool with adequate reliability, validity evidence, and metric properties; the Authors suggest that, unlike other existing scales, MQS is easy to apply and methodological quality profiles can be obtained in different areas of intervention and with different types of methods. Finally, in the field of Pedagogical Science, Belza et al. present a study concerning the application of TPA to identify important aspects of the choreography followed by Pikler educators; results show complex patterns and how educators establish interaction with children.

As Editors of this RT, we are delighted to say that it has been a great pleasure to host such different contributions and from such different fields of research, and we hope that the Reader will have the same pleasure in reading these contributions, which, we are sure, will be able to provide useful insights for all those researchers who intend to use TPA in their research.

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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SYSTEMATIC REVIEW
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A Systematic Review of the Use of T-Pattern and T-String Analysis (TPA) With Theme: An Analysis Using Mixed Methods and Data Mining Techniques

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In recent years, research interest in human and non-human behavioral analysis has increased significantly. One key element in the resulting studies is the use of software that facilitates comparative analysis of behavioral patterns, such as using T-Pattern and T-String analysis -TPA- with THEME. Furthermore, all these studies use mixed methods research. Results from these studies have indicated a certain amount of similarity between the biological, temporal, and spatial patterns of human social interactions and the interactions between the contents of their constituent cells. TPA has become an important, widely-used technique in applied behavioral science research. The objectives of the current review were: (1) To identify the results of research over the last 4 years related to the concepts of T-Pattern, TPA, and THEME, since it is in this period in which more publications on these topics have been detected (2) To examine the key concepts and areas in the selected articles with respect to those concepts, applying data and text mining techniques. The results indicate that, over the last 4 years, 20% of the studies were laboratory focused with non-humans, 18% were in sports environments, 9% were in psychological therapy environments and 9% were in natural human contexts. There were also indications that TPA is beginning to be used in workplace environments, which is a very promising setting for future research in this area.

Keywords: behavioral structure, similarity, systematic review, THEME, T-Pattern, T-String, T-System

INTRODUCTION

The T-System (Temporal System) is a method for analyzing patterns of events over time, often revealing patterns that may be hidden when using other methods of analysis. It refers to a set of temporal data (T-data), which is the accumulation of occurrences over a continuous period of observation (Magnusson, 2020a,b). According to Magnusson (2020a), the T-System indicates the similarity of measurement at a nanometer scale (measurements of physical and chemical properties of matter at scales of one millionth of a millimeter) and analysis of

human and non-human behavioral patterns, analyzed in as microanalytical a manner as possible. T-data can be collected using multimedia encoders—which may be chips embedded in various tissues—that computerize the DNA or protein molecular data, transforming it into two-column text files that are processed via the THEME software (Magnusson, 2020a). The collected data are stored in separate files which in turn can be linked together and analyzed in combination as a multi-sample file within THEME (Magnusson, 2020c). THEME v. 6 Edu is free software that allows us to analyze the characteristics of the data and to represent the results as dendrograms and tree diagrams, among other functions (Arias-Pujol and Anguera, 2020). From this information analyzed in THEME, patterns are established based on a minimum number of occurrences found based on search parameters (Magnusson, 2020b). Patterns will repeat more frequently in a multi-sample file than in a single-sample file (Magnusson, 2020a). Data is collected using mixed methodologies that record qualitative data related to the event being studied and quantitative data linked to the frequency of occurrences of these events in real time (Magnusson, 2020c).

T-Patterns (temporal patterns) are segments of signals that are frequently repeated throughout the temporal signal sequence. For example, temporal signal sequences can be movements of the head, eyes, hand, etc. or of the body in general. T-Pattern detection was developed by Magnusson (1996, 2000, 2004, 2005, 2006, 2009, 2016, 2017, 2018, 2020a,b), who considered patterns to be a combination of events that invariantly follow each other in a given sequential and temporal order. They can also refer to patterns of behavior and habits in humans or non-humans. Detection of T-patterns in the T-System is relevant to understanding the relationship between human behavior and phenomena which occur at different levels of biological, temporal and spatial organization (Magnusson, 2020a). Physical strings containing spatial patterns are called T-Strings (Temporal strings, referring to strings in time) and are considered the latest addition to the T-system, for example, the analysis of patterns in the transformation and encoding of DNA into text (Magnusson, 2020b).

Origin and Description of T-Pattern and T-String Analysis (TPA). Similarity Between Nano and Human Scales

The initial inspiration for the T-Pattern was based on classical theories such as Chomsky's (1957) homogeneity of the human genome for learning language, Skinner's (1969) operant conditioning behaviorism, and Tinbergen's (1963) ethological research relating the behavioral patterns of non-human species in their natural environments. These theories shared the need to understand how pre-established traits are established by the existence of behaviors that occur at the same time, follow each other, and appear with a certain frequency (Magnusson, 1981, 1983, 1989). The technological development of computer science, and especially artificial intelligence, has made it possible to draw lines between phenomena examined in psychological theories such as the computational theory of the mind, cellular-level processes and, in turn, computational algorithms (Magnusson, 2020a).

This mathematization of data facilitates the detection of formal and hidden patterns (referring to behavioral patterns—habits or behaviors—or motor behaviors—movements, stereotypies—that may be explicit or easily detectable, and others that require deeper analysis or different analysis in order to be revealed) and suggests artificial categories of certain temporal configurations (Magnusson, 2018). In particular, Heylighen (2016) it refers to Stigmergy as a universal coordination mechanism and its components and Collignon and Detrain (2020) analyze the relationship between self-organization and stigmergy. Specifically, the T-Pattern can be considered a hierarchical structure similar to a geometric object (akin to a fractal) which repeats itself at different scales in a single discrete dimension, is initially produced in real time, and exhibits similarities between its structures at spatial, temporal and biological levels (Magnusson, 2020b). These structures are characteristic of molecular organization such as genes and the corresponding 3D extension of their folded proteins (Magnusson, 2020a). In this way, the T-Pattern facilitates the detection of hidden structures that support human behaviors at the nanoscale level and allow them to be categorized, and is widely used in various scientific disciplines such as biology, computer engineering, psychology, pedagogy and mathematics (Casarrubea et al., 2018, 2020). Likewise, these findings contribute to the development of artificial intelligence when applied to the study of neuronal interactions (level 10^{-6}) and are combined with applied statistics methods to promote the detection of effects produced by experimental variables (Nicol et al., 2015; Castañer et al., 2020).

The premise of detection in this interactive chain of behaviors is supported by the underlying stable T-Pattern structures (Arias-Pujol and Anguera, 2020; Cenni et al., 2020; Santoyo et al., 2020). T-Pattern analysis (TPA) is based on the use of algorithms that calculate temporal distances between behavioral codes and evaluate the critical interval that remains unchanged (Suárez et al., 2018; Santangelo et al., 2020). This pattern can also be used to decipher unfamiliar non-verbal interactions and to understand how they function and their meaning, as well as contributing to diagnosing individual and group behavioral traits with respect to the experimental conditions in which they occur (Magnusson, 2020b). Standardization of the analysis is serving as a methodological guide for an assessment of social interaction involving 32 European and US universities (Magnusson, 2018). Some of the limitations of TPA noted by Magnusson (2020b) are that the analysis is mainly performed on binary trees, which are inefficient for detecting higher-order structures; the significance is decided by the users controlling the programme and not by the algorithm; and each variant of the pattern can only be detected as a different pattern when it occurs a certain number of times (Portell et al., 2019; Gunst et al., 2020).

TPA allows for the analysis of similarity between the nanoscale and the human scale by encompassing spatio-temporal information from different levels of biological organization (Magnusson, 2018). Recently, advances in cellular and computational biology have allowed T-Strings (spatial

T-Patterns in physical chains) to be analyzed using TPA, allowing analogies to be made between those T-String patterns and the information chains in cellular DNA that have remained stable for millions of years (Arias-Pujol and Anguera, 2020; Karcioglu and Bulut, 2021). These analyzes are helping us to understand the specific and joint tasks performed by organelles within each cell for cell survival, something which has been called "Cell City" (Magnusson, 2020a). The "Cell City" is a way of considering cellular organization made up of different organelles that perform various tasks to ensure the cell remains active. For instance, mitochondria can be thought of as similar to an energy company, the nucleus is the control center, similar to city hall, and the cell membrane resembles the boundaries of a city (Magnusson, 2020b). Ribosomes are made up of RNA and proteins and are the organelles responsible for protein synthesis by reading messenger RNA sequences and using the genetic code to translate those into amino acid sequences (Arias-Pujol and Anguera, 2020). The "Cell City" provides a way of thinking about the behavior of organisms or institutions (schools, factories, etc.) like proteins. Organizations instruct people how to process information, access it and encode it in their working memory so that they can perform whatever tasks are useful for the functioning of the city. The connections between the different institutions comprising different individuals is similar to the connections between neural networks and the different organs that condition behavior (Prat et al., 2019).

From this simile, an organelle can be represented as an entity or institution in the city, each with its own role, and organized interaction will ensure the functioning of the cellular metropolis (Magnusson, 2020b). It has been appreciated that connecting the processing chains between the organelles does not require great intellectual power other than defining the structures for systematic application of data operations that are similar and having a common simplified language to communicate effectively between the participating members of the "Cell City" (Magnusson, 2018). In contrast to the functioning of cellular organelles within the Cell City, the human brain has great intellectual power that could hinder synchronization and coordination between numerous individuals due to a lack of external chains controlling behavior through mass copying and distribution mechanisms (Casarrubea et al., 2019a; Casarrubea and Di Giovanni, 2020). This freedom of human decision-making in T-societies is changing and resembles the functioning of cellular organelles, as human behaviors are tending to become more homogenous globally as virtual connexions to the networks of mass societies are established. This situation promotes the development of increasingly similar social behaviors in what has been understood as globalization (Casarrubea et al., 2015).

Recent technological progress and advances in research support the similarities found between the behavioral and social structures that occur between proteins and human mass societies. Human organization tends to follow the patterns of cellular organization (Santoyo et al., 2020). In addition, there seems to be a similarity between the conversion of codes stored in RNA into DNA and the human capacity for information processing in problem solving or task solving in different situations (Magnusson, 2020b). Genetic structures are made up of purely informational strings and, in turn, the organization of human knowledge is largely underpinned by text processing (Portell et al., 2019; Prat et al., 2019; Camerino et al., 2020). These same analogies comparing the nanoscale functioning of the cell with the functioning of cities have previously been related to the gregarious behavior of insect groups (Merlet et al., 2005). The study of the underlying mathematical, physical and biological principles of T-societies applied to ethology showed that mass societies refer to structured animal groups of more than 10^4 individuals working collectively to achieve a common goal, such as social insects and modern humans (Magnusson, 2020a).

Humans have advanced from nomadic lifestyles to missions of exploration on other planets, linked to eternal colonization and cellular expansion focused on the purpose of securing and enhancing the survival of the species (Casarrubea et al., 2018). It seems that human societies are fully connected and stem from nano-creatures (Magnusson, 2020a). Human specialization is considered unique among animal species, as text coding increasingly resembles the specialization of the various proteins involved in structural and organizational processes within an organism (Dejan et al., 2013). The specific tasks in each human cell are regulated by how they are encoded, and errors in transformation of information can lead to cellular malignancy that can be predicted, detected and prevented if we know the patterns of these behaviors (Nicol et al., 2015). Wars can be compared to cellular miscoding that causes cells to become malignant and invade other tissues, causing the destruction of the organism, while at the human scale, they can devastate the planet (Casarrubea et al., 2019b, 2021b). According to Magnusson (2020b), an analogy of the T-String with religions can also be seen by noting the importance of standardized texts, their distribution and copying to generate a pattern, which in this case, is the codification of the moral rules of conduct to be followed, and by noting that certain religious creeds become dominant over others by replacing existing codes with their own. All this makes us rethink human behavior by suggesting that war, overpopulation, global warming, diplomatic relations, and the control of resources, show that we tend to follow cellular patterns, as do the repetition of historical events that have occurred throughout evolution (Magnusson et al., 2016). As de La Mettrie (1748) explained in "The Machine Man," this could lead us to ask ourselves whether we are just "robots" and that what we are doing is programming other structures similar to ours to repeat the patterns that have been standardized in our genetic code (Anguera et al., 2018).

Similarity from the nanoscale world to the human world started with linking from higher to lower levels in accordance with the discoveries that have been made (Magnusson, 2018). This premise does not indicate that a pattern corresponding to simpler data must always correspond to more complex data and vice versa, but rather that the discovery of similarity is considered to have come from the study of higher-level patterns because they were the data first accessed through natural observation (Santoyo et al., 2020). These similarities are related to the fact that the cell is part of the human body and is therefore one of the smallest structures that make up

mass societies (Arias-Pujol and Anguera, 2020). Analogy is a valuable tool for knowledge and provides a new source of information on the current, rapid, dramatic changes in how humanity lives. Nevertheless, these studies also highlight that there is no simple evolutionary pathway linking the inner workings of cells and human behaviors (Casarrubea et al., 2019c).

The Use of T-Pattern and T-String Analysis in Applied Research

After noting the similarity of human behavioral patterns analyzed in detail at the smallest possible scales of analysis similar to the structure of nanoscales in Temporal Partnership Analysis (TPA-T), the application of TPA in T-Society current research will now be explored. TPA-T is especially important in Behavioral

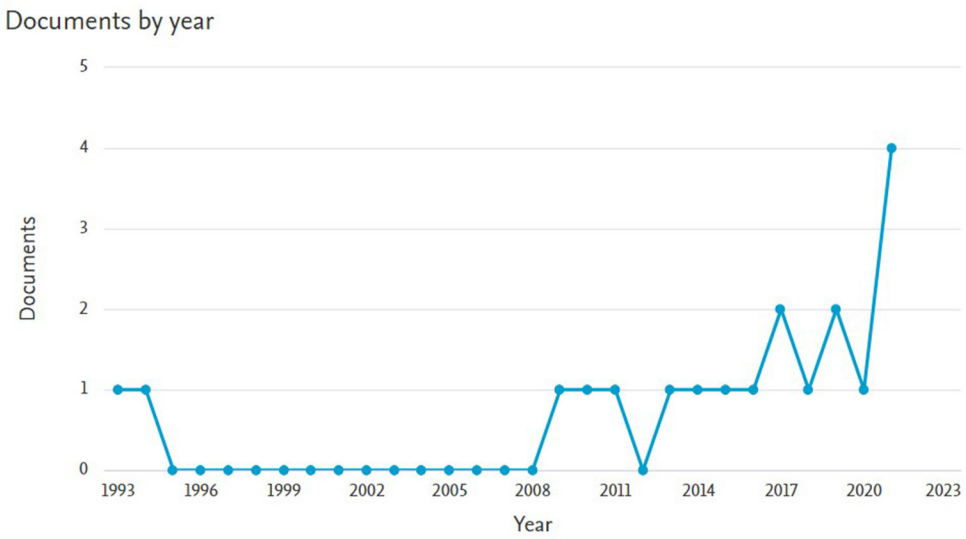

FIGURE 1 | Records found in Scopus for the keyword "THEME TPA."

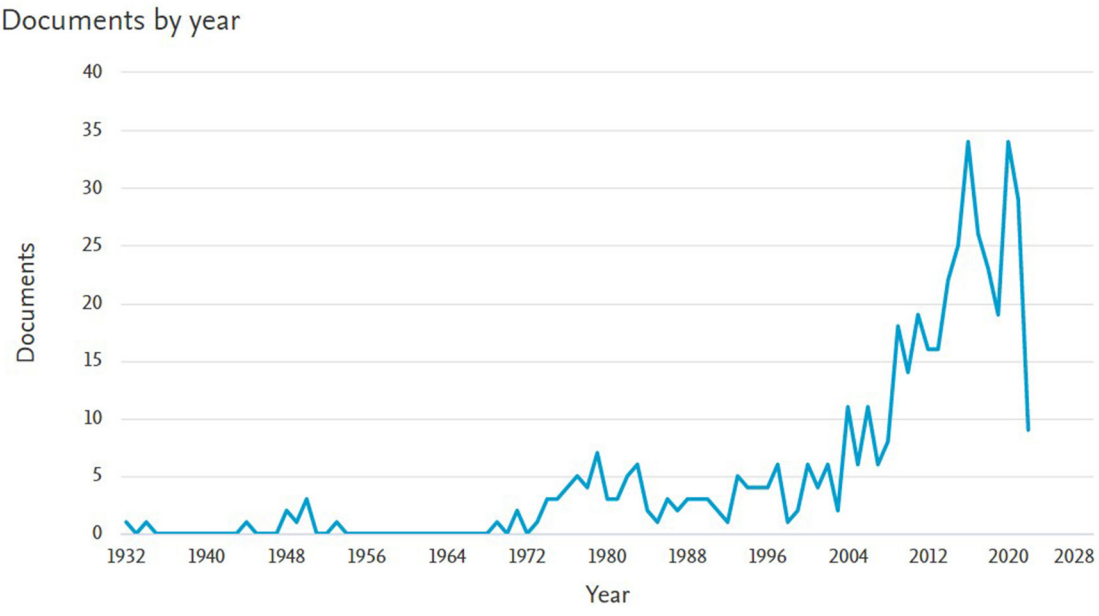

FIGURE 2 | Records found in Scopus for the keyword "T-Pattern."

Sciences because it facilitates the qualitative and quantitative informatisation of data by connecting information at the nanoscale with the human scale (Del Giacco et al., 2019). This extends the applicability of TPA to different disciplines ranging from genetics, proteomics, mass spectrometry, neuroscience, psychology, ethology, biology and mathematics to religious science (Magnusson, 2018).

The systematic review by Casarrubea et al. (2015) summarized application of the T-Pattern in non-human and human behavior. At the no-human level, numerous studies have used these processes to compare and evaluate stereotypical behaviors in captive and wild animals. For example, starlings living in captivity showed more inactivity, greater route-finding and escape behaviors, and less impulsivity in their decisions than those not living in captivity (Feenders and Bateson, 2012, 2013). Using TPA, differences were also found in feeding behaviors of birds and parasitic animals in relation to available resources and nutrient foraging, with patterns indicating increased stress in the absence of these resources (Merlet et al., 2005; Hemerik et al., 2006). TPA was also used to find how Embioptera (an insect) marked its territory and defended it from potential invaders (Dejan et al., 2013). In addition, experimental animal studies have been performed in order to understand the origin of human behaviors. In studies with mice it was discovered that there were prior genetic factors related to Obsessive Compulsive Disorder, as the mice responded differently even though they had all been pharmacologically stimulated (de Haas et al., 2012). In rats, the influence of prior learning was studied, showing patterns of improvement in task performance (Casarrubea et al., 2015, 2021c) and by investigating the structural functional patterns of olfactory bulb cells in these animals, it was discovered that the physiological properties of the neural system form part of the basis for encoding sensory information (Nicol et al., 2015). In addition, the T-Pattern has allowed the study of patterns associated with vomiting in shrews (Horn et al., 2013), the swimming patterns of cod (Jonsson et al., 2010) and the underlying nature of group actions in wolves (Yachmennikova and Poyarkov, 2011). Another study by Casarrubea et al. (2021a) analyzed the effect of smoking on anxiety-like behavior in rats. They used a quantitative and multivariate T-pattern analysis. The latter revealed that rats chronically treated with nicotine continued to show anxiety-like behavior after nicotine challenge.

TPA has also been applied to humans in numerous research studies, starting with examining patterns of various mental illnesses and disorders. The study by Warreyn et al. (2007) analyzed the behaviors of children with autism spectrum

TABLE 1 | Percentages of document type by keyword.

Type of document	Keyword		
	THEME TPA	T-Pattern	T-String
Neuroscience	8.1%	8.9%	3.4%
Multidisciplinary	–	–	3.4%
Biochemistry	8.1%	7.3%	3.4%
Agriculture	–	5.0%	3.4%
Social Sciences	13.5%	3.7%	6.9%
Physics and astronomy	–	–	6.9%
Psychology	10.8%	9.7%	6.9%
Medicine	24.3%	24.4%	10.3%
Mathematics	–	–	27.6%
Computer Science	2.7%	7.5%	27.6%
Engineering	5.4%	5.8%	–
Pharmacology	5.4%	3.8%	–
Other	10.8%	19.0%	–
Health Professions	–	4.9%	–
Nursing	8.1%	–	–
Marketing	2.7%	–	–

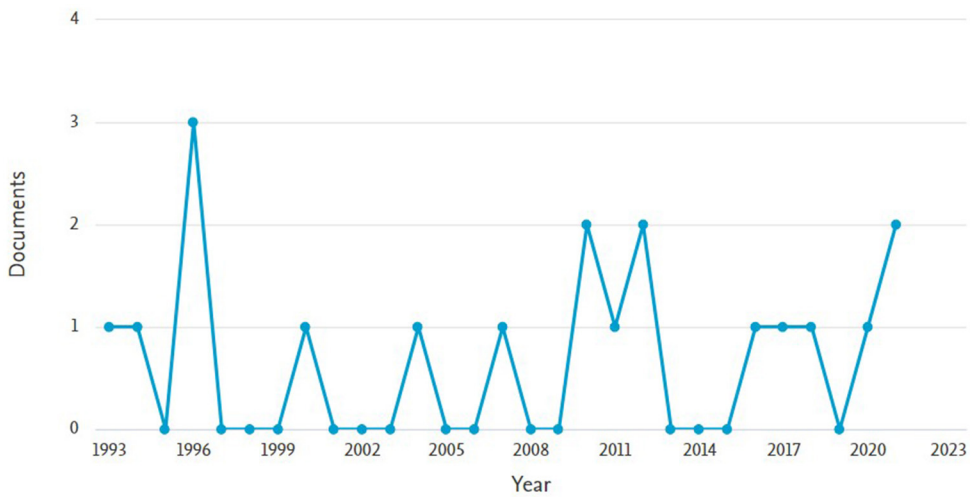

FIGURE 3 | Records found in Scopus for the keyword "T-String."

disorder, showing that the onset of declarative behavior was different and characterized by intermittent attention performance between the object and the person; for example, when pointing, children with autism looked at the pointing finger instead of the object being pointed at. These children exhibited less demand skills and slower task tracking performance. In the study by Masunami et al. (2009), children with Attention Deficit Hyperactivity Disorder (ADHD) exhibited differences in decision-making compared to children without ADHD. Children with ADHD exhibited lower T-Patterns in response to punishments, indicating that they paid less attention to punishments than children without ADHD. Increased detection of different T-Pattern responses has been found in people with schizophrenia taking clozapine (Lyon and Kemp, 2004). Furthermore, this increase in T-Patterns was shown to be exacerbated in people who engaged in self-harm (Sandman et al., 2012). In the field of professional sports, Pic and Jonsson (2021) found higher percentages of T-Pattern recording in boxers who won compared to boxers who lost. From these patterns it was found that winners exhibited greater complexity in decision-making and tended to fight in the area closer to the center of the ring. Along similar lines, Muñoz-Arroyave et al. (2021) took a multidimensional perspective (decisional, relational and energetic) to study the interpersonal relationships established by boys and girls in the traditional game of Elbow Tag. The authors applied classification trees and found that the T-pattern analyzes between girls and boys in a mixed group were unequal. This difference was mainly due to decision making (subrole variable), which had much greater predictive power than the energetic variables. Martín-Martínez et al. (2021) analyzed players' decision making in Marro (a traditional game) using a multimodal approach with Crosstabs, adjusted residuals (AR), classification trees (Chaid model) and T-pattern analysis (TPA). The results indicated that the use of different methodologies in the analysis provided data for an individualized study of player behavior. Similarly, Pic et al. (2018) studied the triadic relationship in the practice of motor games. They used the detection of behavioral patterns not visible to the naked eye, which were analyzed with Theme software to detect temporal regularities in the order of occurrence of events. They found that the temporal location of the motor responses in the triad games was not random.

Other influential studies have focused on analyzing the relationships of T-Patterns with different mental conditions and intra-individual and intergroup processing. These studies have focused on various topics, such as social interaction in infants (Magnusson, 2020a), pervasive growth disorders (Willemsen-Swinkels et al., 2000), behavioral symptoms of dementia (Woods and Yefimova, 2014), self-directed speech and non-verbal behavior (Kuvalja et al., 2014), language and behavior patterns (Blanchet et al., 2005), stressors and routine tasks (Su et al., 2013), effectiveness and interactions in teams (Zijlstra et al., 2012), human-cat interactions (Wedl et al., 2011), and human-robot interactions (Jonsson and Thorisson, 2010).

The Use of T-Patterning and T-String Analysis With Theme Software in Mixed-Methods Research

The use of mixed methods in psychotherapeutic research, including TPA with THEME, has increased in recent years, based on the need to adapt to and capture changes within the

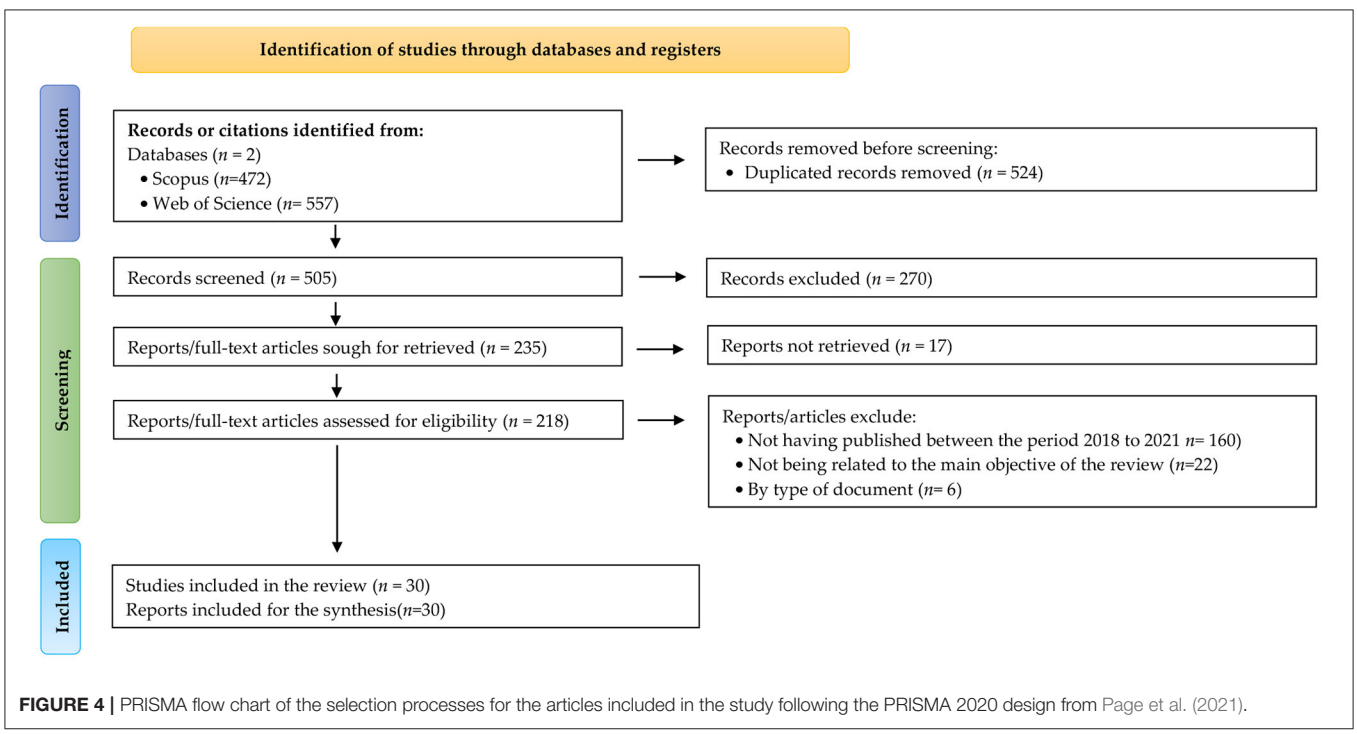

FIGURE 4 | PRISMA flow chart of the selection processes for the articles included in the study following the PRISMA 2020 design from Page et al. (2021).

continuum of therapies (Voutilainen et al., 2018). These tools allow behavioral data to be analyzed, collected and recorded from the beginning to the end of the session, combining qualitative and quantitative data together (Bartholomew and Lockard, 2018). This means that data may have been obtained using a variety of techniques such as observation, narrative, interviews, surveys, physiological testing and a range of other data taken as the therapeutic intervention is being conducted (Voutilainen et al., 2018). Linking these data to patterns allows numerous behavioral coding matrices to be created that facilitate methodological confrontation by promoting the use of mixed methodologies (Roberts and Allen, 2019). In the study by Arias-Pujol and Anguera (2020), these methodologies were considered in analyzing the communication strategies used by a psychotherapist with adolescents before, during and after therapy. Through TPA, patterns were isolated that promoted the good functioning of the therapy; these were related to the mental processes that occurred during the sessions, with the most successful therapies being those in which the therapist used interrogative phrases and paraphrases at the beginning and questioning and mentalization techniques at the end. The results from TPA were the same as those found using two other techniques (delayed sequence and polar coordinates) in the same study.

TPA has also been used in education, for instance in a study by Suárez et al. (2018) with six primary school teachers, it was used to demonstrate that the teachers' skills related to alphabetic knowledge and phonological awareness were used less frequently

TABLE 2 | Classification of articles.

Article	Intervention group	Year	Cluster	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
A_1	1	2021	1	1				1					
A_2	2	2021	1		1			1					
A_3	3	2021	1			1							
A_4	4	2021	1						1				
A_5	4	2021	1				1						
A_6	5	2020	1							1			
A_7	5	2020	1							1			
A_8	6	2020	1							1			
A_9	2	2020	1								1		
A_10	5	2020	1		1								
A_10	7	2020	1						1				
A_11	5	2020	1		1								
A_11	7	2020	1						1				
A_12	8	2020	1							1			
A_13	6	2020	1							1			
A_14	2	2020	1		1								
A_15	4	2020	1						1				
A_16	2	2020	1		1								
A_17	2	2020	1		1								
A_18	2	2020	1		1								
A_19	4	2019	2						1				
A_20	4	2019	2						1				
A_21	5	2021	1						1				
A_21	7	2021	1								1		
A_22	3	2021	1			1							
A_23	5	2018	2					1					
A_24	5	2020	1				1						
A_25	5	2018	2									1	
A_26	5	2018	3	1	1	1	1	1	1	1	1	1	
A_27	5	2019	2										1
A_28	8	2018	2							1			
A_29	4	2019	2						1				
A_30	5	2019	2				1					1	

C1, Research in gamification; C2, Research in sport; C3, Research in genetics; C4, Research in psychological therapies; C5, Research in human behavioral analysis in natural contexts; C6, Research in non-human behavioral analysis in laboratories; C7, Human behavioral analysis in educational contexts; C8, Human behavioral analysis with pharmacological consequences; C9, Research in human behavioral analysis in laboratories; C10, Research in human behavioral analysis in work contexts.

in the classroom than expected, with fewer than 50% of the teachers following the recommendations of the National Reading Panel. The study by Prat et al. (2019) used pattern analysis to evaluate educational interventions based on a pedagogical model of personal and social responsibility. This study made it possible to evaluate the emergent behaviors of each educator, comparing the initial, and final self-assessment of a teacher using traditional methodology with another using innovative methodology. TPA showed that the pedagogical performance of the teachers and the self-evaluations of their students were more positive if the educator used the innovative methodology. This innovative methodology focused on awareness, responsibility for task performance, group meetings and self-assessment. Moreover, analyzing the stability and change of T-Patterns, Santoyo et al. (2020) linked task persistence in preschool children with social interaction between them and their teachers. The study found that teachers attempted to redirect behavior and follow alternative loops to engage children's on-task attention and avoid distracting behaviors, those who did so most effectively consistently responded to children's social signals. Pic et al. (2021) analyzed the play of 23 children aged 12–13 through mixed approaches using TPA. They showed that girls had greater role variability in triadic motor play than boys. Gender roles were also found to influence and bias decision-making, with girls more frequently resorting to peer-release behaviors during play than boys.

Applied research studying the use of human behavioral analysis scales in small measurements or micro-measurements, similar to nanoscales, will foreseeably help in the understanding of behavioral patterns. Likewise, the use of predictive algorithms will facilitate detection of possible patterns of human behavior in different situations. Content classification is important for the creation of models to assess and analyze repeated sequences of behaviors. However, in recent years, the use of these analytical techniques have spread to contexts other than the original field of genetics. This systematic review therefore addresses the challenge of understanding the application of the multivariate approach based on the use of TPA through THEME in different contexts and groups. Mixed research methods were used for the analysis, applying data mining and text mining techniques. This systematic review methodology allows for an analysis which can adapt to different focuses of research interest (Sáiz-Manzanares et al., 2020).

The objectives of this study were:

(1) To identify the results of research in the last four years related to the concepts of THEME, T-Patterns, and T-Strings, applied to human and non-human behavioral analysis.
(2) To apply data mining techniques to analyze the results from studies related to the concepts of THEME, T-Patterns, and T-Strings, applied to human and non-human behavioral analysis.
(3) To apply text mining techniques to analyze the results from studies related to the concepts of THEME, T-Patterns, and T-Strings, applied to human and non-human behavioral analysis.

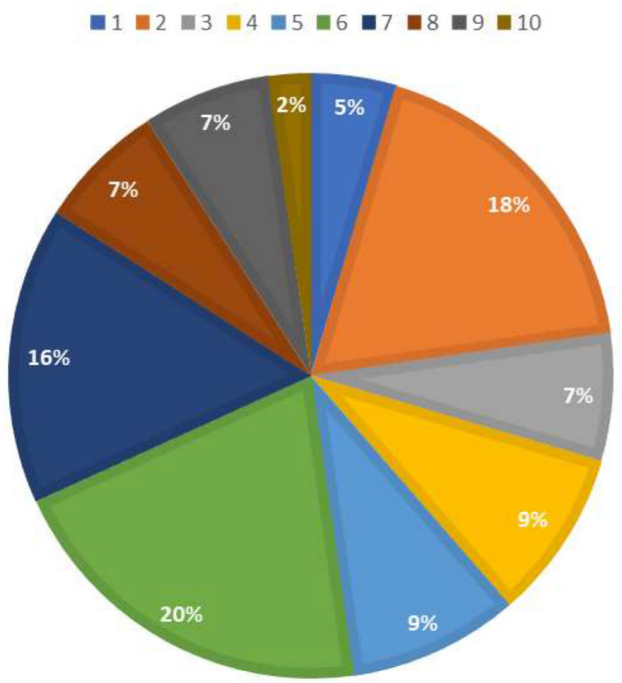

FIGURE 5 | Percentage of studies in the period 2018–2021 by classification category. Note: 1 = C1. Research in gamification; 2 = C2. Research in sport; 3 = C3. Research in genetics; 4 = C4. Research in psychological therapies; 5 = C5. Research in human behavioral analysis in natural contexts; 6 = C6. Research in non-human behavioral analysis in laboratories; 7 = C7. Research in human behavioral analysis in educational contexts; 8 = C8. Research in human behavioral analysis with pharmacological consequences; 9 = C9. Research in human behavioral analysis in laboratories; 10 = C.10. Research in human behavioral analysis in work contexts.

TABLE 3 | Initial and final cluster centres.

Classification criteria	Initial clusters			Final clusters		
	1	2	3	1	2	3
	n = 28	*n* = 1	*n* = 4	*n* = 28	*n* = 1	*n* = 4
C1	1	1	0	0	1	0
C2	0	1	0	0	1	0
C3	0	1	0	0	1	0
C4	0	1	1	0	1	1
C5	1	1	0	0	1	0
C6	0	1	0	0	1	0
C7	0	1	0	0	1	0
C8	0	1	0	0	1	0
C9	0	1	1	0	1	1
C10	0	0	0	0	0	0

C1, Research in gamification; C2, Research in sport; C3, Research in genetics; C4, Research in psychological therapies; C5, Research in human behavioral analysis in natural contexts; C6, Research in non-human behavioral analysis in laboratories; C7, Human behavioral analysis in educational contexts; C8, Human behavioral analysis of pharmacological consequence; C9, Research in human behavioral analysis in laboratories; C10, Research in human behavioral analysis in work contexts.

MATERIALS AND METHODS

Design

A mixed research methodology was used. Firstly, a descriptive design was applied in which the articles were analyzed quantitatively, using data mining and text mining techniques. Secondly, an explanatory design was applied in which the articles were analyzed qualitatively using network analysis techniques with the qualitative analysis programme Atlas.ti v. 9.

Sample

A literature review was performed using the keywords "THEME TPA," "T-Pattern," and "T-String." Joint analysis of the three keywords did not yield any results, hence an individual search was performed for each word individually. "THEME TPA" produced 19 documents from 1993 to 2021. Searching for "T-Pattern" produced 467 documents from 1932 to 2022. For "T-String" 19 records were found from 1993 to 2020. The searches were performed using Scopus and Web of Science databases. **Figure 1** shows the search results for the keyword "THEME TPA," **Figure 2** shows the search results for the keyword "T-Pattern" and **Figure 3** shows the search results for the keyword "T-String."

The knowledge areas for the documents were also examined for each keyword (see **Table 1**).

Instruments

Scopus and Web of Science databases were used to perform the searches.

Procedure

Firstly, a literature search was performed in the aforementioned scientific databases. The search criteria used were "THEME TPA," "T-Pattern," and "T-String." The inclusion criteria were keywords in the period from 2018 to 2021, in the disciplines of psychology, medicine, neuroscience, social sciences and computer Science, other articles were excluded. The reason for this was that the highest proportion of publications including the keywords were published during this time and in these disciplines. Based on these criteria, 30 documents

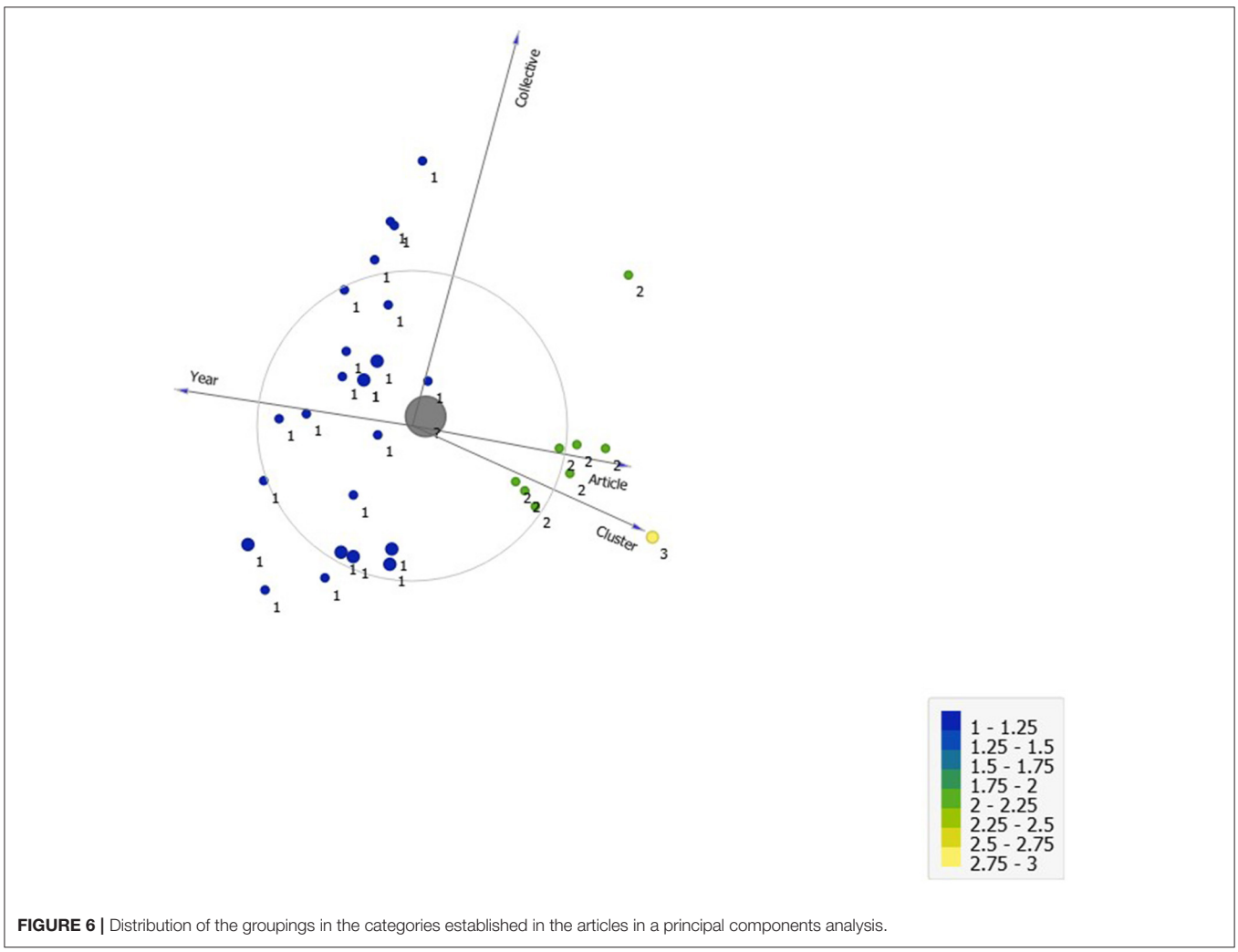

FIGURE 6 | Distribution of the groupings in the categories established in the articles in a principal components analysis.

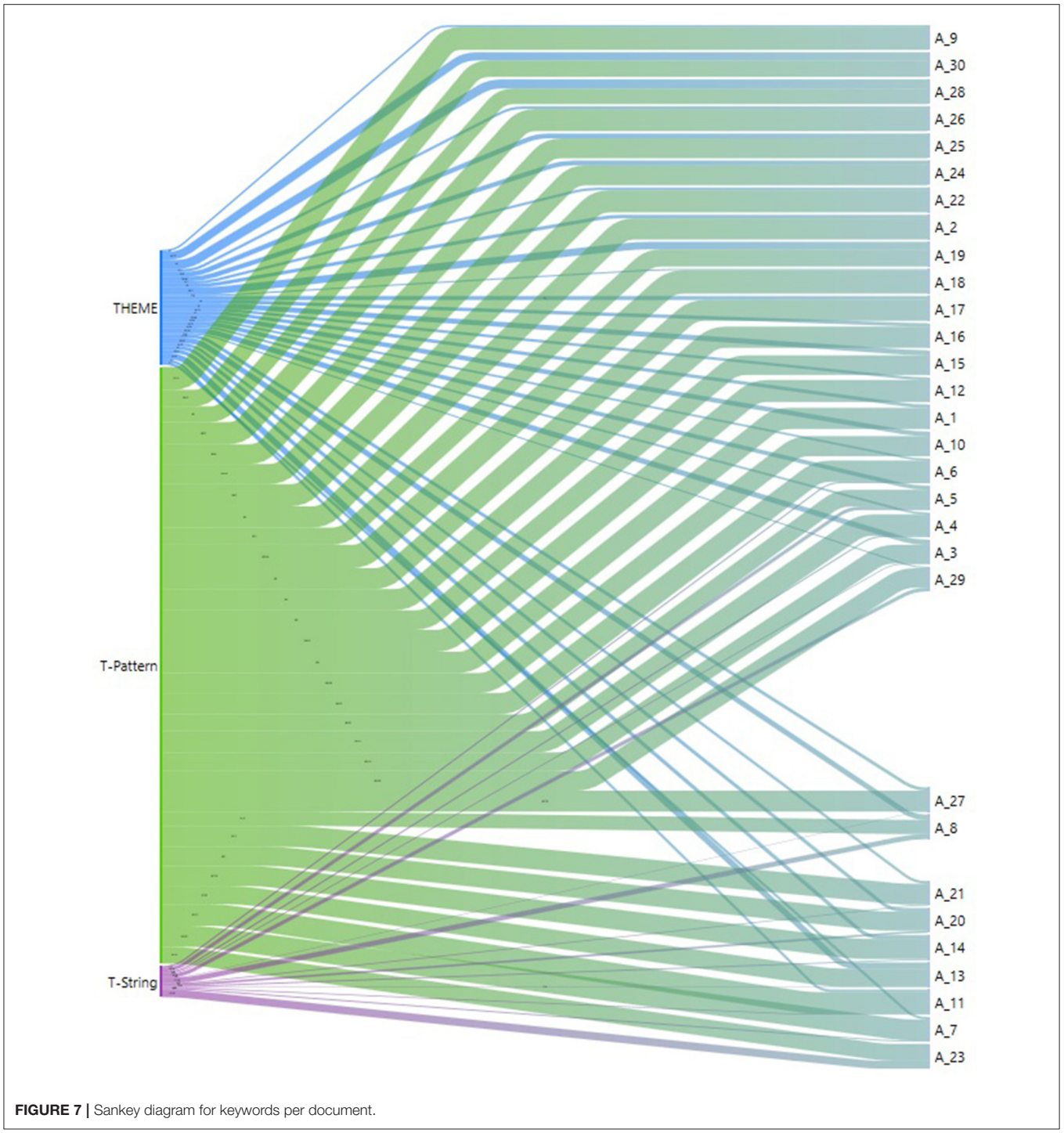

FIGURE 7 | Sankey diagram for keywords per document.

were found, 7 for "THEME TPA," 21 for "T-Pattern," and 2 for "T-String."

Two types of study were then performed. Firstly, a quantitative analysis was conducted by classifying the articles according to the following criteria: keyword, year of publication and study objective. Then data mining and text mining techniques were applied to analyze the results of that classification. Secondly, a qualitative study of the articles was performed to identify the concepts used in the 30 articles, classifying them by category and applying network analysis (see **Figure 4**).

Data Analysis

The following techniques were used for the quantitative study in pursuit of the objectives: descriptive statistics techniques

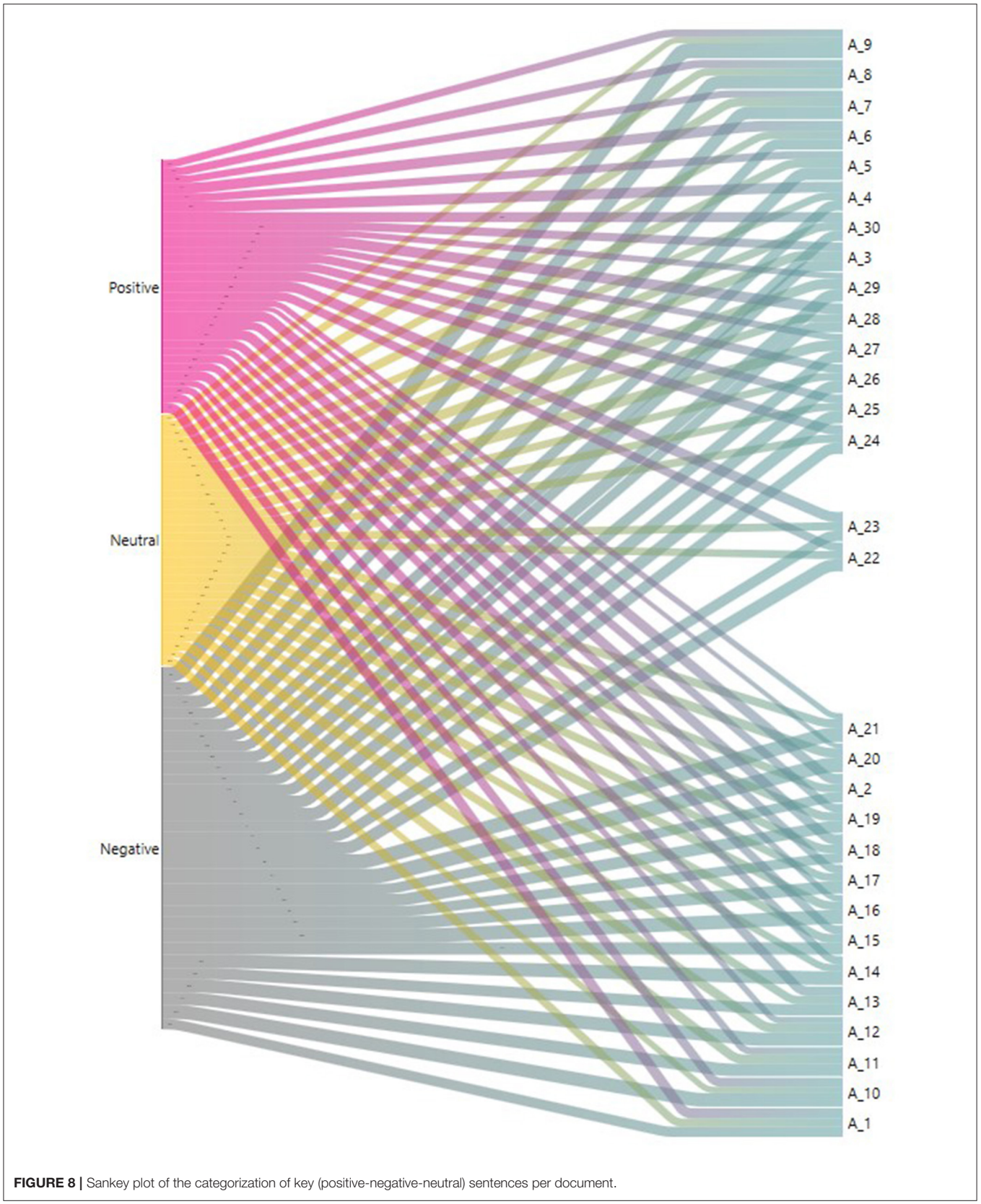

FIGURE 8 | Sankey plot of the categorization of key (positive-negative-neutral) sentences per document.

TABLE 4 | Analysis of document-coding criteria co-occurrence.

Articles	Categorization criteria												
	C1	C2	C4	C5	C6	C7	C10	N	Neu	P	THEME	T-Pattern	T-String
A_1	34	0	0	10	4	2	0	72	58	72	4	19	0
A_2	34	0	0	10	4	2	0	72	58	72	4	19	0
A_3	0	0	0	31	3	0	0	61	53	48	37	101	3
A_4	0	1	14	8	17	0	0	51	38	52	4	46	2
A_5	0	2	1	13	15	0	1	66	48	43	11	44	6
A_6	0	1	14	8	17	0	0	51	38	52	4	46	2
A_7	0	0	0	16	3	0	1	28	20	16	4	26	1
A_8	0	0	0	104	11	0	0	119	70	73	38	86	23
A_9	1	0	0	8	4	0	0	103	40	52	4	41	0
A_10	9	0	0	6	2	0	0	139	63	92	6	17	0
A_11	0	0	0	10	4	0	1	71	53	40	6	38	1
A_12	0	0	0	16	9	0	0	85	60	39	6	39	0
A_13	2	1	0	8	0	8	0	99	72	83	23	52	1
A_14	0	2	0	23	3	0	2	121	63	70	9	59	2
A_15	0	7	0	10	1	2	0	100	69	69	7	27	0
A_16	0	1	0	11	8	0	0	63	39	28	5	27	0
A_17	1	1	0	18	1	1	0	108	69	74	5	27	0
A_18	0	1	0	4	0	0	0	72	58	72	2	20	0
A_19	0	0	4	2	1	0	0	111	81	77	6	11	0
A_20	0	0	0	12	21	0	0	64	41	20	24	135	11
A_21	0	2	0	9	20	0	0	82	47	34	5	37	1
A_22	1	1	0	45	18	1	1	85	53	60	9	64	0
A_23	0	0	0	37	1	0	0	74	57	73	0	70	33
A_24	3	0	0	20	0	0	0	213	154	186	11	37	0
A_25	0	0	0	4	0	1	0	167	104	118	18	58	0
A_26	1	1	0	45	18	1	1	85	53	60	9	64	0
A_27	0	7	0	6	1	0	0	117	112	72	11	52	1
A_28	0	0	0	7	0	8	0	103	85	112	14	19	0
A_29	0	3	0	10	21	0	0	48	39	24	4	41	5
A_30	0	0	0	18	0	0	0	129	112	130	2	3	0

C1, Research in gamification; C2, Research in sport; C4, Research in psychological therapies; C5, Research in human behavioral analysis in natural contexts; C6, Research in laboratory non-human behavioral analysis; C7, Human behavioral analysis in educational contexts; C10, Research in human behavioral analysis in work contexts. Criteria C2, C8, and C9 were removed as they were at very low frequencies. N, Negative; Neu, Neutral; P, Positive.

(frequency and percentage analysis) and unsupervised learning data mining techniques, specifically clustering using the k-means algorithm. The statistical package SPSS v.28 (IBM, 2022) was used for this purpose. In addition, Orange v.3.30.2 (Orange, 2022) was used to visualize the results, and Atlas.ti. (2020) was used to perform the text mining analysis. For the second, qualitative study, frequency recording, co-occurrence analysis and network analysis were applied, using the data management, processing and visualization software Atlas.ti. v9 (Atlas.ti., 2020).

RESULTS

Quantitative Analysis of Articles

Classification of Items

The first objective concerned the analysis of research on the concepts of THEME TPA, T-Pattern, T-String with respect to behavioral, human health and social analysis. Studies including these three traceability references during the time interval from 2018 to 2020 were checked for 30 papers. Subsequently, these studies were sorted by year of publication and categorized according to the group they referred to (1 = THEME TPA, 2 = T-Pattern, 3 = T-String). The articles were then classified according to knowledge area, with ten reference criteria for classifying the research field (C1 = Gamification research; C2 = Sports research; C3 = Genetics research; C4 = Research in psychological therapies; C5 = Research in human behavioral analysis in natural contexts; C6 = Research in non-human behavior analysis in the laboratory; C7 = Research in human behavioral analysis in educational contexts; C8 = Research in human behavioral analysis with pharmacological consequences; C9 = Research on human behavioral analysis in laboratory settings; and C10 = Research on human behavioral analysis in occupational

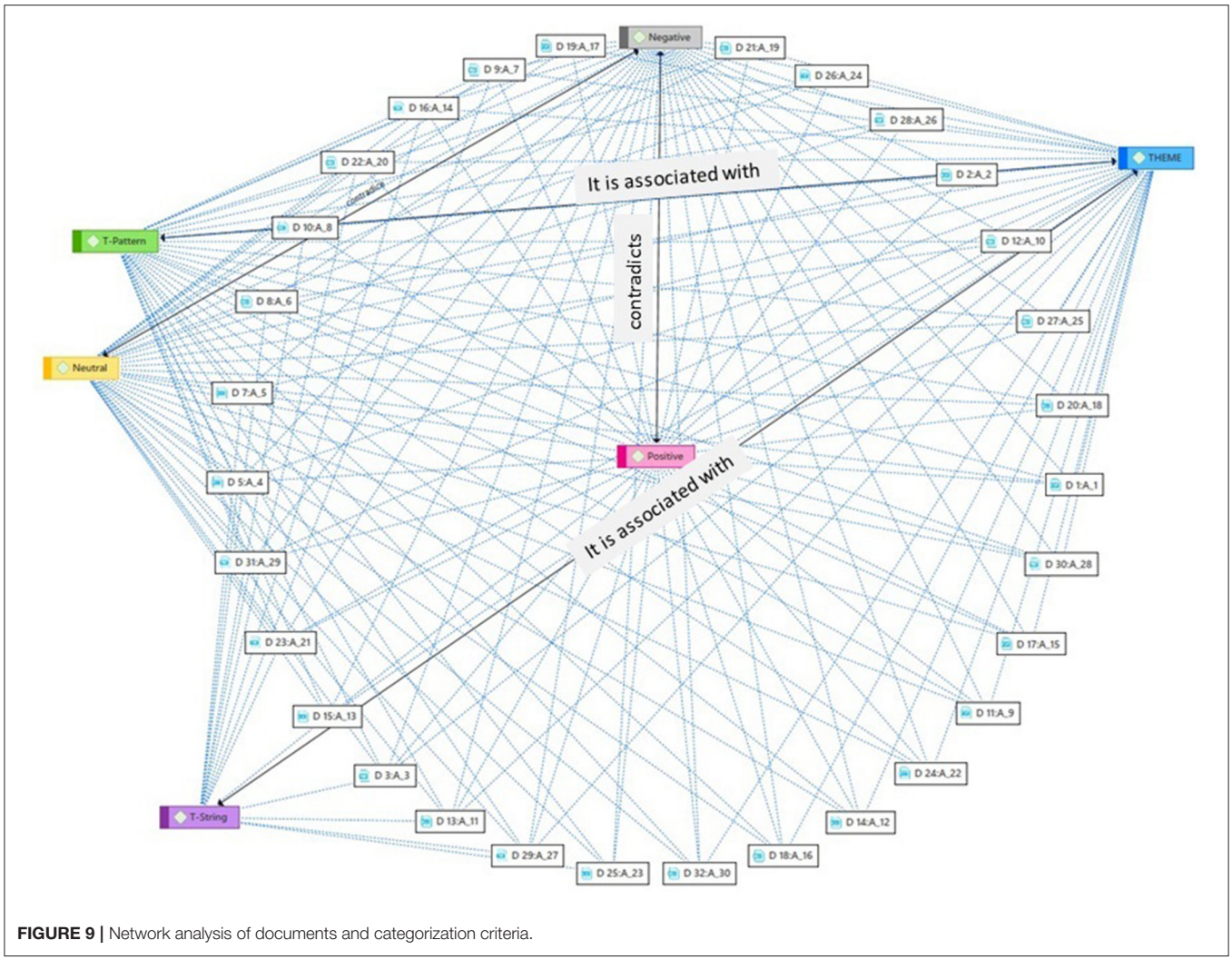

FIGURE 9 | Network analysis of documents and categorization criteria.

settings). The categorization of the individual studies and the frequencies are given in Table S1 (**Supplemental Material**). The percentage per category is shown in **Figure 4**. Furthermore, **Table 2** shows the relationship of the selected articles with respect to the category of type of research and the intervention group (1 = Secondary school students; 2 = Athletes; 3 = Human genetic material; 4 = Rats; 5 = Humans; 6 = University students; 7 = Non-human primates; 8 = Preschool students).

In summary, the types of research with the greatest representation in pattern analysis with THEME software since 2018 were: 20% in non-human research in laboratory contexts, 18% in research in sports contexts, 16% in human behavioral analysis research in educational contexts, and 9% in psychological therapy research and human behavioral analysis research in natural contexts (see **Figure 5**).

Application of Data Mining Techniques

In pursuit of the second study objective, the *k-means* clustering technique was first applied using SPSS v.28 (IBM, 2022) to the frequency data matrix (**Table 2**). Three clusters were found, the distribution of which with respect to the categorization criteria of the articles is shown in **Table 3**. The number of the cluster found for each article is included in **Table 2** in order to more clearly show the assignment relationship.

The classification criteria C4 (Research in psychological therapies) and C9 (Research in human behavioral analysis in the laboratory) exhibited atypical values of belonging to two clusters. This can be explained by the simultaneous categorization of the articles into several categories, specifically article 26. Therefore, it could be reduced to a single category, which would be "Research in psychological therapies."

Subsequently, the results of the application of the *k-means* clustering technique were visualized with Orange Software v.3.30 (Orange, 2022). **Figure 6** shows the distribution of the clusters with respect to the categorization. As the final cluster centers show, Cluster 2 includes all categories except C10 (Research in human behavioral analysis in work contexts). Likewise, Cluster 3 specifically includes C4 (Research in psychological therapies)

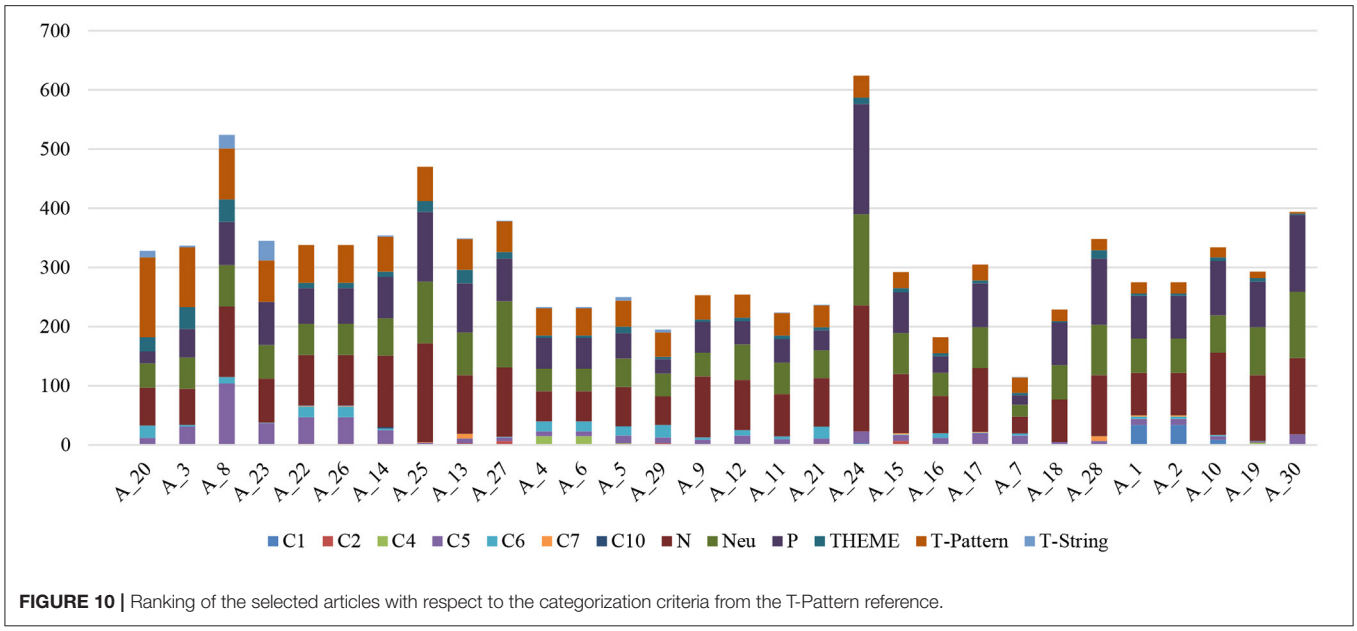

FIGURE 10 | Ranking of the selected articles with respect to the categorization criteria from the T-Pattern reference.

and C9 (Research in human behavioral analysis in laboratory settings). Those criteria could be reduced to a single category, "Research in psychological therapies."

Application of Text Mining Techniques

In consideration of the second study objective, the information in the articles was analyzed by applying text mining using Atlas.ti v. 9 (Atlas.ti., 2020). A total of 3,990 keywords were recorded; THEME TPA $n = 614$, T-Pattern $n = 3{,}209$, T-String $n = 167$. A Sankey diagram of the binarized data with respect to the analysis of keywords per document is shown in **Figure 7**. This information may be very useful as it directly relates the document to the keyword.

In addition, sentiment analysis categorization was applied and a total of 16,590 categorizations were made, of which $n = 4{,}856$ were positive sentiments (sentences without negative particles), $n = 6{,}942$ were negative (sentences that include some negative particles), and $n = 4{,}792$ were neutral (sentences that include neither positive nor negative particles). **Figure 8** shows a Sankey plot of the binarized data with the analysis of the sentiment categories per document. This information may also be useful as it provides information on possible study conclusions.

Application of Qualitative Analysis

In pursuit of the third objective, co-occurrences between the selected documents and the applied categorization codes were analyzed. This analysis may be of great use to the researcher in terms of selecting the documents with respect to the keywords (THEME TPA, T-Pattern, T-String), the selected grouping criteria (C1, C2, C4, C5, C6, C7, C10)—although criteria C2, C8, and C9 were eliminated as they were at very low frequencies—and the type of sentences (positive, neutral and negative), see **Table 4**. Researchers may also find it useful as it provides information on the type of research with THEME and TPA in different fields, the frequencies of the keywords, and the type of sentences for each of the articles analyzed. For example, article 3 (A_3) refers to research in the field of human behavioral analysis in natural contexts, it has a frequency of 48 positive sentences, 61 negative sentences, and 53 neutral sentences. It also includes the keywords THEME TPA, T-Pattern and T-String with a frequency of 37,101 and 3, respectively.

Network analysis was then applied to the selected documents and to the categorization of the documents by type of research and categorization of sentences (positive-negative-neutral). To that end, an orthogonal-radial analysis was performed in which the relationships of each document with the different codes applied can be checked (see **Figure 9**). This visualization may be of great use to the researcher as it makes it easy to choose information according to the object of study graphically and interactively.

Finally, **Figure 10** presents the categorized relationship of the selected articles taking as a reference the frequency of use of T-Pattern with respect to the categorization criteria and the other keywords (THEME and T-String). This relationship allows the researcher to select the article or articles that best fit the object of research related to the use of THEME, T-Pattern and T-String.

CONCLUSIONS

Using THEME to find behavioral patterns in humans and non-humans is an important asset in the understanding of behavior (Magnusson, 2020b). Moreover, incorporating artificial intelligence techniques facilitates relational analysis between human-scale behavior and cellular organization and functions (Anguera et al., 2018; Casarrubea et al., 2018; Arias-Pujol and Anguera, 2020; Magnusson, 2020a,b). Likewise, the use of mixed research methodology applied to TPA allows the analysis of human behavioral traits that are supported by the detected patterns, among other things (Bartholomew and

Lockard, 2018; Roberts and Allen, 2019). This makes it easier to study large amounts of behavioral information, and more significantly, to draw conclusions based on algorithmic measurement. Similarly, approaches that have traditionally been applied in the context of genetic research are being generalized to research in psychological therapy (Bartholomew and Lockard, 2018; Voutilainen et al., 2018; Arias-Pujol and Anguera, 2020; Brill and Schwab, 2020; Gutiérrez-Santiago et al., 2020; Prieto-Lage et al., 2020a,b; Santoyo et al., 2020) and in education (Suárez et al., 2018; Prat et al., 2019).

The specific results from the present study show that, in the last 4 years, the studies that used THEME software to perform TPA were distributed as follows: 20% in laboratory research contexts with non-humans, 18% in behavioral analysis settings in the field of sports, 16% in educational contexts, 9% in therapeutic intervention contexts in psychology, and 9% in natural human contexts. This analysis methodology is also beginning to be used in work environments, although so far in only 2% of the studies. Work is a promising area for behavioral analysis, as it will be possible to establish patterns of occupational risk prevention. The keywords that appeared most frequently in the selected articles were T-Pattern directly associated with THEME and to a lesser extent the keyword T-String, probably because this analysis is implicit in TPA. Sentiment analysis, using Atlas.ti 9, indicated the content of the articles in terms of positive, negative, and neutral sentences, providing information about the possible results of each study. Negative sentences were more frequent, although positive sentences were found in all of the articles. This may be due to difficulties in applying this technology, which are probably related to the training users need in order to be able to apply it properly. This indicates the need for researchers to be trained in the use of these tools. Similarly, the analysis of co-occurrence and network analysis applied to the categorization of the selected articles provides a visual map that will allow researchers to select the documents that best fit their research objectives.

Finally, we would like to emphasize that applying a mixed methodology to a systematic review study allowed us to analyze the state of the art in the chosen topic, providing a great deal of quantitative and qualitative information that may be very useful to future researchers from various research perspectives (Sáiz-Manzanares et al., 2020).

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/**Supplementary Material**, further inquiries can be directed to the corresponding author/s.

AUTHOR CONTRIBUTIONS

MS-M and LA-M: design and initial writing. MS-M, LA-M, and RM-S: review and final writing. All authors contributed to the article and approved the submitted 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/fpsyg.2022.943907/full#supplementary-material

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Verbal interaction pattern analysis in clinical psychology

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Recent developments in pattern analysis research have made this methodology suitable for the study of the processes that are set in motion in psychological interventions. Outcome research, based on the comparison between clinical results from treatment and control groups, has leveraged our empirical knowledge about the efficacy of psychological interventions. However, these methods of research are not precise enough for the analysis of these processes. On the contrary, pattern analysis could be a powerful tool to study moment-to-moment interactions typical of psychological interventions. This is methodology is relevant because clinical psychology is experiencing a paradigm shift from a protocol for syndrome perspective to a principle-based and person-centered intervention. This evidence-based, theory-grounded, and process-oriented paradigm of clinical intervention needs new research methods to thrive (i.e., pattern analysis). The analysis of the therapeutic relationship built into the verbal interaction between the clinician and the client is one of the cornerstones of this new era of research. So, the purpose of this article is three-fold: (1) to discuss the role of the verbal interaction pattern analysis in the clinical context to the development of the principle-based clinical psychology, (2) to analyze the patterns of verbal interaction in a clinical case, and (3) to compare the results using two different methods. To reach these purposes, using the observational methodology, we have coded the verbal interaction of 16 clinical sessions with a person diagnosed with a borderline personality disorder. We have analyzed the data using sequential analysis (GSEQ) and pattern recognition algorithms (i.e., T-Pattern detection). We have been able to detect typical patterns during different phases of psychological intervention (i.e., evaluation, explanation, treatment, and consolidation). Finally, the conceptual, methodological, and empirical implications of this study will be discussed within the realms of pattern analysis research and principle-based clinical psychology.

KEYWORDS

process-based therapy, clinical psychology, pattern analysis, sequential analysis, verbal interaction, principle-based therapy

Introduction

Pattern is a term that refers to a stable repetition of events that arise from specific circumstances. The recognition of patterns in the natural world has had an evolutionary impact on the animal species, it has allowed us to adapt to the environment by taking advantage of these regularities. Moreover, understanding how these patterns work has led

us to control and predict these natural events. Recognition and analysis of patterns are scientific endeavors that have benefited from the efforts of multiple scientific fields (e.g., mathematical definitions, biological theories, etc.) and are useful to improve applied sciences (e.g., engineering, medicine, etc.). Furthermore, the development of new definitions of patterns or the application of existing methods of analysis to new areas could solve contemporary problems in several scientific disciplines, we believe that this is the case in clinical psychology. This paper aims to improve clinical psychology research using pattern analysis methods (e.g., T-pattern Analysis), to do that first we define the state of the art in clinical psychology research highlighting the current challenges, then we analyze the conceptual and practical opportunities that pattern analysis methods open to this field of research, and finally we conduct a proof-of-concept study.

Clinical psychology has reached an important stage of development in regards to the scientific agreement about the efficacy of psychological interventions for specific psychological problems (David et al., 2018; Van Agteren et al., 2021). Thanks to the evidence-based psychotherapy movement, this milestone has ended a historical debate within our field (Forte et al., 2014). While, it has set the opportunity to face new challenges and research questions, as well as analyze the flaws of the current clinical research system. For example, Paul's classic question, "What treatment, by whom, is most effective for this individual with that specific problem, and under which set of circumstances, and how does it come about?" (Paul, 1969, p. 44), is not yet solved. To answer this question we need to implement conceptual, experimental, and applied changes to our clinical research and our validation systems (Tolin et al., 2015). Among these changes, we would like to emphasize the importance of clinical process research rooted in a functional perspective of behavior, experimentally validated processes, and the connection between intervention outcomes and the processes that could explain these behavioral changes (Hayes and Hofmann, 2018; Barnes-Holmes et al., 2020). Especially, two main trends are rising in clinical psychology, the call for personalized psychotherapy and the study of complex interactions between psychological problems, psychological interventions, and treatment outcomes (Hofmann et al., 2020; Wright and Woods, 2020; Mansueto et al., 2022). Due to the nature of these two trends, clinical research needs new methods and approaches to conduct idiographic studies in clinical psychology. There is a long tradition of idiographic research in clinical psychology (Kazdin, 1978; Hayes, 1981; Iwata et al., 1994), but the emphasis on this type of research is renewed (e.g., Molenaar, 2004; Beltz et al., 2016; Piccirillo et al., 2019; Kazdin, 2021). New professional standards for single-case methods (Tate et al., 2016; Horner and Ferron, 2022) and the development of new methods for the interpretation of these designs (Hedges et al., 2013; Kratochwill and Levin, 2014; Pustejovsky, 2018; Manolov et al., 2021) could help us to analyze the learning processes, that occurs at the individual level and are settled in motion by the psychologists' procedures, that account for the clients change.

Specifically, in the psychological interventions with adults, these processes occurred within the verbal interaction between the psychologist and the client. Other important variables explain the therapeutic change of our clients (e.g., contextual, and cultural variables outside of the clinical session, setting variables, motivational variables, etc.), but the verbal interaction with the client is the main channel that psychologists have to implement their procedures (Follette and Bonow, 2009; Tsai et al., 2014; Virues-Ortega and Froxán-Parga, 2015).

The interest in the study of verbal interaction in clinical sessions from a functional perspective is present since the early 60 s (see Moore, 1991). This conceptual development helped to foster empirically-supported psychological treatments like the Functional Analytic Psychotherapy (Kohlenberg and Tsai, 1991) or the Acceptance and Commitment Therapy (ACT; Hayes et al., 1999; Hayes, 2004)[1]. Also, helped to develop coding systems for the observational study of the verbal interaction like the Functional Analytic Psychotherapy Rating Scale (FAPRS; Callaghan et al., 2008); the Multidimensional System for Coding Behaviors in Therapist-Client interaction (SiMCCIT; Zamignani, 2008) or the Verbal Interaction Categorization System in Therapy (Froxán-Parga et al., 2011; Alonso-Vega et al., 2022). Using these coding systems allowed to describe the verbal interaction between psychologist and client in clinical sessions (e.g., Froxán-Parga et al., 2016), to study the effects of it outside of the session (e.g., Lizarazo et al., 2015), to study the molecular learning processes that occur in this interaction (e.g., Busch et al., 2009), to analyze the interaction during specific techniques like cognitive restructuring (e.g., Calero-Elvira et al., 2013; Froxán-Parga et al., 2018), and to conduct experiments to study the verbal shaping during clinical sessions (Pardo-Cebrian et al., 2021). These works helped to analyze the basic principles of change in psychological interventions, however, they report methodological problems to study moment-to-moment interactions. For example, Busch et al. (2009) and Xavier et al. (2012) used transitional probabilities to study these interactions. Transitional probabilities inform us about the probability of an event (X) given other (Y), but this is a limited method to study the verbal interaction in psychological interventions because these probabilities reflect behavior frequencies in a particular session and are not comparable over sessions (Bakeman and Quera, 2011). Other, studies (see Calero-Elvira et al., 2013) opted to use sequential analysis to analyze these moment-to-moment interactions. Sequential analysis techniques help us to study patterns and temporal associations among behaviors within observational sessions (Bakeman and Quera, 2012), these techniques are based on the calculation of contingency indices

1 To analyze the relationship between the early functional conceptualizations of the verbal behavior to the development of empirically supported psychological treatments is beyond the scope of this paper, but it can be found elsewhere (see Hayes, 2004; Froxán-Parga et al., 2018; Hayes and Hofmann, 2018; Barnes-Holmes et al., 2020).

for 2×2 tables so they are limited to two-term contingencies. Also, these sequential analyses, normally are used to confirm an expected sequential relationship between two events and are not used to explore patterns that are hidden from the observer's eyes (Magnusson, 2005). Thus, more sophisticated pattern detection and analysis techniques could help us to detect hidden patterns of verbal interaction in clinical sessions and thus to have more precise data that enable us to better study the learning principles that could explain the client's behavioral changes that are set in motion in the verbal interaction between the psychologist and the client. So, the application of the T-Pattern, using THEME software that allows us the automatic detection of temporal and sequential structures in observational data, could be useful to overcome the methodological limitations of previous studies of the verbal interaction analysis in clinical settings. Consequently, the purpose of this study is to analyze the patterns of verbal interaction in a clinical case using the THEME software and to compare the results with previously used analyses, as in Lapresa et al. (2013).

Materials and methods

Participants

For this observational study we had the participation of a 31-year-old client diagnosed with borderline personality disorder (BPD) for the last 8 years; and a 35-year-old clinical psychologist (a master's degree in General Health Psychology and a master's degree in Behavior Therapy). Both participants came from a public-funded Vocational Rehabilitation and Employment center (VR&E) in the Community of Madrid. The client has been referred to this center due to mood problems (i.e., emotional lability) and substance use problems that directly interfere with the client's chances of accessing employment/training opportunities; and once obtained, problems in keeping his job or completing the required training. Also, this study involved the participation of two trained observers. Both observers are predoctoral students that have been trained in the same research group (i.e., the ACOVEO research group). Observer 1 and Observer 2 have, respectively, 4 and 2 years of experience working with the observational coding system used in this research and they helped in the development of it. Before recording the clinical session, the client and clinician have been informed about the use of the data and the purpose of the research. All participants have signed the study informed consent.

Instruments

We used the Functional Coding System for Verbal Interaction in Clinical Contexts (Alonso-Vega et al., 2022) to code the verbal interaction between the client and the psychologists. This coding system, which focuses on the putative functions of the verbal behavior, has five coding categories for the clinician verbalizations: *Clinical Discriminative Stimulus* (CD) and *Instructional Discriminative Stimulus* (ID), *Conditioned Motivating Operation* (CMO), and *Positive Reinforcer* (R+) and *Aversive Stimulus* (AS). The observational system assumes that the verbal behavior of the client has a response function it is not established any specific categories in the observational system. To code the client's verbal behavior in this case we used eight categories based on the response topography *Giving Information* (GI), *Asking for Information* (AI), *Following Instructions* (FI), *Not Following Instructions* (NFI), *Well-Being* (WB), *Discomfort* (D), *Target Behavior* (TB) and *Problem Behavior* (PB). See Table 1 for a brief description of the coding categories, also more details of the coding system are available in the additional materials.

Materials

Recordings of 16 clinical sessions were obtained through the camera installed on the VR&E psychologist's computer. The recordings were sent to the ACOVEO research group and were treated following the protocol used in the research group in which the recordings are anonymized following the ethical and legal guidelines of the Organic Law 3/2018 on Personal Data Protection and guarantee of digital rights. These recordings were stored on external hard drives kept under lock and key in the group's laboratory at the Autonomous University of Madrid.

The recording of the clinical sessions, the observation project, and the analysis of inter-observer reliability were carried out with *The Observer XT 12* observation software. The data analysis was done in *R* (RStudio Team, 2020) and *Microsoft Excel*. *GSEQ* (Bakeman and Quera, 2016) was the software used to conduct the sequential analysis of the data. We selected this software because it is generally employed in observational research (e.g., Santoyo et al., 2017; Brown et al., 2018); it was specifically used in previous research in the study of verbal interaction in clinical cases (Calero-Elvira et al., 2013; Pardo-Cebrian et al., 2021); and it was specially developed to calculate sequential patterns in observational data (Bakeman and Quera, 1995, 2016). Finally, we used *ThemeEdu* software (Pattern Vision, 2021) for automatic pattern detection. *ThemeEdu* was selected because it has been successfully applied in different research areas (i.e., neuronal interactions, behavioral interactions, etc.; Magnusson, 2020), but it was not employed in the study of verbal interactions in clinical settings. Both programs allowed us to conduct the data analysis described in the section below (see "Data Analysis").

Procedure

In this observational study, we used an intra-subject design with three different phases: Evaluation (EVA.), Treatment

TABLE 1 Brief description of the coding categories.

Coding categories	Abbreviation	Putative function	Example
Clinical Discriminative	CD	Antecedent stimulus that increases the probability of a response class. (e.g., to give clinical information)	"How do you feel about that?"
Instructional Discriminative	ID	Antecedent stimulus that increases the probability of a response class (e.g., to follow instructions)	"I want you to apply the breathing technique every night."
Conditioned Motivating Operation	CMO	Antecedent stimulus that changes the reinforcing value of a consequent stimulus and changes the frequency of responses related with this consequent stimulus	"If you run daily, your situation will improve."
Positive Reinforcer	R+	Consequent stimulus that increases the probability of an operant response with a positive contingency with it	"Very good! You have done great."
Aversive Stimulus	AS	Consequent stimulus that decreases the probability of an operant response with a positive contingency	"I do not agree with what you have done."

This table only displays a brief description of the clinician coding categories. Client coding categories are topographically based and they depend on each clinical case. Please see the additional materials for further details.

Phase 1 (T1), and Treatment Phase 2 (T2). These phases were not experimentally manipulated and have been divided considering the protocols and procedures of the VR&E center (i.e., EVA, first three sessions; TP1, 4–9 sessions; and TP2, 10–16 sessions). The division between the two treatment phases is arbitrary and responds to a need to divide the treatment into, at least, two phases to evaluate differences between various time points.

After the study, both observers received specific training in the observational instrument. The training process was completed when a stable reliability index ($k > 0.70$) was achieved while coding similar clinical sessions. These sessions were from the research team's clinical sessions archive.

After training was completed, observer 1 individually recorded all treatment sessions. Observer 2, also individually, recorded 4 random sessions out of the 16 treatment sessions, representing 25% of the sample, which is above the usual 10% for studies of this type. The inter-observer reliability calculation was carried out after the end of the recording of both observers. One month after the end of the recording phase, observer 1 recorded again two randomly selected treatment sessions to allow the calculation of intra-observer reliability.

Data analysis

The kappa coefficient (k) was used to calculate the inter-observer and intra-observer reliability of the records. Once the records were obtained, the rate per minute of each variable recorded in each session was calculated. Descriptive data (e.g., count, rate per minute, etc.) were obtained to allow a visual inspection of the variables and the patterns through time. To analyze the interaction between variables, we used two types of statistical analysis, which are part of the family of statistical tools for the sequential analysis of temporally distributed data. First, we calculated the Yule's Q, a contingency index of 2×2 tables, using the GSEQ software (Bakeman and Quera, 1995, 2016). This index allows us to calculate the Lag +1 correlation between a given behavior and the one that follows it. The Lag-1 correlation tells us which behavior precedes the behavior we are analyzing. This index allows descriptive and analytical analysis of the association (Bakeman and Quera, 2016) and its scores can also be interpreted in the same way as Cohen's r. To study the association between specific pairs of behaviors we calculated the adjusted residuals (z), which are a normalized index of the extent to which the values of the frequencies observed in each cell of the matrix deviate from their expected values: a value greater than 1.96 indicates that this behavior occurs significantly more than expected and, conversely, a value less than −1.96 implies that it occurs significantly less than expected by chance ($p < 0.05$; see Bakeman and Quera, 2011 for an advance mathematical description).

Moreover, we used a pattern recognition model *T-Pattern Model* (Magnús et al., 2016; Casarrubea et al., 2018), using *ThemeEdu* software (Pattern Vision, 2021). This model allows us to recognize patterns (*T-Patterns*) from observational data (*T-Data*) using the *T-Pattern* detection algorithm. Pattern detection works in a bottom-up fashion, from the data to the pattern detection. The *T-Pattern* is a hierarchical, multi-ordinal, and self-similar pattern type that comprises m ordered components (i.e., behavioral events), $X_{1..m}$, recurring in a single discrete dimension, where each component is a *T-data* category (or pattern primitive, called event-type) or a *T-pattern* (Magnusson, 2020).

In this case, patterns of interaction between client and therapist have been detected in all three phases of observation. We used the pattern recognition default settings with some specifications. We have required that the patterns must be repeated at least three times in each session and all sessions of each phase, with this we want to make sure that the pattern is a characteristic of this phase not a characteristic of one of the sessions. Also, we have excluded the patterns made by the repetition of the same variable and the patterns made by an interaction of variables of the same subject, because we want to study the interaction between variables. Finally, we have required a maximum of 4 levels for the

analysis of the interaction, because more than four levels could be interpreted as chains made of contingencies of two or three members.

To assess the effect of the treatment on the client's behaviors we calculated the effect size, in this study we used the Non-overlap of All Pairs (NAP) which is an index focused on identifying the differences between two phases of a design (A and B; Parker and Vannest, 2009; Carter, 2013).

Results

Reliability

Inter-rater reliability is 0.71–0.86, and intra-rater reliability is 0.82–0.89. Both *k* values can be interpreted as very good and excellent reliability indexes (McHugh, 2012).

Using SDIS-GSEQ

Figures 1, 2 show the results of antecedent (Lag+1) and consequent (Lag-1) sequential analysis using GSEQ. All displayed correlations are significant ($p < 0.01$), positive correlations ($Q > 0$) are painted in green, and negative correlations ($Q < 0$) are painted in red. Data indicate that there is a positive correlation between *Clinical Discriminative Stimulus* with the client's *Giving Information* behavior in all phases of the case (see Figure 1). *Following Instructions* correlates positively with the occurrence of *Instructional Discriminative Stimulus*, but this only occurs in the treatment phases (i.e., it is not found in the assessment phase); *Following Instructions* correlates positively with *Target Behaviors* during Evaluation and T1. Finally, Figure 1 also shows a significant positive correlation between *Conditioned Motivating Operation* and *Target Behaviors* in all phases.

The consequent sequential analysis indicates a positive correlation between *Positive Reinforcers* and *Target Behaviors, Well-being Verbalizations, Following Instructions, Aversive Stimuli,* and *Problem Behavior.* Also Conditioned Motivating Operations were weakly correlated with *Target Behaviors* and *Asking for Information.*

Using THEME

Tables 2, 3 show the frequency of two-, three- and four-term patterns in each part of the clinical case. For example, Table 2 displays a strong relationship between *Clinical Discriminative* and *Giving Information* in all phases of the clinical case, this pattern repeats 888 times through different clinical sessions. Also, there are some patterns especially repeated in the early stages of the treatment (e.g., *Clinical Discriminative* and *Discomfort*, *Instructional Discriminative*

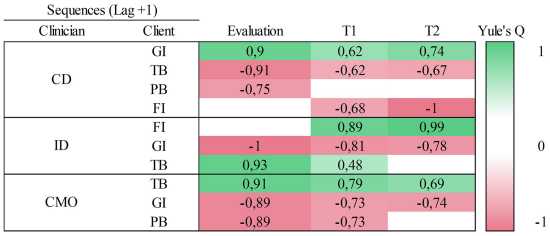

FIGURE 1
Antecedent sequential analysis using GSEQ. This figure displays sequential relationships between clinician's behaviors and the client's behaviors that have been followed by. Here the positive relationships are shown in green and indicate that these are significatively correlated behaviors ($Q>0$; $p<0.01$.). For example, CD was followed by GI in all treatment phases. Negative ones, in red, indicate that those behaviors were not observed together during the verbal interaction ($Q<0$; $p<0.01$). CD, Clinical Discriminative Stimulus; ID, Instructional Discriminative Stimulus; CMO, Conditioned Motivating Operation; GI, Giving Information; TB, Target Behavior; PB, Problem Behavior; FI, Following Instructions; Ti, Treatment phase 1; T2, Treatment phase 2.

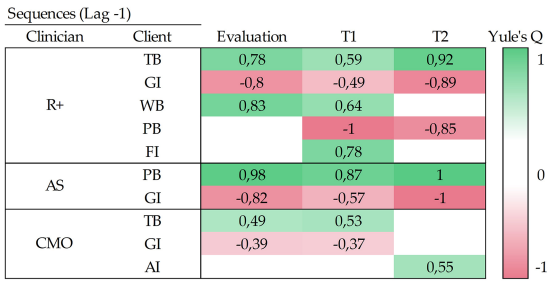

FIGURE 2
Consequent sequential analysis using GSEQ. This figure displays sequential relationships between client's behaviors and the clinician's behaviors that have been followed by. Here the positive relationships are shown in green and indicate that these are significatively correlated behaviors ($Q>0$; $p<0.01$). For example, TB was followed by R+ in all treatment phases. Negative ones, in red, indicate that those behaviors were not observed together during the verbal interaction ($Q<0$; $p<0.01$). R+, Positive Reinforcer; AS, Aversive stimulus; CMO, Conditioned Motivating Operation; GI, Giving Information; TB, Target Behavior; WB, Well-Being; Problem Behavior; FI, Following Instructions; AI, Asking for Information; Ti, Treatment phase 1; T2, Treatment phase 2.

and *Target Behavior*), and in treatment phases (e.g., *Clinical Discriminative* and *Wellbeing*, *Clinical Discriminative*, and *Target Behaviors*). Moreover, we have detected patterns increasing through the phases (e.g., *Conditioned Motivating Operation* and *Target Behaviors*, *Target behaviors* and *Positive Reinforcers*).

Table 3 shows the three- and four-term patterns in each phase. The most repeated three-term patterns involve *Target Behaviors* and *Positive Reinforcers* (e.g., DC TB R+; CMO TB R+). Our analysis reveals similar data with four-term patterns. The most repeated patterns involve *Target Behaviors* and *Positive Reinforcement* (e.g., GI DC TB R+; TB CMO TB R+).

TABLE 2 Two-term pattern analysis using THEME.

Pattern		Number of patterns		
Clinician	***Client***	**Evaluation**	**T1**	**T2**
CD	GI	221	424	243
CD	WB	–	24	13
CD	TB	–	–	81
CD	AI	–	–	19
CD	PB	–	–	27
CD	D	10	–	–
ID	TB	15	19	–
CMO	TB	54	87	104
CMO	AI	–	–	14
Client	*Clinician*	Evaluation	T1	T2
TB	CMO	41	–	25
TB	R+	65	63	97
WB	DC	–	–	16
WB	R+	11	21	–
GI	R+	19	56	–
PB	AS	–	14	14
FI	R+	–	13	–
AI	CMO	–	–	10

CD, Clinical Discriminative Stimulus; ID, Instructional Discriminative Stimulus; CMO, Conditioned Motivating Operation; R+, Positive Reinforcer; AS, Aversive stimulus; GI, Giving Information; WB, Well-Being; AI, Asking for Information; TB, Target Behavior; FI, Following Instructions; PB, Problem Behavior; T1, Treatment phase 1; T2, Treatment phase 2; $p < 0.01$.

Comparison between both software

Table 4 shows a comparison between the patterns with two variables detected with GSEQ and THEME. Specifically, 59% (i.e., 17/29) of the identified patterns were detected by both methods of detection. While 31% (i.e., 9/29) were detected only by THEME, 10% (i.e., 3/29) were detected by GSEQ.

Visual distribution of the patterns

Pattern detection has indicated which variables are moment-to-moment correlated in verbal interaction. These results have allowed us to analyze how these variables change along with the psychological treatment. Figures 3, 4 show the distribution, through a clinical session, of the variables that are present in the most repeated patterns. These figures have been useful for visual analysis of the covariation of correlated variables.

For example, Figure 3 displays the evolution of verbalizations with *Clinical Discriminative* functions among different treatment phases and how are they followed by *Giving information* verbalizations of the client. As we will discuss these visual inspections could help practitioners to evaluate the clinical relationship or the efficacy of the clinical intervention.

TABLE 3 Three- and four-term pattern analysis using THEME.

Pattern type	Number of patterns		
Three-term pattern	**Evaluation**	**T1**	**T2**
CD-GI-R+	15	–	–
CD-TB-R+	–	-	95
ID-TB-CMO	9	15	-
CMO -TB-R+	31	35	66
D-CD-GI	9		–
WB-CD-GI	–	12	–
PB-AS-TB	–	–	10
Four-term pattern			
GI-DC-TB-R+	–	–	55
TB-CMO-TB R+	–	21	–
DC-TB-R + -PB	–	–	9

CD, Clinical Discriminative Stimulus; ID, Instructional Discriminative Stimulus; CMO, Conditioned Motivating Operation; R+, Positive Reinforcer; AS, Aversive stimulus; GI, Giving Information; TB, Target Behavior; PB, Problem Behavior; T1, Treatment phase 1; T2, Treatment phase 2; $p < 0.01$.

TABLE 4 Two-term patterns detected in each software.

Antecedent patterns	Evaluation	T1	T2
CD-GI	GSEQ and THEME	GSEQ and THEME	GSEQ and THEME
CD-WB	–	THEME	THEME
CD-TB	–	–	THEME
CD-AI	–	–	THEME
CD-PB	–	–	THEME
ID-FI	–	GSEQ	GSEQ
ID-TB	GSEQ and THEME	GSEQ and THEME	–
CMO-TB	GSEQ and THEME	GSEQ and THEME	GSEQ and THEME
CMO-AI	–	–	THEME
Consequent patterns			
TB-R+	GSEQ and THEME	GSEQ and THEME	GSEQ and THEME
TB-CMO	THEME	–	GSEQ and THEME
WB-R+	GSEQ and THEME	GSEQ and THEME	–
PB-AS	GSEQ	GSEQ and THEME	GSEQ and THEME
AI-CMO	–	–	GSEQ and THEME
GI-R+	–	–	THEME
FI-R+	–	–	THEME

Antedecent patterns are formed by clinician's behaviors followed by the client's behaviors; Consequent patterns are formed by clinician's behaviors followed by the client's behaviors; CD, Clinical Discriminative Stimulus; ID, Instructional Discriminative Stimulus; CMO, Conditioned Motivating Operation; R+, Positive Reinforcer; AS, Aversive stimulus; GI, Giving Information; WB, Well-Being; AI, Asking for Information; TB, Target Behavior; FI, Following Instructions; PB, Problem Behavior; T1, Treatment phase 1; T2, Treatment phase 2; $p < 0.01$.

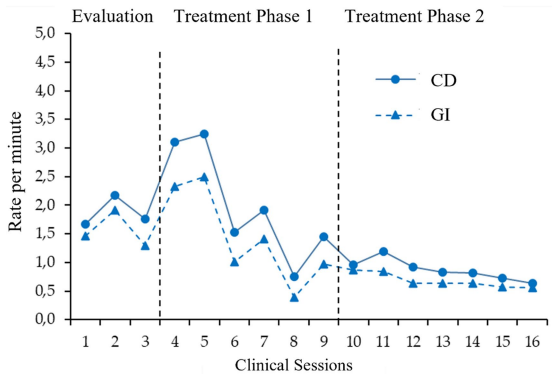

FIGURE 3
Clinical Discriminative and Giving Information distribution though sessions. This figure displays the rate per minute covariation between two sequentially correlated behaviors through different clinical sessions. Specifically, here we can see how the clinician's behavior Clinical Discriminative Stimulus rate matches with the client's behavior Giving Information during the treatment. CD, Clinical Discriminative Stimulus; GI, Giving Information; T1, Treatment phase 1; T2, Treatment phase 2.

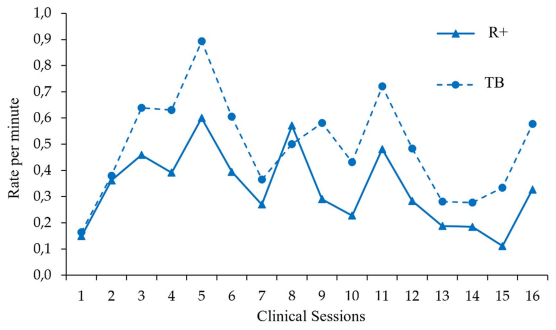

FIGURE 4
Target Behavior and Positive Reinforcer distribution though sessions. This figure displays the rate per minute covariation between two sequentially correlated behaviors through different clinical sessions. Specifically, here we can see how the clinician's behavior Positive Reinforcer rate matches with the client's behavior Target Behavior during the treatment. R+, Positive Reinforcer; TB, Target Behavior.

Effect sizes

Both sequential analysis and pattern analysis indicate positive correlations between the client's *Target Behaviors* and the therapist's *Positive Reinforcers*. To assess the effect of these *Positive Reinforcers* we have calculated the effect size in the client's *Target Behaviors* (e.g., *Positive Reinforcers* should increase the likelihood of emission of the behaviors they follow). In this case, the effect size index indicates that the treatment had a moderate effect on increasing the *Target Behaviors* (NAP = 0.67; Standard Error: 0.21; 95% CI: [0.32–0.89]).

Discussion

The aim of the current article was three-fold. First, we have highlighted the potential relevance of pattern analysis methods in the study of verbal interaction in psychological interventions and we have presented the reasons why these types of analysis could help in the development of the next generation of process analysis in clinical research. Second, we have conducted an observational proof-of-concept study to analyze the verbal interaction in a single-case design using two methods of pattern analysis (e.g., GSEQ and THEME). Using sequential analysis and more complex pattern detection algorithms we could identify more than 25 interaction patterns between a clinical psychologist and his client in different phases of the psychological treatment. These interaction patterns were visually displayed through different sessions, and the effect size of the treatment was measured for the *Target Behaviors* of the client. Third, we have compared the results yielded by these two methods of pattern analysis. In this section of the article, we discuss methodological implications in the search for hidden patterns of interaction in clinical settings, the clinical implications of our results, the limitations of our work, and the main conclusions.

Methodological implications

We have compared the performance of GSEQ and THEME software in the detection of patterns in verbal interaction. They provided similar results in the detection of sequential patterns of two variables; approximately 60% of these patterns were detected by both (see Table 4). Although 60% could seem a low percentage of agreement, they detected in the most repeated patterns and there was not any difference in the main repeated patterns. THEME detected 9 patterns, in different moments of the treatment, that GSEQ did not. It seems that THEME could be more sensible to patterns with lower frequencies than the GSEQ. Thus, if the purpose is to explore hidden patterns of interaction, THEME is more useful in this regard. But if the aim is to detect the most significant patterns of interaction between two variables, both perform equally. At this point, we would like to bring attention to the negative correlations exposed by GSEQ. Both methods could be useful to assess treatment integrity, but the negative correlations give us extra information. It gives us not just about the apparition of psychologist behavior when a specific client's behavior occurs, but also the absence of a certain psychologist behavior after the client's behavior. For example, thanks to this data we could detect that his psychologist has not presented any *positive reinforcer* after a *problem behavior* of the client (see Figure 2).

One of the main differences between both software is the detection of patterns constituted by more than two variables. THEME showed to be powerful enough to automatically detect these patterns. While with GSEQ is possible to calculate different lag distances (e.g., Lag +2, Lag +3, etc.), the interpretation could

lead to erroneous conclusions, because it did not include the variables that are inside of this correlation, and the software simply correlate two variables that are in a specific distance. That is not the case with THEME, it automatically has detected patterns formed by three and four correlated variables. This feature is essential to the study of verbal interaction because it has been useful to detect the repetition of structured patterns that imply a use by the psychologist of three- and four-term contingencies. In this study, we have detected 7 three-term patterns and 3 four-term patterns. This detection imply that we have increased the precision of this analysis, if we compare it with previous research on this topic (e.g., Calero-Elvira et al., 2013). Thus, the combination of both methods seems to be suitable to detect negative correlations and to detect complex patterns (i.e., three- and four-term contingencies).

Clinical implications

As we have discussed, the use of sequential analyses and pattern recognition algorithms to analyze the verbal interaction between psychologist and client could help us to study how the learning processes are set in motion in psychological interventions. The observational data analysis of this paper has permitted us to have a closer look at this interaction and to describe how this interaction has occurred during the treatment. Among the results, we would like to discuss the clinical relevance of several patterns. Specifically, we were able to detect that *Clinical Discriminative Stimulus* correlates significantly with the client's *Giving Information* behavior in all phases of the case, showing antecedent discriminative control by the psychologist of the client's *Giving Information* behavior. Figure 3 shows how the rate of these behaviors changes similarly during treatment. These data could inform us that the psychologist has a good therapeutical relationship with the client, due to the positive correlation between these two variables. The sequential antecedent analysis indicates that *Following Instructions* correlates positively with the occurrence of *Instructional Discriminative Stimulus*, but this only occurs in the treatment phases and it is not found in the assessment phase. These differences between the evaluation phases could be explained by the positive correlation found in the evaluation phase between *Target Behaviors* and *Instructional Discriminative Stimulus*. This contingency also seems to occur to a lesser extent in the first treatment phase and coincides with the lower correlation between *Following Instructions* and *Instructional Discriminative Stimulus* in the treatment phases. *Instructional Discriminative Stimulus* may have correlated in the assessment with topographies of the *Target Behaviors*, but this study is not sensitive to such topographies. Also, we have detected a correlation between *Target Behaviors* and the *Conditioned Motivating Operations*. This correlation could be clinically explained by the conditioning function of the *conditioned motivation operations*. These verbalizations have the purpose of changing the client's motivational value of some stimulus or activities. If the clinician states a verbalization with this function and the client agrees, it is probable that this agreement could be coded as a *target behavior*. Also, if the clients state a *Target Behavior*, the clinician could explain more details about why the client is right or relate it to their therapeutic goals, so these verbalizations could have a motivating function. Moreover, this relationship between *Target Behaviors* and *Conditioned Motivating Operations* also appears to have a key role in patterns with more complex structures (i.e., three- and four-term patterns; see Table 3). Due to this correlation having the potential impact of changing the client's value of events, it could have a significant role in the clients' behavioral change outside the clinical context and it should be studied in detail in future studies.

Also, P*ositive Reinforcers* correlate positively with *Target Behaviors*, in the three phases of the case; with verbalizations of *Well-Being*, in the assessment and the first part of the treatment; and with *Following Instructions*, in the first part of the treatment. This could mean that these behaviors are under a schedule of positive reinforcement applied by the psychologist. At the same time, positive reinforcers do not correlate with problem behaviors in the assessment and correlate negatively in the treatment statements. This could indicate that the therapist identifies problem behaviors once treatment has already begun and he does not apply positive reinforcement schedules. In contrast, *Aversive stimuli* correlate positively with *Problem Behaviors*. Thus, that could mean that these behaviors are under a reduction procedure applied by the psychologist.

As with *Conditioned Motivating Operations*, *Positive Reinforcer* correlates with *Target Behaviors* even in three- and four-term patterns. CMO-TB-R+; CD-TB-R+; GI-DC-TB-R+; and TB-CMO-TB-R+. Figure 4 shows how *Positive Reinforcers* and *Target Behaviors* covary through the treatment. It seems that the psychologist was using reinforcing contingencies that include *Target Behaviors*. The theoretical effects of these contingencies should imply an increment of *Target Behavior* in session. Calculating the effect size in the increment of the *Target Behaviors*, we tried to indirectly assess whether this procedure affects these behaviors. Results showed us that the effect size was moderate. Other potential variables could influence this class of behaviors, further experimental analysis should confirm the relationship that we have detected in this study.

Limitations

We have found problems in the use of the GSEQ and THEME software with raw data obtained using *The Observer XT 12* to the GSEQ and THEME software. Both software could develop techniques to import the results from observational software with ease. Moreover, as we discussed, we have found that the THEME's complex pattern detection performance is superior to the GSEQ performance in the same task. Although THEME seems to be sensible to patterns with low frequency, this is more a challenge in the interpretation of the results to the researcher than a limitation of the software. Also, we have not analyzed all the patterns that THEME has detected, we impose some pre-analysis

requirements. Without these requirements, patterns reported by THEME could increase.

Also, the observational coding of events was not automated. The functional definitions of the variables have increased the complexity of the observational coding. In this sense, the reproducibility of the results is compromised, because this methodology of research is time-consuming, and it requires observers with high standards of training. Although the complexity is an issue, this analysis could be benefited from the inclusion of qualitative data on the verbalizations.

Finally, the results of this study are merely tentative and further experimental analyses need to be conducted to fully study the patterns of interaction that are occurring in the psychological interventions. Also, this experimental control could help to better analyze the effect size of the treatment. The influence of external variables could have affected the behavior of the client. Moreover, we recognize that this study could have all the potential limitations of the single-case research. For example, the results derived and analyzed in this study are not representative of the clinical interaction in all clinical cases, and results could be biased by several factors (e.g., culture, psychologist's training, client's psychological problems, etc.). But, despite all these limitations, we believe in the exploratory value of this paper, it could be useful for the development of new perspectives and methodologies for the study of processes in clinical psychology.

Conclusion

The study of the processes underlying therapeutic change is essential to optimize psychological treatments. The identification of patterns of verbal interaction during therapy is a valuable step in understanding how the processes that make psychological treatments work are set in motion. GSEQ and THEME software have proven to be able to detect those patterns in verbal interaction. THEME has proven to be more powerful in detecting complex interaction patterns and more sensitive in detecting low-frequency patterns, yet both have detected predominant patterns in verbal interaction that may underlie clinical change. This implies that pattern recognition methods could be seen as a promising alternative to studying behavioral change processes in psychological treatments. These methods combined with single-case designs and the development of new recently developed effect sizes for this type of studies (e.g., Pustejovsky, 2018), could have a unique impact on the development of clinical research in the forthcoming years.

Data availability statement

The datasets presented in this study can be found in online repositories. The names of the repository/repositories and accession number(s) can be found at: https://osf.io/ezhmd/?view_only=dbe50c17e90a419e93c87116703ceb27.

Ethics statement

The studies involving human participants were reviewed and approved by Autonomous University of Madrid. The patients/participants provided their written informed consent to participate in this study.

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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Hierarchy and diffusion of organizational forms

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In this paper we first of all summarize and rationalize current typologies of organizational forms, arranging available classifications in a hierarchy of increasing generality. The ensuing structure parallels the classification of living beings into classes of increasing generality such as species, genus, family, order, and so on. Subsequently, we analyze the structure of communications that favored the diffusion of each organizational form. We isolate a few stylized communication structures, pointing to the presence of several sources endowed with global connections as the most efficient diffusion mode. The empirical research that is being carried out on single organizations is close to observing their T-patterns, whereas nothing comparable is in sight for organizational forms as yet. However, at least in some cases, we dare to formulate tentative hypotheses on certain features that the ensuing T-patterns-of-patterns might exhibit.

KEYWORDS

evolutionary social science, organizational ecology, organizational routines, organizational forms, information flows, T-pattern

Introduction

There exists an evolutionary interpretation of human societies which likens organizations to organisms, and their norms, routines, and culture to their genome. This analogy is based on the observation that organizations receive a certain imprinting at foundation, which they do not change throughout their existence (Nelson and Winter, 1982; Hannan and Freeman, 1989). For instance, *Apple* was founded with the aim of producing desktops that would excel in user-friendliness and graphics while addressing the upper end of the market. Today, after switching to portable devices, this focus stayed. Likewise, one may observe that organized religions fix most of their dogmas in the early centuries of their existence, that most States write a Constitution while they are being founded, and so on.

The idea is that the norms, culture, and routines that are set at foundation and during infancy provide an imprinting that single organizations cannot change afterward, albeit novel organizations can be created with different cultures, norms, and routines. Thus, the population of organizations does change, whereas single organizations largely do not.

Obviously, this claim should not be taken too literally. Nobody denies that organizational change takes place, for organizations must continuously adapt to a mutable and unpredictable environment in the course of their existence. What this

approach suggests is that organizational change can only take place insofar it does not destroy an organization's identity, which in its turn can only change at a much slower time scale than the organization itself (Levinthal, 2021). Such qualifications do not destroy the analogy with living organisms, which also adapt their genome to changing circumstances by means of epigenetic mechanisms (Bird, 2007).

One implication of this conceptual scheme is that just like living organisms belong to species, human organizations pertain to a limited number of organizational forms that can be used as templates any time a new organization is founded. In this article, we submit that, just like living organisms can be arranged in classes of increasing generality such as species, genus, family, and other groupings, also human organizations can be arranged in a hierarchy of organizational forms of increasing generality depending on the aspect one looks at. Moreover, we submit that the current inability of evolutionary social science to define what constitutes an organizational form (Romanelli, 1991) originates—among else—from focusing on different aspects of organizations, which in our scheme pertain to different generality levels. Thus, with our hierarchy of organizational forms, we hope to contribute a much-needed conceptual clarification.

Henceforth, we will show that this hierarchy helps make sense of changing information structures within organizations and organizational forms, as well as their origin and diffusion in society at large. In particular, we shall highlight that information about organizational forms diffused in society along different paths depending on the epoch of their invention and the actors who conceived them. By providing a comprehensive framework for information structures at different aggregation levels of human organizations, we hope to offer a conceptual contribution to the comparison of information structures at the human and the nanoscale (Magnusson, 2020). In particular, we highlight that in several instances, there existed several centers from which information radiated, a circumstance that is likely to have generated faster dynamics than either pure broadcast from one single source, or local diffusion.

Our contribution is admittedly more limited insofar as it concerns T-patterns (Magnusson, 2020), for the empirical research on organizational routines is still extremely limited. Only a few organizational routines have been recorded, though it is interesting to remark that patterns have been found, indeed (Hutchins, 1991; Egidi and Narduzzo, 1997; Pentland et al., 2010, 2011). Conceivably, if such analyses would be carried out on large numbers of organizations, the typical time patterns that characterize specific forms would be identified. The current state of research is very far from such a minimal goal, but we point to software engineering as a field where qualitative codification of behavior patterns has made substantial progress (Coplien and Harrison, 2005).

Empirical research is even farther removed from the ability to detect the patterns-of-patterns that likely characterize organizational forms of increasingly higher generality. However, we shall formulate hypotheses concerning possible features of these higher-order patterns.

The rest of this article is organized as follows. The next section illustrates our hierarchy of organizational forms ordered by increasing generality. In this section, we also formulate our hypotheses regarding a few likely features of their T-patterns. Subsequently, we discuss the historical record of their diffusion highlighting the structural properties of the information channels that were used as well as, whenever available, the degree of information centralization within each organizational form. Finally, we discuss a taxonomy of diffusion processes based on communication structure.

Organizational forms

Life scientists identify species out of features that can be observed unambiguously, such as lack of inter-breeding or other indisputable evidence. This is hardly the case for social scientists, who are compelled to make subjective judgments whenever they define an organizational form.

The objective difficulty to ground organizational features on uniquely identifiable indicators has led to endless discussions as to what exactly constitutes an organizational form, how it can be identified, and where are its boundaries, without ever reaching unanimous conclusions (McKelvey, 1982; Hannan and Freeman, 1986; Romanelli, 1991; Pólos et al., 2002; Hannan et al., 2007). In the end, a sort of case-to-case pragmatism has prevailed where organizational forms are defined on indicators that suit each specific investigation, accepting subjectivity as an unavoidable feature of social research (Hannan and Freeman, 1989; Bogaert et al., 2016).

The vast majority of empirical research on organizational forms focuses on combinations of behavioral and technological features, e.g., the emergence of microbreweries as an organizational form distinct from large-scale industrial breweries (Carroll and Swaminathan, 1992, 2000), or multiteam systems whose communication is eventually mediated by information technologies (Mathieu et al., 2002; Zaccaro et al., 2020). This combination of technology and behavior to some extent resembles socio-technical systems research (Trist, 1981), but adds to it an emphasis on typical behavioral patterns that classical socio-technical investigations did not have.

A second stream of research defines organizational forms with respect to structure, originally contrasting multidivisional structures, also called M-form, to more traditional functional structures (Chandler, 1962), but later on extending the analysis to more nuanced structural features such as franchising (Brickley and Dark, 1987; Michael, 2000) or ownership structure (Hasan and Lozano-Vivas, 2002; Erhemjamts and Leverty, 2010). We submit that whenever organizational forms are defined by structure rather than behavior patterns, they simply pertain to a greater level of generality in the sense that structure may constrain, but does not precisely determine behavior. In our hierarchy of

organizational forms, just like an organism belongs to a species as well as a genus, an organization can be an instance of an organizational form defined by its typical behavior patterns as well as a form defined by its structure.

Since nested classifications can be useful in many respects, we propose to define organizational forms on two other dimensions whereby organizations are eventually classified, the institutional dimension—such as being a bureaucracy—and the dimension of organizational ideology. While understanding institutional arrangements as organizational forms is rare but in use (Zucker, 1983; Lee and Pennings, 2002; Hallett and Ventresca, 2006), we found only one instance of an organizational form having been defined on ideology (Schneiberg et al., 2008). Albeit both usages are admittedly uncommon, we submit that substantial advantages can be obtained by adding these dimensions to our understanding of organizational forms. These additional two levels complete a nested scale of four levels, all of which enable us to define organizational forms that exhibit distinct patterns of diffusion along specific information channels and are likely to exhibit their own distinct T-patterns.

Figure 1 illustrates our nested classification of organizational forms aside from the corresponding classifications of living organisms. At the lowest level, we identify organizational forms defined on behavioral patterns (Level 1), which are included in organizational forms defined by structure (Level 2), institutional arrangement (Level 3), and ideology (Level 4). Since each subsequent level includes the previous one in a scale of increasing generality, one specific organization pertains to a form defined by its typical behavior patterns, as well as a form defined by its typical structure, a form defined by a specific institutional arrangement, and a form defined by its ideology.

One important difficulty experienced by the evolutionary understanding of organizations is that, contrary to living species, organizational hybrids do exist. Organizational forms are still useful as pure ideal types to which real organizations can be compared (Weber, 1922), but the distance between theory and the real world is larger than in the life sciences. In this respect, our nested scheme helps reducing this distance because organizations that would have appeared as hybrids along the vertical axis simply belong to organizational forms defined at different generality levels. By contrast, hybrids along the horizontal axis still blur the picture.

Henceforth, we shall describe a few organizational forms that have been identified at each of the above levels, positing for each of them the sort of T-patterns that might be observed. We shall start with behavior patterns to proceed with structure and institutional arrangement and conclude with ideology.

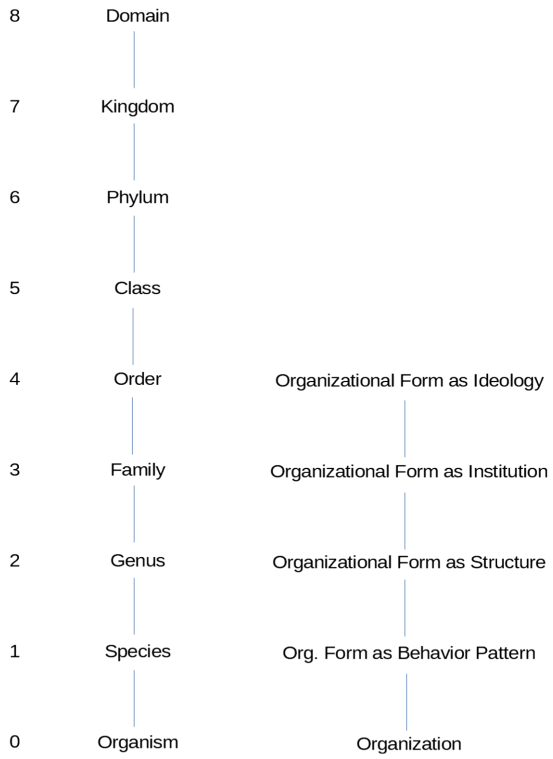

FIGURE 1
Hierarchical classification of living organisms (left) and human organizations (right). The accepted classification of living organisms entails eight levels nested in one another, e.g., Cleopatra is a cat but also a feline and a mammal. For human organizations, we propose four nested levels of organizational forms based on existing classification criteria. Each level is nested in the superior one; hence, each organization displays behavior patterns of a certain sort, has a typical structure, a certain institutional arrangement, and the organization is characterized by a certain ideology.

Patterns of behavior

The simplest class of organizational forms is based on technological and behavioral features, entailing items such as micro-breweries (Carroll and Swaminathan, 1992, 2000) or multiteam systems making use of specific communication routines and technologies (Mathieu et al., 2002; Zaccaro et al., 2020). Unfortunately, in spite of a substantial number of empirical investigations, scholars could not agree on what exactly constitutes one such organizational form (Romanelli, 1991). Tentative definitions have mostly pointed to processes generative of organization boundaries (Hannan and Freeman, 1986), or behavioral codes that generate organizational identities (Pólos et al., 2002).

One attempt at uniting these insights, which we wholeheartedly join, has been recently proposed by Fiol and Romanelli (2012). Upon remarking that stable patterns of behavior are a universal feature of human organizations, they focused on the communities of practice where these patterns arise and are eventually adopted. In a nutshell, such behavior patterns may become sufficiently stable to be perceived as organizational behavior codes, which in their turn contribute to organizational identity while erecting boundaries that separate organizations from one another. One remarkable feature of this approach is that

it justifies the usage of T-patterns in order to identify organizational forms.

Research on organizational routines has focused on patterns that eventually emerge in the sequence of operations that organization members carry out (Hutchins, 1991; Egidi and Narduzzo, 1997; Pentland et al., 2010, 2011). Figure 2 illustrates the sort of data produced by these investigations. The nodes represent actions that could be carried out, edges connect actions that were carried out in sequence.

Such detailed empirical investigations on organizational routines are still rare, but they may become more common in the future. Thus, at least in principle organizational forms based on behavioral patterns could be detected by identifying their typical routines.

For instance, Pentland et al. (2010, 2011) analyzed the routines recorded by one and the same software in as diverse organizations as a labor union, a statistical research institute, a construction company, and a meat packaging plant. They purposedly selected organizations that were as different as possible from one another in order to extract different routines, but if data had been collected for—just to make an example—a set of micro-breweries and a set of large, mass-production breweries, we may expect that the T-patterns of the microbreweries would share common features, as well as those of the large breweries. To the extent that the common features of the firms in the first group would be different from the common features of the firms in the second group, these differences could have been used to discriminate them as belonging to two distinct organizational forms.

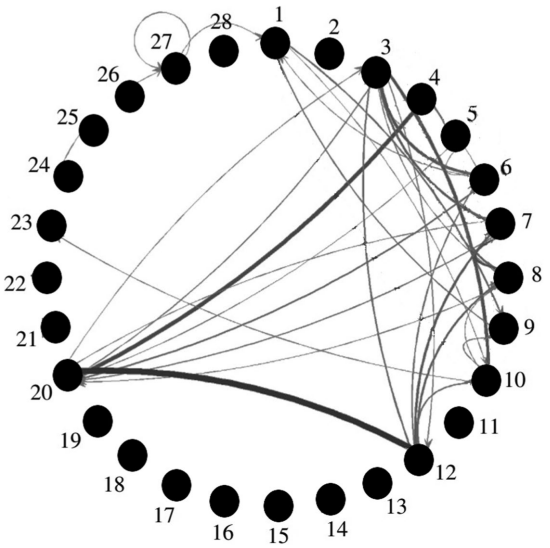

FIGURE 2
The graphical representation of behavioral routines that emerges out of empirical investigations. Nodes represent actions, edges link actions that are carried out in sequence, thickness represents their frequency. It is evident that routines do not merely repeat sequences of actions, but also add some degree of exploration to the received sequence. Our elaboration, loosely inspired by Pentland et al. (2011).

A remarkable step in this direction has been made in the field of software engineering, where behavioral patterns have been qualitatively identified (Coplien and Harrison, 2005). If these qualitative patterns could be expressed as T-patterns, then we would have a quantitative definition of an organizational form based on the coding patterns of software houses.

Notably, in the above example, one single software house would exhibit T-patterns, whereas the organizational form "software houses" (Level 1) would actually be defined on patterns-of-patterns. Thus, henceforth higher-order patterns will be denoted as T-patterns^n, where n is the generality level of organizational forms in our scale. For instance, one single software house would generate T-patterns, whereas all software houses would be expected to exhibit T-patterns^1.

Structure

Contrary to organizational forms based on behavior patterns, those based on structural features were first introduced without any reference to evolutionary theory (Chandler, 1962). Nevertheless, they perfectly fit into our scheme as a higher-level classification that can include forms defined on behavior patterns. The structure generally changes at a slower time scale than patterns of behavior; hence, it makes sense to understand organizational dynamics as being framed by a structure that stays for some time, channels information flows and thereby enables and constrains patterns of behavior without specifying their details.

Several structure-based, Level 2 organizational forms have been identified in the literature. For any organization larger than a handful of individuals, the *functional structure* is the most obvious and the most common among organizations of any sort. It simply consists of arranging in separate units all those who carry out similar activities. In businesses, typical functions are Procurement, Production, and Sales, as well as Marketing or Research & Development.

Some business functions are linked by precedence relations, e.g., procurement comes first, then production, then sales. It is known that this is sufficient to generate oscillations of production (Sterman, 1989). We would not claim that T-patterns^2 of functional structures are necessarily oscillatory, but they could exhibit oscillations even in absence of exogenous disturbances.

A more complex structure is generally adopted by organizations that carry out highly differentiated activities, such as large corporations that are active in different markets, or different geographical areas. Since organizations of this sort must adapt to the different environments where they operate, they create semi-autonomous divisions wherein functions are duplicated. The *multidivisional structure*, also called the M-form (Chandler, 1962), is another structure-based organizational form defined at Level 2. If and when its T-patterns^2 will be observed, we hypothesize that they will differ markedly across its component divisions.

Still at Level 2, the *matrix structure* has two or more bundles of authority lines, for instance, one along functions (as in a functional structure) and the other one along markets or projects. Matrix structures contradict the principle of unity of command and the very fact that their members have two or more bosses makes for difficult decision-making. However, precisely, this feature enables it to combine expertise from different areas in the organization (Galbraith, 2009). It seems sensible to hypothesize that the more diverse fields are combined and the less repetitive its activities, the less regular T-patterns[2] will be observed.

Figure 3 illustrates, left to right, a functional structure, a multidivisional structure, and a matrix structure, respectively. While functional and multidivisional structures are invariant with time, there exist versions of the matrix structure—also called *project organizations*—where the projects heading the horizontal lines change with time, as it happens for instance in large engineering firms. In these cases, a time sequence of structures would be more appropriate.

Finally, *adhocracies* (Mintzberg, 1979), also called *network organizations* (Miles and Snow, 1986), achieve maximum flexibility by quickly adapting their structure to changing environmental conditions. Adhocracies spearhead a trend toward increasingly flexible organizations, whose origin may be placed with the sociotechnical systems of the 1950s (Trist et al., 1963) but which greatly accelerated with lean manufacturing in the 1980s (Sugimori et al., 1977) and recently reached a remarkable peak with flat organizations composed uniquely by work teams indirectly coordinated by one chief executive officer (CEO), and no middle management in between (Bernstein et al., 2016). However, even in these extreme cases, organizational flexibility is limited by clear boundaries to the activities that organization members can undertake (Cabri and Fioretti, 2022). These organizations are capable of extreme plasticity, but only within a given set of possible structures (Levinthal and Marino, 2015). To an even greater extent than in the case of matrix structures, we hypothesize that in adhocracies T-patterns[2] will only appear if flexibility is kept at quite a low level.

There exists a debate whether adhocracies/network organizations constitute a novel organizational form, or are rather just a variation around the theme of bureaucracy (Hales, 2002). Since we conceive organizational forms as nested in one another at increasing levels of generality, we can answer positively to both ends of this conundrum. In our interpretation, adhocracies/network organizations constitute a novel organizational form at the structural level (Level 2), while at the same time, they are still a bureaucracy at the level of the organizational forms defined as institutional arrangements (Level 3). Furthermore, our scheme can accommodate the observation that adhocracies often have a high ideological content (Mintzberg, 1979) by including them in an organizational form defined by ideology (Level 4).

Institutional arrangements

Social scientists understand institutions as either rules, norms, conventions, habits that regulate organizational behavior, or specific organizations that issue those rules (Khalil, 1995; Edquist and Johnson, 2005; Greenwood et al., 2014). Henceforth, we shall adopt the first meaning, eventually employing the expression "institutional arrangement" in order to stress our choice.

One prominent institutional arrangement is the modern bureaucracy, often regarded as paradigmatic of capitalism itself (Weber, 1922). Occasionally, the norms of bureaucracy are used to call it an organizational form (Zucker, 1983; Lee and Pennings, 2002; Hallett and Ventresca, 2006). Albeit this understanding of bureaucracy is uncommon, we judge that it fits our scheme perfectly well.

Thus, we introduce a Level 3 where organizational forms are defined as institutional arrangements, more general than the Level 2 where organizational forms are defined by structure, which in its turn is more general than the Level 1 where organizational forms are defined by their behavior patterns. To our knowledge, three broad organizational forms have been identified at this Level 3.

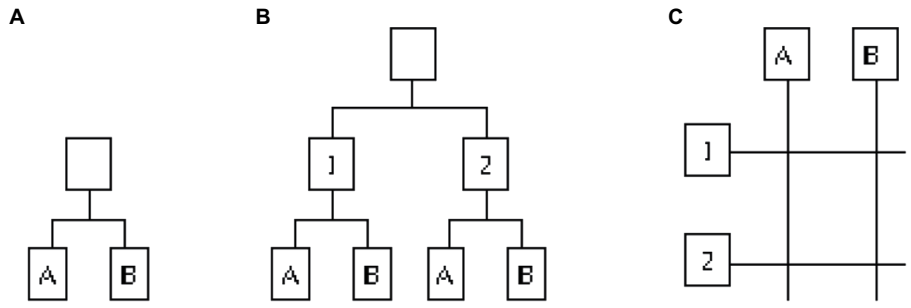

FIGURE 3
Three basic structures, typical of organizational forms at Level 2. Left **(A)**, a functional structure with two functions A and B. Center **(B)**, a multidivisional structure where functions A and B are duplicated across divisions 1 and 2, respectively. Right **(C)**, a matrix structure whose members report to functional units A and B as well as market/area/project specialists 1 and 2, respectively.

We already hinted at bureaucracy as the first instance. Weber (1922) is credited for having highlighted the specific features of modern bureaucracies, above all their ability to define roles and positions before someone has been found to fill them. Weber's bureaucracies, also called *machine bureaucracies* within organization studies (Mintzberg, 1979), are typical of corporations as well as public administrations and probably comprise the vast majority of human organizations today. A clear set of norms, generally made explicit by laws and internal regulations, specify the rights and duties of their members with respect to the organization as well as the relationships with colleagues. These norms result from the huge efforts these organizations typically make to standardize and regulate their operations in as much detail as possible, resulting in somewhat impersonal, but extremely efficient collective machines. Albeit in common parlance bureaucracies are negatively stymied because of their rigidity, organization theorists generally stress that no other organizational form can mobilize collective energies and pursue complex long-term goals to any comparable extent. Machine bureaucracies extend individual means-ends calculative rationality to collective action, eliminating arbitrariness and personal evaluation to an extent unrivaled by any other organizational form (Kalberg, 1980).

Mintzberg (1979) observed that there exists a variety he called *professional bureaucracy*, which includes hospitals and universities among its most notable instances, where standardization is not carried out within each single organization but rather by some external body representing professional interests, e.g., congresses and specialized journals for physicians and scientists. New theories and new clinical practices must obtain legitimation worldwide, a circumstance that typically makes innovation more difficult for professional bureaucracies in comparison to machine bureaucracies. However, professional bureaucracies generally concede their members substantially higher margins of discretion in comparison to machine bureaucracies.

The third category entails organizations where standardization is minimal or absent, bonds between members being largely based on personal relations where favors are made in exchange for unconditional dependence. The members of *patronage-based* organizations (Flap, 1990) are coopted into unequal relations characterized by unlimited loyalty and are expected to follow their patron in their fortunes and misfortunes (Redding, 1985). For instance, new CEOs typically replace the whole top management as soon as they are nominated (Jackall, 1988), but also political parties require fidelity from elected parliament members, whereas criminal gangs are possibly the most extreme instance. Small organizations may slip into patronage when personal relations are more important than rules, but they are also capable of more balanced, sometimes even egalitarian arrangements.

We hypothesize that homogeneous T-patterns[3] will be most easily observed among machine bureaucracies, least easily observed among patronage-based organizations, with professional bureaucracies somewhere in between. Furthermore, we hypothesize that machine bureaucracies will likely exhibit homogeneous T-patterns[3] even when they grow large, whereas this may not be the case for large professional bureaucracies (where, for instance, university professors may hold "chairs" that are substantially independent of one another) as well as some large patronage-based organizations (for instance, political systems characterized by a large number of heterogeneous parties and cleavages within each of them).

Ideology

Ideologies provide a neat interpretation of social phenomena, calling for personal commitment to realize a desired change that is often conceived as a struggle against some figurative or very concrete enemy (Cranston, 1979). Religions are generally not equated to ideologies because of their supernatural aims, but they may acquire an ideological character insofar as their ethos is directed toward mundane objectives (Williams, 1996).

Ideologies concur to build organizational identity by providing a common purpose to their members (Alvesson, 1987) and easing organizational decision/making (Brunsson, 1982). Distinct organizations that share a specific ideology are eventually grouped together and contrasted to competing groups, for instance, in the case of cooperative enterprises (Simons and Ingram, 2004; Schneiberg et al., 2008) or, more recently, corporations leaning toward opposite political ideologies (Gupta and Briscoe, 2020; Swigart et al., 2020). We submit that ideology has the credentials to be taken as a criterion to define organizational forms, which in our scheme is at the most inclusive Level 4.

Exhaustive, universally accepted classifications of ideologies do not exist. However, one may trace a distinction between broadly defined categories such as ethical, political, religious, national, and corporate ideologies, and more specific instances such as gender, diversity, racial, market, educational, language, and even medical and nutrition ideologies. While the former constitute a rather stable set of classifications, the latter is more open to additions.

Quite often, ideology is a matter where top management is the initiator. Its hierarchical, top-down, homogenizing nature (Goll and Zeitz, 1991) suggests us to hypothesize that T-patterns[4] may change abruptly when a new top management steers the organization toward a new vision and a new strategy.

Emergence and diffusion

In this section, we reconstruct—whenever possible—the historical origin of the aforementioned organizational forms, highlighting their diffusion processes. More specifically, whenever possible, we shall attempt to reconstruct the structure of information flows that were at work.

In general, novel organizations are created all the time, whereas the emergence of a novel form is quite a rare event. New

organizational forms appear relatively often at Level 1, in practice with every new production, marketing, or organizational technology. By contrast, the structural forms we listed at Level 2 are quite stable, although one may conceive of sub-forms that are conceived to fit specific niches. The institutional forms of Level 3 are even more stable, whereas the stability of the ideologically-defined forms of Level 4 depends on their ability to encompass a variety of phenomena.

Henceforth, the emergence and diffusion of novel organizational forms at the four generality levels will be discussed in the same sequence as in the previous section.

Patterns of behavior

The emergence of a novel organizational form in terms of a novel behavior pattern is probably more common than organizational forms at a higher generality level. For businesses, it happens any time a novel technology generates a new industry with its own peculiar pattern of interactions between competing firms, their customers, suppliers, and other stakeholders.

The generation of novel behavior patterns involves several actors, including entrepreneurs as well as established firms and public agencies, quite often scientists or reformers who build up a community of practice where ideas are exchanged, tacit knowledge is made explicit, and technologies are developed and refined (Garud and Van de Ven, 1989; Romanelli, 1991; Fiol and Romanelli, 2012). BioTech is a particularly interesting point in case, with cross-contamination between molecular biologists and clinical physicians at the University of California, San Francisco, in mid-1970s acting as a fertile ground for the first companies that would exploit recombinant-deoxyribonucleic acid (DNA) technology (Jong, 2006). Scientific and technological breakthroughs were available, basic intuitions were being made explicit and published in scientific journals, and even managerial techniques were being discussed (Fairtlough, 1994). This is not a detail, because biotech is not based on hierarchically managed research projects such as those that the big pharmaceutical companies were used to manage, but rather thrives by allowing researchers a degree of freedom in proposing projects (James, 2000). Thus, it is really a novel organizational form based on a novel behavior pattern. From our point of view, one interesting aspect is that in spite of all the difficulties in understanding and reproducing it, within a couple of decades several agencies around the world had re-created similar companies and cultural environments (Niosi et al., 2013). This could happen because all the relevant knowledge was quickly codified, published, and even advertised by specialized consulting firms.

In the above example, information diffused rather quickly from its origin to the rest of the world. However, what is normal in contemporary societies may not have always been the case. Consider the following counter-example from the late Middle Age.

Preci, a tiny small village on the Italian Apennines, had developed what was possibly the most advanced surgical knowledge in Europe between the 13th and the 17th century. Their most distinctive secret was that by passing tools on a flame before operating, patients were less likely to die (Davidson, 2016). The nearby village *Cerreto* tried to imitate, but they either could not steal the secret or did not understand its importance (Timio, 2002). The word *charlatans* supposedly derive from crossing the name of its inhabitants, the *Cerretani*, with the onomatopoeic *ciarlare*, a dialect entry for *to chat* (Treccani, 2022).

Albeit a curiosity, this anecdote tells us that the structure of information flows might have been quite different in past ages. It tells us about a world where valuable knowledge was effectively kept secret, local, unexploitable by other actors. If it ever diffused, it did only through local interactions, slowly and imperfectly.

Structure

At the level of organizational forms defined by their structure, we find four broad instances: The functional structure, the multidivisional structure, the matrix, and the adhocracy, or network organization. To our knowledge, no information is available regarding the origin and diffusion of the functional structure, which is perhaps too obvious for its invention to have been recorded. By contrast, we know that the multidivisional structure was invented in two US companies at roughly the same time, in the 1920s, in the two flavors with which this structure is still employed today.

The first company is *DuPont*, a producer of explosives that had made huge profits during World War I but had to reconvert its production once the conflict was over. With huge financial resources available, they diversified into chemicals ranging from colors to artificial fabrics and celluloid. To their surprise, they ended up in the red numbers because their single procurement, production, and sales departments had a hard time at delivering so diverse products on time. Aggregation had been supposed to provide scale economies, but timely delivery was much more important in the consumer goods markets they had just entered. Overcoming immense internal resistance and through a tortuous path of partial experimentations they finally arrived at creating separate divisions for explosives, colors, artificial fabrics, and other products. Historically, this is the first instance of a divisional structure defined by classes of products (Chandler, 1962).

The second company is *Sears & Roebuck*, which used to sell durable goods to rural America shipping them by railway. The Ford Model T changed forever the rules of the game, making it possible for peasants to reach big cities in order to procure the goods they would not find in their village. *Sears* reacted by duplicating its operations in five big stores at the periphery of five big cities, where goods were on sight on scaffolds along paths where customers could freely walk. Since each of these five stores had its own procurement and sales functions, they had invented the multidivisional structure based on geographical areas (Emmet and Jeuck, 1950).

The diffusion of the M-Form was very slow in the 1930s but took off after World War II. The number of firms adopting it increased linearly in the 1950s and 60s to reach saturation in the late 1970s, when nearly all large and diversified companies had adopted it (Teece, 1980). The speed of diffusion reflects different information channels, in the 1930s and 1940s the multidivisional structure used to spread by imitation, whereas since the end of World War II, it was being taught in business schools.

The matrix structure was theorized by management consultants in the 1970s out of the organizational structure of engineering contractors, which typically assign to each new project a team composed of personnel drawn from different functions. Thus, each team member has two bosses, the functional director and the project director. The matrix structure makes this arrangement permanent with the purpose of combining expertise located in different areas of the organization; however, its decision-making processes are typically longer and complex.

The matrix was the management fad of the 1970s. It was applied to a number of organizations for which it had not been appropriate, leading to its dismissal in the 1980s. However, since the 2000s it is enjoying a limited but rising popularity, once it has been understood that it is the proper structure when the value added by combining dispersed information is worth the necessarily more cumbersome decision process (Galbraith, 1971, 2009).

The conceptualization and diffusion of the matrix structure is remarkable in that it has been in the hands of a few global consulting firms. Its dismissal in the 1980s occurred spontaneously, in a wave just as emotional as the one that had brought it to the front. By contrast, its gradual resurrection since the 2000s has been largely managed by academics.

The adhocracy, or network organization, appeared in isolated cases in the 1950s and 1980s but took momentum with the new millennium. It is still poorly conceptualized and little understood, with consultants making use of a series of ever-changing buzzwords that are supporting a never-ending series of management fads (Cabri and Fioretti, 2022). In information-structural terms, it is a series of centrally-managed waves that trigger mass adoptions and mass dismissals without any deep understanding of the conditions and operating principles of this new organizational form.

Institutional arrangements

The machine bureaucracy, the most common and most representative organizational form of modern societies, originated with the Industrial Revolution, in England, in the late XVIII century. Its distinctive emphasis on regulations and norms, as well as clear rights and duties for all of its members, mirrors the ideals of the French Revolution that turned subjects into citizens.

The machine bureaucracy is the organizational form of capitalism, and capitalism is, first of all, a way of thinking. It implies postponing leisure in order to accumulate resources to be invested in some enterprise that will hopefully yield a return in the future, sometimes a distant future. It is based on hard work, well beyond what is needed to enjoy the pleasures of life, and therefore requires, and induces, a mentality change.

In the late XVIII century, even in England, the capitalistic mentality was uncommon. A few early capitalists had it, but the vast majority of the population did not.

The earliest capitalists operated in the textile industry. Initially, they delegated production to contracted craftsmen. This putting-out system was subsequently abandoned in favor of factories where production was directly managed by the capitalists themselves.

According to Marglin (1974), factories had to be set up because craftsmen, with their pre-capitalist mentality, were unwilling to work long hours. They would not renounce leisure in order to earn more money in a world where, in any case, the variety of goods on offer was extremely limited. They would rather accept contracts insofar as they needed money to survive, devoting the rest of their time to inexpensive leisure. Their ideal was the idle noble, not the industrious entrepreneur.

However, nobles had changed a lot in the meantime. In the attempt to keep the pace with the rising capitalists, many of them had started to manage their land efficiently, which implied that all of it had to be put to productive usage. However, the traditional practice of leaving a portion of land unused and available to peasants did have a rationale. It was the peasants' insurance against epidemics, wars, or any natural disaster that could plunge them into misery, for by leveraging on their extended families they could exploit that land and survive. Once the formerly unused land had been enclosed and properly managed, those who had fallen into misery had no choice but moved into cities where they would accept any job available. The urban proletariat was born, and it was essential for capitalism to make its first steps.

According to Marglin (1974), the first factories were built out of this combination of craftsmen unwilling to work as much as requested, land enclosures, and the availability of an urban proletariat. Later on, technical innovations made the factory also more efficient with respect to the putting-out system.

This novel organization, the factory, needed a novel management system because, for the first time in human history, time had become a scarce resource. There was simply no time to check all the details of what subordinates were doing.

Management by exception was invented in these factories, painstakingly, slowly, along more than a century out of continuous comparison between predictions and actual values (Pollard, 1965; Miles and Snow, 1994). Formalize everything, standardize everything, expect goals, and focus only on the exceptions were the means by which many workers could be controlled at a time. The machine bureaucracy, with its rules and norms, was invented in order to escape from the moving sands of micromanagement.

There was little or no awareness of this process. Practitioners invented or refined accounting techniques that slowly diffused from firm to firm, at a time when management itself was not a codified discipline but rather a bundle of how-to that did not command the respect enjoyed by classical culture (Pollard, 1965). It was, for about a 100 years, purely decentralized information diffusion, slowed down by inertia though by no means hampered by legal or institutional

arrangement. Management by exception reached academic dignity only at the beginning of the XX century (Fayol, 1916), after it had been spontaneously adopted by all industrial enterprises.

Far less is known about the historical development of the professional bureaucracy. Medieval guilds have been an outstanding and pervasive instance, with the guilds regulating and codifying all the details of craft production. Precisely because of these regulations, technological innovation was nearly impossible in the Middle Age. Innovators would incur in harsh punishments, from prohibition to work up to ostracism and death.

It was not as absurd as it may appear at first sight. In a globally stationary economy, one innovation made by one craftsman would not have made the pie grow for everybody. Rather, it would have simply shifted resources from the non-innovators to the one innovator. Thus, it was natural for the vast majority of non-innovators to oppose any such move.

However, exceptions did exist. For instance, Benedectine monasteries were not subject to the guilds and therefore they could innovate agricultural techniques, as well as food processing machines (Kieser, 1989). In structural terms, Benedectine monasteries constituted a network of sources of information that let it diffuse into the rest of society.

Modern professional bureaucracies are not as extreme. Max Planck remarked that Science proceeds only after an old generation of scientists has disappeared (Planck, 1950), but in spite of all difficulties scientific revolutions do take place in the end. In this environment, innovative and open-minded journals and researchers' communities may have a similar role as the Benedectine monasteries of the Middle Age.

Identifying the origin of professional bureaucracies may prove to be an impossible task, but evidence of the existence of crafts that standardized technologies and excluded non-members can be traced back to the neolithic age (Sterelny, 2012). Possibly, the professional bureaucracy simply originated with the first tools Man was able to make.

Even less is known about patronage-based organizations. It is known that it was the default organizational form of the kingdoms and empires that existed before the Industrial Revolution, though such a claim should be tempered by the observation that some degree of standardization did take place at key milestones of human history such as Hammurabi's written Code, or Roman Law.

It is known that the first large human settlements originated with the invention of hydraulic agriculture, first with the Sumers about 7,000 B.C.E. and then quite independently along the Nile, the Yellow River, and elsewhere. The possibility of irrigating fields during the dry season enabled those populations to build permanent settlements, cities, and empires whose administrations have been the first large organizations in human history.

We also know that in primitive or archaic societies reciprocity was the fabric that kept humans bound to one another. Exchanging gifts was the ritual that ensured that community members entertained good relationships with one another (Sahlins, 1972).

By combining the two above pieces of knowledge, it has been speculated that patronage originated from gift exchange once the command over valuable resources had created hierarchies that deprived it of its original equality. Exchange was still making for good relations, but the items being exchanged had changed a lot. No longer goods of equal value, but favors in exchange for dependence (Hooper et al., 2018).

The structure of information flows implied by the above reconstruction is quite remarkable, for it is made of multiple independent origins—the Tigris-Euphrates, the Nile, the Yellow River, etc.—that emanated one and the same new organizational form, which subsequently diffused without any sort of information centralization. Obviously, multiple origin was made possible by the supposed ubiquity of gift exchange.

Ideology

In organization studies, terms like ideology, strategy, and tactics differ in grade of detail, closeness to practice, and long- vs. short-term orientation, yet they all denote some form of cognitive framework for taking action (Smithey, 2009; Mackay and Zundel, 2017). Their origin can be ascribed to the innate drive of the human mind to seek coherence, constructing networks of causal linkages that provide orientation in spite of a necessarily uncertain future, sometimes even at the cost of distorting reality to some extent (March and Olsen, 1976; Weick, 1979, 1995; Lane and Maxfield, 2005). As such, ideologies are likely to have been with mankind since the beginnings.

However, the structure of their diffusion might have changed with time. In particular, there exists a very recent trend toward short-lived, divisive ideologies that are almost devoid of content in comparison to those prevailing in the XX century, and sometimes even based on fake news (Freeden, 2019). Their diffusion is often different from the propagation from one single center that characterized the ideologies of the past. Propagation most often occurs through social communication media, where it stems from a small number of hubs that are linked to one another by channels that may use any means, including personal acquaintance (Zhu et al., 2016). Moreover, a similar structure appears to operate within organizations, where a typically small number of members becomes engaged with information hubs (Majchrzak et al., 2013).

Discussion

With this paper we summarized the available knowledge about organizational forms, arranging the existing definitions in a hierarchy of four levels nested in one another. In spite of lack of data, we speculated on possible features of their T-patterns and reconstructed qualitative features of their diffusion. In particular, we identified the following diffusion patterns:

1. Diffusion from one or a few sources relying on local connections, as it has largely been the case for the machine

bureaucracy. This diffusion mode is, quite obviously, very slow.

2. Diffusion from one source with global connections, as it has been the case, for instance, for the diffusion of the ideologically-defined Communist States out of the template provided by the Soviet Union. This diffusion mode is likely to be faster than case (1).
3. Diffusion from a few sources with global connections and closely linked to one another, as it has been the case, for instance, of the diffusion of the matrix structure operated by a few global consultants. Assuming some degree of coordination between the original sources, this diffusion mode is likely to be faster than case (2).
4. Diffusion out of several sources that independently arrived at the same arrangement, as it may have been the case for patronage-based organizations arising out of spontaneous reciprocity once a social hierarchy had been put in place. Differently from case (3), in this case the sources are assumed not to coordinate with one another, hence speed of diffusion may be lower than in case (3).

Sometimes, these three modes are exploited in sequence. For instance, the organizational form of biotech firms was initially conceived by local actors and started diffusing spontaneously in the San Francisco Bay area, but it was eventually picked up by global consultants. In this case, the diffusion mode switched from (1) to (3). Likewise, the diffusion of the multidivisional form initially took place by imitation of two firms that had independently invented it, to be subsequently picked up by global consultants. In this case, the diffusion mode switched from (4) to (3). We may also speculate that many instances of mode (3) diffusion actually started as (2), with one single hub being subsequently imitated by other hubs. Apparently, in quite many cases (3) may have been an attractor toward which other diffusion modes converged over time.

Quite obviously, our conceptual scheme has limitations. We already mentioned the problem of organizational hybrids, which is particularly serious for adhocracies/network organizations but to some extent concerns all organizational forms. Multidivisional structures, for instance, are generally hybridized with functional structures because at least one of their functions—most often, finance—generally remains centralized. Likewise, hospitals and universities are no longer the pure professional bureaucracies they used to be, for they are hybridizing themselves with machine bureaucracies and network organizations (Lega and DePietro, 2005). Our scheme can help accommodate hybridizations along the vertical dimension—from Level (1) to Level (4)—but horizontal hybrids remain a nuisance for the theory, just like attrition for the laws of physics.

A similar difficulty arises with organizations whose portions belong to different organizational forms. This is for instance the case of large machine bureaucracies, whose top hierarchical level is generally based on patronage, as well as large multidivisional companies whose divisions may pertain to different forms in terms of their behavior patterns. It is inevitable that, in such cases, local or partial belongingness must be considered.

Quite similarly, in many instances, a degree of belongingness to ideal-typical organizational forms should be introduced. There is clearly a degree to which an ideology is believed, and real machine bureaucracies conform to the Weberian ideal type only to some degree. Note, however, that to the extent that a lower-than-100% belongingness to an organizational form obtains because of partial belongingness to a different organizational form, we are back to the problem of organizational hybrids.

On the whole, we are very cautious concerning the validity of our hypotheses concerning T-patterns, particularly those of the highest levels. By contrast, we suspect that there exists a real drive toward diffusing information by coordinating a few sources, each of which is endowed with global connections. From Benedectine monasteries to social media, this communication structure possibly turned out to be most effective.

Author contributions

MN contributed to knowledge from sociology. GF contributed to knowledge from management studies. The paper evolved in several rounds of discussion in which the authors tried to arrive at a unified framework that included knowledge from both domains. All authors contributed to the article and approved the submitted version.

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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T-*pattern* analysis of offensive and defensive actions of youth football goalkeepers

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Nowadays, football goalkeepers (GKs) play an important role in the team's organization, namely, considering the offensive and defensive processes. The purpose of our investigation focuses on the notational and T-*pattern* analysis of the offensive and defensive actions of elite young football GKs. The participating GKs (n = 3, mean age of 16.6 years) presented 8 years of experience in the specific position, were internationally selected for the national team of Portugal, and competed in the national U-17 championship of Portugal. Thirty football matches were observed. The observational sample consisted of defensive actions (n = 225) and offensive actions (n = 296). Two observational instruments were used to codify the actions: the observation system of defensive technical-tactical actions of GKs and the observation system of offensive technical-tactical actions of GKs. Both instruments underwent a validation process, and inter- and intra-observer reliability was tested. The codification of the actions was performed with the *LINCE* program, and later the data were exported to Microsoft Excel and *THEME 5.0*. The notational data were analyzed in *SPSS,* and T-*pattern* detection analysis was performed in *THEME 5.0*. The predominant actions of young observed GKs were fundamentally goal defense and participation in the team's offensive process construction through actions performed with the foot and hand. The analysis of T-*patterns* allowed to identify T-*pattern* actions in the defensive actions of goal defense and exit of the goal, as well as related to the defensive set pieces. In the offensive process, the analysis of T-*patterns* reinforced the participation of the GK in the team's first phase of construction and in the execution of goal kicks and actions that start as a result of the actions of the opponent. The GK's defensive actions are mostly focused on the objective of goal defense and offensive actions with the hands and feet are important for their participation in positional attack construction. Our study contributes to a better knowledge of the GK's actions in the competition and is relevant to be considered by the specific position coaches in the training process organization.

KEYWORDS

goalkeeper, match, soccer (football), analysis, T-*pattern*

Introduction

Football is currently one of the most popular sports in the world, resulting in an increase in the number of season competitions and matches (Aurélio et al., 2016; Santos et al., 2021a). It requires an efficient collective organization and, simultaneously, specific development of each player with the consideration of individual and group perspectives (Espada et al., 2018). A detailed evaluation of players' performance is of particular interest because the available time and conditions for training sessions are not always desirable for coaches, who always look for strategies to develop athletes' physical and tactical skills and improve their performance in the competitive environment (Santos et al., 2021b).

In modern football, a goalkeeper (GK) has a massive relevance not only in the goal defense, but also in the offensive process participation of the team (Goméz-Millán and Esquiva, 2017). This evidence is related to the evolution of the characteristics of the players in this specific pitch position and to the regulatory changes introduced by the Federation Internationale de Football Association (FIFA). Consequently, the effective execution of technical-tactical actions is crucial in their performance, requiring the improvement of technical skills and the development of the ability to execute them according to the tactical context of the game (López-Gajardo et al., 2020).

It is also essential to work on the specific individual needs of players according to their pitch positions during the football training process to promote the achievement of the necessary required fitness levels to efficiently perform on match days (Espada et al., 2020). Notably, performance analysis is key to collecting information about players and teams, helping the coach make decisions about training and competition (O'Donoghue, 2006) related to GKs, which is essential not only for training to meet their needs for evolution, but also regarding the requirements related to the team's play style (West, 2018).

In the field of research, studies have been carried out to understand the defensive and offensive actions of the GK and to verify how they are influenced considering the level of the opponents (Liu et al., 2015; Sainz de Baranda et al., 2019), the competitive level (López-Gajardo et al., 2020), the game result (Kubayi, 2020), and the status of home or away game (López-Gajardo et al., 2020). Although Ortega and García-Angulo (2015) suggested that the main studied disciplines are motor control, namely, focusing on taking penalties (Furley et al., 2017) and sports medicine, most articles analyze injuries based on players' positions on the pitch (Hägglund et al., 2013) or physiological profiles (Ziv and Lidor, 2011). This is somewhat surprising, considering the GK is the most specialized position in a football team (Frick, 2007), and their actions are considered to have a significant bearing on final match outcomes (Liu et al., 2015).

Nonetheless, in performance analysis, it is extremely important to observe and analyze (Martin et al., 2018) in order to collect key information for the development of players and teams through the training process, preparing them for the requirements of a competition (Sampaio and Macas, 2012), based on the training sessions designed to address the needs of the players and teams, the task where sports coaches play a key role (Rodrigues et al., 2021). Recently, López-Gajardo et al. (2020) verified that in GKs, the defensive fitting action is the one that has more occurrences in the different levels of competition analyzed, being a technique referred to as relevant, since it avoids second finalizations of the opponents and allows ball possession. Regarding the result of the game, Kubayi (2020) verified more occurrences of goal defense actions in the GK to win the game, and other forms of defensive interventions were previously observed with great frequency, namely, the exit of the goal to the crossing (Soares et al., 2018), block (López-Gajardo et al., 2020), and grab the ball (Szwarc et al., 2010). In defensive terms, it was previously observed that the intervention zones of GKs are fundamentally located within the penalty area (Sainz de Baranda et al., 2008; Lapresa Ajamil et al., 2018).

The GK's action with their feet, after recovery of the ball, is essential to change the center of the game to the areas of the lower pressure of the opponent (Barreira et al., 2014). Recently, Sainz de Baranda et al. (2019) observed that in high-level teams, the game with the GK's feet had a great relevance, and Serrano et al. (2019) reported that in La Liga, the prevalence of GK's passes increased throughout the editions of the competition. Among GKs aged 14–16 years, great effectiveness of passing was demonstrated, and there were behavior patterns in these actions with the foot and hands (Lapresa Ajamil et al., 2018). In the offensive process, Santos et al. (2022) observed that the participation of a GK resulted from late passes of teammates, showing fundamental technical actions with the feet in the offensive construction of the team, preferably to the side flanks.

Despite the fact that GKs are nowadays observed as key players who can win or lose football games based on their individual and collective actions, associated to the fact that some of the highest financial transfers in modern football are associated with elite players in this specific football game position, the study of the specific actions of GKs is scarce compared to many other areas of the football game. It becomes important and relevant to analyze the actions associated with the role of GKs in the football game, with a perspective of constituting an important assessment tool for athletes who play in this specific pitch position in the football game and for the coaches in order to create the best training tasks to optimize the individual and collective performance of the team.

Many of the previous developed studies focused on observing the technical and tactical actions of elite senior GK, and research carried out in this specific football playing position focused on top-level GKs (Oberstone, 2010) with scarce scientific output investigating youth football GKs

(Sainz de Baranda et al., 2005). This is of relevant interest for the coaching staff aiming for knowledge and the improvement of daily training tasks. Even though some previous studies focused on the notational analysis, the analysis through T-*patterns* provides information related to time and sequential structures of defensive and offensive technical actions. Hence, the aim of the present study was to detect T-*patterns* of offensive and defensive actions of youth football GKs. The following hypotheses were established in our study: (1) in the defensive process, the GK performs more T-*patterns* related to goal defense actions within the penalty area, and (2) in the offensive process, GK performs more T-*patterns* related to actions with the feet in the direction of the side zones of the flanks.

Methodology

Observational design

The procedures related to the observational methodology were considered, with the objective of analyzing the defensive and offensive GK actions, and two observational instruments were constructed to codify perceptive behaviors, in an official game situation (Anguera et al., 2018a,b; Chacón-Moscoso et al., 2018), giving the investigation an ecological validity (Portell et al., 2015). The observational design of the study is part of quadrant III, being considered ideographic (participants in GK), follow-up (observations made over the competitive season), and multidimensional (actions categorized into various response levels) (I/S/M) (Anguera et al., 2018a).

The investigation considered the procedures enshrined in the Declaration of Helsinki (Harriss and Atkinson, 2011). The observed GKs were previously clarified about the objectives of the study, and they agreed to participate, while at the same time the legal representatives signed informed consent. The study was approved by the Ethics Committee of the Polytechnic Institute of Leiria (CE/ IPLEIRIA/22/2021).

Participants

Three U-17 GKs (M = 16.6 years of age) participated in the study, competing in the national championship of Portugal. The GKs represented a 5-star club (top-level certification by the Portuguese Football Federation) and were regularly present in the training sessions at the national and international levels. They had 8 years of experience playing in the position and had international participation in international tournaments in the representation of the National Team of Portugal.

The 30 football matches of the entire official football season were observed (GK A-10, GK B-8, and GK C-12), constituting an observational sample of 225 defensive actions and 296 offensive actions. For each GK, defensive actions (GK A-63—28%; GK B-45—20%; and GK C-97—43.11%) and offensive actions (GK A-109—36.82%; GK B-64—21.62%; and GK C-123—41.55%) were analyzed.

TABLE 1 Observational system of defensive technical-tactical actions.

Criterion	Category
Intervention form	Crossing
	Goal defense
	Set pieces
	Goal exit
Technical action	1×1 shot
	1×1 divided
	Frontal attack
	Action as last defense
	High lateral drop deviation
	Deviation lateral creep
	Block
	Deviation to punch
	High deviation
	Enchase
	High reception
	High lateral fall reception
	Reception lateral fall creeping
	Creeping interception
Forms of execution the technical action	1 hand
	2 hands
	Feet
	Chest
	Fists
	1 hand
End action field zones	Field zones 1–10

Observational instruments

Two observation systems were used to codify the actions: the observational system of defensive technical-tactical actions and the observational system of offensive technical-tactical actions. Both observation systems underwent a validation process (Santos et al., 2022). Table 1 shows the observational system of defensive technical-tactical actions of GKs, consisting of four criteria and 34 categories.

Figure 1 shows us the campogram with the final zones of defensive actions.

The system of observation of offensive technical-tactical actions of GK (Table 2) consists of six criteria and 50 categories.

The campogram visualized in Figure 2 demonstrates the start and end zones of offensive actions.

FIGURE 1
Campogram for defensive technical-tactical actions (adapted from Lapresa Ajamil et al., 2018).

Reliability

Reliability analysis is fundamental in observational methodology with the objective of ensuring data quality (Blanco-Villaseñor et al., 2014). In the first phase, the observers were trained, followed by the intra- and inter-observer reliability test (Brewer and Jones, 2002). Reliability testing was performed using Cohen's K agreement measure (Cohen, 1960), using the LINCE program (Hernández Mendo et al., 2014). Intra- and inter-observer reliability values above 0.80 were verified (Table 3) in all criteria, and on average, the values were found to be above 0.88.

Procedures

The collected images, for later coding, were retrieved through the camera (Sony HD—HDCR—CX240 9.2 megapixels), placed on a tripod, and positioned in a high plane with an open angle, so that the beginning and end of each action could be identified. The images after being collected and edited were encoded using the *LINCE*® computer program (Gabin et al., 2012). Subsequently, the data were exported from *LINCE*® to the *THEME 5.0*® program to make the T-*pattern* analysis.

Data analysis

The defensive and offensive action patterns of GKs were analyzed using the *THEME 5.0*® program. The detection and analysis of T-*patterns* enable the identification of the sequence of events that repeat in the same order and in a relatively invariable time distance. In this sense, the concept of the critical interval is essential for the design of time structures and sequences of a series of data. The algorithm for building and identification T-*patterns* is based on critical interval detection, patterns building, and complete patterns competition. This algorithm

TABLE 2 Observational system of offensive technical-tactical actions.

Criterion	Categories
How the ball arrives the GK	Delay
	Opponent's action
	Rules
Zone field start action	Field zones-—1–12
Technical action	Short pass with 2 touches
	Short hand replacement
	Long hand replacement
	Goalkeeper kick
	Long pass at 1st touch
	Long pass at 2nd touches
	Long goal kick
	Short goal kick
	Short pass at 1st touch
	Ball conducting + Short pass
	Ball conducting + Long pass
	Short free kick
	Long free kick
	Short pass with 2 touches
	Short hand replacement
	Long hand replacement
	Goalkeeper kick
Tactical decision	Positional attack
	Fast attack
	Counterattack
End of technical action	Intercepted ball
	Maintenance of ball possession
	Ball out
End field action zones	Field zones 1–12

works from the bottom up, level by level, by eliminating partial and equivalent T-*patterns* (Magnusson, 2000, 2020; Casarrubea et al., 2015, 2018). The criteria defined for the selection of detected T-*patterns* were as follows: (a) significance level 0.005 ($p < 0.005$); (b) the number of occurrences of T-*pattern* ≥ 3; (c) redundancy reduction setting at 90%; (d) deactivation of free heuristic critical interval setting; (e) T-*pattern* validation through data randomization on five occasions, proceeding to compare the randomization data with the real data; and (f) randomization through the simulation filter according to the defined significance level.

Results

The results presented are related to the T-*patterns* of defensive and defensive actions. Tables 4, 5 show all the recorded T-*patterns*.

It is possible to verify in Table 4 that we recorded 15 T-*patterns* of the GK's defensive actions. The T-*patterns* which occurred more frequently were related to goal defense ($n = 16$), goal exit ($n = 14$), and set pieces ($n = 13$). The recorded T-*patterns* are related to actions of goal defense, set pieces, crosses, and goal exit, and occurred in a large area. Considering the intervention forms, we can verify that technical actions that characterize the T-*patterns* are the superior deviations (set pieces and goal defense), high reception (set pieces and crossing), enchase (crossing), high lateral drop deviation (goal defense), frontal attack, 1×1 shot, and 1×1 divided (goal exit).

Figure 3 presents the T-*patterns* of defensive action showing more occurrences of goal defense.

In Table 5, we observe T-*patterns* in which the offensive play of the GK is a result of the rules, delay of teammates, and opponent's actions, through the feet game (short and long pass) and ball replacement with the hand, contributing to the positional attack construction. The T-*patterns* with the highest occurrences are related to the circumstances the ball reaches the GK through the rules ($n = 14$ and $n = 11$) and the opponent's action ($n = 7$).

Figure 4 presents the T-*patterns* of offensive actions with more occurrences.

Discussion

The purpose of our research was to record T-*patterns* of defensive and offensive actions in official football matches in young GK. The action of GK in official matches is still a topic that needs further investigation, particularly in youth football (West, 2018; White et al., 2018). In our study, it was possible to verify the T-*patterns* of GK's defensive and offensive actions. In defensive action, we observed T-*patterns* associated with goal defense, goal exit, crosses, and set pieces. The recorded offensive T-*patterns* emphasize the importance of the game with GK's feet in today's football, and their participation in the construction of the team's offensive process is also evident (positional attack).

In the first hypothesis defined, it was proven that the T-*patterns* with more occurrences are related to the goal defense within the penalty area. In the defensive process, studies have verified that the predominant form of intervention is goal defense (Sainz de Baranda et al., 2008; Liu et al., 2015), a fact that was also evident in our study in the recorded T-*patterns*, since it demonstrates that this intervention form is associated with high lateral drop deviation, with one and two hands, in the central zones of the penalty area. Another aspect that is evident in the patterns found is that the GK's defensive actions predominantly occur within the penalty area (Sainz de Baranda et al., 2008; Lapresa Ajamil et al., 2018; Szwarc et al., 2019).

The action of GKs in set pieces also provides relevance of evidence (Santos et al., 2022), an important moment that contributes in many matches to the definition of the results (Kubayi and Toriola, 2019; Leite, 2020). T-*patterns* have been

FIGURE 2
Campogram for offensive technical-tactical actions (adapted from Lapresa Ajamil et al., 2018).

recorded in this form of intervention through the technical actions of high deviation and reception of the ball with two hands. It should be noted that there has been frequent recording of technical actions of high deviation and high reception in senior (López-Gajardo et al., 2020) and young GKs (Santos et al., 2021c, 2022).

It was also possible to verify T-*patterns* related to the form of crossing intervention, with technical action of fitting and high reception. Airspace control is of great importance to GKs, and considerable ineffectiveness in this type of action is verified in young GKs (Lapresa Ajamil et al., 2018). Developed studies show us the importance of these actions, considering the significant number of occurrences (Soares et al., 2018; Santos et al., 2021c, 2022).

In defensive terms, it was still possible to find T-*patterns* related to the goal exit (Berto and Magalhães, 2017; Lapresa Ajamil et al., 2018), with the technical execution of 1×1 shot, 1×1 frontal attack, and 1×1 divided. The literature points out that these types of actions of the GKs are more evident in high-level teams (Szwarc et al., 2010; Filho et al., 2018), since the last defensive line plays very high, and the action of the GK is fundamental for depth control.

Regarding the second hypothesis established for the study, it was partially proven. We checked T-*pattern* actions in which GK's foot play is critical, through the execution of goal kicks, short passes, and long passes. However, the final zone of the T-*patterns* of the offensive actions are the three corridors (lateral and central), a fact that is not entirely in accordance with the defined hypothesis. T-*patterns* recorded in the offensive actions showed that GK had strong participation in the construction of the offensive process of the team, through long and short passes, demonstrating the high importance of the pass technique domain (West, 2018), pass effectiveness, and corresponding maintenance of ball possession (Szwarc et al., 2010; Seaton and Campos, 2011), and that this is more evident in high-level teams (Sainz de Baranda et al., 2008; Liu et al., 2015; Lapresa Ajamil et al., 2018; Soares et al., 2018; Serrano et al., 2019; Kubayi, 2020).

TABLE 3 Intra- and inter-observer reliability.

Observation system	Criterion	Inter-observer	Intra-observer 1	Intra-observer 2
		K	*K*	*K*
Observational system of offensive technical-tactical actions	Intervention form	0.87	1.00	1.00
	Technical action	0.88	0.90	0.81
	Forms of execution the technical action	0.90	0.82	0.82
	End action field zones	0.88	0.90	0.90
	Mean	0.88	0.91	0.88
Observational system of offensive technical-tactical actions	How the ball arrives the GK	1.00	0.96	1.00
	Zone field start action	0.95	0.84	0.93
	Technical action	1.00	0.88	0.97
	Tactical decision	0.82	0.84	1.00
	End of technical action	1.00	1.00	0.90
	End field action zones	0.95	0.86	0.95
	Mean	0.95	0.90	0.96

TABLE 4 T-*patterns* related to the GK defensive actions.

T-*pattern*	Occurrences (*n*)			
	GK A	GK B	GK C	Total
Goal defense—High lateral drop deviation-−2 hands—End zone 1	6	3	7	**16**
Goal defense—High lateral drop deviation-−1 hand—End zone 1	-	-	3	3
Goal defense—High lateral drop deviations-−2 hands—End zone 4	-	-	3	3
Goal defense—High deviations-−2 hands—End zone 1	-	-	3	3
Set pieces—High deviation-−2 hands—End zone 4	-	5	8	**13**
Set pieces—High deviation-−2 hands—End zone 1	-	-	8	8
Set pieces—High reception-−2 hands—End zone 4	4	-	4	8
Set pieces—High reception-−2 hands—End zone 1	-	-	4	4
Crossing—High reception-−2 hands—End zone 4	-	5	-	5
Crossing—High reception-−2 hands—End zone 1	-	-	4	4
Crossing—Enchase—Chest—End zone 4	-	-	4	4
Goal exit-−1×1 shot-−2 hands—End zone 5	-	-	4	4
Goal exit-−1×1 divided—Chest—End zone 4	-	-	4	4
Goal exit—Frontal attack-−2 hands—End zone 4	-	5	9	**14**

The bold values indicate the T-patterns with the most occurrences.

Another example of this was the record in T-*patterns*, where it was shaped that the ball reaches the GK through ball delays performed by teammates, reflecting the importance of GK in building the team's offensive process, as well as in varying the game center through GK to less pressure zones after retrieval of the ball (Barreira et al., 2014; López-Gajardo et al., 2020). In the moments when the ball reaches the GK through the opponent's action, it was verified in our study that the option of the GK is to perform the replacement of the ball with the hand, kick, or short passes. In situations of play in which the exit of the ball happened by the final line (rules) and the GK executes the goal kick, it was evident in the T-*patterns* the option of performing long passes to the areas of the offensive midfield (10–12).

Our research is another contribution, through the identification of T-*patterns*, aiming that young GK coaches, who also harbor a specific role in the football coaching staff, may have more information about how a GK operates in the offensive and defensive process, thus adding knowledge to a more effective training planning program. It is true that our investigation has some limitations that come into not having considered the level of the opponent, the home-away condition, as well as the outcome of the game. The number of GKs observed can also be considered a limitation of the study, a fact that should be considered when analyzing the results obtained. Future research should take these considerations into account, as well as carry out

TABLE 5 T-*patterns* related to the GK offensive actions.

T-*pattern*	Occurrences (*n*)			
	GK A	GK B	GK C	Total
Rules—Start zone 1—Long goal kick—Positional attack—Maintenance of ball possession—End zone 10	8	-	6	**14**
Rules—Start zone 1—Long goal kick—Positional attack—Maintenance of ball possession—End zone 12	7	-	4	**11**
Rules—Start zone 1—Long goal kick—Positional attack—Intercepted ball—End zone 12	-	-	5	5
Rules—Start zone 1—Long goal kick—Positional attack—Intercepted ball—End zone 11	-	-	3	3
Delay—Start zone 8—Ball conducting + Long pass—Positional attack—Maintenance of ball possession—End zone 10	-	-	4	4
Delay—Start zone 8—Long Pass at 1st touch—Positional Attack—Maintenance of ball possession—End zone 10	-	-	4	4
Delay—Start zone 3—Short pass with 2 touches—Positional attack—Maintenance of ball possession—End zone 8	3	-	-	3
Delay—Start zone 3—Short pass with 2 touches—Positional attack—Maintenance of ball possession—End zone 9	3	-	-	3
Delay—Start zone 7—Long pass at 2nd touch—Positional attack—Maintenance of ball possession—End zone 10	3	-	-	3
Delay—End zone 3—Short pass 2 touches—Positional attack—Maintenance of ball possession—End zone 10	3	-	-	3
Delay—Start zone 7—Short pass with 2 touches—Positional attack—Maintenance of ball possession—End zone 8	-	3	-	3
Opponent's action—Start zone 4—Short hand replacement—Positional attack—Maintenance of ball possession—End zone 8	7	-	-	**7**
Opponent's action—Start zone 4—Short hand replacement—Positional attack—Maintenance of ball possession—End zone 7	4	-	-	4
Opponent's action—Start zone 4—Short hand replacement—Positional attack—Maintenance of ball possession—End zone 5	4	-	-	4
Opponent's action—Start zone 4—Short pass with 2 touches—Positional attack—Maintenance of ball possession—End zone 8	-	3	-	3
Opponent's action—Start zone 4—Goalkeeper kick—Counterattack—Intercepted ball—End zone 11	-	3	-	3
Opponent's action—Start zone 4—Short pass with 2 touches—Positional attack—Maintenance of ball possession—End zone 7	-	3	-	3

The bold values indicate the T-patterns with the most occurrences.

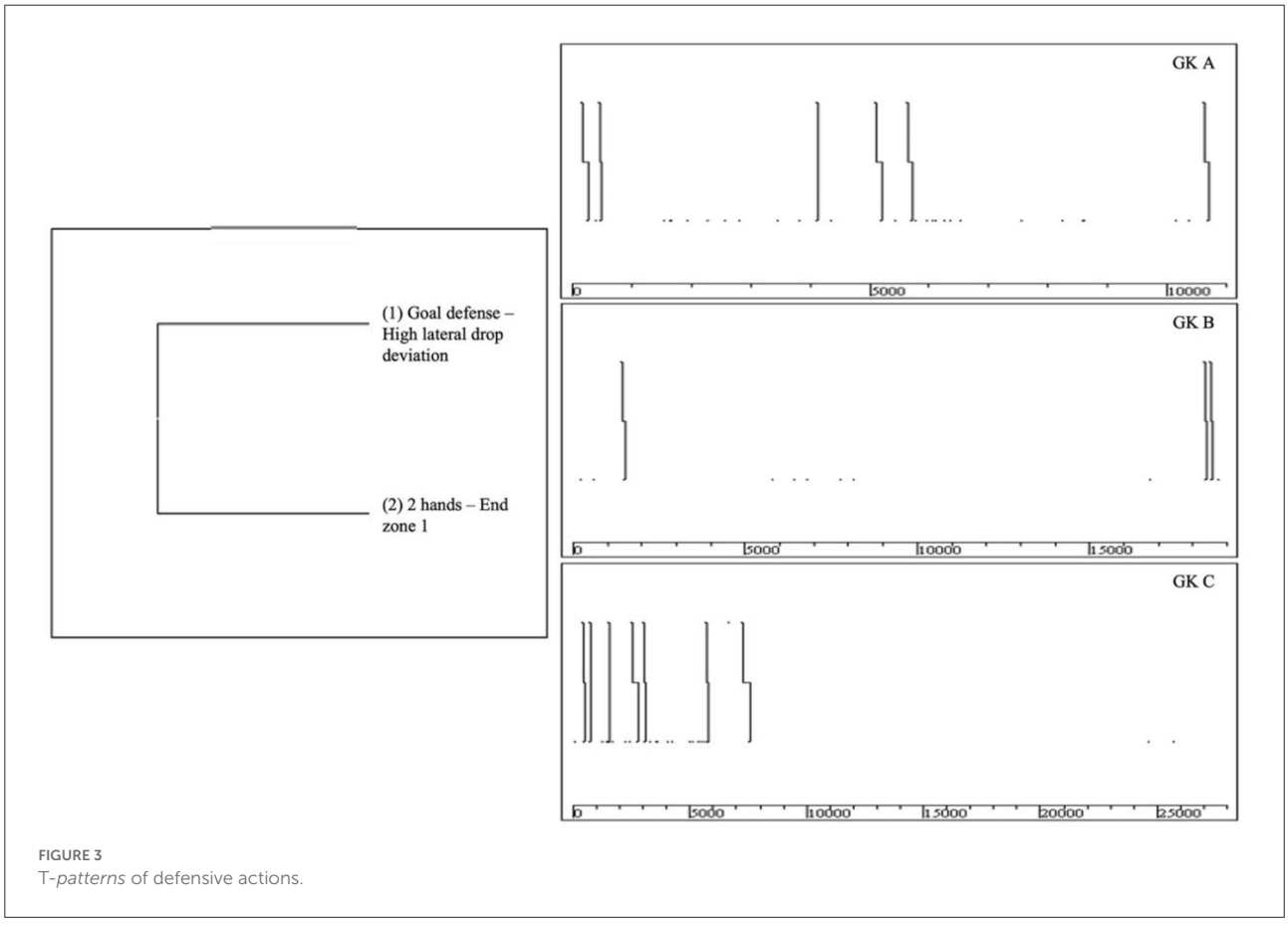

FIGURE 3
T-*patterns* of defensive actions.

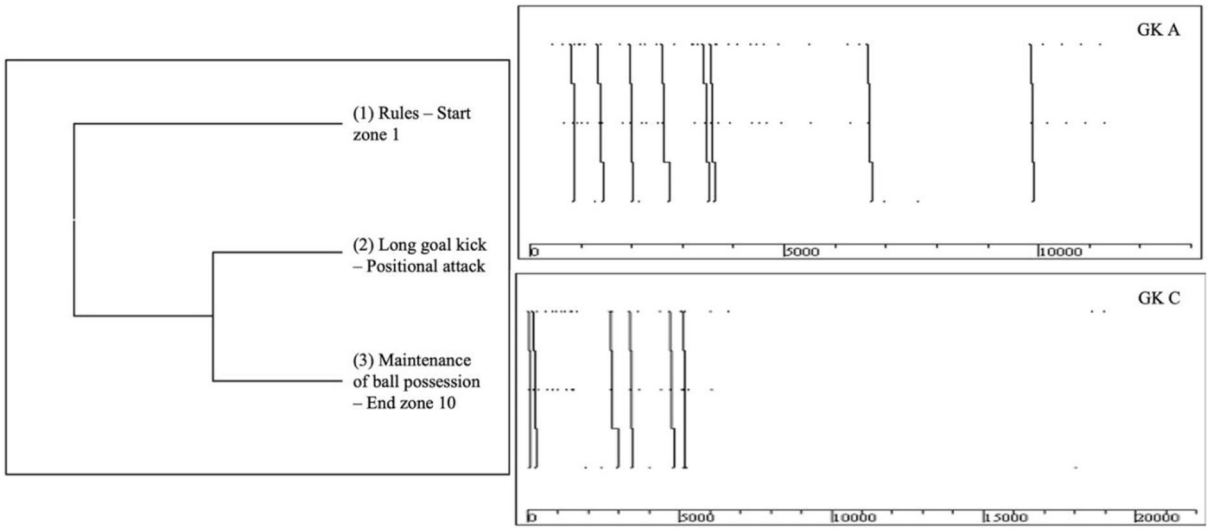

FIGURE 4
T-*patterns* of offensive actions.

this line of research in different age groups and women's football teams.

Practical implications

The present study contributes, through the analysis of T-*patterns*, to the increase of knowledge about the fundamental defensive and offensive technical actions performed by young football GKs, which can represent an important contribution to the planning of training by specific coaches. In defensive terms, the training of technical actions of goal defense and set pieces are fundamental to the performance of the GK action in the competition environment. For teams with very advanced defensive lines, the 1×1 confrontation actions can be decisive for the match result. With respect to offensive actions, the technical training of short and long passes should be considered important in training, considering the importance of GK actions for building the team's offensive game. It is also worth noting that the ball replacement with the hand, as a technical action, needs to be taken into consideration by the specific GK coaches.

Conclusion

The U-17 GKs present as fundamental forms of intervention for the goal defense, goal exit, and set pieces. The execution forms evidenced in the patterns were high lateral drop deviations, high deviation, high reception, fitting, 1×1 divided, 1×1 shot, and 1×1 frontal attack. The intervention zones are predominantly those corresponding to the penalty area.

The recorded T-*patterns* demonstrate the importance of GK actions in the offensive process of the team, evidencing the need for effective execution of short and long passes. The replacement of the ball with the hand, the goal kick, and the GK kick are also techniques evidenced in the registered standards.

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 Ethics Committee of the Polytechnic Institute of Leiria (CE/ IPLEIRIA/22/2021). Written informed consent to participate in this study was provided by the participants' legal guardian/next of kin.

Author contributions

FS and JS conceived and developed the research, as well as excreted this article. ME and CF contributed to the literature review and article review. VP and PS reviewed the article and made important contributions to the various sections of the

article. All authors read and approved the final version of the manuscript.

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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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Interaction microanalysis of foster care research using THEME

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Environmental stress is a key element to the understanding of the psychopathology of children in foster care. Such children often present a wide range of symptoms from anxiety to depression, including abnormal behaviors in their interactions with adults that can be related to experience suffered in their family of origin (e.g., abandonment, abuse, etc.). Foster care should provide a safe environment, both to protect children from abuse and to help them build a well-adjusted developmental trajectory. The relationships with the family of origin may also be maintained. How do children in foster care behave in relation to caregivers given the differences between the families they grow up in? This study focuses on three adult-child relationships: those with a foster carer, a mother and a father. Each adult-child interaction was recorded several times in a day-to-day environment. On each occasion the instruction was given to behave naturally while interacting with a child. No additional material was supplied. Our observations concern the verbal and non-verbal comportment of a 4-year-old foster child named Julia when entering the study, with her caregivers. Once the principal elements had been coded (behaviors, verbalizations), a sequential behavioral patterns analysis was performed using the THEME© program. For this purpose, a 2-min interaction was chosen from the third video of an event which appeared particularly representative of the relationship between Julia and her different caregivers. According to whom Julia was with, the results reveal very different interactive processes. We observe, for example, that with the foster carer the interaction patterns were primarily focused on play objects, whereas they involved more collaborative activity with the father and distraction/avoidance behaviors with the mother. The study identifies the use of disengaging and self-exciting behaviors in all types of interaction. Those emotion regulation strategies are particularly developed during parent–child sessions, showing pathological processes of relationship.

KEYWORDS

interaction analysis, foster care, emotion regulation, clinical psychology, pattern detection

Introduction

In France, more than 20,000 children under 6 years old are in foster care; this represents 4.5‰ of the child population in that age range and 14.3% of the children outplaced for protection [Observatoire National de la Protection de l'Enfance (ONPE), 2019]. This number has been stable over the past 15 years, the psycho-emotional developmental conditions among foster children needs attention. Serious neglect, psychological or physical violence within a family are the main reasons for placement. Such dangers faced by children oblige a judge to pronounce parent–child separation if health, safety or morality are deemed to be seriously compromised (Civil Code, 2016). Foster care is intended to provide protection for a child while maintaining his or her bonds with the biological parents. In France, the primary objective is always to restore family life so that the child can return to his or her original home.

Abused children face experiences that severely compromise their emotional, cognitive, and social development (Cicchetti et al., 2016). All of these damaging experiences need to be considered in relation to a child's maturation and developmental age in order to understand how adverse experience impacts on emotion regulation development.

Negative consequences of abuse and placement

The proportion of prolonged and repeated experiences of trauma (Villodas et al., 2016) among foster children is high (Vasileva and Petermann, 2017). This has a considerable impact on the child's attachment style, which is often insecure or disorganized (Van Ijzendoorn et al., 1999). Attachment theory provide a framework to understand how interactive processes lead to the internalization of attachment through Internal Working Models (Bowlby, 1980). Attachment is considered to be secure and insecure-anxious/avoidant, insecure-anxious/ambivalent or insecure-disorganized. Disorganized behaviors are associated with a constant need for reassurance and comfort, while impulsive attitudes and a lack of inhibitory control may develop in a child's relationships with caregivers and peers leading to severe mental illness processes (Kim and Cicchetti, 2010). The authors were evaluating the links between heterogenous experience of maltreatment and emotion dysregulation and psychopathology. They found that cumulative risks of maltreatment are related to emotion dysregulation, internalized and externalized symptoms and negative peer relationships. The more a child has experienced traumatic events, the more likely he or she is to present high levels of disorganization and symptoms of Post-Traumatic Stress Disorder and depression (Haselgruber et al., 2021).

The role of the foster carer is to provide a stable and secure setting for abused children (Dozier, 2005; Yarger et al., 2020). To this end, it is essential to work to reduce stress in the child's environment (Healey and Fisher, 2011; Vasileva and Petermann, 2017). The capacity of caregivers to understand and adapt to a child's needs is crucial to developing resilience and reducing symptoms (Dubois-Comtois et al., 2015; Yarger et al., 2020). Professional training based on developing mentalization processes and sensitivity, help to enhance the foster child's safety, well-being and needs satisfaction (Fonagy et al., 2004; Steenbakkers et al., 2018).

Impact on emotion regulation development

Emotion Regulation (ER) refers to the ability to be aware of one's emotions to the extent that it is possible to modify their intensity and temporality toward the achievement of a specific goal (Thompson, 1994). ER develops in the interactions that very young children have with their environment through a bio-feedback process (Gergely and Watson, 1999). This mechanism consists of mirroring a child's emotions so that he/she is made aware of what is expressed and so encouraged to recognize it. By learning Emotion Regulation Strategies (ERS) in interpersonal relationships, children develop and consolidate future internalized ERS (Holodynski and Friedlmeier, 2011; Thompson, 2014), the whole process taking place within the family (Morris et al., 2007). When encountering a new attachment figure, however, such as a foster carer who may have different parenting practices from those of a child's natural parents, many children are potentially disturbed. Emotional self-regulation, arising in infancy as a child's response to the reactions of those around him or her, reflects a child's need to find an appropriate balance between security and stimulation (Cole and Deater-Deckard, 2009).

It is for this reason that it is important to focus on disorganized behaviors and ERS when working with foster children (Haselgruber et al., 2021), since a foster carer's generally greater sensitivity to a child's difficulties tends to reduce externalizing behaviors and improve both emotional security and cognitive and socio-emotional development (Poitras et al., 2021). It is particularly in language strategies – promoting verbal communication and cognitive reappraisal – that foster carer-child interactions provide support to a child's development and resilience (Simon-Herrera et al., 2022). Although foster care has as a primary objective to sustain child development and restore family life, there is moderate evidence that parent–child visits are often related to higher likelihood of externalizing symptoms manifested by a lack of behavioral control and psychomotor instability (Poitras et al., 2021). Thus, while foster care may be beneficial, there remains a risk that contact between parent and child during placement will tend to sustain or reinvigorate the impact of previous traumatic experiences.

Objective of the study

The aim of this study is to analyze the ERS processes in child-caregiver relationships. Children evolve in an environment where,

in educational, affective and emotional terms, they may have several parental references. The observational methodology and microanalysis used here is exclusively concerned with the ER processes of one particular child in foster care. The study aims at giving a case-report of a foster child interplay with caregivers and to support a fruitful use of ethological methods such as video-based analysis of behaviors and T-pattern analysis.

It was expected that the interactions between child and foster carer would show a higher rate of verbal exchange and mental elaboration, whereas in those between child and parents, a greater negativity and lack of emotional control were expected. Because foster carer are trained professionals, their level of positivity would ensure warmer interactions processes supported by adult-child conversations.

Materials and methods

An exploratory, clinical study to analyze ER learning processes was conducted within the French child protection service. To illustrate that study, a single case is detailed here: that of Julia, a foster child aged 4. She was chosen because she showed particularly clearly how a foster child can develop heterogeneous ER processes that may range widely from suitably adapted to highly pathological mechanisms. Julia showed a wide variability in her behavior according to whom she was interacting with: mother, father or foster carer. Her attitudes were primarily evaluated by the psychologist proceeding at the video-recording through direct expert observation. She was observed through video-recording with her caregivers: mother, father and foster carer. Each session lasted 1 h and were replicated three times with every caregiver for a total of nine sessions. Meetings between Julia and her parents occurred separately respecting the parent–child conditions of visits authorized by the judge. The video material was then transcripted and coded according to ERS observed.

The use of THEME© software allowed us to study in detail how ERS manifested in the course of interactions.

Participant recruitment and data collection

Adult participants were contacted by telephone and were offered the opportunity to participate in a study assessing child development in foster care, based on interactions between child, parents and foster carer. During this phone call, it was explained that the meetings would take place in the child's usual home circumstances and that they would be videotaped to allow further detailed analysis. Observations were made within the framework set out for parent–child visits and at the foster carer's home. Julia resided with her foster carer for 19 months. Julia and her caregivers knew the psychologist proceeding at the video-recording since the beginning of her placement because of the clinical work done when entering and following the development of Julia in foster care. The actual recordings took place at home, in the living room, with the foster carer and in a supervised visits room for each parent. In France, foster care is a controlled and regulated profession whose purpose is to provide a secure home for foster children. The French welfare system does not consider the foster carer as a parent but as a professional only. For this reason, the carer's own family did not participate in the study.

A consent form was signed by all participants, parents signing for their child. This form included information about both the design of the study and the video recordings. It also included information about: the confidentiality of the data, the anonymity of the participants, the possibility of withdrawing participation at any time or refusing to answer (without any consequences for the person), the possibility of obtaining additional information and the fact that the research would result in scientific publication.

Data, drawn from the video-recordings, were collected on three occasions at six-monthly intervals. Observation in the child's usual environment allowed for a closer look at the child's reality and to perceive the real conditions of adult-child interactions. The psychologist, who was present throughout the recordings, asked the participants to behave normally and offered no indications as to any expectations. No specific material was given. A debriefing time to collect the adult's feelings about the session and to discuss the child's behaviors, was systematically held at the end of each recording. The primary function of this period was to verify that the recorded scenes corresponded to the adults' perception of their own and their children's usual behavior, since it was understood that the presence of a video camera could have an impact on spontaneity. From an ethical point of view, any problematic adult behavior was discussed with the person concerned in order to find the best strategy to help the child.

Presentation of Julia

Julia was a 4-year-old girl, placed in foster care at the age of 2 years 5 months, worryingly thin and in a state of severe undernutrition for which there was no known organic cause. This anorexia was accompanied by a major delay in development and behavioral problems (rocking). Julia's parents both had addictions: her father, who had suffered physical abuse in his own family as a child, to alcohol; her mother, whose father had abandoned her, to cannabis. Julia was taken in by a foster carer who described her as having food refusal behaviors, vomiting and significant psychomotor instability. Unable to control her psychomotor impulses, Julia's behavior was reported to be massively disorganized even at school. Julia could also exhibit compulsive masturbation. She received psychological, medical and speech therapy help. She always met with her parents in a neutral place and saw them separately every 2 weeks. Under the responsibility of the child protection service, she had one visit per week with one of her parents.

Analysis of the data

Child's and adults' behaviors were coded, to assess the ERS used in their interactions. Double coding was performed and led

to significant consistency between the two. An iterative method was preferred for its degree of relevance to the calculation of the degree of concordance between observers not involved in the study problem.

The coding system used in this study was analyzed regarding behaviors that can be related to ERS observed in adults and children. From the videographic records, sequences were first transcripted in details and then behaviors were coded following the ERS that are presented below. The Table 1 give the details of all coded behaviors.

The child's ERS were assessed on each of the recordings in terms of adult-child interactions. Strategies used by the child were coded according to the following behaviors: *Engagement object* (concerning a child's ability to focus and be attentive to things or tasks presented); *Disengagement* (seeking out or manipulating an object different from the one involved in a current action); *Self-soothing* (self-manipulative behavior, e.g., sucking a thumb or touching the hair); *Self-excitement* (e.g., clapping hands, singing, or talking to self); *Physical venting* (e.g., throwing an object, hitting, banging in play); *Escape* (e.g., fleeing from an uncomfortable situation as it develops); *Visual exploration* (looking for visual distractions without completely turning away from an activity in progress) selected from the studies of Blandon et al. (2010) and *positive or negative verbalization* (the verbal expression of emotion in speech, e.g., yelling or giggling).

Adults' ERS were assessed in the same way. The strategies used by the adults were coded according to the following behaviors: *Comfort* (physical or verbal behaviors, e.g., hugging); *Attention Refocusing* (attempts to redirect a child's – or the adult's own – attention to another stimulus); and *Instrumental strategies* (changing a situation or eliminating a source of frustration) selected from the work of Morris et al. (2011). Other ERS can be added: *Emotion expression positive or negative* (e.g., expressing joy or showing aggression). Finally, an important parenting skill is the ability to *identify a child's emotions:* this ERS is a form of cognitive reappraisal (Holodynski and Friedlmeier, 2011).

Some strategies were coded for adult and child: *Help seeking* (a willingness to be with a person or to vocalize for help for children/attempting to get help with emotional regulation from a third party) and *Cognitive reevaluation* (reinterpreting and explaining a situation to an adult/a child) from Mikolajczak et al. (2016).

In addition to the ERS that had been previously coded, behaviors were specified to further detail the correspondence between ERS and body, expressive, or tonal attitude. For example, tones of voice were specified based on whether the tone was perceived as calm, firm or even cheerful, to characterize – as positive or negative – the type of verbalization/expression. Laughter attitudes were also reported. Finally, the perceived basic emotions – joy, anger, fear, sadness, disgust, (Ekman, 2016) – were associated with positive or negative expression. We give some examples of how emotional behaviors and basic emotions are coded: laughing is coded as a visual and auditive manifestation; smiling is coded as a visual manifestation only; joy is expressed inside the interaction, with multiple body gestures and is related to the emotional context of the relationship. Joy implies behaviors that are more complex that smiling and laughing only.

To have an in-depth exploration of the interactive processes in adult-child relationship, THEME6EDU© software was chosen because it is able to detect interaction patterns invisible to the naked eye: the algorithm it employs recognizes T-patterns, that is, patterns that emerge from the analysis of behaviors/events over time and level by level and, in our case, specifies that the fractals should include feedback loops characterized by symmetric translation (Magnusson, 2017). The T-Pattern analysis "has allowed the description and detection of intra- and inter-individual causal and non-causal patterns frequently sharing the T-pattern structure, but the detection of intra-individual patterns may be a precondition for the detection of more complex inter-individual patterns" (Magnusson, 2020). For this microanalysis a 2-min interaction deemed particularly representative of the adult-child relationship, was selected from all the recordings of the child's interactions with caregivers; a similar sequence occurred repeatedly with a

TABLE 1 Coded ERS and behaviors.

Coded ERS child	Coded ERS adults	Coded ERS all participants	Coded behaviors all participants	Coded basic emotions all participants
Engagement object	Comfort	Help seeking: examiner, pe (father), me (mother), fc (foster carer)	Calm voice	Joy
Disengagement	Attention refocusing	Cognitive reevaluation	Cheerful voice	Anger
Self-soothing	Instrumental strategies		Groan	Fear
Self-excitement	Emotion expression positive or negative		Smile	Sadness
Physical venting	Identify the child's emotions		Laugh	Disgust
Escape			Agressive voice	
Visual exploration			Ferm voice	
Positive and negative verbalization			Sigh	

significance in the THEME© software where $p < 0.005$. The choice of sequence was also guided by an analysis of clinical elements. Video analysis was performed in order to identify interactional patterns that were replicating within relationships. The adult reacts to the child's ERS and with feedback the child will respond to this adult input and will adjust his or her own ERS. The video micro-analyses provided essential information on the deep structure of interactions and allowed us to identify a network of interacting loops (Simon-Herrera and Duriez, 2021). Only the most complex and heuristic patterns are presented. The THEME© software also provides information about occurrences of behaviors and ERS as well as percent values of interaction initiated by Julia with her different caregivers. To ensure the validity of the data, the Monte Carlo test was performed on THEME©. This test consists of comparing the number and complexity of the real data versus the randomized data to obtain statistical validation.

Debriefing and video-feedback with the participants ensured that the coding matched the emotional intent expressed by the adults. The child's behaviors were debriefed with the adult only.

Results

Occurrence of behaviors by type of interaction

Table 2 shows the occurrence of ERS by adult and by child in the different interactions. Those occurences are directly generated

TABLE 2 Occurrences of behaviors for each interaction.

Julia and her FC	Julia and her mother	Julia and her father
1 ju, engagementobject (41)	1 ju, selfexcitement (43)	1 pe, cognitivereevaluation (34)
2 fc, calmvoice (37)	2 ju, positiveverbalization (33)	2 pe, calmvoice (33)
3 fc, cognitivereevaluation (33)	3 ju, engagementobject5 (29)	3 ju, positiveverbalization (29)
4 ju, positiveverbalization (30)	4 ju, disengagement (17)	4 ju, selfexcitement (25)
5 ju, cognitivereevaluation (24)	5 ju, engagementobject2 (17)	5 ju, cognitivereevaluation (20)
6 ju, calmvoice (17)	6 ju, joy (16)	6 ju, calmvoice (17)
7 ju, selfexcitment (14)	7 ju, engagementobject (15)	7 ju, helpseekingexaminer (12)
8 ju, visualexploration (12)	8 ju, cognitivereevaluation (13)	8 ju, joy (12)
9 ju, helpseekingfc (11)	9 ju, calmvoice (12)	9 pe, instrumentalstrategy (11)
10 ju, cheerfulvoice (10)	10 ju, helpseekingexaminer (12)	10 ju, engagementobject2 (10)
11 ju, helpseekingexaminer (10)	11 ju, cheerfulvoice (10)	11 ju, laugh (10)
12 fc, instrumentalstrategy (9)	12 ju, laugh (10)	12 ju, disengagement (6)
13 ju, selfsoothing (9)	13 me, smile (10)	13 pe, smile (6)
14 fc, helpseekingexaminer (8)	14 ju, visualexploration (8)	14 ju, agressivevoice (5)
15 ju, joy (8)	15 ju, helpseekingme	15 ju, cheerfulvoice (5)
16 fc, attentionrefocusing (7)	16 ju, smile (7)	16 ju, negativeverbalization (5)
17 ju, negativeverbalization (5)	17 me, calmvoice (6)	17 ju, engagementobject3 (4)
18 ju, disengagement (4)	18 me, cognitivereevaluation (5)	18 ju, physicalventing (4)
19 ju, groan (4)	19 ju, engagementobject3 (4)	19 ju, anger (3)
20 ju, physicalventing (4)	20 ju, physicalventing (4)	20 ju, engagementobject (3)
21 ju, smile (4)	21 me, helpseekingexaminer (4)	21 ju, helpseekingpe (3)
22 ju, laugh (3)	22 ju, engagementobject4 (2)	22 ju, smile (3)
23 ex, cognitivereevaluation (2)	23 me, attentionrefocusing (2)	23 ju, groan (2)
24 fc, emotionexpressionnegative (2)	24 me, instrumentalstrategy (2)	24 ju, visualexploration (2)
25 ju, fear (2)	25 ex, cognitivereevaluation (1)	25 pe, attentionrefocusing (2)
26 fc, agressivevoice (1)	26 ju, engagementobject6 (1)	26 pe, helpseekingexaminer (2)
27 fc, cheerfulvoice (1)	27 ju, groan (1)	27 pe, cheerfulvoice (1)
28 fc, comfort (1)	28 me, cheerfulvoice (1)	28 pe, emotionexpressionnegative (1)
29 fc, fermvoice (1)		
30 fc, smile (1)		
31 ju, agressivevoice (1)		
32 ju, sad (1)		
33 ju, sigh (1)		

Ju: Julia; fc, foster carer; me, mother; pe, father. Helpseeking is followed by fc, me, pe or examiner regarding the person that is called for support. Engagementobject is often followed by a number which indicates the number of objects Julia is playing with and how long she actually plays with every object (e.g., with her foster carer she only played with one object with 41 occurrences while she invested six objects with her mother).

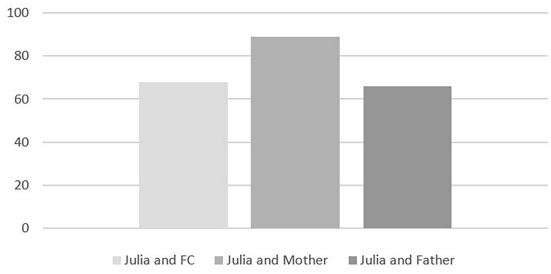

FIGURE 1
Interaction initiated by Julia in %.

by the THEME software and give a first look at the most used ERS in each type of interaction.

Figure 1 shows how often Julia initiated the interaction with her caregivers.

We can see that the percentage of interaction initiation of Julia is superior with her mother rather than when she is with, her foster mother or her father.

It indicates that 68% of the interactions between Julia and her foster carer were initiated by Julia. Her behaviors were focused on engagement with an object while the foster carer spoke with her in a calm voice, employing cognitive reassessment; Julia similarly showed a preference for positive verbalizations and language elaboration.

In the company of her mother, 89% of acts were performed by Julia. Self-excitement behaviors (e.g., making noises, jumping up and down) were most present in this relationship. There were both numerous avoidance behaviors and multiple object engagements. The table also shows that Julia's mother was very passive in the interaction, mostly smiling for instance.

In the presence of her father, 66% of actions were performed by Julia. In a calm voice he would frequently use cognitive reappraisal; she would tend to use the same strategies while exhibiting self-exciting attitudes. Her engagements with objects were less frequent while he tended to use more instrumental strategies. In this interaction Julia was more prone to seek support from the psychologist present.

The overall tone of the interactions remained positive in each case.

Interaction patterns analysis

Analysis of interaction patterns, derived from analyses performed with the THEME© software, highlights the processes and behavioral chains that are established during exchanges between the child and each of her reference adults.

Figure 2 shows the patterns of interaction between Julia and her foster carer. Together they performed 129 acts. It shows that when Julia was engaged with an object (e.g., painting, playing with a doll), her foster carer spoke in a calm voice, prompting cognitive reappraisal and reinforcing Julia's object engagement. This in turn led to positive verbalization and mental elaboration by both Julia and her foster carer, who continued the exchange in a conversational mode so long as Julia remained engaged with an object. The blue lines indicate the self-excitation behaviors that occurred, mainly during pauses in this pattern. The green lines indicate the rare instances of disengagement when distraction behavior was employed. The pattern of interaction in general between Julia and her foster carer indicates a tendency toward thoughtful action and collaboration. The Monte Carlo results are shown in Figure 3.

Figure 4 shows the patterns of interaction between Julia and her mother. Together they performed 111 acts. It shows that when Julia interacted with her mother and spoke calmly, she tended to be engaged with an object and would produce positive verbalizations. This sequence recurred and led Julia to cognitive reappraisal, triggering a maternal smile. Julia then re-engaged with the object, verbalizing positively. In this episode Julia was more or less the only active participant; her mother reacted little and largely non-verbally. Disengagement is significant in the first half of the sequence (green lines) and is followed by a succession of self-excitation events (blue lines) where the interactive pattern no longer appears in the background. The relationship between Julia and her mother here suggests that the child is acting alone. Object engagement is really more a question of object manipulation (e.g., dolls, cubes, boxes) than any deliberately developed game. The Monte Carlo results are shown in Figure 5.

Figure 6 shows the patterns of interaction between Julia and her father. Together they performed 114 acts. It indicates how Julia's laughter triggers her father to intervene. He speaks calmly, using cognitive reappraisal, stimulating the same process in Julia, who verbalizes positively and elaborates. These behaviors prompt a third-party support-seeking intervention by Julia, who smiles. There follows a repetition of the first pattern, Julia using mental elaboration in a calm and positive exchange with her father. The blue lines indicate Julia's regular self-excitations. Disengagement occurs but is relatively infrequent, the interaction between Julia and her father taking the form of a coupling of attitudes that includes many mirror reactions. Julia's need for support within the relationship is apparent in her solicitation of a third party during the episode. We also note the absence of engagement with an object. The Monte Carlo results are shown in Figure 7.

The T-pattern chosen to explore Julia's interactions with her caregivers did not show the disengagement and self-excitement strategies in the pattern itself. Because those behaviors appeared to occur frequently within the interactions of Julia and her caregivers, they were selected as a marker in the figures presented in the results.

Discussion

This analysis of interactive patterns between Julia and her adult carers indicates a wide disparity in relational modalities. While communication is based on verbal exchange and mental

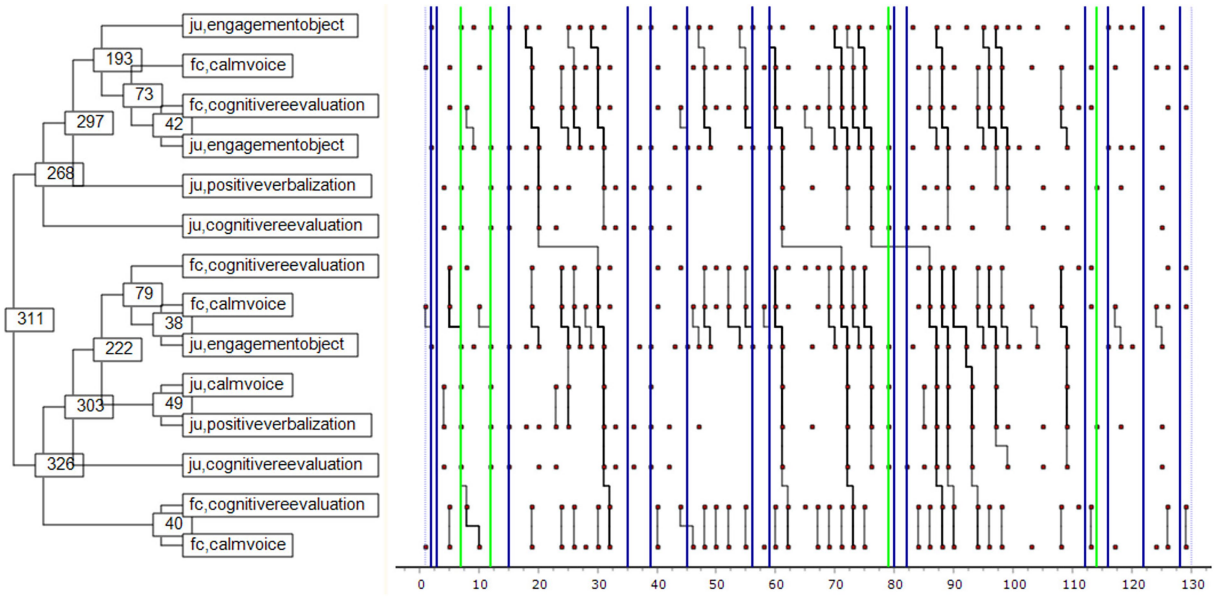

FIGURE 2
Julia-Foster Carer interaction pattern. ju: Julia, fc: foster carer. The X-axis shows the number of behavioral units occurring within the selected 2-min interaction (129 acts overall). Green lines highlight the disengagement behaviors and blue lines are related to self-excitement attitudes. The numbers appearing in the left side of the figure are related to an identification number of each node and is not related with the appearing occurrence of each behavior.

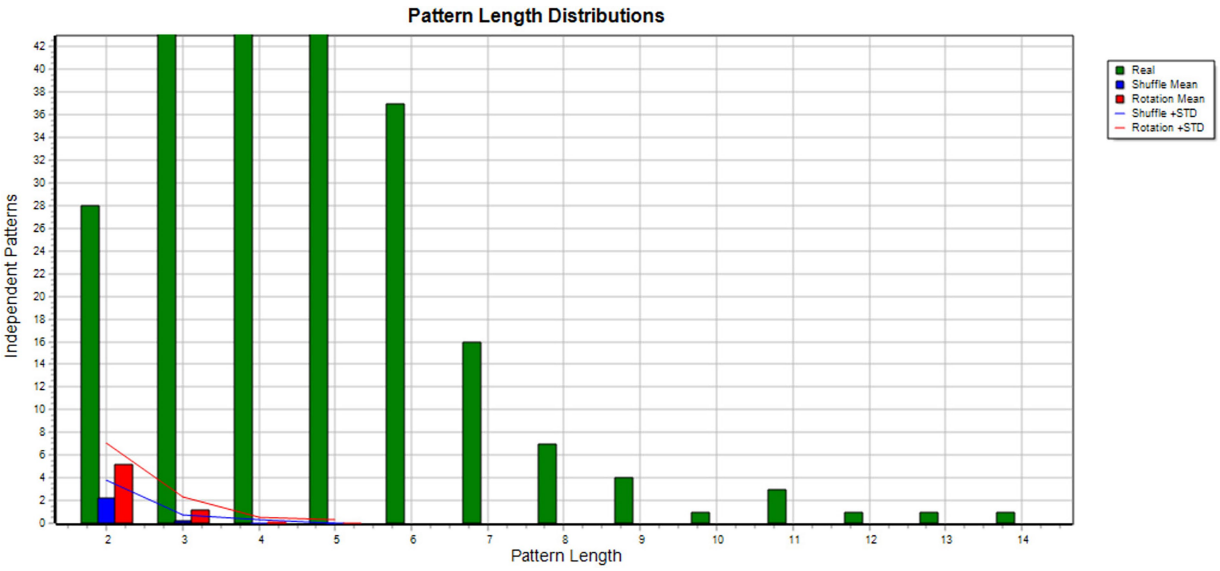

FIGURE 3
Monte Carlo test results. Shows the results of T-shuffling (blue) and T-rotation (red) for TPA of Julia and her foster carer interactions where 282 patterns were found. The difference between real and randomized data is important and no are found in the randomized data with the longer patterns.

elaboration between Julia and her foster carer, there is a near absence of exchange between the child and her mother. The relationship between Julia and her father on the other hand is organized around a reactionary symmetry, within which Julia chooses to seek support from a third party. Focused on the various objects available in the foster carer's home, Julia and her foster carer show real cooperation. Games are jointly developed between them, creating a bilateral relationship with a strong element of collaboration; that it is supported by cognitive reappraisals and regular verbal exchange, positively reinforces the

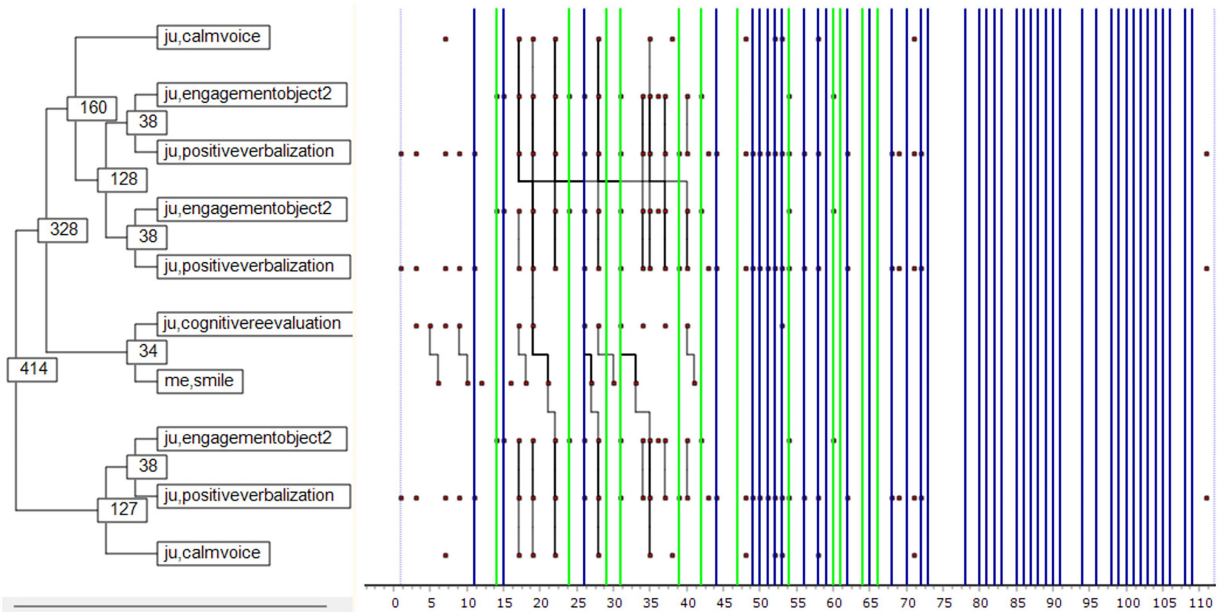

FIGURE 4
Julia-Mother interaction pattern. ju: Julia, me: mother. The X-axis shows the number of behavioral units occurring within the selected 2-min interaction (111 acts overall). Green lines highlight the disengagement behaviors and blue lines are related to self-excitement attitudes. The numbers appearing in the left side of the figure are related to an identification number of each node and is not related with the appearing occurrence of each behavior.

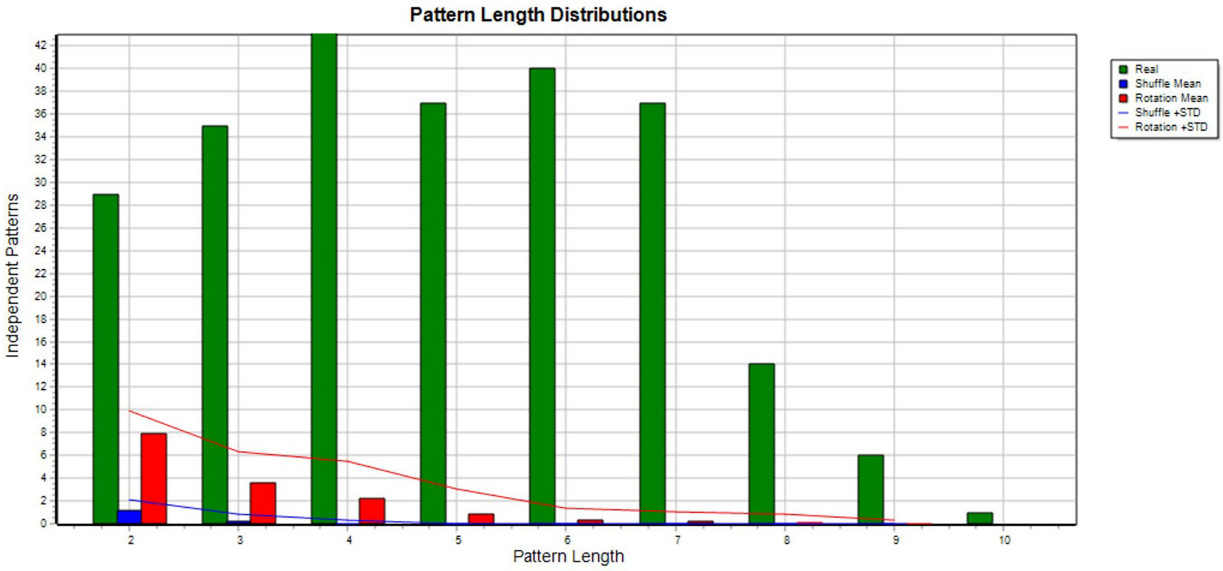

FIGURE 5
Monte Carlo test results. Shows the results of T-shuffling (blue) and T-rotation (red) for TPA of Julia and her mother interactions where 293 patterns were found. The difference between the real and randomized data is great and with longer patterns, none are found in the randomized data.

interaction. The emotional atmosphere remains positive, while the attention that the foster carer brings, encourages Julia to develop language ERS within a secure relationship (Labella et al., 2020; Simon-Herrera et al., 2022), an observation that the analysis confirms.

Between Julia and her mother, however, there is an isolating gulf. Julia seems to want to animate the mother figure at all costs, whereas the mother locks herself into a pathological passivity. The relational and emotional detachment manifested by the mother induces violent reactions from Julia who adopts a seriously disorganized attitude.

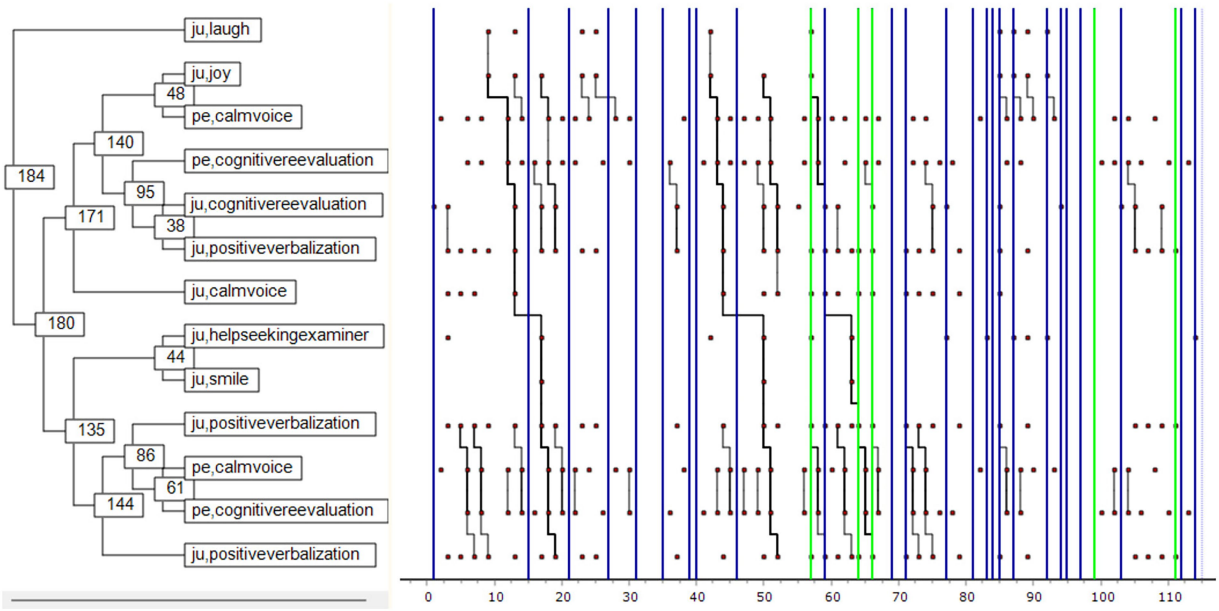

FIGURE 6
Julia-Father interaction pattern. ju : Julia, pe : father. The X-axis shows the number of behavioral units occurring within the selected 2-min interaction (114 acts overall). Green lines highlight the disengagement behaviors and blue lines are related to self-excitement attitudes. The numbers appearing in the left side of the figure are related to an identification number of each node and is not related with the appearing occurrence of each behavior.

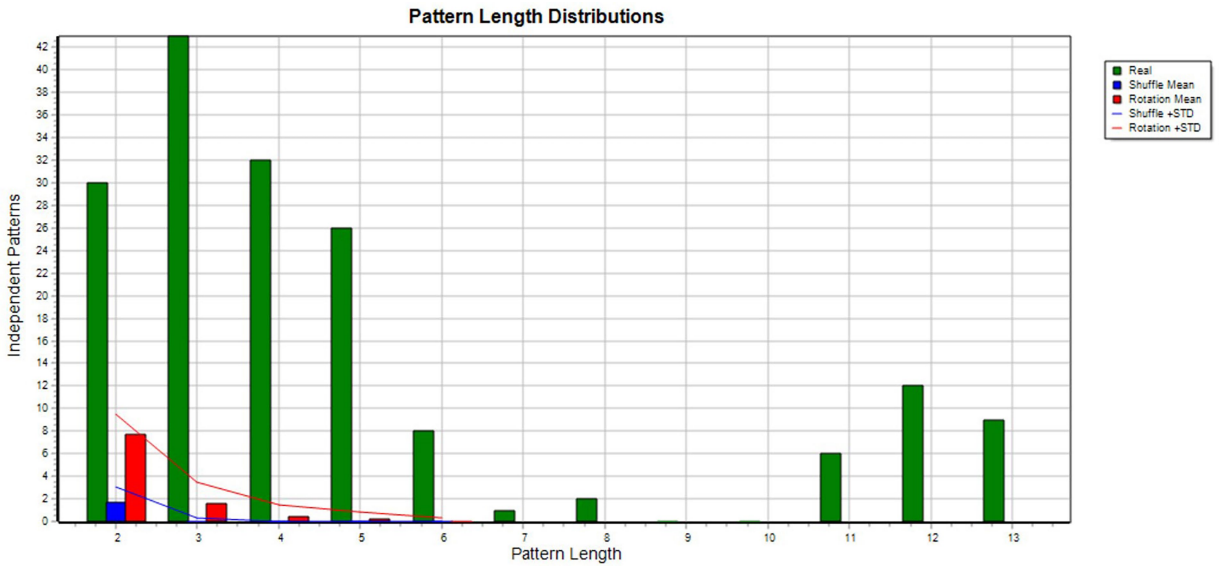

FIGURE 7
Monte Carlo test results. Shows the results of T-shuffling (blue) and T-rotation (red) for TPA of Julia and her father interactions where 169 patterns were found. The difference between real and randomized data is great and no pattern are found in the randomized data when pattern length increase.

She experiences forms of micro-abandonment during her mother's visits, while her impulsive behavior – her numerous self-excitations and disengagements – shows the extent of disorganization in her psychic state, a condition that is visibly neither understood nor supported by her mother. These elements support the hypothesis that there is a loop of negativity between the child and her mother

– a traumatic repetition from which it is difficult to escape (Vasileva and Petermann, 2017). Self-excitation, although non-violent, may also be interpreted as intense self-aggressive behavior in which Julia relinquishes control over her body and cognitions. The number of engagements with object are up to six while Julia is interacting with her mother, showing a great disorganization of her behavior in a 2-min sequence.

The relationship between Julia and her father could be related to what Bion (1961) called "*coupling*" in his work on small groups. There is a significant similarity and correspondence between the attitudes of Julia and her father, yet the girl feels the need to ask a third party for support – the only relational modality where this occurs. Disengagement remains very present, suggesting that it is difficult for Julia to sustain a stable and prolonged interaction with her father. Thus, despite what seems tacit support between them, their relationship appears organized around attitudes of approach-retreat. The lack of investment in objects indicates that their interaction is focused on themselves and thus on their bodies and speech. Regarding Julia's ERS, it appears that she presents a disorganized attachment style with multiple aggressive behaviors and a tendency to feel some distress while interacting with her parents.

The analysis of the results shows how Julia's ER tends to develop differently according to the adult with whom she interacts, as previous case studies have suggested (Simon-Herrera et al., 2022). It is complicated for a foster child such as Julia to develop ERS within multiple parenting systems. It is important to consider as a limitation the fact that a single-case study is presented and the results cannot be globalized. However, the methodology detailed here offered the opportunity to analyze in-depth interaction processes in foster care. The microanalysis carried out with the THEME© software clearly highlights these mechanisms and their disparities according to the type of adult-child relationship, making it an invaluable tool in the search for relational patterns in clinical psychology. These patterns must be understood as interactive loops that are reproduced throughout the exchange (Simon-Herrera et al., 2022).

While disengagement and self-excitement behaviors seemed to be particularly present in the interaction between Julia and her caregivers, no specific pattern showed the process explaining the use of those specific strategies. It can be hypothesized that those behaviors are relatively invasive, especially in mother-daughter interaction, then replicating in other types of relationships. Disengagement behavior is a sign of difficulty in a relationship and indicative of the problem posed by having to maintain contact between a parent and a child at risk, as in the case of Julia and her mother. It questions the whole mother-daughter relationship support system. Since any intervention must have a beginning and an end, the principal difficulty is nonetheless delimiting an objective. In Julia's case, the highly pathological modalities of the relationship with her mother and the dubious interactions with her father, make it almost impossible to envisage withdrawing the relationship support system. Parent–child visits provoke a form of traumatic reviviscence that impacts on emotional co-regulation (Wekerle et al., 2006): an intervention in the relationship seems inevitable if the child is not to be left in a state of traumatic collapse at each visit. Thus, video feedback can be considered a therapeutic tool that may help an adult to identify, understand and respond to both a child's, and his or her own, emotional states (Simon-Herrera and Duriez, 2021).

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

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 patient/participants' or patient/participants legal guardian/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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Patterns of verbal interaction in newly formed music ensembles

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Ensemble rehearsal in the European classical music tradition has a relatively homogenised format in which play-through, discussion, and practice of excerpts are employed to establish and agree on performance parameters of notated music. This research analyses patterns in such verbal communication during rehearsals and their development over time. Analysing two newly established ensembles that work over several months to a performance, it investigates the interaction dynamics of two closely collaborating groups and adaptation depending on task demands, familiarity with each other and an upcoming deadline. A case study approach with two groups of five singers allowed in-depth exploration of individual behaviours and contributions; results are reported descriptively and supported by qualitative data. The results highlight changes over time that reflect the development of implicit (faster decisions) interactions from explicit (slower decisions). They show a trajectory of opening up and closing down in terms of interactional flexibility, enabling members to significantly contribute to the group, followed by tightening the interaction to establish stability for performance. These findings and novel employment of T-pattern analysis contribute to the understanding of human group behaviour and interaction patterns leading to expert team performance.

KEYWORDS

music groups, verbal behaviour, T-pattern analysis, case study, emergence

Introduction

Playing with other musicians in a group ('ensemble') setting is a common part of professional practice within the European classical music tradition. For performance preparation, this generally takes the form of one or more rehearsals, through which the ensemble develops a shared approach to performance of the music, and solves problems related to execution, often alongside individual preparation which happens away from the rehearsal setting (Keller, 2014). This working environment encompasses social and musical interactions. Ways of working together are often drawn from customary practice, learned from peers and through specialist music education; and are implicitly rather than explicitly agreed as individual and joint goals are negotiated (Macritchie et al., 2018). Given this emphasis on implicit coordination processes, identifying the underlying organisational mechanisms in music groups can be challenging. The approach adopted in this study is to focus on explicit behaviours, in the form of verbal interactions, investigating ways they evolve over time, and analysing the formation and development of verbal interaction patterns.

Nonverbal communication is increasingly recognised as the primary mode of conveying timing and expressive meaning in musical coordination (Timmers et al., 2022), whilst a combination of both verbal and nonverbal communication modes have been suggested to determine the quality of the musical output (Kokotsaki, 2007). The amount, type, and purpose of verbal interactions in music ensembles is idiosyncratic, and subject to changes over time within and across rehearsals (King and Ginsborg, 2011; Ginsborg and King, 2012). Verbal behaviour plays a key role in clarification and consensus building, and in supporting the development of social relationships, but is not conventionally used in performance. Hence, a core purpose of rehearsal is to establish patterns of interactions, which can then be 'replayed' (nonverbally) in the moment during performance (King and Gritten (2017), p. 318). This supports the connection between verbal interactions in rehearsal and performance outcomes, in which patterns of behaviour are embodied, and part of the 'implicit communication strategy' of performance which Gilboa and Tal-Shmotkin (2012) describe as,

> … an implicit communication strategy to make time-critical decisions … the performance phase[1] combines anxiety and artistry; performance remains mysterious even to the musicians themselves (Gilboa and Tal-Shmotkin, 2012, p. 34).

Whilst there is some evidence of this shift from verbal to nonverbal communication from previous studies, there have been few longitudinal studies with groups, and none to date to explore the transition from 'communication' to 'interaction' modes (King and Gritten, 2017). In particular, very little is known about the emergence and development of patterned interactions from initial rehearsal to public performance, which the employment of T-pattern analysis can assist with (Magnusson, 2000). Small groups arise in many contexts within human society. When a consensus or collaboration is required, people often come together in groups to cooperate, or share skills and resources. Over the past 50 years, a number of theoretical perspectives on small group working have come to the fore, of particular relevance to purposive, goal-orientated groups, such as music ensembles working towards a future performance (Poole and Hollingshead, 2004). For our research, we adopt a temporal perspective, in which time acts as context for group development, a resource to be allocated, or as a mediating variable; and which foregrounds process over outcome (Arrow et al., 2004). Within this framing, our focus was on how the groups under consideration systematically changed over time, and the role of patterned interactions in those changes. Prior research in a workplace setting has shown that groups working on projects with deadlines exhibit temporal patterning in their interaction, which are reflected in the internal rhythms and pacing by which they structure and coordinate activities. These patterns include the 'midpoint transition', whereby a marked change in behaviour occurs around halfway through a given preparation period (Gersick, 1988; McGrath, 1991), and which can be attributed to a number of causes, including deadline pressure and evolving team dynamics (Seers and Woodruff, 1997). Gersick and Hackman (1990) posit that these patterns are indicative of a groups' efforts to establish routine, and that patterns persist unless a new focus or challenge arises, such as that which might arise when deadline pressure increases. They further propose that changes in patterns are influenced by the severity and frequency of changes and hypothesised that 'importation' of task habits (whereby prior experiences shape a new setting), the creation of unique new patterns, and their evolution, are all factors in how new groups establish themselves and develop over time. These factors may be also subject to further variation in the absence of formal roles or where groups are under greater time pressure or experiencing different task demands (Kelly et al., 1997).

In order to investigate such temporal phenomena and behaviours, a number of researchers have adopted temporal pattern ('T-pattern') analysis as part of a mixed-methods approach to reveal self-similarity in sequences of behaviours (Magnusson, 2020), for a review, see Casarrubea et al. (2015). T-pattern analysis can detect the presence, timing, and complexity of patterns of repeated behaviours such as verbal and social interactions and can contribute to a greater understanding of ways that members of a group work together, including turn-taking, brief sequences of verbal behaviours and to identify emergent changes or transitions. Interaction patterns have been studied in a range of settings including small groups of professionals working to deadlines (Ballard et al., 2008), in crisis situations (Stachowski et al., 2009) and in emergency teams (Zijlstra et al., 2012). The THEME® software algorithm (Patternvision Ltd) was chosen as the analysis tool for pattern detection, which in group behaviour research has been used to investigate interactions during sports (Camerino et al., 2012; Pic and Jonsson, 2021), in contemporary dance (Castañer et al., 2009; Torrents et al., 2013; Harrison and Rouse, 2014), as well as in the study of complex interactions in teams during information sharing (Hoogeboom and Wilderom, 2019). These studies provide useful models for our research into groups in the musical context. In addition, T-pattern analysis has been used as a tool in the study of verbal and nonverbal communication; Castañer et al. (2016) investigated 'paraverbal' communication in teachers, to identify ways in which kinesic (gesture and posture) and proxemic (use of space) modes were used alongside verbal communication during delivery.

Our study investigated the changes over time in the verbal interactions arising during performance preparation in two small, newly formed music ensembles in a series of rehearsals. The primary aim was to identify T-patterns of interaction to highlight the existence of underlying structures in the real-time behaviour, and the contributions of group members. We had the unique opportunity to gain insights from the early start of an ensemble (first time they came together). This allowed us to follow the changes in interaction, how ensemble members contributed to the

1 Magnusson, (2000).

progression of the rehearsal process, and how changes of tasks and task context may contribute to changes in T-patterns. Investigating interaction patterns offers insight into working practises amongst highly specialised team members including insight into patterns of distributed and democratic leadership vs. hierarchical or autocratic forms of direction (Bathurst and Ladkin, 2012).

As such the following research questions were addressed:

- What were the observable patterns of verbal interaction between ensemble members during rehearsals?
- How did these develop over time, across rehearsals, in the context of changes in rehearsal context from early encounters to polishing for performance?
- What light do these patterns shed onto the roles of ensemble members at various stages of the rehearsals?

Materials and methods

The music context was a specialist higher education setting, in which postgraduate students, selected by audition for suitability, were participating in a professional practice programme. This setting enabled tracking behaviours in bi-weekly rehearsals of the groups for 2–3 months from day 1 of their musical interactions.

Participants

The participants were two vocal groups, each comprising five pre-professional level solo singers, at a United Kingdom university. There were three women and two men in each group. They were allocated to vocal parts as follows:

Group 1

Singer A, female – soprano.
Singer B, female – mezzo-soprano.
Singer C, female – alto.
Singer D, male – tenor.
Singer E, male – bass.

Group 2

Singer V, female – Soprano.
Singer W, female – Mezzo-Soprano 1.
Singer X, female – Mezzo-Soprano 2.
Singer Y, male – Tenor.
Singer Z, male – Bass.

Materials

Materials for analysis came from video recordings of rehearsals. Verbal exchanges were transcribed and coded using the Behaviour Analysis (BA) observational instrument (Rackham and Morgan, 1977; Farley et al., 2018; see Table 1). Four main categories were used for analysis, as behaviours were grouped into the categories of 'Clarifying' (ensuring a common understanding); 'Initiating' (to create ideas and possibilities); 'Reacting' (to ensure agreement and resolve disagreement); and 'Participating' (which bring in or shut out others or lighten the mood through humour). The first author was trained in the use of this scheme prior to coding, and her coding consistency was checked against a benchmarked standard as part of the training she received and checked by an independent coder.

Group 1

The group was provided with a video camera (Sony MV1 Music Video recorder). In order to minimise disruption to their normal working processes, members of the group were shown how to use the camera and submit the recordings post-rehearsal. They scheduled and directed their own rehearsals, and they were asked to rehearse and interact as normal. Multiple rehearsals were recorded, and the camera became a customary part of their rehearsal process. Rehearsals were dedicated to trying and refining different repertoire. At the end of the rehearsal series, a selection of this repertoire was performed in front of an audience and panel as part of a formal assessment.

Group 2

For the second group, five sessions were pre-arranged by the researchers and recorded in a laboratory setting. Musical materials were provided in the form of two original pieces which were created for the purpose of the study (for details of the scores, see D'Amario et al., 2020b). Neither piece had text, nor were sung to the vowel sound 'e'. No expressive markings were included – the singers were asked to develop their own expressive interpretation as a goal of rehearsals. In the final session, the group were invited

TABLE 1 Behaviour analysis coding scheme used as observational instrument for categorising verbal behaviours.

Behaviour analysis category	Code	Sub-category
Initiating behaviours	I	Proposing ideas
		Proposing behaviours
		Building ideas
Participating behaviours	P	Bringing in
		Shutting out
		Lightening the mood
Clarifying behaviours	C	Giving task information
		Giving personal information
		Seeking task information
		Seeking personal information
		Checking understanding
Reacting behaviours	R	Supporting ideas
		Supporting people
		Disagreeing
		Defending/attacking

to perform for a recording, which took place within the lab setting. The contrast in the structure of the two pieces was primarily in the texture, whereby Piece 1 was in rhythmic unison ('homophonic', literally 'one voice'), and Piece 2 contained multiple, overlapping melodic lines with differences in rhythms to each other ('polyphonic' or 'many voices'). The participants only had access to the material during the session; no rehearsal on these pieces happened outside the study sessions. However, the singers were regularly working together on other materials, both independently and in coached sessions, in the intervening days and weeks between sessions. A single video camera was set up to record all interactions throughout the session, using a tripod-mounted Sony MV1 Music Video recorder. The camera recording was started at the beginning of the session and left running throughout.

Procedure

The participants were approached to take part in the study before their first rehearsal took place. Ethical approval was obtained for the study and informed consent for participation arranged in time to organise a first recording session in the first week that the vocal group was formed.

The protocol for each group was as follows:

Group 1 were given an initial briefing and shown how to use the equipment. Subsequently, the group were allowed to proceed as they chose, recording rehearsals whenever possible. From these recordings, selections for further study were made based on time-interval to provide regularly spaced samples. Where group members were obscured by camera angles or more than one member was absent, recordings were not used. Four sessions were selected for analysis related to Weeks 1, 3, 5, and 7, and the first 30 min of each rehearsal was analysed. All five singers were present in weeks 1, 3 and 7; in Week 5 Singer B was absent due to illness.

Group 2 were presented with two set excerpts to rehearse. In the first session the task was explained to the participants, and they were asked to prepare both pieces for a possible future performance, and to create an expressive interpretation. The singers were not aware of the purpose of the study. The same procedure was followed each time: the group performed the excerpt of music, rehearsed it for a short, timed period, and then performed it again. This procedure was repeated for the second musical excerpt. The rehearsal sessions were video-recorded and verbal interactions transcribed and coded as for Group 1. The two pieces were randomised for order in which they were presented (see Table 2). Five sessions were recorded over a 16-week period in week 1, 3, 6, 8, and 16, respectively. Apart from controlling the music that was rehearsed, the duration of rehearsals and the rehearsal venue, the participants were asked to work independently as they normally would, and the researcher left the room. The sessions were timed using a digital timer and after 10 min the researcher returned to the rehearsal room at which point the rehearsal stopped. Each session was approximately 1 h long. All five recording sessions were used in the analysis. Only the rehearsal part of the sessions was analysed. Analyses of tuning and synchronisation in the performances have been reported in earlier publications (D'Amario et al., 2020a,b).

Data preparation

Exchanges during rehearsals were transcribed verbatim to produce time-stamped, line-by-line utterances. The first author and a second, independent rater who was also trained in the BA coding scheme coded the utterances with an agreement score (Cohen's kappa) of 0.67 at sub-category level, comfortably above the 'substantial agreement' boundary of 0.6 as defined by Landis and Koch (1977). There was a higher agreement at category level, which was then used in the final analysis. Occurrences and durations of the whole group singing together were also recorded. Only single codes were assigned. During the transcription process the duration of each utterance was noted. A text file was created with the time-stamped output (in seconds) and coded with the person speaking ('actor') and the category of behaviour. In the pattern descriptions each pair of letters represents first the singer(s) (A, B, C, D, E; V, W, X, Y, Z; SOME or ALL), followed by the category of interaction (Clarifying (C), Initiating (P), Reacting (R), or Participating (P)). For example, 'A, I' described an event type in which Singer A exhibited Initiating behaviour. Two additional categories were included to support the pattern detection; M (Music-making) and N (no specific category assigned). For this analysis, subcategories were not used.

Analysis

First, the main characteristics of rehearsals and behaviour were analysed examining frequencies of behaviours. Secondly, interaction patterns were analysed, including developments across the rehearsal period. Comparing frequency and complexity of interaction patterns was used as an indicator for how the rehearsal processes are unfolding; for example, how fast-paced decision-making is. This has implications too for how much implicit (related to faster decisions) versus explicit (slower decisions) communication there is.

The amount of time spent singing and talking in the first 30 min (Group 1) or the 2×10 minutes (Group 2) was analysed. Patterned interactions were analysed using THEME® v 6.0 and were based on the distribution of behaviour categories and actors over time. The following search parameters were set [based on guidance in the manual (Magnusson, 2022)]: (a) frequency of occurrence of ≥ 3; (b) significance level of 0.005 (0.5% probability of critical interval being due to chance); (c) deactivation of fast requirement and selection of free critical interval algorithm in which, if present, at least one critical interval is found; (d) validation of results through randomisation of data on five occasions. These settings were arrived at through a series of validation tests with varying flexibility of statistical margins ($p < 0.05$ and $p < 0.001$), and minimum number of occurrences (2 and 4). This is consistent with previous studies, which utilised

TABLE 2 Singing, talking and number of utterances in sampled period (Groups 1 and 2).

	Rehearsal activity	Week 1	Week 3	Week 5	Week 6	Week 7	Week 8	Week 16
Group 1	Singing (% of time)	33.5	28.9	60.9		53.1		
	Talking (% of time)	66.5	71.1	39.1		46.9		
	Number of utterances (*N*)	179	260	250		196		
Group 2	Singing (% of time)	35.1	42.7		31.5		21.8	45.5
	Talking (% of time)	64.9	57.3		68.5		78.2	55.5
	Number of utterances (*N*)	222	159		248		218	251

similar settings (Zijlstra et al., 2012; Amatria et al., 2017; Hoogeboom and Wilderom, 2019; Pic et al., 2021). Repeated sequences of events were detected from which patterns were inferred. Pattern length (number of events in a pattern), number of levels (an index of complexity based on hierarchical structure of the pattern), number of actor switches (an indicator of turn-taking) were used as the basis for summarising the main behaviours. Occurrences of 'mono-actor' patterns, where the pattern involved a single actor (Stachowski et al., 2009) were also recorded, as an indicator of balance of contributions – more mono-actor patterns have been reported in less effective groups, which may suggest less 'balanced' interaction between group members. Dyadic (two-person) patterns were also recorded, which can provide an indication of emergence of group member social relationships (Kozlowski et al., 1999).

Other events not appearing in patterns were excluded from the subsequent analysis. Each remaining pattern represents a sequence of events that recurs at least three times within a so-called 'critical interval'. This interval is different for each data set and defined as follows.

> 'If A is an earlier and B a later component of the same recurring T-pattern, then, after an occurrence of A at t, there is an interval $(t+d1, t+d2)$ $(d2 \geq d1 \geq d0)$ that tends to contain at least one occurrence of B more often than would be expected by chance.' (Magnusson, 2000, pp. 94–95).

From the main patterns extracted the verbal content was compared to the original transcript. From this process, a coded description was created.

Results

Given the differences in goals and settings for data collection, results are presented for Groups 1 and 2 separately, before discussing emerging shared features.

Allocation of time talking and singing during rehearsal period

For Group 1, there were frequent brief verbal exchanges in all rehearsals, which were highest in number in Week 3. When examined by duration, the total amount of time spent talking was high in Weeks 1 (66.5%) and 3 (71.1%), and less in Weeks 5 (39.1%) and 7 (46.9%), Conversely, time singing together was greatest in Week 5, which also contained the fewest singing episodes (where a singing episode involved the group singing together a passage, movement, or piece). In Group 2, the total amount of time spent talking ranged from a low of 55.5% in Week 16 up to 78.2% in Week 8. This transition from Weeks 8 to 16 indicates a marked shift from a rehearsal where there is much discussion, to one where changes and ideas are tried out by music-making, ready for the final recording. See Table 2 for summary of singing and talking episodes for Groups 1 and 2.

The different profiles of talking/singing in the two groups may be explained by the different settings and tasks, amongst others – Group 1 was more typical of how a group may work over a series of rehearsals towards an end goal, whilst Group 2 experienced shorter sessions, with a change of task, and shorter-term goals for each session. The task switching activity may have generated further stimulus for discussion, and the number of utterances remained a high proportion of the time. The laboratory setting, time-constraints and provided materials made the rehearsal circumstances a bit artificial, and although different from Group 1, this is not entirely unusual when musicians have only limited time to rehearse musical material.

Behaviour over time and T-pattern detection

T-pattern results are presented per analysed rehearsal, reflecting the rehearsal context and quality of the verbal exchanges associated with each pattern. Possible interpretations are offered having referred to the original transcript and video for further context, and further possible interpretations made of the ways in which individuals contributed to these patterns. Selected dendrograms from the THEME® analysis are used to illustrate features of the emerging patterns.

Group 1 emerging interaction patterns

First, the basic pattern data is summarised (Table 3) and differences and themes over time by rehearsal session are explored.

TABLE 3 Group 1: Summary of pattern data by rehearsal.

Week	Length of main pattern (N of events)	Event types in patterns	Duration (secs) mean	Duration (secs) S.D.	Actor switches mean	Actor switches S.D.	Duration of patterned behaviour (% total)
1	4	25	2.82	0.86	1.25	0.84	44
3	7	24	3.21	1.26	0.77	0.72	41
5	15	23	5.91	2.39	1.05	1.15	80
7	6	24	2.50	0.88	0.53	0.74	34

Group 1, rehearsal 1 (week 1)

The main pattern identified consisted of the sequence [(ALL,N [A,I C,R]) D,P]: This can be qualitatively described as the group engaging in a shared activity, followed by an interaction between singers A and C, whereby A Initiated an event, and C Reacted. This was followed by singer D Participating.

The pattern occurred three times, and the duration of patterned behaviour was 44% of the 30-min rehearsal time. The number of events (pattern length) was 4. From the transcript these were characterised as light-hearted interactions, triggered by a collective activity (e.g., all referring to a musical score) and ending with a jokey remark. There were no mono-actor patterns detected.

Group 1, rehearsal 2 (week 3)

Compared with Week 1, the patterns in Week 3 were longer, and more fragmented into sub patterns. Longer patterns have been associated with the development of implicit coordination modes associated with groups adapting to a task (Uitdewilligen et al., 2018).

The main pattern was: (D,P (((E,C B,C)(D,C E,I))(E,C B,C))) comprising;

Singer D – Participating;
Singers E and B – Clarifying;
Singer D – Clarifying;
Singer E – Initiating;
and Singers E and B – Clarifying.

The pattern occurred three times, and patterned behaviour occupied 41% of the Week 3 rehearsal time. The length of the pattern was 7 events (Figure 1).

Group 1, rehearsal 3 (week 5)

Week 5 was highly patterned. The dendrogram from THEME® (Figure 2) shows short bursts of patterned interaction, prominently featuring Singer C, combined with longer, complex patterns involving all members. The dendrogram also illustrates how the patterns span, and indeed incorporate, an episode of singing. More sub patterns were evident compared to Week 3, in the form of short, dyadic interactions. As with Week 3, Singer D's Participating behaviour initiates the main long pattern. Otherwise, there are three mono-actor patterns occurring with a high frequency, concerning Singer A (20 occurrences), Singer C (27 occurrences), and Singer D (19 occurrences). This may be due to the absence of Singer B from the rehearsal affecting the dynamics of the interactions between the remaining four members.

The main pattern was (D,P (((C,C C,C) ((E,C C,C) ALL,M)) (((A,C A,C) C,R) (((D,C C,C) (E,C C,C) (D,C D,C))))).

with Singer D – Participating;
Singer C – Clarifying;
Singers E and C – Clarifying;
ALL – Music-making;
Singer A – Clarifying;
Singer C – Reacting;
Singers D and C – Clarifying;
Singers E and C – Clarifying;
and Singer D – Clarifying.

This main pattern occurred three times, occupying 80% of the Week 5 rehearsal time. The length of the pattern was 15 events.

A combination of simple and complex patterns is reflected in the patterns of behaviour which precede and follow a singing episode, in which Singer C has a role in harnessing the ideas to try out, whilst Singer A has a key role in responding to what has been tried:

a. Preceding singing: (D,P (((C,C C,C) ((E,C C,C)). This sequence is dominated by Singer C providing suggestions about how to approach the task and seeking to clarify what is required.
b. Pattern following singing: ((A,C A,C) C,R) ((D,C C,C) (E,C C,C) (D,C D,C)). Singer A is the first to respond to what has just been tried and Singer C reacts.

Group 1, rehearsal 4 (week 7)

In Week 7, there are fewer, simpler patterns. All members except Singer D are involved in the main pattern. There are also fewer sub-exchanges or dyads. Singer E shifts from Clarifying to Initiating mode, and Singer A plays a consistent role in Initiating singing episodes.

The main pattern is (B,C C,C)((E,C E,I)(A,I ALL,M))). This involves:

Singers B and C – Clarifying;

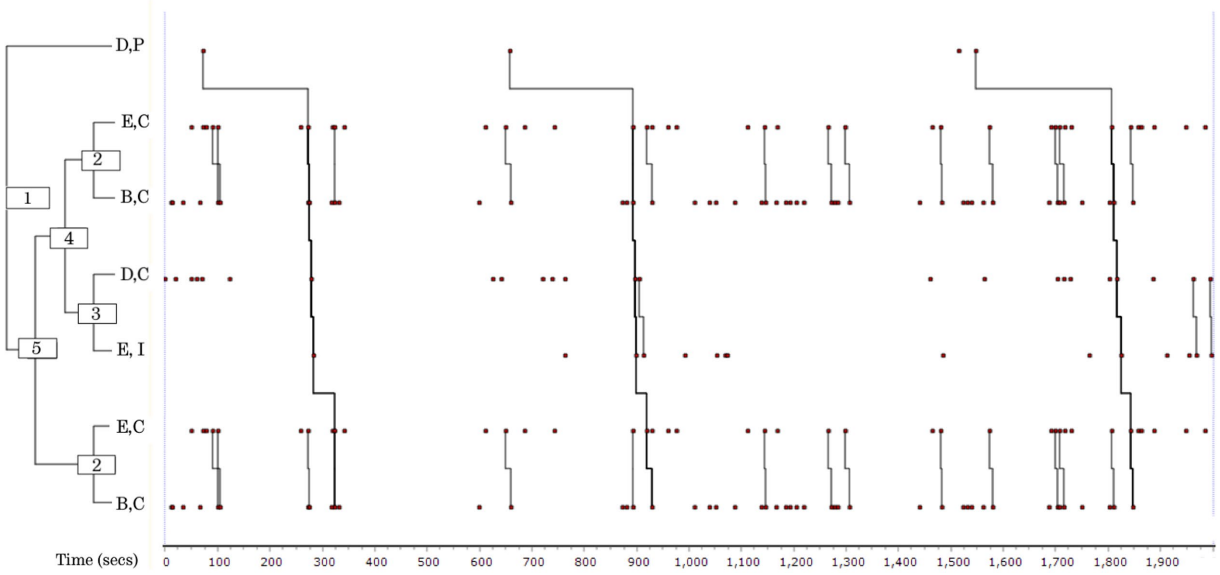

FIGURE 1

Pattern diagram (dendrogram) output from THEME® analysis showing main patterns and frequent sub patterns (Group 1, Week 3). Three members of the ensemble featured in the patterns; interactions were a mixture of light-hearted and more task-focussed discussions of technical aspects, such as choice of speed, expression, or repertoire. The first event in all long patterns was a humorous contribution from Singer D (1), followed by dyadic interactions between Singers E and B (2), and between D and E (3), which appear in combination (4) and in the main pattern (5).

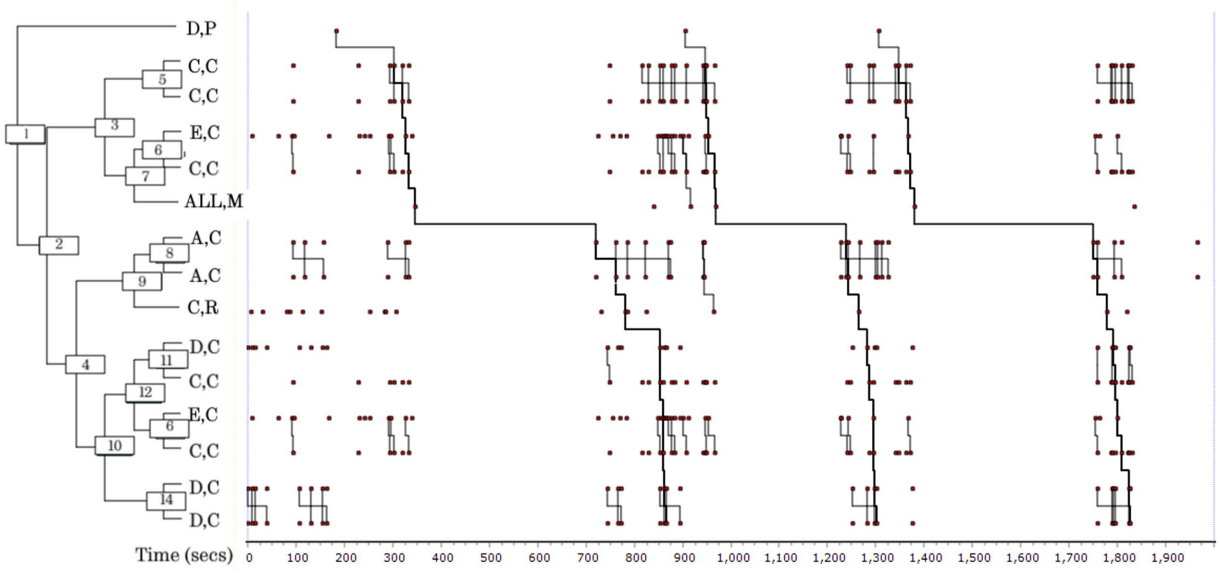

FIGURE 2

Pattern diagram (dendrogram) output from THEME® analysis showing main patterns and frequent sub patterns (Group 1, Week 5). In this week, patterns precede and follow group singing episodes (All, M). Features include longer patterns and numerous dyadic and mono-actor sub patterns. A light-hearted or humorous contribution from Singer D is followed by mono-actor Clarifying interactions (2, 8, 14) and dyadic exchanges between E and C, and D and C (6, 11). Patterns following singing (4) involved each of the singers engaged in Clarifying, apart from one sub pattern including Reacting (9).

Singer E – Clarifying and Initiating;
Singer A – Initiating;
and ALL – Singing.

This main pattern occurred three times, occupying 34% of the rehearsal period. The length of the pattern was 6 events. There is a high degree of similarity of the qualitative content of the

verbal interactions appearing in the patterns consistent with the emergence of a common understanding as the group achieves a greater coherence and consistency. The pattern each time includes checking of pronunciation by Singer A; clarified by Singer C; Singer E gives an opinion on the interpretation or expression; Singer A makes a suggestion relating to the current task, then they all sing a passage or piece.

Group 1 – observations across rehearsals

Between Weeks 1, 3 and 5 there was an increase in pattern length and amount of patterned behaviour. In Week 5, patterns were longest with more actor switches (number of different participants in a pattern), as well as the highest duration of patterned behaviour. Week 5 also coincided with the calendar midpoint of the group's preparation timetable (with a performance in Week 9). This is consistent with previous studies which report groups exhibiting a type of 'tipping' point transition around the midpoint, as their impending deadline creates a new sense of urgency and focus (Gersick, 1988, 1989).

In Week 7, after the complex patterns of Week 5, simpler patterns were evident, suggesting that as they approached their performance deadline, the group were achieving greater consistency in their interactions. They need to balance exploratory behaviours with more predictable outcomes.

Some recurring interactions between individuals emerged. Singer E featured more in the patterns from Week 3 and from observation of the group he was vocal and active throughout. Other patterns involved the 'quieter' members of the group, and their contribution was accordingly harder to detect using traditional observation methods – for example, the Initiating behaviour of Singer A in Weeks 1 and 7, and the Participating role of Singer D in Weeks 3 and 5. Reviewing the transcripts through the lens offered by the patterns gave a nuanced perspective on how different individual members influenced the overall group dynamics. Table 4 shows how these individual traits were expressed in the patterns. Singers A and E showed Initiating behaviour, often shortly before or after singing. Singer C was the only one to show Reacting behaviour. Singer D often contributed Participating behaviour in the form of humorous remarks which triggered a shift to a new focus.

In summary, the following informal roles were identified:

Singer A: Initiated and follows up after singing episodes.

Singer B: Vocal in early rehearsals due to a technical specialism (language).

TABLE 4 Singer behaviour types occurring in patterns, by week.

Behaviour type in pattern	Week 1	Week 3	Week 5	Week 7
Clarifying		B, D, E	A, C, E	B, C, E
Initiating	A	E		A, E
Reacting	C		C	
Participating	D		D	

Singer C: Often contributed opinions prior to a singing episode.

Singer D: Quiet, but use of humour creates shifts of focus and subsequent interactions.

Singer E: Increasingly active over time from week 3.

Over time, more members of the group were involved in the patterned behaviours from 2 in Week 1 to 4 in Weeks 5 and 7.

Group 2 emerging interaction patterns

For Group 2, emerging patterns in behaviours for each session were analysed and summarised (Table 5). Additionally, the design allowed for further analyses to explore the ways these patterns and behaviours varied according to the changing tasks.

Group 2, rehearsal 1 (week 1)

In the first rehearsal there were three occurrences of a long pattern; occurring once during rehearsal of Piece 1, and twice for Piece 2.

The pattern was:

(((SOME, M SOME, M) X,I)Y, C ALL, M))

In this pattern, a subset of singers ('SOME') rehearsed an extract, after which Singer X Initiated further suggestions or ideas. Singer Y offered Clarification relating to what was needed, and they all sang a passage together. There was a total of 21 occurrences of two dyadic sub patterns, and the first dyadic pattern occurred within the first minute. Both dyadic interactions comprised group events (those coded 'ALL'), so whilst they may represent the origination of a longer pattern, in this instance they do not represent specific, nascent social relationships. However, it highlights a significant role for Singer Y as there are 14 instances when an idea or clarification offered by Singer Y is followed shortly afterwards by a singing episode.

Group 2, rehearsal 2 (week 3)

The main pattern in Rehearsal 2 was short and had four occurrences.

The pattern was:

((X,C Y,C) ALL,M)

In the main pattern, Singers X and Y exchanged task Clarifications, followed by the whole group singing. There were 5 occurrences of the dyadic sub pattern between Singer X and Y, suggesting this as an important developing interaction. The second part of Rehearsal 2 was cut slightly short as one member had to leave the room for a few minutes.

Group 2, rehearsal 3 (week 6)

In Rehearsal 3 the main pattern was:

((X,I V,R)(Z.R X,I))

TABLE 5 Group 2: summary of pattern data by rehearsal.

Week	Length of main pattern (no. of events)	Event types in patterns	Duration (secs) mean	Duration (secs) S.D.	Actor switches mean	Actor switches S.D.	Duration of patterned behaviour (% total)	Total observation time (secs)
1	5	15	2.48	0.77	1.26	0.73	29	1,238
3	3	19	2.30	0.48	1.20	0.63	29	905
5	4	18	2.46	0.63	1.04	0.65	30	1,512
8	8	11	3.29	1.49	1.95	1.16	56	1,234
16	9	18	3.68	1.63	2.04	1.40	47	1,651

In the main pattern Singer X Initiated an activity, to which Singer V Reacted. This was followed by an exchange between Singers Z and Singer X – who again Initiated an idea. There were 9 occurrences of the dyadic sub patterns.

Group 2, rehearsal 4 (week 8)

Rehearsal 4 was more highly patterned than Rehearsal 3. The main pattern was:

((W,C Z,C)(((W, I Y,C) All, M)((W,C V,C) Y,C)))

In the main pattern, which was dominated by Clarifying exchanges, Singer W made multiple contributions to Clarify and Initiate. Singer Y also featured prominently, both in the sub pattern prior to the singing episodes, suggesting he was providing direction or otherwise prompting the group to try an idea, and also following on from a dyadic exchange between Singers W and V. This was the most highly patterned rehearsal for Group 2. The dendrogram is shown in Figure 3, indicating the change of piece and how the sub patterns persisted across rehearsals of the two pieces.

Group 2, rehearsal 5 (week 16)

Rehearsal 5 was also highly patterned.

The main pattern was:

(((Y, I (Z,R ALL, M))(V,I Y,R)(Z,P (V,P Z,P)))

The main pattern in Rehearsal 5 included Participating behaviours, which were light-hearted or social in nature, and featured Singer Z more than in previous patterns. The pattern ran as follows: Singer Y Initiated an action, to which Singer Z Reacted, followed by All singing. Singer V Initiated, and Singer Y Reacted. Finally, Singer Z engaged in Participating behaviour, then Singers V and Z exchanged Participating behaviours. There was a total of 18 dyadic sub patterns.

In summary, the following informal roles were identified:

Singer V: In a prominent vocal role when singing but only featured in patterns from week 3.

Singer W: Quiet at first, increasingly active in final two rehearsals.

Singer X: Often initiated, contributed and reacted in first three session.

Singer Y: Active in all rehearsals, often initiating and reacting.

Singer Z: Generally quiet, active in rehearsal 3, but most contributions in rehearsal 5.

Patterns in Weeks 1 and 3 only included Singers X and Y, but in later rehearsals more singers contributed. Notably, Singers W and Z were initially quiet, but became more active in weeks 8 (W) and 16 (Z).

Changing task requirements of the musical material in group 2

The number of patterns, events, actor switches and dyads occurring during the rehearsals of Pieces 1 and 2, are shown in Table 6. There were three main patterns detected in all except Rehearsal 4, where there were 4. The number of events was highest in Rehearsals 4 and 5. The number of dyadic interactions in rehearsals ranged from 5 (Rehearsal 2) to 30 (Rehearsal 4). In all except Rehearsal 2, more dyadic patterns are evident during rehearsals of Piece 1 (mean = 9.2, S.D. = 5.8) than Piece 2 (mean = 7.4, S.D. = 4.2). Actor switches were most active in the final two rehearsals (Rehearsals 4 and 5), which is consistent with the observation of more members of the group contributing to the discussion.

The interaction pattern data shows a change in pattern event and dyad frequency after Rehearsal 3, and considerable variation across rehearsals in contributions and behaviour types. There were no marked differences between piece types. Although Rehearsal 1 did show a largish number of dyads, in other respects it was comparable to Rehearsals 2 and 3 in terms of number of actor switches, mean duration of pattern, and length. Indeed, up to Rehearsal 3, the number of events making up a pattern was steady, the amount of turn-taking was low (as indicated by actor switches) and the mean duration was relatively low. Rehearsals 4 and 5 showed an increase in all three measures (Table 5), with the longest patterns and most turn-taking in Rehearsal 5. There was a change between Rehearsals 3 and 4, with an increase in pattern complexity, which persisted to Rehearsal 5. The increase in pattern events over time suggests that sequences of individual contributions were sustained for longer. It may be that the group were experimenting with different ways of interacting up to Rehearsal 3.

From the pattern descriptions it is apparent that qualitatively they differ from each other too – Rehearsal 4 has more of a

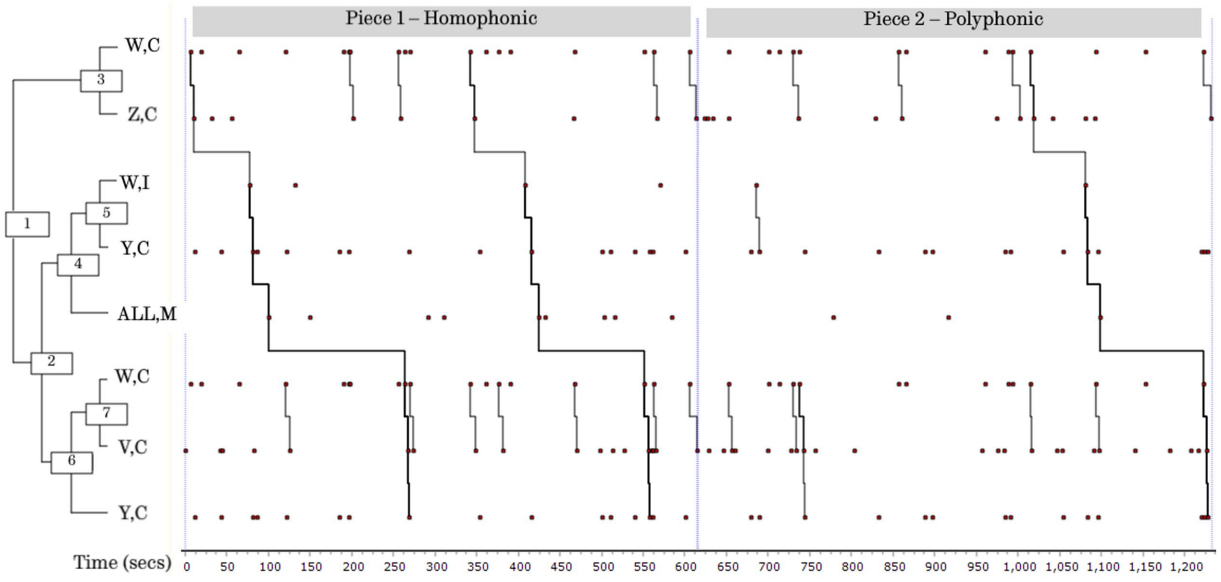

FIGURE 3

Pattern diagram (dendrogram) from THEME® showing main patterns and frequent sub patterns (Group 2, Rehearsal 4). This pattern involves change of piece and shows persistence of sub patterns. The whole pattern ran as follows: first Singer W and Singer Z engaged in Clarifying behaviour (3). Singer W then Initiated, and Singer Y Clarified, after which All sang a passage (4). Singers W and V Clarified (7) and, finally, Singer Y Clarified (6). There were a large number of dyadic sub patterns (30 in total) distributed across the session, all featuring Singer W (3, 5, 7).

TABLE 6 Summary of main patterns by rehearsal and piece; number of main patterns, number of dyads, number of actors, duration and actor switches, and talk time as % of session time.

Rehearsal	Piece order	Number of patterns	Number of dyads	Duration (secs) (mean)	No of actors (mean)	Actor switches (mean)	Levels (mean)	Amount of talk (% session)
1	H	1	11	2.17	2.00	1.00	1.17	59.5
	P	2	10	2.40	2.13	1.27	1.33	70.2
		3	21	2.29	2.07	1.14	1.25	64.9
2	P	3	3	2.20	2.00	1.00	1.20	61.4
	H	1	2	2.00	2.00	1.00	1.00	53.3
		4	5	2.10	2.00	1.00	1.10	57.4
3	P	2	4	2.11	1.78	1.11	1.11	65.1
	H	1	5	2.36	2.05	1.36	1.36	71.9
		3	9	2.24	1.92	1.24	1.24	68.5
4	H	2	17	2.58	2.33	1.33	1.58	73.0
	P	1	13	2.33	2.33	1.33	1.33	84.4
		3	30	2.46	2.33	1.33	1.46	78.7
5	H	2	11	2.15	1.77	0.77	1.15	51.4
	P	1	7	2.94	2.34	1.66	1.72	59.1
		3	18	2.55	2.06	1.22	1.44	55.3

Clarifying task emphasis, consistent with a focussed, problem-solving approach, whilst Rehearsal 5 patterns are more light-hearted in tone, including more Reacting, Initiating and Participating behaviour. Notably, these two rehearsals also incorporate episodes of 'All singing' as part of the main patterns, reinforcing their focus on performance outcomes. The number of dyadic sub patterns is greatest in Rehearsal 4. This supports the prediction of the team compilation model advanced by Kozlowski et al. (1999), in which dyadic interactions increase over time but are ultimately a stage towards holistic team function.

Pattern length (duration), level (number of levels in the hierarchy of patterns) and number of actor switches were summarised by piece structure (Table 6; Figure 4). For the polyphonic piece, patterns were observed to be generally longer,

more complex and with more actor switches, so may warrant further investigation with larger samples. These observations together suggest that the more 'complex' musical task (in this case rehearsal of the polyphonic piece) is associated with more patterned behaviour and greater amount of talk. However, other measures were less conclusive, as dyadic interactions and number of patterns tended to be greater during the homophonic piece.

The distribution of main patterns between the segments of rehearsal allocated to the first or second piece that was rehearsed was not consistent. In Rehearsals 1–3, more patterns appeared in the second rehearsed piece segments; however, in Rehearsals 4 and 5 this was reversed. It may rather be an order effect – in all except Rehearsal 1 the first segment contained more patterns, regardless of whether the piece was homophonic or polyphonic. Again, sample sizes were not large enough to examine this statistically.

In summary, there were some indications from these findings that piece structure may influence behaviour and perceptions of group interactions, resulting in more talk and more complex interactions during rehearsal of more complex material. Future research with a larger sample and even more contrasting musical material could usefully explore whether rehearsals of pieces of different structure or complexity indeed result in differences in amount and type of verbal interactions, and in complexity of patterns.

Discussion

In both groups, there were observed changes over time in the amount of talking and singing and developing patterned interactions. The observed changes suggest transitional shifts in the group's collaborative processes as evidenced in verbal interactions and patterns of behaviour. We consider in our discussion the role of the individual in the group, implications for underlying structure and transitions for group development, and how these findings may contribute to the ongoing study of small groups as complex adaptive systems.

Changes in interaction patterns

Early patterns formed in both groups and were evident even in very short rehearsals investigated in Group 2. In Group 1, patterns appeared within 2 min, in Group 2 within 1 min. There was an increase in pattern number and complexity over time, even though less time was spent talking. More group members were involved in patterns in later sessions. Appearance of dyadic patterns, most marked in Group 1, but also present in Group 2, may provide a mechanism to support the formation of longer patterns (Kozlowski et al., 1999). In both groups, roles and contributions in the patterns were flexible and involved all group members in different formations, depending on rehearsal. This ongoing emergence and changing of interaction patterns, happening over short time periods (seconds and minutes, as well as the larger timescale of a series of rehearsals) reflects moments of incremental as well as longer-term changes over time, showing fluidity rather than rigidity in interaction.

The larger scale changes evident in Group 1 of an increase followed by a decrease in pattern complexity was only partially apparent in Group 2, who showed an initial, limited increase in complexity. A difference here was that Group 1 had a longer-term goal to which all members were fully committed and engaged with

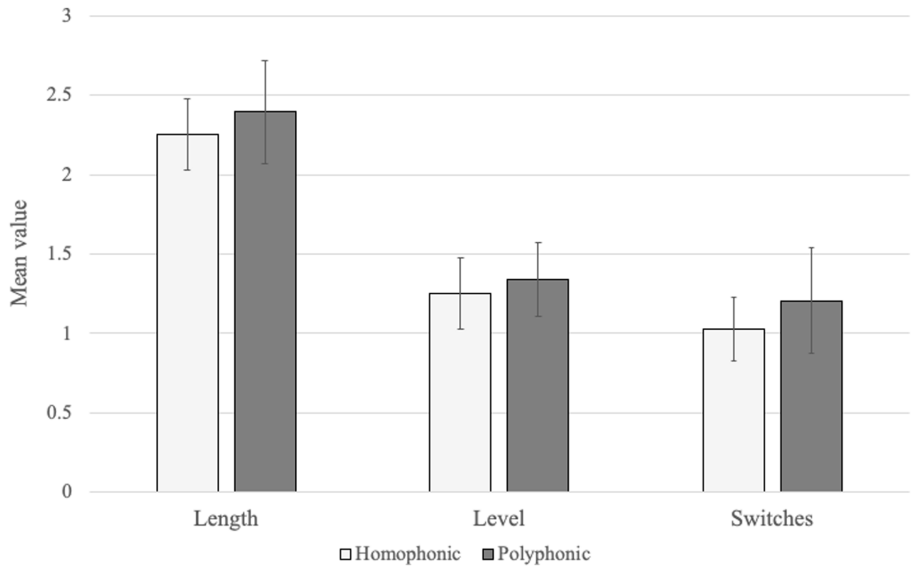

FIGURE 4
Mean value and standard deviation of pattern length, number of levels, and number of actor switches, by homophonic and polyphonic piece structure (Group 2).

(a final, assessed performance), whilst Group 2 were set goals by the researchers which were appropriate for the laboratory setting. Alongside this, however, Group 2 were working on their own material for a planned assessment, so some evidence of group development was to be expected. Even though the two musical tasks given to Group 2 had different levels of demand, there may have been a sense in which from the second rehearsal both became more 'routine', as the group knew what to expect, whereas Group 1 were operating in what could be described as a more knowledge-intensive, non-routine environment as they were consistently exposed to new experiences and material. In such a context, there is a demand for more sharing and interpretation of complex information amongst team members (Kozlowski and Bell, 2003), with greater need for exchange of ideas and development of a shared understanding of the changing task environment (Lei et al., 2016). Looking at complexity of tasks in teams, Hoogeboom and Wilderom (2019) found a stronger effect of participative team interaction patterns in a nonroutine (versus routine) task context. Hence, the environment in which Group 1 was operating may have allowed more inclusive patterned behaviour to develop and adapt to the changing task demands week by week. On the other hand, working on routinised tasks as was more characteristic for Group 2 can offer opportunities for sharing of expertise, social bonding, and planning (Marks et al., 2001; Chung and Jackson, 2013). Indeed, the final rehearsal of Group 2 was largely social featuring behaviours of Participation and Reaction rather Clarifying.

No major differences were found in pattern type and complexity with change of piece (Group 2), suggesting that the level of shared knowledge was sufficient to provide resilience to a change of task (Uitdewilligen et al., 2018). We recognise the limitations of the sample size and the analysis method as analyses were conducted across the two pieces, taking the rehearsal as a whole. Exploring the extent to which changing rehearsal material (a very usual practice for musicians) represents changing task demand remains an area of potential further study.

The role of the individual

The simpler patterns found in both groups in Week 1 illustrate how the groups were getting started, where individual members may be drawing on their existing knowledge of normal, 'routine' rehearsal practises without getting into elaborate discussions. As the weeks progressed, the roles of group members changed, evidenced by their degree of involvement in interaction patterns, and in emerging specialisms within the group, for example, the tendency of Singer D to contribute light-hearted comments that triggered a change in activity. In Group 2, Singers W and Y tended to contribute more task-focussed ('Clarifying') behaviours, particularly expressed in Rehearsal 4. These examples illustrate how individual roles not only serve to influence the interactions in the group, but also how the patterns identified by THEME® can provide further insights into the roles of individuals and their development.

As they became familiar with each other and rehearsing together, the groups had more time to explicitly coordinate their work and to anticipate the actions of others. The presence of mono-actor patterns may indicate a lack of balance in contributions from all team members, resulting in lower effectiveness of group working (Zijlstra et al., 2012). We found that mono-actor patterns were relatively infrequent, suggesting that a good balance of contributions was achieved. For Group 1, there were three mono-actor patterns in Week 5; whilst there are other differences in the patterns in Week 5, this may reflect the absence of one group member. Dyadic sub patterns were a feature of Weeks 3 and 5 (Week 3: Singers B and E, 27 occurrences; Week 5: Singers C and E, 19 occurrences) which may be an indicator of the development of social relationships. A 'contagion' effect was reported in basketball teams by Bourbousson et al. (2015), whereby the presence of tightly coupled dyads made it easier for a third member to join and create a triad, resulting in longer patterned interactions. In Group 2, the number of dyadic sub patterns was greatest in Rehearsal 4, reducing in Rehearsal 5, suggesting integration beyond dyadic relationships.

Structure and transitions

One way in which these changes can be interpreted is as a series of emergent phases. First, the early encounters provided opportunities for the groups to self-organise and establish patterns of behaviour, and social relationships. The groups sought to gain knowledge of one another to establish order, to be able to predict the behaviour of their fellow group members (Okhuysen and Bechky, 2009) and establish a flow to their interactions (van Oortmerssen et al., 2015). These early interaction patterns enable and facilitate progress in unfamiliar teams, by providing a mechanism to quickly establish a balanced communication involving multiple (although not necessarily all) members (Zijlstra et al., 2012). The patterns are generally 'hidden' from the group members, and obscured by overt, vocal exchanges, especially by dominant personality types. In Group 1, early patterns involved a shared task and three group members. It is also notable that in Week 1 the most vocal member (Singer B) does not feature in the pattern, reinforcing the idea that the patterned behaviours exist at a different level of interaction as Singer B did contribute strongly to the first rehearsal in terms of total speaking time (Pennill, 2019). The non-conscious and unfolding patterns of interaction may therefore enable 'quieter' members to contribute and for their influence to be expressed and endure through patterns in small group contexts. After the initial emergence of simple, short patterns, further developments were apparent. This was apparent in an increase in length and complexity of the interactions and the number of people involved. In Group 1, there was a marked change in patterned behaviour in Week 5, as patterns increased in length, and with more people and switching involved in the discussions. This also coincided with the calendar midpoint, as deadline pressure starts to become more urgent (Gersick, 1988,

1989). In Group 2, a tipping point was less evident, although there was an increase in pattern length and duration in Rehearsal 4 (the calendar midpoint), this increase persisted to Rehearsal 5. For the final stage of Group 1, there were signs of integration, or convergence.

To interpret these developments, it is helpful to draw on the framework by Okhuysen and Bechky (2009) in which the three pillars of accountability, predictability and common understanding contribute to a shared sense of alignment, integration, and, ultimately, coordination. In dancers, divergence and even separation ('de-integration') have been shown to be important precursors to group coordination (Harrison and Rouse, 2014). In Group 1, the simple, short patterns are consistent with integration (a coming together of ideas) in Weeks 1 and 3. However, the increase in length and complexity suggests a period of de-integration in Week 5, followed by further integration of ideas and interactions as patterns simplify in Week 7. In Group 1, there was a marked convergence in Week 7 as patterns showed their strongest self-similarities – not only between group members, their timing and type of behaviour, but also in the content of what was addressed. The high degree of similarity in both interactions and musical content suggests an effect of increasing familiarity and the influence of developing predictability of contribution. As with other types of work groups, achievement of integration proceeds in a cyclical or episodic, rather than linear way (Marks et al., 2001). An episodic process of integration is also evident in Group 2. Over the five rehearsals, the patterns show increasing complexity to Rehearsal 4, as measured by the number of hierarchical levels and constituent events. Given that there was an aim for coherence and convergence in the output of the group, Rehearsal 4 represents a pivotal session in creating conditions for further integration in Rehearsal 5. In terms of elapsed time, Rehearsal 4 occurs at the mid-point of the timeline. In later rehearsals, there was an emerging sense of integration which was evident in both groups. In Group 2, more group members (as measured by 'actor switches') were involved in the patterns over time. This also reflected the willingness amongst members for more involvement and created more balanced team interactions, contributing to greater common understanding and accountability.

Adaptation and emergence

In this research we found evidence of adaptation and emergence, which are features of complex adaptive systems (CAS). In their research on adaptation in teams, Kozlowski et al. (1999) suggest that dyad formation is an indicator that a team is forming social bonds and developing task mastery in response to changing stimuli. It is also consistent with the theory of small groups as complex systems, which relates the achievement of coordination goals to "ongoing patterns of interaction amongst the group's constituent elements as the group pursues its function" (Arrow et al., 2000, p. 55). A further example of this arose in Group 2, where complex patterning was retained over a break. This may be an effect of attunement to the task, whereby patterns that fit the task requirement tend to be retained (Uitdewilligen et al., 2018). Interaction patterns generally increased in complexity over time. This is consistent with research in other dynamic work situations, where teams demonstrated increasing pattern complexity (Lei et al., 2016; Uitdewilligen et al., 2018; Hoogeboom and Wilderom, 2019). This emergent behaviour may have been impacted by the setting; whilst the groups were rehearsing independently, they were working within the framework provided by a higher education institution. Any coaching or guidance offered was outside the scope of the study but may have had an impact on the ways that the students approached their rehearsals. Indeed, emergent self-expression in dance performance students was found to be moderated by the way tasks were framed (Torrents et al., 2013). There may be other, more subtle, mechanisms at work, too, in the way the groups moved towards more balanced and inclusive interactions, however, there were many parallels with the ways that professional musicians have been shown to prepare for performance (Ginsborg, 2017).

Concluding remarks

This research took an organisational approach to better understand how musicians work together on tasks which are related to their real-world experiences. It demonstrated the feasibility of investigating communication in ensembles longitudinally using BA and T-pattern analysis and the powerful, richness of insight. The contribution of individual group members, the types of verbal behaviours exhibited, and the patterns identified within them contributed to our understanding of how these newly formed groups established aspects of their musical practice.

Both groups came together as experienced musicians who had diverse knowledge but shared a common understanding of the conventions of vocal ensemble rehearsal in their chosen genre. This shared vocabulary and experience enabled them to quickly establish effective ways of working. Their homogeneity in stage of career, prior training and chosen musical genre contributed to a solid basis for collaborative work and progression. Within this broad structure, the roles of group members emerged and changed, evidenced by their degree of involvement in interaction patterns, and in their vocal specialisms within the group.

A focus on verbal behaviours, their frequency and patterns highlight qualitative differences too. For example, Clarifying behaviours were a feature of the longer, more complex patterns, and related to problem-solving activities or information gathering by group members as discussions or explorations unfolded. Conversely, Reacting behaviours appeared in the simpler patterns. In several instances, Participating behaviours were a trigger for shift in focus or activity. The patterns within these interactions provided a way to explore the 'flow' of the groups over time, and the ways that simple and complex patterns emerged at different points, for example in Group 1, an increase

in pattern complexity as the challenges of the material and deadline pressure increased.

This study contributes to an ongoing exploration of human group behaviour and interaction patterns in team performance. In the specialised context of European classical music, musicians rehearsing for a future performance, there is an intentional shift to nonverbal (more implicit) processes (King and Gritten, 2017). Observed changes in behaviour and interaction patterns, both over time and with changing tasks, are consistent with emergence of these implicit behaviours (Rico et al., 2008).

Data availability statement

The datasets presented in this study can be found in online repositories. The names of the repository/repositories and accession number(s) can be found at: The University of Sheffield's online data repository (ORDA) 10.15131/shef.data.20231877.

Ethics statement

The research was reviewed and approved by the Physical Science Ethics Committee (PSEC) at the University of York (United Kingdom), reference 070817. The participants provided their written informed consent to participate in the study.

Author contributions

NP was the principal investigator and made substantial contributions to the conception and design of the study, data acquisition, analysis, and interpretation. She drafted the article and approved the submitted version. RT acted as supervisor of the research, contributed to the design of the study and interpretation of the results, critically revised 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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Structural analyses in the study of behavior: From rodents to non-human primates

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The term "*structure*" indicates a set of components that, in relation to each other, shape an organic complex. Such a complex takes on essential connotations of functionally unitary entity resulting from the mutual relationships of its constituent elements. In a broader sense, we can use the word "*structure*" to define the set of relationships among the elements of an emergent system that is not determined by the mere algebraic sum of these elements, but by the interdependence relationships of these components from which the function of the entire structure itself derives. The behavior of an integrated living being can be described in structural terms *via* an ethogram, defined as an itemized list of behavioral units. Akin to an architectural structure, a *behavioral structure* arises from the reciprocal relationships that the individual units of behavior establish. Like an architectural structure, the *function* of the resulting behaving complex emerges from the relationships of the parts. Hence, studying behavior in its wholeness necessitates not only the identification of its constitutive units in their autarchic individuality, but also, and importantly, some understanding of their relationships. This paper aimed to critically review different methods to study behavior in structural terms. First, we emphasized the utilization of T-pattern analysis, i.e., one of the most effective and reliable tools to provide structural information on behavior. Second, we discussed the application of other methodological approaches that are based on the analysis of transition matrices, such as hierarchical clustering, stochastic analyses, and adjusted residuals. Unlike T-pattern analysis, these methods allow researchers to explore behavioral structure beyond its temporal characteristics and through other relational constraints. After an overview of how these methods are used in the study of animal behavior, from rodents to non-human primates, we discussed the specificities, advantages and challenges of each approach. This paper could represent a useful background for all scientists who intend to study behavior both quantitatively and structurally, that is in terms of the reciprocal relationships that the various units of a given behavioral repertoire normally weave together.

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KEYWORDS

hierarchical clustering, transition probabilities, adjusted residuals, T-pattern analysis, behavioral structure–function interface

Introduction

> "*The ability to reduce everything to simple fundamental laws does not imply the ability to start from those laws and reconstruct the universe*."
>
> Anderson (1972)

This paper deals with behavior and with a number of approaches useful to study it. We asked: "*what* is the behavior of a living being?" Such a question, simple and straightforward, cannot be propaedeutic to an answer characterized by the same features. Using a common scientific database and searching the term "*behavior*" produce thousands of definitions, explanations, points of view, theories etc. Some definitions are very cryptic, others fanciful, others difficult to understand and others more or less agreeable. Not surprisingly, some of the strongest definitions of behavior were proposed by the founding Figures of Ethology such as Konrad Lorenz, Nikolaas Tinbergen or Irenäus Eibl-Eibesfeldt: behavior is the reaction of a living being to external (Tinbergen, 1951a) or internal (Tinbergen, 1951b) *causal factors* and it is *organized* on the basis of a *sequence* of events in *time* (Eibl-Eibesfeldt, 1970). These words echo a central dogma in ethology and in most disciplines belonging to behavioral sciences. Indeed, they relate to the causality and temporal organization of behavior. One thing is self-evident: like its definition, the methods to study behavior are not simple and straightforward.

Structures, functions, and processes

In his well-known writing titled "Principles of the self-organizing system," the brilliant English psychiatrist William Ross Ashby stated that if the relationship between two entities, e.g., "A" and "B," becomes conditional on "C," then a necessary component of organization is present and, as a result, a whole composed of interacting parts (i.e., a structure) emerges (Ashby, 1962). Closely related to the concept of "structure" is the dual and dynamic relationship between function and process. The concept of "*function*" is permeated with purely finalistic, i.e., teleological, connotations. Thus, the word "*function*" denotes the purpose of the object "*sensu lato*," whether it is a very simple or extremely complex item. Two common questions, that is "*what is it for?*" and "*what is its purpose?*," perfectly express the teleological nature of any object. What is the purpose of one of the many walls we can easily observe in a house? While trivial, this example gives a good understanding of the concept of teleology: it serves to separate two rooms, or an interior space from the exterior of the house. The wall, then, does create a division that makes possible a better use of two rooms that would otherwise be a single, much less usable space. However, this explanation says nothing about *how* the wall came to be. As much as the answer just given regarding the finalistic aspects is more or less articulated, in fact, we have left out the second and essential part of the above binomial: the processual component. In contrast to function, the concept of "*process*" is imbued with purely mechanistic connotations. The term "*process*" therefore indicates *how* something happens. The fundamental question related to it is no longer "*what does it do*?" but "*how does it do it*?." Returning to our example, then, we may say that a wall, capable of performing the above functions, consists of the juxtaposition of bricks, with a specific orientation within the apartment, properly joined together thanks to a specific amalgam that prevents displacements between neighboring bricks and gives greater stability to the structure. As will be noted, these purely mechanistic aspects complement and explicate the question about the above purpose.

Even the unexperienced reader will not miss the enormous difference between the concepts of "*function*" and "*process*" and their very close connection with the structure generating them. All of this, while of wide application in numerous fields (such as the example of wall and bricks), finds extraordinary congruity, in the biological realm, with one discipline in particular. The concepts of "function" and "process" permeate Physiology to the extent that they constitute the deeper and essential "*raison d'ĕtre*" of this entire discipline. In Physiology, these two concepts are the two sides of the same coin. The examples are potentially endless and all, conceptually, similar to the example of the bricks and the wall. For instance, when studying the heart, physiologists typically describe the various properties of this extraordinary organ, pointing out how its prodigious morphological characteristics (i.e., structure) enable it to constantly and tirelessly feed blood into the aorta and pulmonary vessels (i.e., functions) through specific mechanisms involving both electrical and purely mechanical phenomena (i.e., processes). Everything in the domain of Physiology orbits around functions and processes, and arguably, there is no system, organ, tissue and/or even single cell, able to escape such a binomial. Studying Physiology means, therefore, being able to describe with absolute precision each of the two sides of this coin: the functions and processes, the *why* and the *how*. These concepts apply to the study of behavior for the reasons discussed below.

Detailed knowledge about behavioral structure contributes to testing hypotheses about behavioral function. The "design-feature argument" holds that thorough structural analysis of a given

behavior pattern provides valid information about its hypothesized function (Martin and Caro, 1985; Moran, 1985). The heuristic power of this behavioral structure–function interface is reflected in the following statement by Pellis and Pellis (1998): "*Therefore, behavioral description informs functional inference, which in turn, influences further description*" (p. 115). Thus, broad similarities and subtle differences in the structural organization of evolutionarily related behaviors are indicative of their respective motivational underpinnings and functional features. This approach has proved particularly useful to compare pairs of behavioral traits that are developmentally and evolutionary linked, but vary in their functional constraints. For example, among different types of object manipulation in non-human primates and pre-school children, researchers used structural variables, either based on kinematic or temporal components, to infer underlying psychological mechanisms and explain the actions being performed in terms of relative purpose and utility (e.g., object play and object exploration: Hughes, 1978, 1979; percussive object play and extractive foraging: Pelletier et al., 2017; Pellis et al., 2019). These studies indicate that utilitarian motivational processes and functional constraints in object manipulation covary with behavioral structure. When comparing two types of manipulative activities, the more product-oriented one (e.g., object exploration, extractive foraging) show higher levels of kinematic and/or temporal structure than the more process-oriented one (e.g., object play; see also Rasa, 1984).

In line with one of the basic tenets of Darwinian evolution, holding that selection strength and phenotypic variability are negatively correlated, more functionally constrained behaviors are subjected to higher selection pressures, which in turn, lead to less structurally variable behaviors. Thus, the behavioral structure of object-directed activities may be used as a proxy to assess their relative functionality. Theoretically, this powerful structure–function interface could be applied to other pairs of behavioral traits that are linked at the proximate levels (i.e., in their developmental trajectories and underlying sensori-motor and cognitive mechanisms) and at the ultimate levels (i.e., in their functional consequences and phylogenetic pathways; Tinbergen, 1963). Among other pairs of behavioral traits that were subjected to differential functional constraints and whose putative mechanistic and evolutionary connections are unravelled by in-depth structural analysis, let us mention object play and tool use (Cenni et al., 2020, 2022) as well as female-to-female mounting and female-to-male mounting (Gunst et al. 2020, 2022).

Physiology of behavior

Behavior, whether of an insect or a primate, can be broken down into simpler units, each indicative of a specific and characteristic part of the subject's behavioral repertoire. Imagine a fruit fly flying in a room, a rat moving through an Open Field, a non-human primate exploring a new part of a forest. Ethologists typically divide each of these activities into several behavioral sub-units, use simple and unambiguous names to label them, and generate operational definitions to describe them, thereby constructing an "*ethogram*." For example, the behavior of a rodent may be referred to as "Walking" when the animal moves relatively slowly and quadrupedally from one quadrant of the arena to another, "Climbing" when its upper body leans against the perimeter walls, "Rearing" when it lifts up on its hind legs without leaning against any of the nearby walls, "Face Grooming" or "Body Grooming" when it picks at or scratches its head or other body parts, respectively, with its paws or mouth, etc. Identifying each of these behavioral units is a relatively simple task that only requires a fairly short training period. Practically, the observer watches the video of the animal's behavior and, through a specific computer program, e.g., The Observer software coder (Noldus Information Technology, Netherlands), scores the occurrences of each behavioral unit. The product of this simple, but terribly time-consuming, process is called *event log-file* and consists of a generally long list of the behavioral events performed by the animal with their respective onset times. An event log-file can be conveniently illustrated by means of an event plot. Figure 1 is an example of an event plot obtained from one, specific pathogen-free, 2-month-old male C57/BL wild-type mouse (Jackson Laboratories, United States), belonging to a group of subjects, observed in the open-field for 10 min (Casarrubea et al., 2020b). A simple question arises: after watching 10 min of this video, after carefully observing the rodent's exploratory behavior through the open field, after recognizing hundreds of Walking, Climbing, Rearing, Face Grooming etc., what to do with these data? Figure 1 shows more than 300 behavioral units. In abscissa we report the time, in ordinate the behavioral unit performed. The plot highlights where each behavioral unit falls in time. Walking occurred 114 times, Rearing 9 times, Immobile-Sniffing 136 times etc. Table 1 shows the name, frequency, percentage and overall duration of the behavioral units plotted in Figure 1. This table can be enriched with numerous additional quantitative evaluations such as, for example, the average duration of each behavior, the latency of the first appearance of each behavior etc.; one may also do somewhat more complex analysis such as, for example, evaluating the average duration of each item in relation to the time of observation, so as to provide a time course for each minute of observation. The first evidence, even with a very first glance of Table 1, is the remarkable feeling of completeness and comprehensiveness. The catch is, however, just around the corner. All these numbers *per se* tell us little about the complexity of an individual's behavior. Taking into consideration our trivial example with the wall and the bricks, we argue that describing behavior in terms of individual units is like considering individual bricks and their many characteristics (i.e., weight, height, length, width etc.); however, it ignores the most important aspect, namely, what flows from their relationships both in terms of structure and the related functional and processual elements. As we previously noted, using a different and perhaps more effective metaphorical image, evaluating a subject's behavior by considering only the individual units and not their relationships "[…] *is not different*

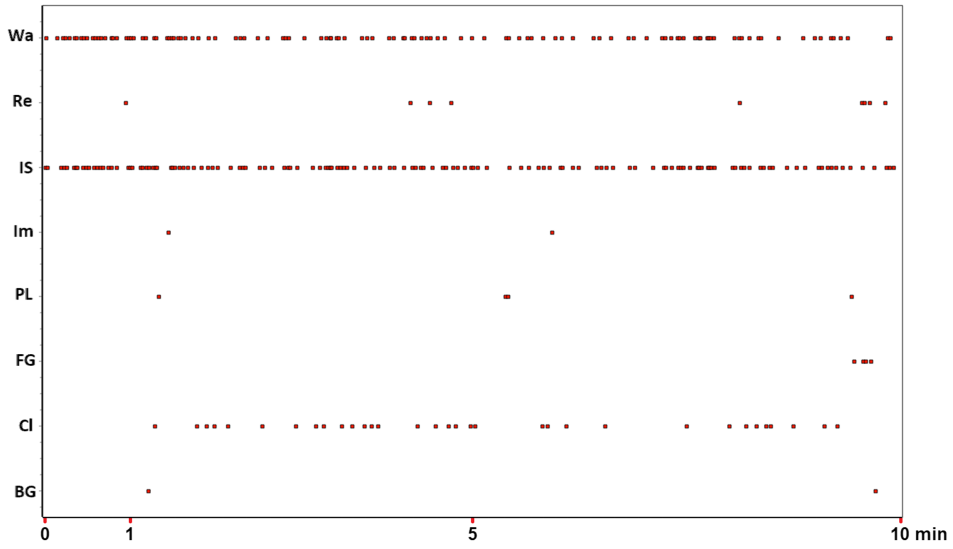

FIGURE 1
Event plot of 8 behavioral units (Y-axis) occurring during a 10-min (X-axis) observation window. For abbreviations of behavioral units on Y-axis see Table 1. Data from one subject taken from Casarrubea et al. (2020b). See text for details.

TABLE 1 Synoptic table summarizing occurrences, percent distribution and duration of behavioral units listed in the first column (abbreviations in brackets) and illustrated by means of event plot in Figure 1.

Component	Occurrences	Percent (%)	Duration (sec)
Walking (Wa)	114	37.50	181.57
Rearing (Re)	9	2.96	7.63
Immobile-sniffing (IS)	136	44.74	329.25
Immobility (Im)	2	0.65	2.75
Paw licking (PL)	4	1.32	8.67
Face grooming (FG)	4	1.32	11.7
Climbing (Cl)	33	10.86	50.93
Body grooming (BG)	2	0.65	7.5
Tot	304	100	600

Data from 1 subject taken from Casarrubea et al. (2020b). See text for details.

from classifying all the single pieces of a puzzle missing the comprehensive picture. The functional meaning of a behavior, i.e., *the study of the existing interplay between an animal and the context, is a picture lying in its intrinsic structural features*" (Casarrubea et al., 2019a). Actually, Figure 1 contains the bricks of our wall. Each dot in the plot highlights the specific "brick" shown on the Y axis and the time in which it occurred, shown on the X axis. Not all bricks are the same, just as the different types of adhesives we can use to build the given structure are not the same at all. However, if proper glue is not used between the individual units, they will not have solid reciprocal relationships and the final structure will not only be more unstable and/or difficult to build, but also prone to a rapid collapse. There is more. Not only we need the appropriate bricks and cement for the structure we want to build, the means we employ should also be adequate for the purpose. The question, then, is about where the meaning of behavior lies. Is it in the study of isolated behavioral units, each characterized by dozens of numbers, but still fragments of what is the animal's true behavior? Or, conversely, is it in trying to relate all the behavioral units described in our observation in an attempt to reconstruct the true behavior? The answer is obvious. Studying behavior in its wholeness therefore means relating the individual units because only from these relationships arises the structure that is, in turn, preparatory to the functions and processes it serves and performs. In this lies the Physiology of Behavior. However, before delving into the different methods to study the relationships existing between the different units of the behavioral repertoire, it is important to clear the field from possible misunderstandings.

Simple quantities and their usefulness

What we discussed in section "physiology of behavior" might lead to a seemingly logical but deeply flawed juxtaposition: one might believe that a purely quantitative approach is somewhat useless in the context of a behavioral study. We clearly do not support such a biased view. The meticulous description of each unit of behavior, albeit unconnected with the relational dynamics of the different units, can find numerous applications. If, for example, we look again at Table 1, it is certainly useful to know the more frequent and the less frequent behavior, or those that last longer and those that are shorter etc. Based on this information, it becomes possible to know what the subject does and, importantly, how long it takes to do it. In addition, one may examine if and how these items change following the administration of an independent variable such as the benzodiazepine Diazepam, a drug with anxiolytic action, that induces a conspicuous increase in Walking

(Casarrubea et al., 2009b), or the administration of the beta-carboline FG7142, a potent anxiety inducing molecule, causing a significant decrease in Walking (Casarrubea et al., 2017). The explanation lies in the modulation of the state of anxiety of the two molecules: with reduced anxiety, the animal explores the environment more (and therefore walks more), whereas with increased anxiety the subject tends to move much more circumspectly (and therefore walks less). These examples highlight the usefulness of the descriptive/quantitative approach when dealing with discrete variables. However, in both cases, nothing can be said about what strategies the animal deploys, how it relates to the environment etc. In short, we still know little about exactly what the animal is doing and precisely how it is doing it; specifically, information about the pharmacological underpinnings of the structure of its behavior in its organic entirety remains scanty.

Structural analyses in the study of behavior

Three prerequisites, propaedeutic to each other, are essential to study behavior through the relationships among the different units of the behavioral repertoire: one must (a) clarify what these relationships are, (b) have the appropriate means to study these relationships, (c) use these methods to tie together the different units of the behavioral repertoire before any discussion about behavioral structure can occur.

How do the different behaviors illustrated in Figure 1 and carefully described in Table 1 relate to each other? Are there constraints of any kind applied to them? If so, what methods can researchers use to describe such constraints? One way to assess the relationships between a behavior and the following one is to calculate reciprocal transition frequencies. Probabilistic constraints may also be evaluated by determining the probability of behavioral unit "A" shifting to behavioral unit "B." One may also examine whether the transitions between these two units occur more or less frequently than an expected value. Furthermore, it is essential to consider what is certainly the most important relational constraint: the temporal one. Here the question becomes: Is it possible for different behavioral units to occur at fixed intervals or, at the very least, is it possible to identify specific temporal distances among different behaviors or only between some? Such temporal constraints may not be, and in fact rarely are, rigidly sequential.

All these techniques describing, and sometimes unravelling, relationships between units of the subject's behavioral repertoire, belong to the realm of multivariate analyses. These methods, although not recently conceived and introduced in behavioral research, have seen a growing and steady diffusion only in recent decades, hand in hand with the development of, and easy access to, personal computers. Indeed, most of these analyses are very complex and involve considerable amounts of data, the management of which greatly benefits from the continuing growth of computational capabilities allowed by modern personal computers. In the following sections, we present some useful approaches to describing behavior in structural terms, that is, through the relationships among different units of the behavioral repertoire. These sections do not claim to be exhaustive regarding the totality of methods that can be employed to solve these problems. Rather, we present a number of approaches that, from our 30 years of experience in the field, have proven to be more than efficient and useful in this regard. These approaches can be divided into two major groups: methods based on the use of transition matrices and methods based on the use of T-pattern analysis.

Transition matrices and related analyses

The structure of a hypothetical transition matrix is illustrated in Figure 2. The utilization of transition matrices implies three requirements (1) the number of transitions contained in a transition matrix must be at least five times the number of units of the behavioral repertoire (Spruijt and Gispen, 1984); (2), the number of empty cells must be no more than 20% (Spruijt and Gispen, 1984; Casarrubea et al., 2008); and (3) the number of subjects used should be at least three times the number of behavioral units (Short and Horn, 1984; Espejo and Mir, 1993). These three requirements allow researchers to generate a number of transitions sufficient to avoid a poorly filled matrix (Spruijt and Gispen, 1984).

Hierarchical clustering

Cluster analysis aims to highlight constraints among units of the behavioral repertoire on the basis of the overall number of reciprocal transitions occurring during the overall observation period. To this purpose, a transition matrix must be transformed into a similarity matrix by using an aggregative procedure. Several aggregative procedures are available. For instance, in Figure 2, the similarity between the behavioral unit A and B can be obtained by using the procedure described by Mos et al. (1987):

$$S = \left(\alpha / a + \alpha / b + \beta / a + \beta / b\right)50$$

where S is the "similarity" value between units "A" and "B," Greek letters "α" and "β" respectively indicate number of transitions from unit A to unit B and from unit B to A, lowercase letters "a" and "b" respectively indicate the total occurrences of A and B, and 50 is a normalization factor. This procedure must be repeated for each pair of cells within the matrix. The result is a half matrix where each cell does not express a transition but the "*vicinity*" between two variables (rows and columns names). This approach thus assumes that the number of transitions can be considered a valid index of aggregation between two or more elements, a premise that should be taken into serious consideration when interpreting the data. Indeed, talking about "*similarity*" value between two behavioral units might be misconstrued as

	A	B	C	Total
A	X_A	α	γ	a
B	β	X_B	ε	b
C	δ	ζ	X_C	c

FIGURE 2
Example of transition matrix. A, B, C: names of three hypothetical behavioral units; α, number of transitions from unit A to B; γ: number of transitions from A to C; β: number of transitions from B to A; ε: number of transitions from B to C; δ: number of transitions from C to A; ζ: number of transitions from C to B; X_A, X_B and X_C: number of auto-transitions from A to A, B to B, and C to C, respectively; a: total occurrences of A; b: total occurrences of B; c: total occurrences of C.

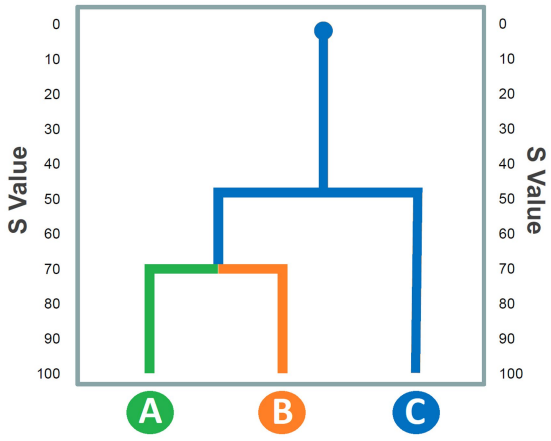

FIGURE 3
Hypothetical dendrogram representing similarity values (S: *Y*-axis) among behavioral units (*X*-axis) on the basis of a half matrix arranged following an aggregative clustering procedure. See text for details.

these two units being qualitatively similar. In reality, the *closeness* expresses a high number of mutual transitions, not a phenomenological similarity at all. For example, in rats, Edge-Sniff behavior (i.e., when the animal sniffs the edge of the hole in a test called "Hole-Board") and Head-dip behavior (i.e., when the animal inserts its head inside the hole), although qualitatively very different, form a stable cluster in untreated subjects (Casarrubea et al., 2009a) but highly sensitive to pharmacological manipulation of the animal's anxiety condition (Casarrubea et al., 2009b, 2017). Therefore, the strong temporal link between these two behaviors is highly evocative of the rodent's anxious state. From the half-matrix obtained *via* this procedure, researchers should create a dendrogram, i.e., a graphical tree representation that shows in a very simple and intuitive way the "*closeness*" between the various clusters of behaviors. A hypothetical dendrogram is presented in Figure 3. The S values of the half-matrix are shown in the ordinate. In practice, this Figure indicates that units A and B, based on the number of reciprocal transitions, are linked by a high S value, which is matched by the value of unit C, that occupies a more "peripheral" position. This illustrative approach has been fruitfully used in numerous papers (Espejo and Mir, 1993, 1994; Espejo et al., 1994; Casarrubea et al., 2008, 2009a,b, 2011a, 2012, 2015c, 2017). From a functional point of view, these analyses made it possible to categorize the different units of behavior into clusters, that is, "behavioral sets" in turn indicative of a more complex activity contextualized to the explored environment. For example, in the work of Espejo and Mir (1993) as well as in that of Casarrubea et al. (2006), three different clusters of behavioral units have been described with regard to rat behavior on the hot-plate: sniffing, primary noxious-evoked and escape responses. This categorization, highlighting the animals' response to the nociceptive stimulus, allowed for a better interpretation of the rodent's behavior in the specific experimental context. Importantly, these studies also demonstrated that these three categories are extremely sensitive to the administration of independent variables, such as, for example, specific drugs.

Probabilities of transitions

A stochastic approach is useful to emphasize probabilities of transitions among units of the behavioral repertoire. First, on the basis of relative frequencies of transitions among behavioral units, the transition matrix is transformed in a stochastic matrix. Following this step, the final matrix must meet three criteria: (1) for each row, the sum of all cells should be equal to 1; (2) the value of each cell should be between 0 and 1; and (3) the transition probability from one cell to the remaining cells should be equal to 1. A consistent advantage of such a matrix is that it can be graphically expressed through a pathway diagram, where transition probabilities among cells can be represented by means of arrows, with higher probability ranges showing as thicker arrows (Hemerik et al., 2006). Like the dendrograms briefly discussed in section 2.1., the use of probability diagrams is intuitive and emphasizes the temporal constraints between different behavioral units, providing a unified view of the behavioral repertoire. A hypothetical probabilistic pathway diagram is presented in Figure 4. In practice, it can be inferred from the Figure that units A and B share higher probabilities of mutual transitions than units B and C or units A and C. These probabilistic representations have been successfully used in several studies (Espejo and Mir, 1993; Espejo, 1997; Lino-de-Oliveira et al., 2005; Casarrubea et al., 2008, 2009a,b; Santangelo et al., 2018). Functionally speaking and similar to what was mentioned in the previous section regarding dendrograms, these analyses of the relationships among behavioral units in terms of probabilistic constraints allowed researchers to unravel otherwise

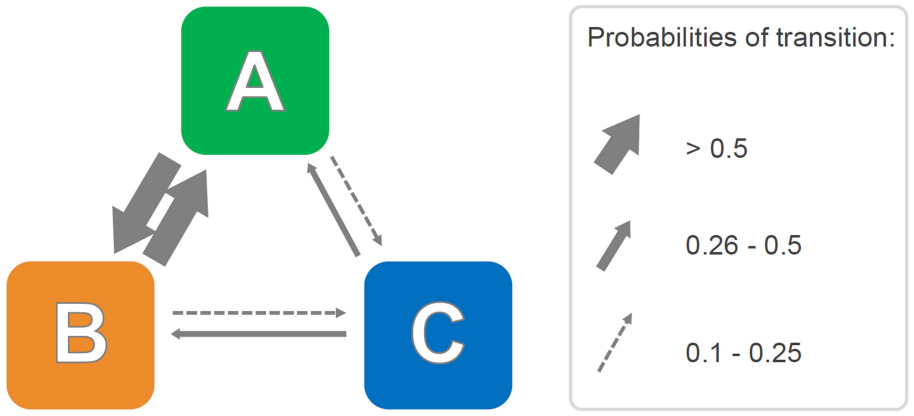

FIGURE 4
Hypothetical probabilistic pathway diagram representing transition probabilities among behavioral units. Right side, the selected probability ranges used to draw probability arrows of matching thickness. See text for details.

unnoticeable behavioral dynamics characterizing subjects' activity in the specific environment. For instance, Espejo (1997), in the Elevated Plus Maze, revealed the existence of a behavior heavily polarized toward sniffing episodes and the occurrence of two behavioral units (Stretched Attend Posture and Protected Dipping) sharing high reciprocal probabilities of transitions. The authors suggested that these two behavioral units may have a common behavioral significance in the form of "*anxiety-related behaviors, which mice usually display in succession and from relatively secure closed and central sections of the maze*" (Espejo, 1997, p. 109).

Lag sequential analyses

Lag sequential analyses are an example of analytical techniques that rely on transition matrices (Sackett, 1979; Quera and Estany, 1984). LSA is a type of temporal analysis applied to behavioral sequences that calculates the frequency of transitions between pairs of behavioral units within a certain lag. The first event of the pair is called "Criterion" and the second "Target" (Faraone and Dorfman, 1987). Depending on which direction in time researchers are interested in investigating (i.e., positive or negative), they calculate how often the Criterion (e.g., Event A) was followed by the Target (e.g., Event B), or how often Target (e.g., Event B) preceded the Criterion (e.g., Event A), respectively. There are two types of LSA, depending on the type of transitions between a Criterion and a Target. First, a "time lag" sequential analysis requires the comparison of the same time window before and after the Criterion, and considers transitions between a Criterion and a Target within these specific time windows, independent of how many other events are between them. Researchers then calculate the number of transitions from a Criterion to those Targets occurring within a specific time window following or preceding the Criterion (Figure 5). Second, a "state lag" sequential analysis considers the transitions between a Target that directly followed or directly preceded a Criterion (i.e., lag +1 or lag-1, respectively). Other pairs of lag are possible, such as lag +2 or lag-2, lag +3 or lag-3, etc. (Figure 6). Among other examples, lag sequential analyses have been employed to investigate the motivational underpinnings and functional components of specific behavioral elements expressed within sequences of actions performed during playful or sexual activities in free-ranging macaques (Cenni et al., 2022; Gunst et al., 2022a,b, 2022).

Adjusted residuals

One question that neither clustering procedures nor probability matrices can answer is the statistical significance of the transitions between behavioral units. To this effect, Haberman (1973) and Everitt (1977) proposed the conversion of a transition matrix into a matrix containing adjusted residuals. Adjusted residuals are standardized residuals divided by their respective standard deviations (Haberman, 1973; Everitt, 1977). Even though a specific formula is available to calculate residuals, a dedicated software allows for the automatization of this task when matrices reach hundreds cells. Various computer programs, such as Matman (Noldus Information Technology, Netherlands), make the calculation of adjusted residuals significantly faster and more reliable. The most important benefit of adjusted residuals is the possibility to utilize a common Z table for their interpretation: values $\geq +1.96$ and ≤ -1.96 indicate statistically significant ($p < 0.05$) transitions occurring more often ($\geq +1.96$) or less often (≤ -1.96) than expected. Like probability matrices, matrices of adjusted residuals can be illustrated by means of pathway diagrams (Spruijt and Gispen, 1984; Spruijt, 1992; Vanderschuren et al., 1996; Van Den Berg et al., 1999), where the thickness of the arrows is also indicative of the significance level of the given transition. However, pathway diagrams of adjusted residuals come with a caveat. While representing positive residuals arrows is intuitive, representing negative residuals is problematic as negative residuals are transitions occurring significantly less often than expected, making their representation as arrows counter-intuitive. One solution, in this regard, is to present the residuals by means of

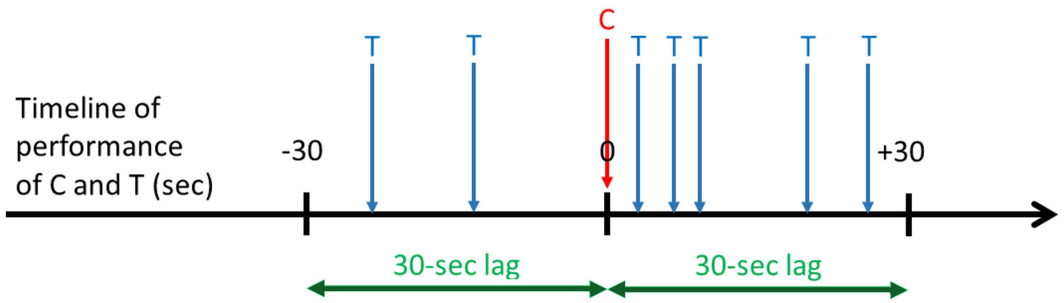

FIGURE 5
Hypothetical example of a 30-s time lag sequential analysis along a timeline of performance of a given Criterion behavior (C) in seconds. This analysis is used to compare the frequency of a Target behavior (T) within a 30-s window before and within a 30-s window after the start of C. For instance, T can be "being approached and being looked at by close neighbors." This example indicates that T is more frequent shortly after the performance of C than shortly before.

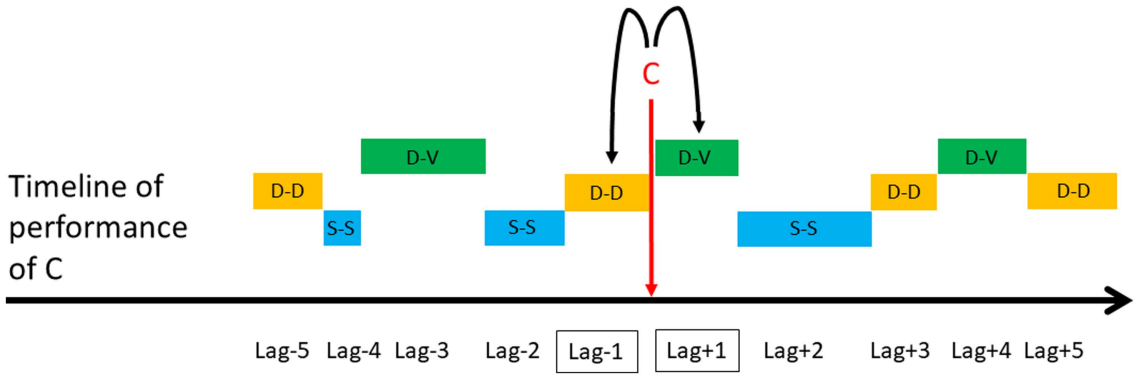

FIGURE 6
Hypothetical example of a state lag sequential analysis used to compare the frequency of a dorso-ventral (D-V) position (i.e., Target) adopted by the female consort partner immediately before (i.e., lag-1) versus immediately after (i.e., lag +1) the performance of a female-to-male mount (i.e., Criterion: C). Other positions relative to the male consort partner during intermount intervals include dorso-dorsal (D-D) and side-by-side (S-S). Other pairs of lag are lag +2 and lag-2, lag +3 and lag-3, etc. (Gunst et al. 2022).

positive and negative bars indicative of positive and negative residuals, respectively. A hypothetical representation of residuals using such an approach is shown in Figure 7. Examples of such an approach have been used in several studies (van Lier et al., 2003; Casarrubea et al., 2008, 2009a,b, 2012).

Adjusted residuals are extremely sensitive to changes in the transition matrix from which they derive, and their intrinsic statistical connotations make it possible to establish an important and useful "boundary" (that is, the significance level) to the various transitions that are taken into account or shown. For example, regardless of the illustrative approach used, one may therefore choose to present only those transitions that are statistically significant. This important aspect has been stressed by Spruijt and Gispen (1984) in a pioneering study going back almost four decades. In brief, this study showed the effects of ACTH on grooming behavior in rats and highlighted that observed changes should inform future interpretations of the animal's behavior in the specific context in which it is observed.

The temporal dimension

The temporal dimension adds an additional layer of complexity to the analysis of the possible relationships existing between different units of the behavioral repertoire. Indeed, such relationships may not be linear. What does it mean? In a sequence A➔B➔C➔D[…]➔W➔X➔Y➔Z, where each letter represents a behavioral event (*from a conceptual view, it is more correct to refer to units of behavior occurring over time in terms of "events"*), statistically significant relationships may not occur between events in direct succession (that is, between B and A, C and B etc.); actually, the opposite is almost always true and significantly related events are often not in direct succession (e.g., D and A, Y and W etc.). This makes temporal sequences difficult to be perceived and elusive to the naked eye. Eibl-Eibesfeldt (1970) himself emphasized this essential aspect by stating that investigations of behavior must deal with sequences that are not easily perceivable and this is why researchers need improved

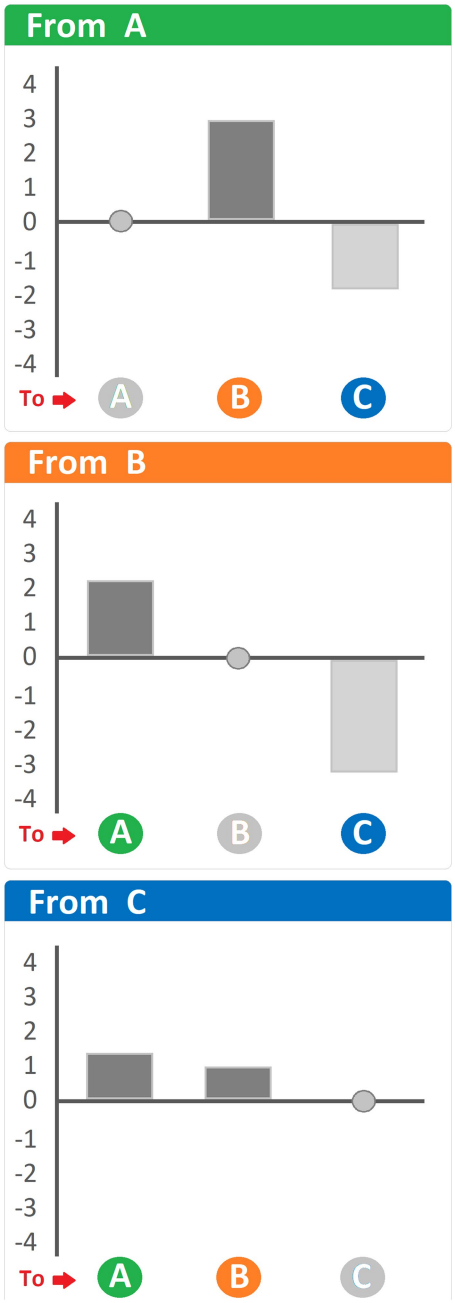

FIGURE 7
Hypothetical histogram of adjusted residuals representing the differences between observed and expected values. Heading of each panel: behavioral unit antecedent to the ones indicated at the bottom. Dark bars, positive residuals (i.e., transitions occurring more often than expected); light grey bars, negative residuals (i.e., transitions occurring less often than expected). See text for details.

methods of detection and analysis of the temporal dimension of behavioral sequences.

The study of the temporal structure of behavior was, for many years, a difficult shore to reach mainly because of an unfortunate combination consisting of the lack of adequate computational resources compounded by the lack of efficient models to conduct these analyses. These difficulties have been gradually reduced over the past 30 years thanks to considerable technological development and the introduction of an elegant technique suitable for studying the temporal structure of behavior: the T-pattern analysis (TPA; Magnusson, 1996, 2000, 2004, 2005, 2017, 2020; Casarrubea et al., 2015a, 2018; Magnusson et al., 2016; Casarrubea and Di Giovanni, 2020). Through this approach, recurrent sequences of events, called T-patterns, can be easily highlighted and, therefore, studied. A remarkable aspect of the method is its complete independence from the underlying time scale. Indeed, TPA allows for the study of events that occur in the order of milliseconds (e.g., those related to the firing of neurons) as well as events that span much larger time windows (e.g., those related to rodent behavior). The detection of T-patterns can be performed by means of a software tool known as THEME (Patternvision Ltd., Reykjavik, Iceland).

A T-pattern can be described using the following expression:

$$X_1 \approx dt_1 X_2 \approx dt_2 X_3 \ldots X_i \approx dt_i X_{i+1}$$

where, X terms are the events belonging to a hypothetical T-pattern and ≈dt terms represent the time distances separating these events. Thus, the term $X_1 \approx dt_1\ X_2$ indicates that the X_1 event is followed dt_1 time units later by the X_2 event; so, $X_i \approx dt_i\ X_{i+1}$ symbolizes that X_i is followed dt_i time units later by X_{i+1}. Figure 8 shows a sequence of 30 hypothetical events (letters near the axis) occurring in the context of an observation time window T_0-T_x. The detection algorithm compares the distribution of each pair of events (e.g., A and B) searching for an interval in which A is followed by B more often than expected by chance. If B does not fall within such an interval, another event (e.g., C) is tested, and so on, for all the events; if event B falls within the interval, A and B represent a T-pattern encompassing only two events and will be indicated as (A B). This (A B) T-pattern is then used by the algorithm to detect higher-order patterns, e.g., [(A B) C], [(A B) (C D)] etc. Such a bottom-up detection process runs up to any level and stops when no more T-patterns are identified. The use of TPA allows for the identification of three important qualitative aspects related to the temporal structure of behavior: its *variability*, *complexity* and *recursiveness* (Casarrubea et al., 2021b). The variability is represented by the amount of T-patterns of different composition detected, the complexity is the length of T-patterns (i.e., the number of events in their sequences), and the recursiveness is the number of times each T-pattern is repeated. More details concerning concepts, theories and procedures underlying the detection and analysis of T-patterns can be found in numerous papers of Magnusson (Magnusson, 1996, 2000, 2004, 2005, 2017, 2020; Magnusson et al., 2016) and in a number of works from our laboratory and field studies (Casarrubea et al., 2015a, 2018; Casarrubea and Di Giovanni, 2020; Cenni et al., 2020; Gunst et al., 2020). These studies have successfully shown that the temporal dimension of behavioral sequences represents a powerful structural variable to infer underlying behavioral and psychological mechanisms, and explain the actions being performed in terms of functional components.

FIGURE 8
Hypothetical observation period (T0–Tx) consisting of 30 events (black letters near time axis). The [(A B) C] T-pattern becomes evident when all the remaining behavioral occurrences are left out (light grey letters). See text for details.

From rodents to non-human primates

Even though the above-outlined methods are not the only ones used to identify and describe the structural relationships between the different units of a behavioral repertoire, they are fruitful approaches. After providing examples of significant studies employing these analytical techniques across disciplines and animal taxa, we discuss the benefits and challenges associated with the use of these methods.

Transition matrices and related analyses

Behavioral studies based on the analysis and transformation of transition matrices have produced a large number of publications straddling various scientific disciplines and including a wide range of animal taxa from insects (e.g., Berman et al., 2016) to reptiles (e.g., McElroy et al., 2012), fishes (e.g., Van Der Heijden et al., 1990), birds (e.g., Eens et al., 1989), rodents (e.g., Espejo and Mir, 1993), all the way to non-human primates (e.g., Skorupa, 1983) and humans (e.g., McCune and McCune, 2019). Despite the common use of transition matrices, these studies employ a great deal of different procedures, and it is beyond the scope of this article to explore the enormous variability in the application of these analytical methods. That said, within the research employing transition matrices the work conducted on the behavioral structure in rodents certainly stands out. This is not surprising, since mice and rats are, by far, the preferred species in biomedical research due to their relatively low cost, basic housing conditions, and availability of many genetic variants that are extremely useful from a translational point of view (Bryda, 2013). The approaches used in most of the articles in which transition matrices are used in the study of rodent behavior fall into one or more of the methods outlined above.

Among these studies, pioneering works include those by Spruijt and Colleagues, in which adjusted residuals are predominantly employed (Spruijt and Gispen, 1984; Spruijt, 1992; Vanderschuren et al., 1996; Van Den Berg et al., 1999) and those by Espejo and Colleagues, that often involves the simultaneous use of probabilistic evaluations and aggregative clustering techniques (Espejo and Mir, 1993, 1994; Espejo et al., 1994; Espejo, 1997). In the same vein, let us just mention a study by Lino-de-Oliveira et al. (2005) pertaining to locomotory behavior of rats subjected to the forced swimming test, an elegant study by Takahashi et al. (2010) on rats' ultrasonic vocalizations, and numerous studies by Casarrubea and Colleagues focusing on the structure of exploratory behavior, anxiety-related response, and reaction to pain in rats and mice, and involving various lab apparatuses such an Open Field (e.g., Casarrubea et al., 2008; Santangelo et al., 2018), Hole Board (e.g., Casarrubea et al., 2009b, 2017) and Hot-Plate (e.g., Casarrubea et al., 2006, 2012).

In non-human primates, both "time lag" and "state lag" sequential analyses have been successfully used to demonstrate that female-to-male mounting in Japanese macaques is a supernormal courtship behavior that functions to focus the male consort partner's attention and prompt subsequent male-to-female mounting (Gunst et al. 2022).

What are the strengths and weaknesses of the utilization of transition matrices? As far as benefits are concerned, whether the applications lie in a deep understanding of the structure of behavior in rodents or primates, these methods are unified by the possibility of presenting the results in an extremely direct and intuitive way, which makes the publications pleasant to read and the findings easy to understand for a wide and non-expert audience. One only has to look at the dendrogram (Figure 3), the pathway diagram (Figure 4) and/or the histogram of residuals (Figure 7) to immediately grasp the meaning of these graphical representations and how they relate to the original transition matrices, that would otherwise look obscure. Regarding which of these methods may better convey information about behavioral structure, probabilistic analysis and pathway diagrams make it more intuitive than the clustering procedure and/or dendrograms. However, both pathway diagrams and dendrograms require statistical support. This can be done by analyzing the individual transitions in the source matrices and adding the corresponding adjusted residuals that stand for the different transitions in statistical terms.

Let us now address some problems associated with using transition matrices. Unlike the simplistic graphical representations featured in Figures 3, 4, 7 that contain only three behavioral units, a typical transition matrix is a table containing dozens or even hundreds of numbers. Therefore, reading, analyzing, and interpreting a transition matrix is generally no simple matter not

even an option for researchers accustomed to generating matrix analysis from data sets. Beyond the considerable work required to obtain the event log-files from which a transition matrix is derived (see section "Physiology of Behavior"), the matrix should then be subjected to specific transformations that direct the subsequent analysis toward clustering, probabilities, and/or residuals. Once this step is completed, the matrix is still an analytical item that only contains a large amount of numerical data and requires graphical treatment to be usable for interpretation (i.e., to obtain dendrograms, probability pathway diagrams, and histograms with residuals). In other words, one of the main problems associated with the use of transition matrices is the enormous amount of time required for their processing, analysis, and graphical transformation to make them intelligible. Yet, there is an even greater problem. The dendrograms, pathway diagrams and histograms containing positive and negative residuals are analogous to photographs with a very long exposure: on the one hand, they describe the entire observation period but, on the other hand, they lack one essential feature for any behavior: its temporal dimension. As pointed out by Eibl-Eibesfeldt (1970), behavior is structured on the basis of a flow of events that runs through time.

Temporal dynamics of behavior

Over the past three decades or so, the search and analysis of T-patterns have been successfully and widely used by scientists from a number of different fields, including psychology, psychiatry, computer science, physiology, biology, and sport science. The reasons underlying the inter-disciplinary popularity of TPA is that this technique offers researchers a great level of detail in the temporal structure of the behaviors under study. TPA has been successfully employed to explore the temporal organization of behavior in numerous species, ranging from rodents to primates.

In rodents, TPA allowed researchers to describe the qualitative and quantitative aspects of feeding behavior in rats under different dietary regimes (Casarrubea et al., 2019a), analyze anxiety-related behaviors in different rat strains (Casarrubea et al., 2010, 2011b, 2013a,b, 2014, 2015b, 2016, 2020a, 2021a), examine psychostimulant-evoked route-tracing stereotypies in mice (Bonasera et al., 2008), as well as generate a model of Tourette's syndrome (Santangelo et al., 2018) and a model of Parkinson's Disease (Casarrubea et al., 2019b) in rats.

In non-human primates, TPA has recently been used to demonstrate that the temporal dynamics of a behavior is informative to infer its function, and this, in two different behavioral domains: tool use (Cenni et al., 2020) and non-conceptive sex (Gunst et al., 2020). First, in a free-ranging population of Balinese long-tailed macaques in which versatile stone play was identified as a behavioral tradition, the monkeys were reported to repeatedly tap and rub stones onto their genital area (Pelletier et al., 2017). Despite those two stone-directed actions being integrated into stone play episodes, TPA revealed that the temporal structure of stone play sequences with genital stone-tapping and genital stone-rubbing performed by males was less structurally flexible and less exaggerated than that of stone play sequences without genital stone-tapping and genital stone-rubbing, suggesting functional attributes of these two specific behavioral units (Cenni et al., 2020). Thus, the performance of genital stone-tapping and genital stone-rubbing by male Balinese long-tailed macaques could be an example of stone play actions being functionally recycled into stone tool-assisted masturbation (Cenni et al., 2020). This result supports the view that object play can serve as a pool of behavioral variability and has the exaptive potential to be subsequently co-opted into tool use (Leca and Gunst, in press). Second, in a free-ranging population of Japanese macaques in which female-to-male mounting was identified as a culturally-maintained form of non-conceptive sex, TPA showed that the occurrence of female-to-male mounting conferred further functional constraints to mating sequences with more hierarchically organized and less repeatable courtship behaviors than in mating sequences without female-to-male mounting (Gunst et al., 2020). This result supports the view that female-to-male mounting in Japanese macaques is a supernormal courtship display more efficient than species-typical female-to-male sexual solicitations at prompting subsequent male-to-female mounts (Gunst et al. 2022).

In humans, TPA has been widely applied to detect tactical movements or prevent injuries in several sports and physical activities, such as boxing (Pic and Jonsson, 2021), taekwondo (Gutiérrez-Santiago et al., 2020), and football (Prieto-Lage et al., 2020), as well as to explore the relationships between impulsivity and physical activity (Castañer et al., 2020). TPA was also used in the study of human-animal interactions (Kerepesi et al., 2005), human-robot interactions (Kerepesi et al., 2006), hormones and behavior (Hirschenhauser et al., 2002), decision-making processes (Pic et al., 2021), eye-blinking behavior (Brill and Schwab, 2020), movement and behavioral disorders (Aiello et al., 2020), neuropsychiatric diseases (Lyon and Kemp, 2004; Kemp et al., 2008, 2016; Sandman et al., 2012) and the behavior of preschool-age children (Santoyo et al., 2020).

The first advantage of using TPA in behavioral research is directly related to the outputs of this approach: providing detailed information, otherwise impossible to access, about the temporal structure of behavior. To the best of our knowledge, no other analytical techniques allow for the study of the temporal dynamics of behavior at such a fine-grained resolution. Another benefit of TPA is its independence from the observed time window; whether it is a few seconds (typical of neuron firing measurements), a few minutes (typical of experimentally-induced behavioral measurements in lab rodents), or hours (typical of the assessment of a daily activity budget in free-ranging primates), the principles of T-pattern detection remain the same. Finally, TPA allows researchers to obtain three essential qualitative characteristics of the temporal texture of behavior, namely its variability, complexity, and recursiveness (Casarrubea et al., 2019a, 2021b). The evaluation of such qualitative aspects, combined with the

possibility to analyze specific events in the structure of the identified sequences allow for a further understanding of the behavior. For example, comparisons between rats treated with standard diet and rats treated with hyperglycidic diet revealed profound variations in those qualitative parameters. Specifically, animals under standard diet showed a behavior characterized by fewer T-patterns of different composition (i.e., lower temporal variability) which are more often repeated (i.e., higher recursiveness); on the other hand, rats under a hyperglycidic diet showed a behavior characterized by a noticeably higher number of different T-patterns (i.e., higher temporal variability) but that are repeated less often (i.e., lower recursiveness). The evaluation of the qualitative aspects of these patterns showed a significantly higher percentage of T-patterns specifically associated with two behavioral units, the so called Focusing-Sniffing (i.e., when the rat sniffs the rim of the pellet box without inserting the head inside) and Feeding (i.e., when the rat inserts the head inside the pellet box and eats) in the hyperglicidic group than in the control group. These results allowed researchers to hypothesize an increased salience of food-related stimuli in rats under hyperglycidic diet and a behavior highly evocative of craving (Casarrubea et al., 2019a).

One of the main challenges associated with the use of TPA is to fine-tune the use of the software with the data at hand. The most recent versions of the software tool utilized to perform T-patterns' detection analysis do feature numerous options; a thorough knowledge and practice of each of them is crucial to the reliability and validity of any outputs. Conversely, poor use of the software parameters can lead to the detections of T-patterns that might not be salient to the research question or difficult to interpret. An additional set of difficulties pertaining to the use of TPA is common with the analysis of transition matrices. TPA software also require event log-files to perform T-pattern detection. The creation and organization of such log-files before import into the software tool, albeit not complex in theory, are extremely time-consuming tasks (see section Physiology of behavior.). Although we often speak of "T-pattern analysis" to refer to the entire analytical process, this essential preparatory step should be kept in mind.

Conclusion

In this paper, we aimed to present the main methods that have accompanied us in the structural analysis of behavior over the past two decades. Our goal was not to present an excursus on the use of multivariate analyses in this line of behavioral research. Instead, we sought to provide some theoretical background for beginners in the exploration of behavioral structure and for already experienced researchers who wish to implement some of the approaches outlined here. Structural behavioral analyses provide substantial benefits that, by far, compensate for the large amount of time required for their use. The main advantage of these methods consists in producing qualitative and quantitative descriptions of complex behavioral dynamics that would otherwise be difficult or impossible to obtain.

Author contributions

MC conceived the study. J-BL, NG, GJ, GC, and MC wrote the manuscript. MC, J-BL, NG, and SA conducted field-and laboratory-based research and performed data analysis. MC prepared tables and Figures. GC, GG, J-BL, NG, GJ, and MP reviewed and edited 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.

The reviewer MB declared a past co-authorship with the authors MC and GG to the handling Editor.

Publisher's note

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New insights into the behavioral structure of Pikler educators: An application of T-pattern detection and analysis with THEME

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Introduction: The recent generalization of early childhood schooling has given rise to a need for the development of rigorous, specific training programs aimed at early education professionals (0–3 years of age). This work emanates from the unique nature of Pikler-Lóczy education as a reference for early childhood education centers, and its expertise in providing quality care in an everyday classroom situation. The aim of the study is to use T-pattern detection and analysis, within the framework of observational methodology, to identify relevant aspects of the *choreography* followed by Pikler educators during breakfast, and thus provide substantial material with a view to creating a training plan.

Methods: Two expert educators in Pikler-Lóczy education were directly and systematically observed in their own classrooms, following a nomothetic, follow-up and multidimensional design. The observation instrument underwent a molarization process so that the detected elements would be more significant and understandable for novice educators.

Results: Using THEME, the invariant aspects of the educators' behavior were analyzed. The significance level for the critical interval was the THEME default ($\alpha = 0.005$). The results show: on the one hand, changes expected in T-patterns in accordance with the observation instrument molarity; and on the other hand, stability in terms of the comparison between the two educators.

Discussion: These results help us to identify the complex structure of the breakfast choreography, and how educators establish interaction with children. In addition to specific issues pertaining to Pikler-Lóczy education, the conclusions highlight the advantages of using T-pattern analysis within the framework of observational methodology, in order to dissect a mealtime routine in its natural context, and explain components of early childhood education intervention that satisfy basic childhood needs. This constitutes a starting point from which to generate instructive material for the training of professionals working in early education.

KEYWORDS

Pikler-Lóczy education, observational methodology, T-pattern, THEME, observation instrument, early childhood

1. Introduction

Over the last few decades, early childhood schooling (0–3 years of age) has grown exponentially to become a generalized reality (European Commission, 2019). This has given rise to an increase in studies centered on the assessment of educational programs and interventions in nursery schools (Kaufman et al., 2015; Escolano-Pérez, 2020). A number of these studies warn of poor quality in such centers, especially in terms of educator-child interaction (Turnbull et al., 2009; Durlak, 2010; Hallam et al., 2016). This is largely due to the fact that this educational phase lacks its own identity (Herrán et al., 2014) for two reasons: on the one hand it has inherited educational traditions from successive cycles, introducing content that does not fit with the specific characteristics of early childhood (Sarmento and Ruiz, 2011); and, on the other hand the job is carried out in an intuitive, affectionate, maternal way, neglecting the professional dimension of daily tasks (Herrán, 2013; Falk, 2018a). Considering the proven effect of early experiences on human psychological development (Bick and Nelson, 2017), more and more authors are calling for a system rooted in the natural circumstances of infant daily life (Duncan and Magnuson, 2013; McLachlan et al., 2018), that helps to fulfill their early developmental needs (Csibra and Gergely, 2009; Bonawitz et al., 2011; Hallam et al., 2016; Tomasello, 2016; Salcuni et al., 2017). However, there are few rigorous training programs aimed at educators and early education professionals that provide a specific guide as to how to carry out everyday activities in the infant classroom, as well as how to assess progress in the performance of these activities.

Previous works have justified the interest and unique nature of the Pikler-Lóczy education (PikLEd) system as a reference for early education centers covering the 0–3 age group (Tardos, 2007; McCall et al., 2010; Herrán, 2013, 2018; Herrán et al., 2014; Salamon and Harrison, 2015). The PikLEd is an institutional childcare proposal exclusive to early childhood. It is based on over 70 years of practical and professional experience in the Lóczy Institute of Budapest (Pikler, 1968, 1971; David and Appell, 1986, 2010; Falk, 2002), which began as a foster home (1946–2011) but later became a nursery school (from 2006 to the present day). Assuming that an early experience of competence is crucial for the future shaping of the psyche (Bruner, 1972, 1973; Wallon, 1980; Pikler, 2018), this model revolves around two fundamental axes of everyday infant life: daily care and autonomous infant activity. It entails a set of original action protocols, known as *choreographies*, that transform everyday activities (for example, breakfast) into an educational field (Belza et al., 2019, 2020). The authors who have gone deeper into analyzing the practice of PikLEd have highlighted its relevance as a responsive care system (Hevesi, 2018; Pikler, 2018; Falk, 2018b) that is truly paedocentric (Falk, 2008; David and Appell, 2010; Herrán, 2013; Tardos and David, 2018; Vincze, 2018), and which facilitates infant socialization without violence (Kàllò, 2014, 2016; Pikler, 2018).

Over the last few years, a number of studies have provided new knowledge about PikLEd through the application of observational methodology (OM; Belasko et al., 2019, 2022; Belza et al., 2019, 2020; Sagastui et al., 2020, 2022). OM allows us to assess spontaneous behavior in its everyday context (Anguera, 1979, 2003; Portell et al., 2015). This methodological option offers valuable procedural resources for the study of daily life in the classroom and the adult-child relationships that are established therein (Anguera, 2001a). It also provides the objectivity and rigor essential for educational assessment, whilst at the same time affording the necessary flexibility for capturing the many, often complex processes of development and early learning in real life environments (Anguera, 2001b; Herrán, 2008; Early Head Start National Resource Center, 2013; Escolano-Pérez et al., 2017; Escolano-Pérez, 2020). OM offers guidelines for justifying and analyzing the quality of the records obtained using study dimensions and segmentation criteria of the spontaneous behavioral continuum in its natural context. Thus, OM involves the systematization of initial descriptive records – first dataset – through an observation instrument in order to obtain an equivalent code matrix – second dataset – that is built on the first (still qualitative data, where columns are dimensions/sub-dimensions, and rows are the successive units), which will be analyzed through specific quantitative techniques for categorical data. This way of connecting qualitative information and quantitative data has led to OM being considered as mixed-method in itself (Anguera and Hernández-Mendo, 2016; Anguera et al., 2017, 2018a; Onwuegbuzie and Johnson, 2021; Hitchcock and Onwuegbuzie, 2022).

Beneath the scope of OM, observational instruments were legitimized and applied, in order to capture details about the behavior of the expert PikLEd educator that facilitate the detection of two dimensional, instrumental and relational patterns in the daily performance of each everyday activity: breakfast, dressing and undressing, free play, etc (Belasko et al., 2019, 2022; Belza et al., 2019, 2020; Sagastui et al., 2020, 2022). This research shows that the habitual behavior of the expert PikLEd educator ensures the stability of the environment and the consistency of educational behaviors, these being understood as precise and adjusted ways of responding to the development of infant autonomy. Within the research line begun by Herrán (2013, 2014, 2016) and Herrán et al. (2014), important progress has been made in characterizing the action protocols or choreographies followed by these professionals in each educational field, thanks to the use of procedures designed to capture essential details of the sequence of educators' instrumental actions and their connection with relational behaviors deployed with the child.

One of the everyday activities transformed into an educational field for PikLEd is breakfast. The systematic observation of this activity has revealed the sequence of basic actions that the educators repeat, as many times as necessary, so that the child has breakfast in a way that *suits them*, meaning that the child eats comfortably, calmly and quietly, in accordance with the hunger they feel at the time and their own perception of being full. These sequences are the *detours* (Wallon, 1985) they carry out in order to provide each child, at the table, with the utensils and food laid out on the countertop (Belza et al., 2019). The reiterative circularity of this instrumental sequence, together with the specific, unique and meaningful management of distances and postures (proxemic behavior), has shown that the expert PikLEd educator promotes the appearance of shared intentionality (Tomasello et al., 2005) in the development of mealtime routines (Belza et al., 2019). It is this shared intentionality that forms the basis of early cultural, instrumental and social learning (Tomasello, 2016). Furthermore, enlightening results have been obtained through analyzing the differentiated use of the utensils specific to the activity, along the lines of object pragmatics (Rodriguez and Moro, 1999) which views objects in terms of their social use and functions in everyday life, functions which children gradually appropriate thanks to adult-instigated mediation. Significant relationships were detected

between various breakfast utensils with differing complexity and each child protagonist, showing that the educators adapt, and provide utensils depending on the level of autonomy and interest of each child (Belza et al., 2020).

The evidence provided by the aforementioned studies about the breakfast activity was made possible thanks to the diachronic analysis of observational data (Anguera et al., 2021); more specifically, lag sequential analysis (Bakeman and Gottman, 1989; Bakeman and Quera, 2011; Quera, 2018) and polar coordinate analysis (Sackett, 1980; Anguera, 1997). Lag sequential analysis detects regularities in behavior, making patterns of behavior visible, whereas polar coordinate analysis enables the vectorization of behavior, creating a complete map of interrelationships between behaviors. These techniques enabled the characterization of significant parts of the choreography, but not the choreography as a whole. A third very important technique for diachronic analysis in OM is based on the algorithm developed by Magnusson (1996, 2000) and used in THEME software, which makes the description and detection of complex real-time patterns possible. Its basic concept is the T-pattern, a statistical, hierarchical, self-similar (pseudo-fractal) pattern, recurring with significant translation symmetry since detected in human, animal, and brain network behavior (Casarrubea et al., 2015, 2018; Magnusson, 2020). T-pattern detection and analysis (TPA) with THEME has led to new insight into the structure of behavior. This third technique used for diachronic analysis in OM may be the best option for a complete characterization of the choreography. Until now, the use of TPA within the framework of OM, in the field of education, has made it possible: to identify patterns of academic persistency in pre-school age-groups (Santoyo et al., 2020), to examine the development of cognitive skills in infancy (Escolano-Pérez et al., 2019; Escolano-Pérez, 2020), to evaluate teaching-learning strategies in motor skills (Castañer et al., 2009), to assess the interaction and communication models of physical education teachers (García-Fariña et al., 2018; Camerino et al., 2019; Valero-Valenzuela et al., 2020), and to design and assess training programs focused on the professionals' change in behavior (Portell et al., 2019; Sene-Mir et al., 2020).

Therefore, through the use of TPA within the framework of OM, it is possible to facilitate the design and evaluation of formative interventions of PikLEd aimed at novice educators; and this application would allow us to compensate for an important deficiency in the generalization of the PikLEd model. The Lóczy Institute in Budapest – now the Emmi Pikler nursery school – rigorously prepares its educators *in situ,* with periodical observations of their actions with the children which are then discussed by the pedagogic team as a whole (Kelemen, 2016). However, in other centers there is no training material for novice educators associated to evaluation guidelines, that would allow professionals to track the acquisition process of essential elements of the choreography (what to do) and non-verbal communication (how to do) inherent to PikLEd. The general aim of this research is to provide new insight into the choreography followed by the expert PikLEd educator, which is considered seminal for the creation of an innovative training plan that includes T-patterns as elements of a self-modeling strategy (Dowrick, 1999, 2012). Based on the main dimensions that have been established to structure the breakfast activity (Belza et al., 2019), the specific aims are: (1) to adapt the instrument *Giving Breakfast in the Emmi Pikler Nursery School, GBEPNS* (Belza, 2020) which increases the molarity of its instrumental and proxemic dimensions, in such a way as to make it easier for an educator who is not an expert in PikLEd to understand the training material created from its elements; (2) to identify invariant aspects that structure the expert educator's behavior by analyzing the T-patterns from both an intra-individual perspective – between patterns obtained from the same expert educator when modifying the molarity of the observation system –, and an inter-individual perspective – between the behavior patterns of different expert PikLEd educators.

2. Materials and methods

This work forms part of a line of research into PikLEd developed under the scope of OM. In accordance with the design classification established in OM (Anguera et al., 2001), the study design as a whole is nomothetic, follow-up and multidimensional (N/F/M design), since the observation units are greater than one; there are two educators, to be exact. However, it is worth qualifying that, for each educator, the design used is ideographic given that the behavior of each one was observed and recorded as an independent unit, with an intra-session and inter-session follow-up over a 3 month period; and is multidimensional since it includes different criteria in the observation instruments used to record and code behavior (I/F/M design). This study applied systematic, direct, non-participative observation.

2.1. Participants

Eligibility criteria were established for the educators so as to increase the probability of the behavioral records obtained being representative of the PikLEd model. These criteria are: (1) having done their professional training in the Lóczy foster home itself, under the direction of the pediatrician Emmi Pikler; and (2) having actively taken part in the continuous training programs organized by the institution. Furthermore, applying the logic of multiple case study repetition (Yin, 2014), this study seeks to integrate most of the school educators involved in the breakfast activity.

There are three classrooms in the Emmi Pikler nursery school in Budapest, with a maximum of 12 children and three educators in each one. Applying the aforementioned criteria, two educators were selected (henceforth, Educator-1 and Educator-2) who habitually manage breakfast in their groups. Various studies within the OM framework show that, despite working with a reduced number of participants, the intensive monitoring of their everyday activity makes it possible to collect a large quantity of data and extract insightful conclusions about the studied reality (Rodríguez-Medina et al., 2018; Belza, 2020; Lapresa et al., 2020; Sagastui et al., 2020; Arias-Pujol et al., 2022).

In terms of the groups, it is worth highlighting that this school endeavors to maintain the same three educators in each group in order to establish a close relationship with the children as well as to enable a continuous monitoring of the children. For this reason, the placing of children into groups is not done in accordance with the age criterion, but depending on the number of available places in each classroom and the characteristics of the children themselves. To be specific, Educator-1's group was made up of four boys and eight girls between the ages of 26 and 47 months at the start of the observations. Educator-2's group was made up of five girls and five

boys aged between 20 and 36 months. As breakfast is an option offered to all the children, participation varied from session to session.

It was agreed with the school directors to film one session per week in each classroom first thing in the morning, from 8.30 to 9.30, over a 3 month period. As recordings are frequently made in the classrooms, both the educators and the children are familiar with the presence of a camera. This is undoubtedly a relevant aspect to consider in relation to reactivity (Behar and Riba, 1993).

A total of 28 sessions were filmed over 3 months, 11 in Educator-1's classroom and 17 in that of Educator-2. The acceptance criteria for the sessions was established in line with the following aspects: (1) Observability of the educators and their activity: the camera follows them continuously from the moment the first child arrives to have breakfast until the last breakfast is cleared away; (2) Inter-session consistency (or fulfillment of formal minimums of situation and space homogeneity) – all the sessions correspond to the same two classrooms in which the activity takes place, mainly in the dining room area or in the adjoining lobby or bathroom; (3) Intra-session consistency (or temporal completeness of the criteria that define the session) – all the sessions must temporally cover the aim, which is to serve and complete breakfast within the established time slot. The following exclusion criteria were formulated: (1) Change of classroom for organizational or maintenance reasons; (2) Insufficient recording time to analyze the complete breakfast of at least one child. Despite 25 sessions being recorded, the application of this last criterion excluded three of Educator-2's sessions from the analysis. Finally, the sample of analyzed breakfasts was made up of 10 sessions in Educator-1's classroom and 12 sessions in that of Educator-2. Each session lasted between 10 and 40 min, depending on how many children had breakfast and what time each child began.

The research project was assessed and approved by the Committee for Ethics in Research and Teaching from the University of two of the authors (INA0139), after obtaining the informed consent of the two educators and gaining the permission of the authorities responsible for the Emmi Pikler nursery school in Budapest, in accordance with Law 41/2002 of patient autonomy. The data has been treated in line with the regulation included in RD1720/2007 of development of the Organic Law 15/1999 of Personal Data Protection and in Law 14/2007 of Biomedical Research.

2.2. Instruments

2.2.1. Observation instrument

The observation instrument used is an adaptation of the field format *Giving Breakfast in the Emmi Pikler Nursery School, GBEPNS* (Belza, 2015, 2020; Belza et al., 2019, 2020), an *ad hoc* creation (Anguera et al., 2007) to observe the habitual behavior of the expert PikLEd educators during breakfast. This instrument is made up of six dimensions grouped into two macro-dimensions: instrumental, associated with the material conditions of the specific activity of breakfast; and relational, appertaining to the interaction and communication that the educators establish with the children at different levels (paralinguistic, proxemic, kinesic, and verbal). Each dimension is displayed in a feature list type catalog of behaviors (Anguera et al., 2018b).

GBEPNS was developed for a very molecular level of description, which allows us to collect the smallest details of the educators' behavior during breakfast, but which may hinder the subsequent explanation and interpretation of this behavior when it is dissected. In accordance with the aims of this study, the initial field format underwent a molarization process through which the catalogs of behaviors, spaces and objects (utensils in this case) were redefined and reordered, with a view to making the detected elements more significant and understandable for novice educators. In order to carry out this adaptation of GBEPNS, in its instrumental and proxemic dimensions (henceforth GBEPNS-IP), a dynamic process of initial formulation of tentative groups was followed, subsequently modified in line with an empirical-inductive strategy, and once again, consistent with a deductive strategy. A group of PikLEd and OM experts intervened in this process. Similar aspects were grouped together in relation to their educational significance and their transferability to other classrooms, maintaining the specifics in terms of behavior related to children. The result of this process of adaptation of the GBEPNS-IP instrument is referred to as GBEPNS-IPv2. Table 1 shows the structure of GBEPNS-IPv2 and its correspondence with GBEPNS-IP.

It can be noticed that each dimension is broken down into three sub-dimensions so as to structure the elements and guarantee mutual exclusiveness. The instrumental dimension includes the spaces in which the activity takes place, the educator's actions (what she does) and which utensils she uses. Proxemic behavior refers to how the educator uses the space, and covers two facets: the static character that refers to the choice of place and posture within a space; and the dynamic character that involves the set of movements inherent to the activity itself. In aiming to capture the interactive dynamic that the educator establishes with the children in her care, the static facet is divided into two criteria: that of solitary static which refers to posture or position; and that of static in relation to the child present with whom she can make contact or stay very close to without moving. Once the catalogs of behaviors, spaces and utensils for each sub-dimension had been compiled, a system of alphanumerical codes was created to enable the coding of each of these elements.

2.2.2. Recording and analysis software

The free software program HOISAN, version 1.6.3[1] (Hernández-Mendo et al., 2012, 2014) was used to record and code all the sessions based on the system established in the field format. This program enables the databases to be exported to MS-EXCEL. Thus, the record files can easily be transformed into the syntactic structure of other programs for data analysis. In this case, we used the program THEME 6 Edu (Magnusson, 2000) for data management and analysis, which is freely available for download.[2]

2.3. Procedure

From the observation instruments GBEPNS-IP and GBEPNS-IPv2 we obtained records of the 22 sessions. The basic unit in field format record is the configuration or co-occurrence of codes from different dimensions. The configuration is formed by as many

1 www.menpas.com

2 www.patternvision.com

10.3389/fpsyg.2023.1081785

TABLE 1 Dimensions, sub-dimensions, and catalogs of the behaviors/spaces/utensils of the GBEPNS-IPv2 instrument and their concordance with the catalogs of the GBEPNS-IP instrument.

GBEPNS-IPv2			GBEPNS-IP
Dimensions	Sub-dimensions	Catalogs	Catalogs
Instrumental	Space	Counter	Counter 1, counter 2, counter 3, breakfast basket, trashcan, paper tissue repository, wall closet
		Table	Tables 1, 2
		Her place/chair	
		Other sub-area of the dining room	Door, entrance, corridor, handrail
		Other area of the classroom	Play area 1, play area 2, sanitation area, washbasin, lobby, lobby window
	Action	Greets/welcomes	Greets from where she is, welcomes approaching the door, farewell to parents ritual
		Offers food	
		Puts	Replaces
		Takes/leaves/goes in search	Moves
		Serves	
		Other breakfast action	Prepares food,/spreads/cuts/opens, Puts away, Organizes, throws away leftovers, cleans objects, sweeps, mops
		Gets child to use napkin	
		Collects child's breakfast	Takes it away if uneaten
		No action	
		Other (hers)	Puts glasses on/blows nose/washes hands, writes in notebook, opens-closes handrail
	Utensil	Glass	
		Jug/bag/ recipient	
		Glass and jug	
		Bowl	
		Plate	
		Napkin	Handkerchief (nose)
		Breakfast kit: various	
		Other (hers)	Knife,/scissors, fork, spoon, mop, broom, cloth, stool, notebook and pen, other
		Soother/transitory object	
		None	
Proxemic behavior	Static alone	On foot	
		Bent forward	Leaning forward
		Crouching/kneeling	Kneeling, sitting on knees
		Sitting	
	Static with child	None	
		Takes/places him/her	Takes him/her in her arms, places him/her on her lap, places him/her between her legs, Puts her arm around him/her, lowers him/her to the floor
		Surrounds him/her in order to maneuver	
		Next to her	
		Opposite	
	Movement	None	
		Approaches	
		Moves away	
		With child	Follows him/her, carries him/her in her arms, they go hand in hand, they walk in parallel, the child follows her
		Without relationship to the child	

codes – at most – as there are number of sub-dimensions. When a behavioral aspect changes, the next configuration begins, thus enabling an exhaustive record of behavioral flow. In this way, the maximum systematization of the record is achieved, which produces large code matrices. At the same time, the duration that includes information about both the position of the code within the sequence and its occurrence, was used as a primary record parameter (Anguera et al., 2001; Bakeman and Quera, 2011). This enables the detection and analysis of T-patterns (TPA).

The HOISAN computer program allows us to obtain and store a large quantity of data and subject them to quality control. The files with the record made in HOISAN were exported to MS-EXCEL to be prepared in accordance with the instrument GBEPNS-IPv2. In this way two new code matrices were obtained, one for each educator, which were transformed into the syntactic structure compatible with the THEME program. This program was used to analyze the data of Educator-1, obtained with GBEPNS-IP and with GBEPNS-IPv2; and those of Educator-2, obtained with GBEPNS-IPv2.

2.4. Data quality check

Both qualitative and quantitative quality control procedures were carried out on the data. Consensual concordance (Anguera, 1990) took place in the last stage of construction of the observation instrument. This procedure, that seeks to achieve convergence between two observers, is increasingly present in OM (Arana et al., 2016). To this end, two of the authors of this study jointly carried out record trials with 15% of the sample, to decide which code to assign to each of the observed behaviors. The definitions of the behaviors in the catalog were therefore shaped and nuanced, thus strengthening the observation instrument.

In terms of quantitative quality control of the data, Krippendorff (2013) alpha coefficient was calculated, both intra-observer and inter-observer, *via* the HOISAN program. Ten per cent of the sample was recorded twice at different times for comparison, and once more by an external observer. In both cases the coefficient value was satisfactory since the degree of agreement between the two observers was 0.89, whilst it was 0.92 between the two records at different times.

2.5. Data analysis

According to Magnusson (2016), the THEME software considers data as a series of points that represent the occurrence of events during a period of observation (in TPA the event refers to the configuration or chain linking of codes from each sub-dimension of the field format in each of the event-types). The number of appearances of an event-type, divided by the duration of the observation period, produces the mean probability of this event-type occurring in a given unit of time, which is later used as the reference probability for the detection algorithms. When THEME detects an occurrence of a followed by B within a critical interval, it generates a simple T-pattern (AB). The critical interval is a key concept in TPA, and it refers a particular relationship between pairs of events in a time series—for an extended explanation of this concept see Magnusson (2000) and Casarrubea et al. (2015, 2018). The occurrences of simple T-patterns become events that subsequently constitute focal event-types in the next detection level. This process is repeated upwards level by level, in search of critical interval relationships with the patterns detected in previous levels, in order to generate ever more complex T-patterns.

This study independently analyzed the three aforementioned databases – in each one, the included sessions were concatenated into one multi-sample base – using the same search and selection criteria parameters to compare the obtained T-patterns (Amatria et al., 2017; Pic et al., 2021; Pic and Jonsson, 2021). More specifically, the search parameters applied were (Magnusson, 2017): (1) an occurrence frequency greater than 3; (2) a significance level of 0.005 (0.5% probability that the critical interval was randomly produced); (3) a minimum pattern occurrence in 50% of the sample. TPA detection was validated by simulation, through data randomization with shuffled and rotated randomized versions of the data sets. We used the standard number of randomization-searches (5 runs per type). The only accepted patterns were those for which the concordance probability between the randomized data and the real data was zero.

Given that the aim of this study was to analyze individual patterns, it is necessary to operationalize the selection conditions to make them comparable. Since the aim is that the patterns help to characterize the structure of everyday educational behavior as a whole, three selection criteria were applied to the patterns detected by THEME: (1) maximum length (patterns that include the greatest quantity of event-type or configurations); (2) maximum level of hierarchical structuring; (3) greatest session time coverage.

3. Results

In relation to the behavior of Educator-1, 4,716 configurations or data points were analyzed, whilst 2,319 configurations were analyzed in the case of Educator-2. The number of configurations was maintained both with GBEPNS-IP, and with GBEPNS-IPv2. In line with the second specific aim, we present the results below, in two sub-sections that show the intra-individual and inter-individual comparisons between patterns.

3.1. Changes in the structure of Educator-1's behavior with the GBEPNS-IP and GBEPNS-IPv2 instrument

Starting from the code matrix based on GBEPNS-IP and applying the parameters and criteria defined in the data analysis section, the obtained pattern, among the 133 detected, is shown in Figure 1. It can be seen that in this T-pattern there is a certain structuring of Educator-1's behavior, made up of two sub-sets of simpler patterns: on the one hand, the pattern shows the hidden structure concerning the management of breakfast in the different sessions (*takes an item from the cupboard*, *serves table 1*, *serves table 2, returns to the counter*); and on the other hand, a highly recurrent pattern that reflects accompaniment when there is *no action*.

Figure 2 shows the pattern resulting from the application of the selection criteria for the 849 T-patterns detected with the same search parameters, when using GBEPNS-IPv2. The level of behavioral

Sample	Data points=4716	event-type=1712	T-patterns=133
T-pattern 1880	Length=7	Level=4	Duration=4709; 24%

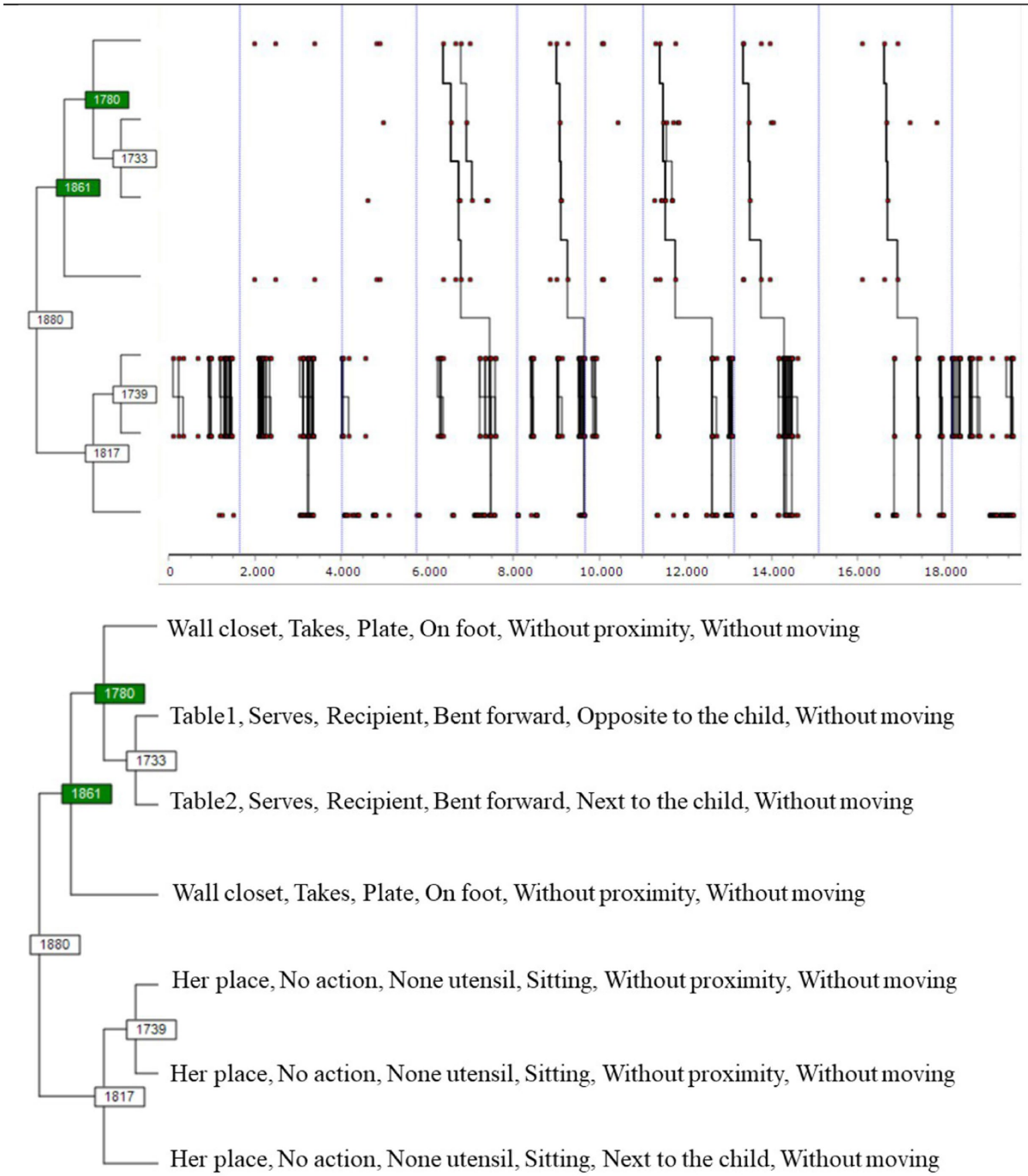

FIGURE 1
T-pattern of Educator-1's behavior obtained with GBEPNS-IP.

structuring in this case is visibly greater, above all in reference to the instrumental actions; and at the same time, it integrates the simple pattern *no action*, again demonstrating the high recurrence of this event. Furthermore, this complex T-pattern reveals the appearance of new educational behaviors, such as closing the activity with the *gets child to use the napkin* action.

3.2. Stability in the behavioral structure between Educator-1 and Educator-2 with the GBEPNS-IPv2 instrument

Using the same selection criteria as in the previous analysis, we obtained the pattern shown in Figure 3 of the 201 T-patterns

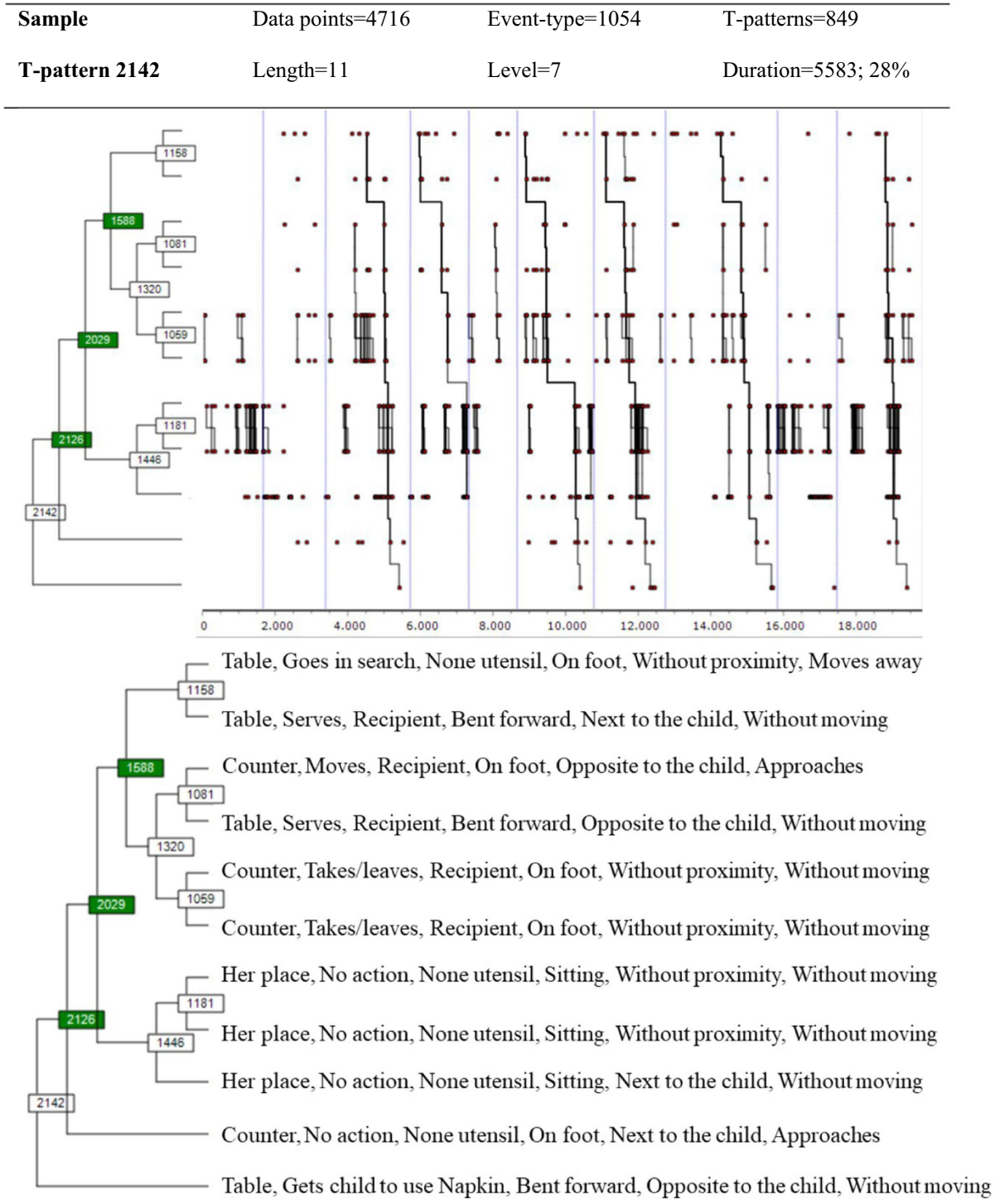

FIGURE 2
T-pattern of Educator-1's behavior obtained with GBEPNS-IPv2.

detected in the behavior of Educator-2. In this pattern there are three event-type sub-sets, which, although differing slightly in how they are structured in relation to Educator-1's T-pattern, they practically replicate its composition: chain linking of instrumental actions (*serves, puts, moves, takes/leaves*) that alternate movements (*moves nearer, moves away*) between the *counter* and the *table*; again, there are repetitions of the central sub-set of accompaniment when there is *no action*, and finally, the use of the *napkin*.

4. Discussion

This study focused on two dimensions: one of instrumental behavior, and the other of the expert PikLEd educator's non-verbal behavior during the breakfast activity. The relevance of both these dimensions, instrumental and proxemic, has been revealed in previous studies as backbones of behavior flow on two levels – physical/instrumental and human/relational (Belza et al., 2019; Belza, 2020).

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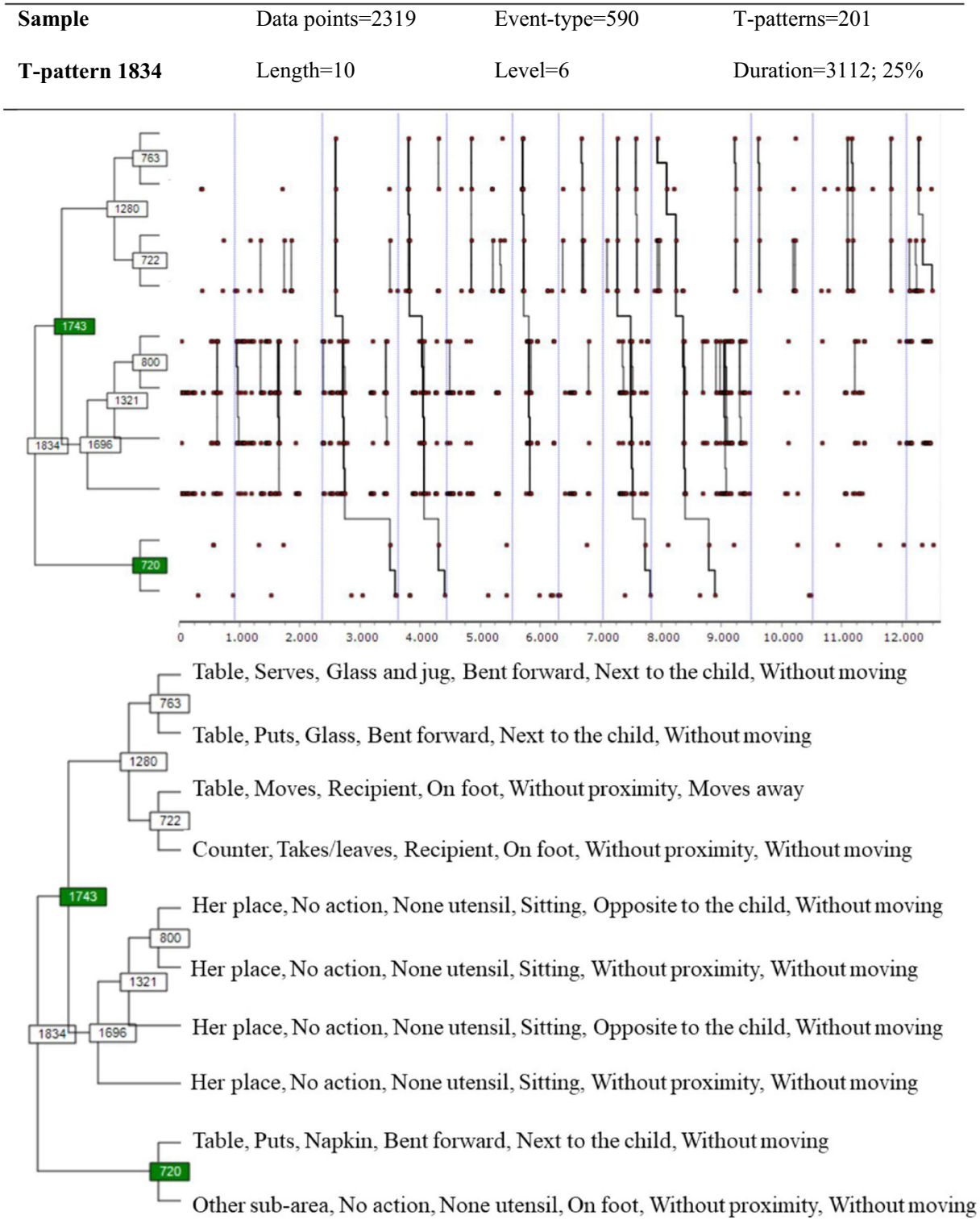

FIGURE 3
T-pattern Educator-2's behavior obtained with GBEPNS-IPv2.

Furthermore, due to their high degree of perceptibility and relationship with reality, these dimensions offer better training opportunities for novice educators than others perceived in the GBEPNS instrument. It was expected that the detection of T-patterns would identify greater levels of structuring in everyday behavior compared to other diachronic analysis techniques, and thus provide an account of the choreography as a whole. Below we discuss the results obtained relating to Educator-1's behavior, in order to compare the identifying and explanatory capacity of the two observation instruments, GBEPNS-IP and GBEPNS-IPv2. Subsequently,

we explain the T-patterns of Educator-1 and Educator-2, obtained with GBEPNS-IPv2, in order to clarify the potential behavioral homogeneity between the two.

Firstly, we can see that the variability of event-types drops to almost half when GBEPNS-IPv2 is applied to the analysis of Educator-1's behavior, compared with the use of GBEPNS-IP. This fact adds more consistency to the record and reduces the dismembering of the behavior by residual aspects, without prejudicing significant information, given that the versatility of the events compared to the total is still high. The amount of different event-types, interpreted as behavior variability, shows that the PikLEd expert constantly adjusts to each moment, circumstance and child (Kàllò, 2016; Hevesi, 2018). If one of the defining aspects of early education is the educators' capacity to adapt their practice to the children's basic needs (Durlak, 2010; Escolano-Pérez, 2020), then PikLEd prioritizes the establishment of a close, continued relationship between the educator and the children in her/his care. In this way, everyday interactions can be furnished with the particular and individualized traits that come from mutual knowledge and which are so necessary at early ages (Falk, 2008). Despite this variability, the obtained results relating to Educator-1 support the use of the GBEPNS-IPv2 instrument which, combined with TPA, has allowed us to discover a more complex everyday behavioral structure for the expert PikLEd educator. It also provides new aspects of the choreography during breakfast whilst integrating the findings of previous studies (Belza et al., 2019, 2020) – the basic sequences that instrumentally order this mealtime routine and its cultural-socializing character. Therefore, the results sustain the idea that THEME is effective in obtaining clarifying patterns of this intervention in its natural context – a nursery school classroom.

Secondly, the aim was to check whether applying the most molar GBEPNS-IPv2 instrument and the same analysis strategy with THEME would lead to Educator-1's results being replicated in Educator-2. Before going on to compare the patterns obtained from both, we want to highlight differences in the two breakfast situations. Since the temporality of the sessions was marked by the children's attendance, together with the desire and rhythm in the breakfast itself, the duration of the sessions was disparate. This means, for example, that Educator-2's sample, although including a greater number of sessions than that of Educator-1, produced a lower quantity of data due to fewer children having breakfast and the sessions being shorter. However, this fact does not appear to impede the detection of a similar structure in the behavior of both educators. The two T-patterns obtained are made up of event-type symmetries and have similar characteristics: (1) Chain linking of instrumental actions for breakfast management, (2) Recurrent cycles of accompaniment without action, (3) Finalization using a napkin. These results provide evidence about the stability of everyday intervention at breakfast time in this school, in two senses: On the one hand, they add evidence about the detours (Belza et al., 2019) made by the educators from the counter where the utensils – that they move, put down or serve, moving closer to the children at the table – are kept, until they return to the counter. Furthermore, the T-patterns obtained illustrate that it is the proxemic dimension that characterizes this instrumental sequence; guaranteeing coherence between the physical and human elements that make up the early educational breakfast environment, and showing the relevance of the intentional use of the space when it comes to establishing educator-child relationships. The expert PikLEd educator's choice of posture and distance is neither accidental nor improvised, but is a response to the level of intervention/interaction that she needs to establish for the *joint action* (Tomasello et al., 2005; Sagastui et al., 2022). On the other hand, that both educators should display such similar behavior is due to the fact that, since its beginnings as a foster home, the main aim of the Lóczy Institute has been to provide the emotional security necessary for the healthy psychological development of institutionalized infancy (Pikler, 1971). Such important acquisitions in the earliest years cannot be integrated into the personality being structured if the child does not carry out her/his experiences within the framework of an interpersonal system of stable, continuous relationships (Falk, 2008). To this end, the aspects that make up each care were detailed and examined, in order to organize them in the form of a choreography, and thus ensure the continuity and homogeneity in the daily tasks of the educators who interact with the children (Herrán, 2013).

On an educational level, two other components of this choreography stand out. The *accompaniment without action* pattern is where the educator sits on her chair, and from that position accompanies both the breakfast of the child sitting at the table next to, or opposite her, along with the rest of those present, including those who are already in the play area. This sub-set of event-types is a recurring loop that is inserted into the choreography. They are attention intervals dependent on the aspiring action of the children, which allows the educator to attend and respond to the requirements of each moment in an appropriate way, even preempting them, thus displaying responsive care (Hevesi, 2018; Pikler, 2018). Her presence increases as the session progresses; something which is logical given that most of the children have been served, are finishing or are already playing. Even so, the fact that this pattern is repeated throughout the session characterizes the delimited space known as "her place" – i.e., her chair, situated near to the breakfast table, between this and the counter – as a transitional space between one action and the next, or between one interaction and the next. This shows another way of organizing and regulating the activity through the use of the space. Finally, it is worth highlighting the appearance of a previously unknown action – the culmination of the breakfast, consisting in the use and placement of the napkin, which closes the activity. In fact, in the case of Educator-2 this action takes place in another sub-area of the dining room – the handrail or corridor that connects to the play area. Therefore, the napkin, which denotes a certain degree of acceptance of social norms or conventions by the child (Belza et al., 2020), marks another important transition: from the breakfast activity to the one that immediately follows, which is play. Once the basic, affective needs have been covered – dietary, emotional and adaptable to nursery school – the children can then unleash their abilities associated with autonomous activity and free play. According to Tardos (2014), attending school involves facing certain daily challenges on the children's part. In this sense, breakfast constitutes an activity that supports the transition from home to school; each child receives a welcome and a personalized breakfast so that they feel expected and comfortable (Tardos, 2014; Belza, 2015). These transitions are fundamental in infant daily life in order to ensure security and welfare. The expert PikLEd educator prepares them in such a way as to create a solid framework in which children can integrate references that help them settle, find their place and build structure (Falk, 2008).

In short, what can be deduced from this work, in addition to the specific matters relating to PikLEd, are the advantages of using TPA within the OM framework to dissect an everyday activity in its natural context, and explain the components of early education intervention that satisfy basic infant needs. The results reveal a complex structure of the everyday behavior of these educators, which provides insightful

information about the breakfast choreography, and how the expert PikLEd educators establish interaction with the children. This represents a starting point from which to generate instructive material for training early education professionals. In this sense, since the detected patterns integrate and structure various dimensions of instrumental and non-verbal behavior, they allow us not only to assess the result of such training, but also to create feedback during the process itself (Santoyo et al., 2020; Sene-Mir et al., 2020). Therefore, this work makes a significant contribution in terms of addressing the gap that exists in specific training programs for professionals working with the 0–3 age group; a gap that has been highlighted by various authors (Herrán et al., 2014; Escolano-Pérez, 2020).

As previously mentioned, one of the limitations of this study was the sample composition. Since the emphasis was on carrying out a detailed study of everyday interactions, the number of sessions was somewhat limited, in addition to its heterogeneity for enabling the analysis of the relationships and integration of the different dimensions of the educators' behavior with each child in particular. To be exact, it would be interesting to be able to integrate the role of kinesic behavior into these patterns, so that instruction in responsive communicative abilities in early education could be added to the training plan.

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 Committee for Ethics in Research and Teaching from the University of the Basque Country (UPV/EHU). Written informed consent to participate in this study was provided by the participants' legal guardian/next of kin. Written informed consent was obtained from the individual(s) for the publication of any potentially identifiable images or data included in this article.

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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T-pattern detection in the scientific literature of this century: A systematic review

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Introduction: Scientific literature contains mainly systematic reviews focused on substantial aspects, but there are also approaches that have combined both substantial and methodological aspects, which is our preferred option since it undeniably adds value. The aims of this study were: (1) to carry out a systematic review of the literatura on T-Pattern analysis (TPA), and (2) to explore the possible contribution of mixed methods research to the integration of qualitative and quantitative elements on a synthesis level.

Methods: Based on PRISMA guidelines, searches were carried out in the Scopus, PsycINFO, and Web of Science databases. The general search syntax was: "THEME" AND ("T-Patterns" OR "T Patterns") carried out in title, keywords and abstract. In addition, we included empirical articles on THEME and T-Patterns collected in other sources based on citations in several empirical works and consultations with different authors. This selection process resulted in 125 primary documents making up this systematic review.

Results: The results showed that the detection of structures in behavior patterns forms a nexus between studies carried out in very diverse fields and contexts. Most studies are observational, whilst the applicability and power of T-Pattern detection are extraordinary. It allows the researcher to go deeper in a robust analysis that responds to the integration of qualitative and quantitative elements which constitutes the leit motive of mixed methods; and also to discover the deep, hidden structure that underlies the respective databases, regardless of the methodology used in each study. The possibilities in assigning parameters notably increase the options for obtaining results and their interpretation.

Discussion: It is relevant the extraordinary strength and applicability of T-pattern detection. There is a high presence of T-pattern detection and analysis in studies using observational methodology. It is necessary commit to consolidating the methodological analysis of selected works, as taking individual and collective responsibility for improving methodological quality of TPA studies, taking advantage of the resources provided by the THEME program.

KEYWORDS

systematic review, PRISMA guidelines, T-pattern, TPA, THEME, mixed methods

1. Introduction

1.1. Toward a systematic review focused on methodology

The systematic review is a special type of literature review that confers added advantages, characterized by being "methodical, comprehensive, transparent, and replicable" (Siddaway et al., 2019, p. 751), and its use in decision making has rendered it extremely effective, especially given the significant increase in scientific literature (Anderson et al., 2013). The general requirement of the systematic review is to obtain a comprehensive synthesis of evidence (Higgins and Green, 2011).

The great advantage of systematic reviews, within their plurality, is that they enable the researcher to summarize many works that have a common nexus —specified as the focus— and to organize scientific evidence (Pluye et al., 2016). The expression *systematic review* was popularized in the 1990s, and its main defining feature is that it uses explicit criteria and procedures to identify, critically assess and synthesize relevant literature. As Greenhalgh points out (Greenhalgh, 1997, p. 672): "A systematic review is an overview of primary studies which contains an explicit statement of objectives, materials and methods and has been conducted according to explicit and reproducible methodology."

One of the challenges of the systematic review that Hawker et al. (2002) perceived at the beginning of this century, was the inclusion of evidence from different perspectives and methodologies; and their intention was to create a database that would serve as a resource for other researchers. We too are equally interested in combining the advantages of the conventional systematic review with a methodological approach, as we have demonstrated in previous works (Sarmento et al., 2018; Preciado et al., 2019, 2021; Alarcón-Espinoza et al., 2022; Tronchoni et al., 2022), thus going deeper into methodological development.

Scientific literature contains mainly systematic reviews that have focused on substantial aspects, but there are also approaches that have combined both substantial and methodological aspects (Durach et al., 2017), which is our preferred option since we believe it undeniably adds value. As Smalborne and Quinton (2011) affirm, systematic reviews in turn create an analytical framework for analyzing primary data, and our commitment is to consolidating the methodological analysis of the selected works.

In this sense, Hong and Pluye (2019) consider that by taking methodological aspects into account, new challenges arise in relation with how to carry out a critical assessment of the selected primary documents, and which differ from the methodologies used (Harden and Thomas, 2005). In order to tackle this challenge, it is necessary to delve deeper into the understanding of primary document profiles with a view to synthesizing and integrating the evidence contained in them (Hong et al., 2017); while Hong and Pluye (2019) suggest using critical appraisal, which has been successful in systematic reviews over the last few years (Katrak et al., 2004; Bai et al., 2012).

This systematic review arises from the desire to carry out a transparent synthesis study (Smalborne and Quinton, 2011) focusing on the common nexus in methodological aspects that cuts across two points. The main point is the review of the use of T-pattern detection, exploring their application within the framework of observational methodology (Anguera, 1979, 2003; Anguera et al., 2019, 2021) in comparison to other methodological approaches. The second methodological point that singularizes this study is that it places it in the crossroads of systematic review and mixed methods. Throughout the remainder of the introduction, we will both summarize the framework derived from the interaction between the systematic review and mixed methods, and also justify the interest of this systematic review of T-patterns.

1.2. The systematic review from mixed methods

In previous works we have dealt with the relevance of mixed methods, specifically how observational studies —both direct (Anguera and Hernández-Mendo, 2016; Anguera et al., 2017a) and indirect observation (Anguera et al., 2017b, 2018; Anguera, 2020)— can be considered mixed-method in themselves.

Over the last few years there has been an exponential growth in scientific literature relating to mixed methods, which is also undeniably relevant within the systematic review as well as in other types of synthesizing research evidence. Systematic reviews have traditionally shown a preference for quantitative evidence (Hong et al., 2017), but interest in qualitative evidence has grown progressively, especially in: the integrative review (Whittemore and Knafl, 2005), mixed-method review (Harden and Thomas, 2005), mixed-method research synthesis (Heyvaert et al., 2016), mixed research synthesis (Sandelowski et al., 2006), and mixed studies review (Pluye et al., 2009; Pluye and Hong, 2014). As Hong et al. (2017) reaffirm, these reviews enable a greater understanding of quantitative evidence, of qualitative evidence, and a corroboration of the knowledge obtained from both.

Quantitative output is based on the numerical values of variables or dimensions and on the results of statistical analysis, whilst it is considered qualitative when data is interpreted or summarized to generate outputs such as concepts, categories or theories. However, the distinction between qualitative and quantitative analysis is not clear, particularly since the interest in *continuum* between quantitative and qualitative poles has been gaining ground (Onwuegbuzie et al., 2011; Anguera, 2022).

In this sense, we can affirm the existence of a wide range of possibilities. Considering there are no quantitative methods that do not imply qualitative elements in some stages of the process (Chang et al., 2009; Sandelowski, 2014), nor research that is "inherently quantitative, qualitative, or mixed-method" (Newman and Hitchcock, 2011, p. 382), and "radical middle point" (Onwuegbuzie, 2012, p. 210) stands out. This represents an added value which opens the MIXED space (M: Methodological thinker; I: Integrative, integrated, and integral researcher; X: Xenophilous researcher; E: Empower; D: Development) that will mesh with the *mixed analysis crossover* (Onwuegbuzie and Johnson, 2021) where the analyses of the primary documents can be found, and which reaffirms the *continuum* between qualitative and quantitative elements rather than the opposition.

Over the last few years interesting advances have been made relating to qualitative and quantitative evidence review, centered both on quality (Pluye et al., 2009; Crowe and Sheppard, 2011;

Sirriyeh et al., 2012) and on the integration of evidence (Dixon-Woods et al., 2004; Mays et al., 2005; Tricco et al., 2016), at the same time that new modalities of synthesis have been proposed (Hong et al., 2017).

Heyvaert et al. (2013) illustrate how mixed methods contribute to the integration of qualitative and quantitative research in terms of synthesis. On a primary level, the researcher collects qualitative and quantitative data from the participants (interviews, systematic observation, surveys, etc.), combining them in a study; whilst in terms of synthesis, the systematic review applies the principles of mixed-method research, coming together in *mixed methods research synthesis* (MMRS). Even though the scientific literature about mixed methods on a primary level is exponential, much less attention has been paid to the possibilities of integration on a synthesis level (Sandelowski et al., 2006; Dellinger and Leech, 2007; Voils et al., 2008); although different terms have been coined to refer to ways of synthesizing empirical evidence (Heyvaert et al., 2013); such as *systematic review*, *integrative review*, *research synthesis*, *realist synthesis*, *qualitative review*, *narrative review*, *meta-analysis*.

Prior to the implementation of the *mixed methods research synthesis* (MMRS) modality (Harden and Thomas, 2010; Heyvaert et al., 2013), historically two main approaches to synthesis studies had been developed which highlighted the systematic review as a qualitative modality, and meta-analysis as a quantitative modality.

In the last few years there has been a growing interest in synthesizing evidence derived from studies with differing designs, and with qualitative, quantitative and mixed-method approaches. Similarly, there have been methodological advances in the integration of qualitative and quantitative evidence (Hong et al., 2017), along with those relating to the quality of primary documents (Pluye et al., 2009; Crowe and Sheppard, 2011; Sirriyeh et al., 2012).

Within the framework of primary studies that form the basis of systematic reviews, we find qualitative data (observational records, interview transcripts, diverse documents, etc.), with the predictable aim of adequately interpreting the proposals of the actors involved. Nevertheless, there are essentially two main problems that may arise, depending on the level of abstraction. On the one hand there is the analysis of patterns of simultaneous occurrence or lack of co-occurrence —if the risk of disaggregation is not avoided— that would imply transforming multi-dimensionality into one-dimensionality (Sivesind, 1999), thus impoverishing the batch information by reducing the length of the event-types in THEME, which is at the core of this research.

The connection between phases plays a crucial role in integration, and has recently been ratified by Pluye et al. (2018). We propose to adopt *quantitizing*, schematized in QUAL-QUAN-QUAL (Anguera et al., 2020), as a guide for the methodological analysis of primary documents in this systematic review. This allows us to move upwards in the integration typical of mixed methods on a synthesis level, tying in assimilation and configuration on the one hand, and dimensionality and case aggregation on the other.

Given that this systematic review of T-pattern detection has been carried out from a mixed-method approach, it is worth mentioning the words of Magnusson (2020a, p. 2):

> As a Mixed Methods approach, T-pattern analysis (TPA) passes repeatedly between qualitative and quantitative analyses, from data collection logging the occurrences of qualities (categories) and their real-time (quantitative) locations resulting in time-stamped data, here T-data, to the detection of T-patterns (qualities) [. . .], typically followed by both qualitative and quantitative analyses of the detected patterns.

1.3. The interest of a systematic review of T-patterns

The research question undoubtedly determines the structure and reach of the systematic review, and needs to be clearly defined (Perestelo-Pérez, 2013).

Our reasons for focusing on T-pattern analysis are as follows: (a) The relevance of an analysis centered on the description and detection of complex real-time patterns, which provides unsubstitutable analytical resources to psychological research; (b) the scientific community has at its disposal the computer program THEME, which, almost in its 7th version, and an academic version freely available for number of years; and (c) its extremely high applicability in the fields of psychology (Agliati et al., 2005; Diana et al., 2018 -primary document 37-; Portell et al., 2019 -primary document 90-), sport (Lapresa et al., 2013a -primary document 69-; Castañer et al., 2016 -primary document 30-; Amatria et al., 2017 -primary document 6-), ethology (Kerepesi et al., 2006 -primary document 66-; Jonsson et al., 2010), health (Blanchet et al., 2005 -primary document 66-; Haynal-Reymond et al., 2005; Arias-Pujol and Anguera, 2020 -primary document 10-), education (Suárez et al., 2018 -primary document 111-; Terrenghi et al., 2019; Escolano-Pérez, 2020 -primary document 39-), etc., regardless of the methodology used, whether it be observational (Gutiérrez-Santiago et al., 2011 -primary document 53-; Escolano-Pérez et al., 2019 -primary document 40-; Terroba et al., 2021 -primary document 116-) or experimental (Hocking et al., 2007 -primary document 58-; Casarrubea et al., 2015), and the scale, from micro (Hirschenhauser et al., 2002; Nicol et al., 2015) to macro (Koch et al., 2005).

The T-pattern project began in 1970 in the field of ethology (Magnusson, 1981), studying social interaction and organization in insects and primates, including humans, inspired by the work of Lorenz, von Frisch and Tinbergen. Throughout the decades since then, Magnusson (1975, 1978, 1981, 1996, 2000, 2005, 2006, 2016, 2017, 2018, 2020a,b; Magnusson et al., 2016) has worked unceasingly on the definition and mathematical development of T-patterns, or temporal patterns, as well as on the construction of the necessary algorithms. A T-Pattern is defined as the structure formed by a series of events that take place concurrently or sequentially with greater frequency than would randomly be expected if all the events were independently distributed. These events —that in observational methodology terms we shall call multi-events (Bakeman and Quera, 1996)— occur in the same order, maintaining temporal distances between them that remain invariant, or at least relatively, with respect to the null hypothesis that each event is independent and randomly

distributed temporally (Magnusson, 1996, 2000). According to Magnusson (2000, pp. 94–95), when THEME detects an occurrence of "A" followed by "B" within a critical interval, it generates a simple T-pattern (AB). Occurrences of simple T-patterns become events, which are then treated as initial event-types at the subsequent detection level. Theme repeats this process, level by level (from 1 to n) in search of critical interval relationships featuring T-patterns detected in previous levels. Accordingly, all T-patterns, $Q = X_1\ X_2\ \ldots\ X_m$, can be divided into at least two events within a critical interval. In other words QLeft [d1,d2] QRight; QLeft and QRight can be part of a more complex T-pattern X1. . .Xm expressed as the terminals of a binary-tree. In other words, critical interval relationships may be detected between a simple T-pattern (AB) and an event-type K, giving rise to a level-2 T-pattern with three events [(AB)K] or (see **Figure 1**) between two simple T-patterns (AB) and (CD), giving rise to a more complex level-2 T-pattern with four events [(AB)(CD)].

The essence of a T-pattern project is the discovery of hidden structures from the critical interval between point series with respect to the temporal dimension; thus revealing itself to be a highly valuable analytical instrument which, at the same time, entails a permanent dialogue with the respective conceptual framework.

The basic premise of T-pattern detection is that the interactive flow, or chain of behaviors, consists of structures of variable stability that can be visualized through the detection of underlying T-patterns (Suárez et al., 2018 -primary document 111-; Portell et al., 2019 -primary document 90-; Arias-Pujol and Anguera, 2020 -primary document 10-; Santoyo et al., 2020 -primary document 105-). It is not easily visible nature increases its potential for discovery, given that the researcher's interest lies in being able to extract the internal structure that shows the key to the occurring behavior (Arbulu et al., 2016). One great advantage of T-pattern detection lies in the fact that it is not constrained by implicit suppositions about the distribution of studied behaviors; and it enables the selection of minimum number of occurrences and significance level –among other parameters– thus aiming to achieve a clear control over random discoveries.

The relevance that interest in T-pattern detection has gained, along with the applicability it has shown in the last few years justify this systematic review, whose intention is to highlight its possibilities and contribute to a better understanding of this analytical technique. We will not include a systematic review of the T-system (T-Bursts, T-Markers, T-Predictors, T-Retrodictors, ±T-Associates, T-Packets, and T-Composition), because publications regarding these figures are still scarce and so it will be a future aim, although a systematic review of some of these figures has already been carried out (Sáiz-Manzanares et al., 2022).

Having demonstrated the interest contained in this study, the aim is to carry out a systematic review of T-Pattern detection, focused particularly from a methodological perspective.

2. Materials and methods

The bibliographical search was carried out in the following databases: SCOPUS, PsycINFO of the American Psychological Association, and Web of Science of Clarivate Analytics (WOS), in line with PRISMA guidelines (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) (Liberati et al., 2009; Moher et al., 2009; Siddaway et al., 2019; Page et al., 2021). The search was performed in title, keywords and abstract; and the general search syntax was: "THEME" AND ("T-Patterns" OR "T Patterns").

The following inclusion criteria were used, which enabled the application of the corresponding filters: (a) A period from 2000 to 2022; (b) articles published in scientific journals; (c) empirical studies; (d) the thematic areas of Psychology, Behavioral Sciences, and Sport Sciences; (e) English or Spanish languages; (f) access to the whole text (open access, access through the institutions of authors, or purchase).

The following exclusion criteria were taken into account: (a) Documents whose content did not conform to either THEME or T-patterns (these terms were used in a different sense to that defined in the previous sections); (b) document published with a double work codification: as if it were articles in the journal *Neuromethods* and book chapter, but are in fact chapters of the work of Magnusson et al. (2016); and (c) articles that focus on T-patterns and THEME, but are conceptual-methodological in nature and not empirical studies nor systematic reviews.

In addition, the references of the first sample of papers were reviewed in order to request new articles that could meet the criteria indicated.

The included works were reviewed in order to codify: (1) general extrinsic characteristics; (2) bibliometric aspects related to recognition within the scientific community; (3) methodological characteristics considering three levels of codification. Those

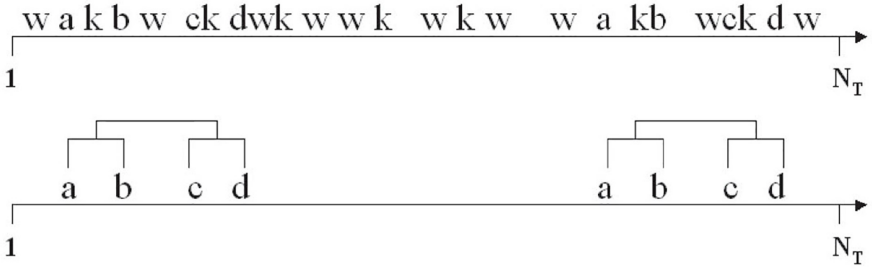

FIGURE 1
T-pattern detection (Magnusson, 2000, p. 95), with permission of the author.

levels of codification were as follows: (3.1) identify the method explicitly declared by the authors in order to identify the studies based on observational methodology; (3.2) when the paper used observational methodology, the main aspect link to the T-pattern analysis is codified based on Guidelines Reporting Evaluations based on Observational Methodology GREOM (Portell et al., 2015); (3.3) in all the papers that characterize the THEME parameters used to detect T-patterns.

The review of each article was carried out independently by two researchers. The degree of initial agreement was calculated with the Cohen's kappa coefficient ($\kappa = 0.96$).

3. Results

3.1. Study selection

Figure 2 presents the PRISMA diagram (Page et al., 2021) that shows the selection process of the 125 primary documents that make up this systematic review (see Supplementary Table 1).

3.2. Primary document profile

The selected primary documents are of diverse descriptive criteria which we will address here with a view to better clarifying their characteristics.

3.2.1. Extrinsic characteristics of the primary documents

Supplementary Table 2 shows the extrinsic characteristics of the primary documents, and includes information corresponding to: code, authors, number of authors, country of origin, year, research field, and sub-field. It provides a broader view of this scientific production along with highlighting some aspects of it.

Publication date (Figure 3) illustrates an increase from 2010, after some anecdotal years, showing a succession of peaks and troughs since then, which, in any case, justifies a consolidation in the use of T-pattern detection analysis.

We quantified the number of authors from each publication, and Figure 4 shows the authors' provenance. Most notably, Spain stands out, with three hundred and forty-two primary documents, well ahead of Italy (65), Portugal (51), and Iceland (31).

In terms of the substantive scope (Figure 5), sport is significantly striking, and it has been applied successfully to different sports modalities. Other less prominent fields of study were animal behavior, physical activity, school, and health.

3.2.2. Bibliometric characteristics of the primary documents

Supplementary Table 3 presents the bibliometric characteristics of the primary documents, with the following information: code, authors, database, journal, impact factor, quartile (in accordance with the Web of Science), and quotations.

As previously indicated in the Section "2. Materials and methods," the primary documents were taken from the SCOPUS, PsycINFO, and WOS databases, in addition to other sources (28 documents, therefore 22.4%) which were accessed from references. We believe it interesting that thirty-seven primary documents (29.6%) were found in the three databases simultaneously (Figure 6).

Given our interest in the scientific quality of the primary documents, we considered it relevant to know whether or not the respective journals —in the years that the documents were published— were included in *Web of Science*. A total of sixty-six articles (52.8%) has an impact factor, with a clear majority of the primary documents (26) being found in quartile 2 (Figure 7).

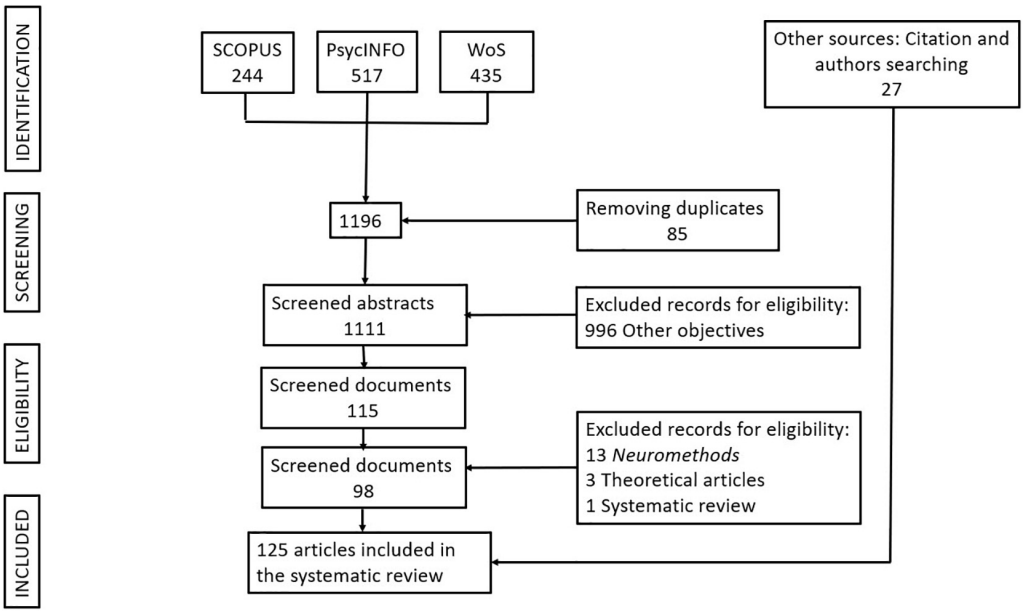

FIGURE 2
PRISMA diagram.

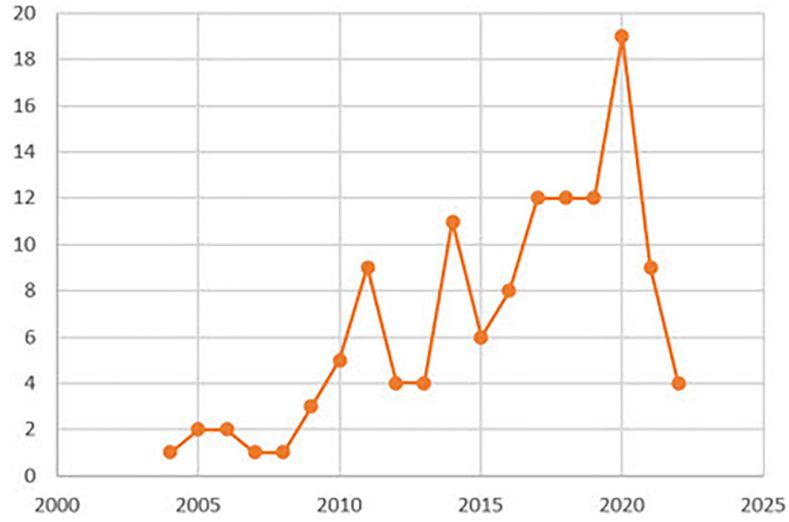

FIGURE 3
Distribution of primary documents by years.

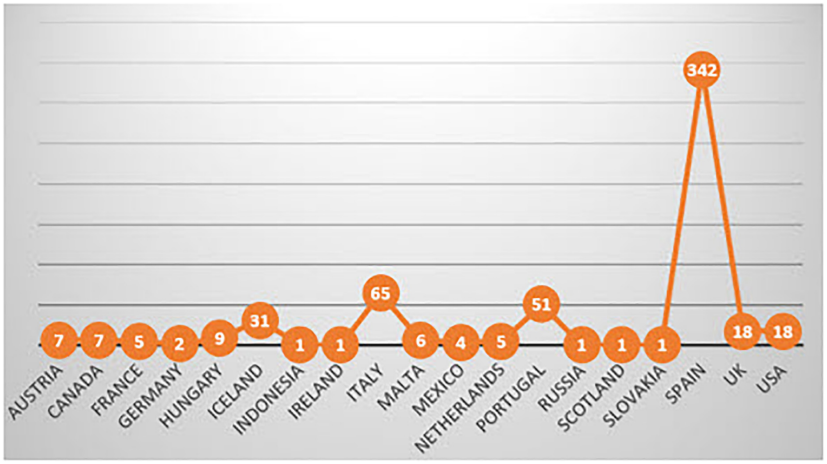

FIGURE 4
Authors' countries.

3.2.3. Methodological characteristics of the primary documents [I]: Data collection, management, data quality control, computer programs, and data analysis

Supplementary Table 4 shows part of the methodological characteristics of the primary documents, providing information about: codes, authors, methodology, design, participants, ethical standards, instrument for collecting data, and number dimensions/categories.

It seems evident that the most repeatedly applied methodology is observational, whether alone (93), or in multi-method studies, in which it is complemented with experimental (6), or with quasi-experimental (5), or with interview (1) (see **Figure 8**). It is curious that in 6 primary documents the mixed method is explicitly named as the methodology to be applied. Based on previous developments (Anguera and Hernández-Mendo, 2016; Anguera et al., 2017a), we consider that the application of observational methodology implies regarding it as mixed-method in itself. Similarly, we have witnessed the same scenario in indirect observation studies (Anguera et al., 2018).

In **Supplementary Table 4** we have included information corresponding to the design, when indicated, which was in 68% of the primary documents. Furthermore, 95.2% of the primary documents specified participant characteristics. The percentage of primary documents that mention ethical standards is lower, at 52%.

In terms of data collection, it is explicitly mentioned in 88% of the primary documents. Due to observational methodology being the most widely applied, there is logically an abundance—84.8%— of made-to-measure (*ad hoc*) instruments. Many of them have been given proper names (SOBL-2, SOCIN, SOPROX, SCOT, SOF5, SOBJUDO-KSGA, OSMOS, SOFEO, SOFCO, ADDEF, OI-INJURIES-FOOTBALL, OTSJUDO, IOUPPERLIMB_FLEX_EXT, OBKA, SINCROBS, ESGRIMOBS, SORPS) or have used an existing

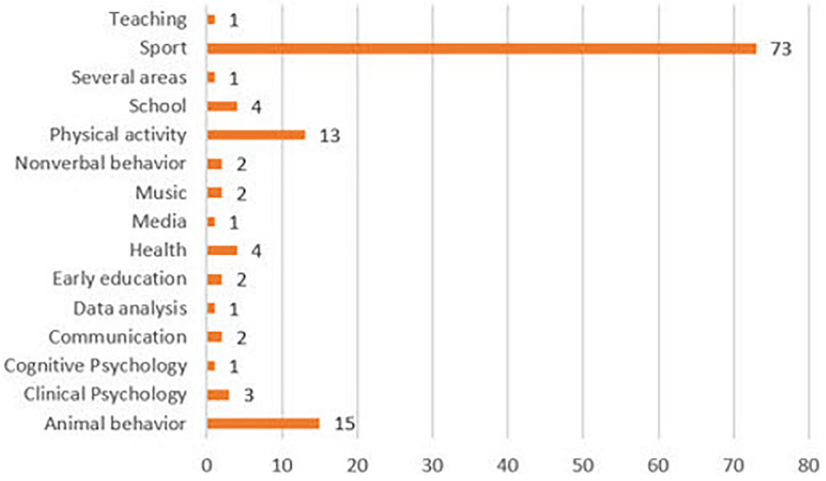

FIGURE 5
Field.

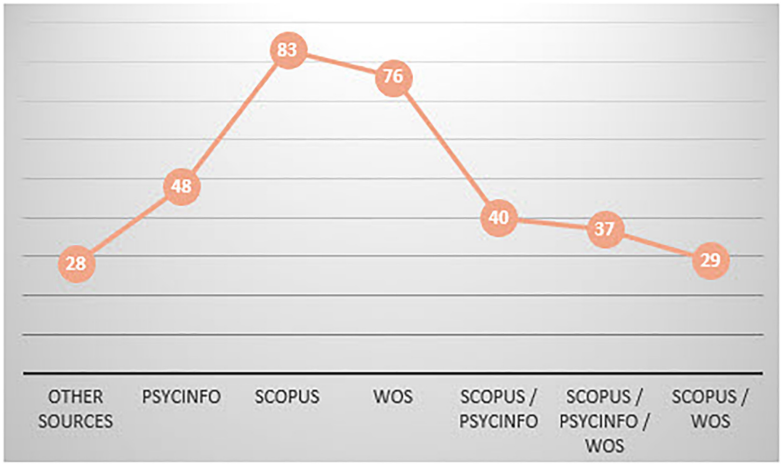

FIGURE 6
Database.

proper name (SOF, SOBL, SOFBAS, SOCTM, SsObserWork). The number of dimensions/categories is very heterogeneous.

The methodological characteristics of the primary documents are completed in **Supplementary Table 5**, including information about computer recording programs, data quality control and the computer programs used, computer programs for data analysis, and data analysis.

In terms of recording programs, whilst being secondary to the aims in this systematic review, out of the a hundred-three studies that specified it, what stands out is the use of LINCE/LINCE PLUS, in 41.6% of the primary documents (records can be directly exported to THEME), whilst the percentage for MATCH VISION STUDIO was 15.2%.

Seventy-two primary documents included data quality control programs, with the majority using GSEQ (48.6%) and LINCE/LINCE PLUS (33.3%).

The use of THEME is inevitable for T-Pattern detection, since it is the only program that allows it. Given that THEME was part of the search syntax, it was obviously used in all the primary studies; however not all the primary documents specified which of the different versions of THEME, available since the year 2000, were used. Among the 31.2% of primary documents who did mention it, the versions used were: THEME 5.0, THEME 6.0, and THEME Edu.

It is clear that T-pattern detection can be complemented with other analysis techniques, as is shown in **Supplementary Table 5** and **Figure 9**; this being the chosen option for seventy primary documents, notably with the following: χ^2(11.2%), lag sequential analysis (11.2%), and descriptive analysis (7.2%).

3.2.4. Methodological characteristics of the primary documents (II): T-pattern detection

This forms the study core of this systematic review, which focuses precisely on T-pattern detection (**Supplementary Table 6**).

We are especially interested in knowing how the primary document search parameters were set. In accordance with the *Reference Manual Pattern Vision Ltd* (2018), decisions are required

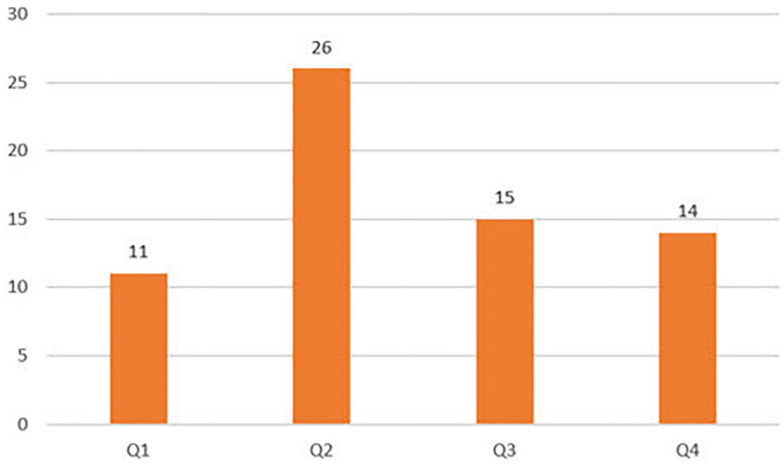

FIGURE 7
Quartils (from 66 articles).

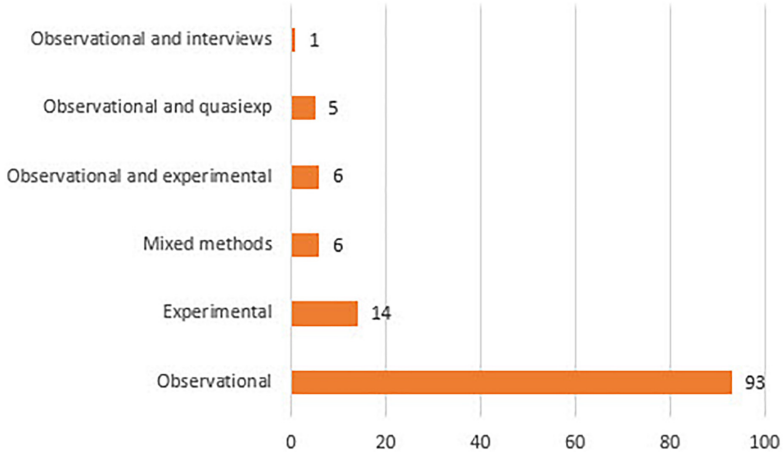

FIGURE 8
Methodology.

about: Critical Interval Type, Baseline Probability Type, Minimum Occurrences, Burst Detection, Significance Level, Max Search Levels, Lumping Factor, Exclude Frequent Event Types (Events), Minimum Samples. However, there are no published studies that include information about all of them.

Firstly, information was collected regarding the *Minimum Occurrences* (with a minimum value of 2) (see **Figure 10**), with 59.2% of the primary documents containing this information.

Given that some primary documents (22.4%) take into account redundancy reduction (*FARR*) (the recommended value is 90%), it is included in **Supplementary Table 6**. Furthermore, *randomization* is recommended in order to know whether the detected T-patterns deviate significantly from *random expectation*. The types of *randomization* offered by THEME that some primary documents do mention (28%) are: *shuffling*, *rotation*, and *shuffling and rotation*. We did not include the following parameters in the table: *Minimum samples*, or *FARR*, which usually adopts a standard value of 99 but in some primary documents is different (Wedl et al., 2011 -primary document 123- is 90); *levels of hierarchy*, typical of each database (Wedl et al., 2011 -primary document 123- is 5); *selection of free heuristic critical interval setting* (Pic et al., 2021 -primary document 89-); or "minimum sample," which can vary greatly depending on the study [is 51 in Casarrubea et al. (2011) -primary document 25-; 100 in Wedl et al. (2011) -primary document 123-].

The number of selected T-Patterns is highly heterogeneous in the primary documents.

In terms of T-pattern selection (15.2% of the studies), the existing options are quantitative, qualitative and structural; moreover, in one of the primary documents (Amatria et al., 2017 -primary document 6-) there is a proposal for qualitative and quantitative filters that was taken into account in later works.

A massive 92% of the primary documents present results, and we have included basic information. Among the results, 15 use tables, 29 use figures, 47 use tables and figures, 10 use tables and figures with incorporated photographs, 1 uses figures with diagrams, 1 uses figures with drawings, and 1 uses tables with photographs.

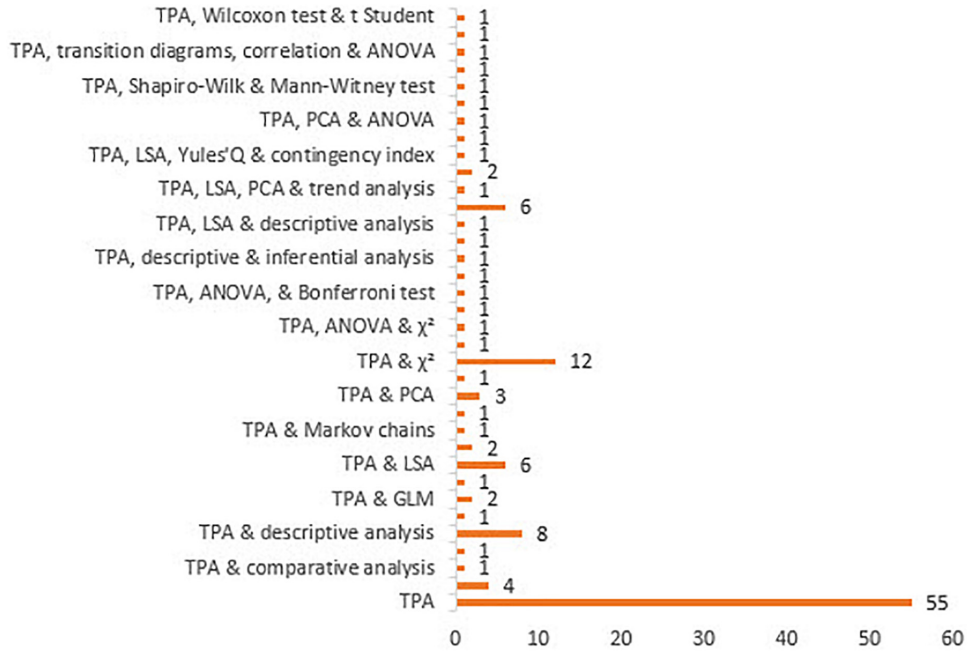

FIGURE 9
Data analysis.

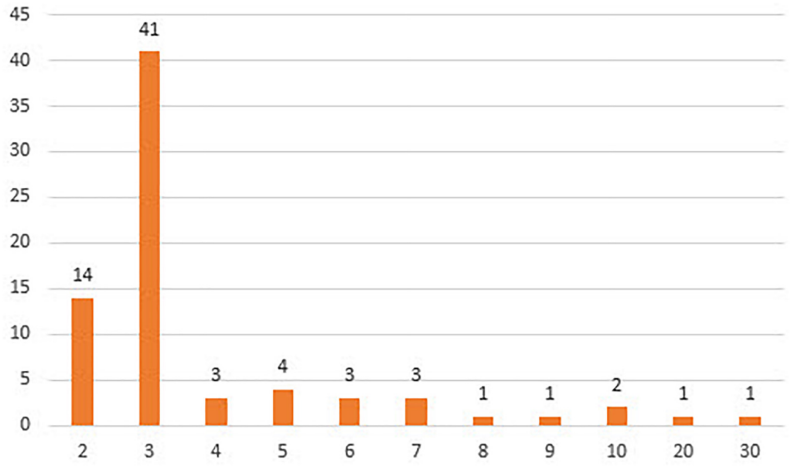

FIGURE 10
Minimum occurrences.

4. Discussion and conclusion

The discovery of hidden patterns in behavior is a task frequently faced by numerous researchers across many investigation areas, e.g., biology, psychology, psychiatry, sport science, robotics, finances, etc. But discovering such patterns has proven to be a challenging task due to a lack of three key matters: first of all, adequate formalized models of the kinds of patterns to look for; secondly, corresponding detection algorithms and, last but not least, their implementation in available software. Over the last decades, these obstacles have been progressively overcome as a result of the introduction of the mathematical T-pattern model and the continued improvement of a technique known as T-pattern detection and analysis (TPA). Several recently published papers have addressed the concepts and examples concerning the applications of TPA in the study of behavior both in human and non-human subjects (Casarrubea et al., 2015, 2018, 2022), that could, together with this systematic review, assist beginners in TPA methodology striving to gain an overview of TPA research.

We highlight the relevance of T-pattern detection in the broad spectrum of fields and sub-fields covered in this systematic review. The detection of structures in behavioral records forms the common nexus between studies carried out in very diverse variants and fields; whether it be from human participants (with highly diversified characteristics, in very different contexts, and analyzing the relationship with behavior, hormone levels, personality, culture,

etc.); or animals (dogs, cats, rats, starlings, chickens…); or in studies about the interaction between hormones and behavior; or from movements involved in an individual's facial expressions, to extensive migratory movements in the marine environment.

A necessary demarcation, as we have justified since our seminal work on observational methodology, is the difference between the use of observation as a method or as a technique (Anguera, 1979, 2003). This difference is well-illustrated in the papers reviewed. They are mainly works that use observation as a method, although T-pattern detection is also used in experimental studies carried out in laboratories, in which observation plays a merely technical role. One cornerstone element is the observation of visually —or even acoustically— perceptible events or behaviors, that are nearly always organized in clusters, and which on many occasions correspond to interactive situations.

Regarding the type of observational design used by studies that apply THEME (I/P/U, I/P/M, I/F/U, I/F/M, N/P/U, N/F/M) —these initials correspond, respectively, to the observational designs Idiographic/Punctual/Unidimensional, Idiographic/Punctual/Multidimensional, Idiographic/Follow-up/Unidimensional/, Idiographic/Follow-up/Multidimensional, Nomothetic/Punctual/Unidimensional, and Nomothetic/Follow-up/Multidimensional- (Anguera et al., 2001; Sánchez-Algarra and Anguera, 2013), it is interesting to highlight that the design is multidimensional in every case (although in two of them the authors define it as one-dimensional). This is consistent with the interest in the use of THEME for the analysis of concurrences, not only between behaviors but also between behaviors and other elements within the context. There is more variability in the other two characteristics of the observational design—idiographic/nomothetic and punctual/follow-up. One element that should be taken into account is that in cases where the design includes just one session, it is intra-sessional monitoring that is analyzed with THEME.

Due to our interest in the methodological aspects that we feel enrich a systematic review, we are aware that in this particular review there are primary documents of varying quality, as can be seen in **Supplementary Tables 3–6**. For this reason we decided to find out the impact indexes of those which have it (**Supplementary Table 3**), with a view to identifying those primary documents which are formally considered of better quality.

Whilst THEME appears to be sensitive to low frequency T-patterns, the greatest challenge for the researcher lies in interpreting the results. In most of the studies not all the T-patterns are interpreted, although there are primary studies in which they are interpreted in terms of their growing length (number of successive codes implicated).

While the main contribution of the THEME program is the detection of temporal patterns, it is also possible to detect regular and hidden behavioral patterns depending on the order parameter; and from the assignation of a constant duration to each unit of behavior, which supposes new possibilities for sequential data analysis (Lapresa et al., 2013a,b). There are a number of prominent studies (Alsasua et al., 2018 -primary document 3-; Amatria et al., 2019 -primary document 7-; Alsasua et al., 2021 -primary document 2-) in which T-pattern selection is carried out in accordance with multi-events that show a sequence of consecutive behaviors which make up a specific action. These are identified by the T-patterns themselves (for example, a shot on goal or an attacking tactic in soccer, or a basketball shot), and show efficient-type sequential examples.

Similarly, we would like to highlight that T-pattern detection has been successfully used to differentiate individuals with stereotypes or atypical behavior (Brilot et al., 2009 -primary document 14-), as well as certain profiles of psychiatric patients.

Some primary documents (Burgoon et al., 2014 -primary document 15-) do not only emphasize that T-pattern detection confirms the regularities that show up in behavioral sequences, but they also highlight the role of THEME in discovering patterns that remain "hidden." Ultimately, the strength of T-pattern detection lies in its ability to localize the connections between temporally related events —although not necessarily contiguous— with the aim of identifying combinations of behaviors that make up a pattern-type structure.

We consider it relevant —due to the possibilities it presents— that in different primary documents (Lapresa et al., 2013b -primary document 69-; Tarragó et al., 2015 -primary document 113-) a constant duration (=1) was conventionally assigned to each event-type, using the THEME program v.6 Edu for the detection of regular structures; bearing in mind that the importance of the analysis does not lie in the duration of each one of the behavior chains, nor in the distance between them, but precisely in their internal sequentiality.

Likewise, we highlight the importance of the qualitative and quantitative filters proposed by Amatria et al. (2017) (-primary document 6-), that were taken into account in some of the primary documents (Amatria et al., 2019 -primary document 7-; Lapresa et al., 2018 -primary document 73-).

In many of the primary documents, the T-pattern detection was complemented by other analysis techniques, and this complementarity is considered recommendable, as indicated in Lapresa et al. (2018) (-primary document 73-), for various reasons. Said reasons are as follows: (a) Lag sequential analysis identifies relationships between individual events that make up a multi-event (Bakeman and Quera, 2011), whilst THEME is able to identify significant relationships between multi-events, or clusters (Tarragó et al., 2017 -primary document 114-); (b) Although THEME (v.6 Edu) detects a negative gravity or repulsion zone in the calculations, it can only generate an inhibiting T-taboo structure (Magnusson, 2000, 2005) when the taboo behavior does not occur. We have not found any studies in which T-taboos have been investigated in THEME (v.6 Edu), although they are relatively common in lag sequential analysis studies based on inhibiting relationships (Tarragó et al., 2017 -primary document 114-).

We would also like to underline that in the primary documents containing other T-pattern detection techniques, there is agreement that THEME detected more T-patterns than the regularities detected by other analyses (Alonso-Vega et al., 2022-primarydocument 1-), and, at least, was maintained in one significant correlation (Brilot et al., 2009 -primary document 14-).

Some primary documents (Brilot et al., 2009 -primary document 14-) consider it difficult to validate T-pattern detection when there is a large quantity of data, and their recommendation in these cases is a statistical comparison with random data, with the aim of achieving an objective confirmation of T-pattern significance.

There five primary documents that were considered atypical (Asher et al., 2009 -primary document 12-; Jonsson et al., 2010 -primary document 63-; Casarrubea et al., 2018 -primary document 24-; Hunyadi, 2019 -primary document 59-; Szekrényes, 2019 -primary document 112-), due to them consisting of brief references to different studies.

There are three main conclusions that can be drawn from this systematic review:

Firstly, there is the extraordinary strength and applicability of T-pattern detection. This enables the researcher to go deeper into a robust analysis, which satisfies the integration of the qualitative and quantitative elements that make up the mixed methods *leitmotif*; thus enabling the discovery of the deep, hidden structure that lies beneath the respective databases, regardless of the methodology used in the study they come from. The diverse possibilities that exist in parameter assignation notably increase the options for obtaining results and for their interpretation.

Secondly, there is the greater presence of T-pattern analysis (TPA) in studies using observational methodology, relative to the use of this technique when other research methods are used.

Thirdly, as systematic reviews can create a framework for analyzing primary data, we musts commit to consolidating the methodological analysis of selected works as well, as taking individual and collective responsibility for improving methodological quality of TPA studies, taking advantage of the resources provided by the THEME program. At the heart of TPA is a pattern detection algorithm that has been in use in number of different scientific fields for over 30 years, were future improvements will deliver more advanced display of results, data import/export, parallel processing, and faster pattern detection.

Data availability statement

The original contributions presented in this study are included in this article/**Supplementary material**, further inquiries can be directed to the corresponding author.

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.

Publisher's note

Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpsyg.2023.1085980/full#supplementary-material

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Sudden bio-mathematical self-similarity and the uniqueness of human mass societies: from T-patterns and T-strings to T-societies

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With the explosive growth of human knowledge especially in the twenteeth century with even greater facilitation of access to knowledge, the world of even relatively recent great thinkers becomes daunting as seen from a modern viewpoint. Recently, humans ignored the existence of the complex intracellular world of cell organs, giant information molecules such as DNA, societies of specialized worker molecules (proteins), and generally the surprising nanoscale world visible to humanity since only a few decades ago. Moreover, computational power and video technology were inaccessible to all scientists from, for example, Aristotle to Freud, so new views and ideas seem to be expected about phenomena at all scales including nano and human. Some have arrived very recently. Thus urgently needed knowledge about the biology of animal and human behavior received the first Nobel Prize as late as 1973, in Physiology and Medicine, shared by Karl von Frisch, Konrad Lorenz, and Niko Tinbergen. Lorenz's Nobel lecture was entitled "Analogy as a Source of Knowledge" which did not mention self-analogy (self-similarity) as none of the species studied were part of others and knowledge of the nanoscale phenomena at the heart of this article had barely become available. The views and empirical findings presented in this article depend on such recent intracellular nanoscale insights and the development of a set of mathematical patterns, called T-system, of which only two are considered, the self-similar (i.e., parts having a structure similar to the whole) T-pattern and the derived T-string, a T-patterned material string (here, polymer or text). Specially developed algorithms implemented in the THEME^{TM} software for T-pattern detection and analysis (TPA) allowed the detection of interaction T-patterns in humans, animals, and brain neuronal networks, showing self-similarity between animal interaction patterns and neuronal interaction patterns in their brains. TPA of DNA and text also showed unique self-similarity between modern human literate mass societies and the protein societies of their body cells, both with Giant Extra-Individual Purely Informational T-strings (GEIPIT; genomes or textomes) defining the behavioral potentials of their specialized citizens. This kind of society is here called T-society and only exists in humans and proteins, while the self-similarity between them only exists in human T-societies.

KEYWORDS

interaction, T-pattern, mass societies, RNA to DNA-worlds, self-similarity, interactive emergence society, T-society, human uniqueness

1. Introduction

This article is a part of the Frontiers Research Topic collection: "Behavior and Self-Similarity between Nano and Human Scales: From T-pattern and T-string Analysis (TPA) with THEME to T-Societies" with a common reference free online article "T-patterns, external memory, and mass-societies in proteins and humans: In an eye-blink, the naked ape became a string-controlled citizen" (Magnusson, 2020b). The research presented here has, since the 1970s, created a still-growing set of temporal and spatial (string) mathematical patterns, called the *T-system* as a tool and language for the detection, analysis, and description of behavioral and other biological structures. Here, the focus is on its latest addition, called the T-society, which only implicates two of its earlier patterns, the T-pattern and the T-patterned material string called a T-string (see below).

Discoveries in the biology of animal and human behavior received the first Nobel Prize as late as 1973, in Physiology and Medicine, shared by Karl von Frisch, Konrad Lorenz, and Niko Tinbergen. In his Nobel Prize lecture "Analogy as a Source of Knowledge," Konrad Z. Lorenz wrote "Ethologists are often accused of drawing *false* analogies between animal and human behavior. However, no such thing as a *false* analogy exists: an analogy can be more or less detailed and hence more or less informative" (Lorenz, 1973, p. 98, or see Lorenz, 1974). "There is, in my opinion, only one possibility of an error that might conceivably be described as the 'drawing of a false analogy' and that is mistaking a *homology* for an analogy. Homology can be defined as any resemblance between two species that can be explained by their common descent from an ancestor possessing the character in which they are similar to each other" (Lorenz, 1973, p. 99, or see Lorenz, 1974).

Lorenz did not mention self-analogy (self-similarity) as none of the species studied was a part of another. Knowledge was also still limited about intracellular nanoscale phenomena such as the ribosome discovered in 1952 by G. E. Palade who received the Nobel Prize in 1974 for its further study[1] The central role of the ribosome has since been widely recognized: "The ribosome translates the DNA code into life. The Nobel Prize in Chemistry for 2009 awards studies of one of life's core processes: the ribosome's translation of DNA information into life. Ribosomes produce proteins, which in turn control the chemistry in all living organisms." [2] "At the beginning of the twentieth century, the chemical foundations of life were mysterious. Today we know how many of the most important processes function, all the way down to the atomic level." The Nobel Prize in Chemistry for 2009 was awarded jointly to V. Ramakrishnan, T. A. Steitz, and A. E. Yonath (Ramakrishnan, 2018) "*for studies of the structure and function of the ribosome*." [3]

The ribosome and the RNA World hypothesis[4] are at the heart of this article.

The empirical and theoretical approach began with a study of both individual and social behavior of other animals from ethological, behavioristic, and linguistic viewpoints with varying emphasis on direct observation in natural settings or on laboratory experiments regarding verbal and non-verbal probabilistic interaction contingencies, as well as the (temporal) syntactic structure of verbal behavior (vocal and written) and creativity. The present study is the latest in a series with mainly an ethological viewpoint (Magnusson, 1975, 1983, 1988, 1989, 1996, 2000, 2004, 2005, 2006, 2009, 2016b, 2017, 2018, 2020a,b, 2022; Magnusson and Beaudichon, 1997; Magnusson et al., 2016). This study began in the 1970s with a study of communication and social organization in social insects and primates (including humans) (Magnusson, 1975) searching for a valid and useful definition of what distinguishes humans from other animals. One suggested answer is presented here, found through the intracellular polymer nanoworld of DNA, RNA, proteins, and ribosomes combined with the T-system concepts of T-string and the latest addition T-society which is the focus of this study.

1.1. The mathematical and computational approach

Computers made it possible to search for hidden patterns given adequate mathematical definitions and detection algorithms implemented in computer programs both still in short supply. After considering and testing standard multivariate statistical methods and software (see, for example, Colgan, 1978) available in major statistical software packages, notably, SAS and SPSS (Magnusson, 1983), it appeared that for the analysis of real-time behavioral records, more adequate pattern models were needed with corresponding detection algorithms and software which led to the so-called temporal configuration and later T-pattern (Magnusson, 1983, 1988, 1996, 2000). The detection algorithms were initially developed and implemented as a 3k-line THEME PDP 8 Fortran IV software (Magnusson, 1983), but now the >300k-line versions have been extensively used mostly for temporal T-pattern detection and analysis (TPA) of human, animal, and neuronal brain network interactions (Anolli et al., 2005; Casarrubea et al., 2015, 2022; Nicol et al., 2015; Magnusson et al., 2016; Anguera et al., 2023). This has gradually led to the T-system, a set of mathematical patterns and a language and tool for the analysis and comparison of temporal and spatial structure across species, scales, and organizational levels (Magnusson, 2020b).

T-pattern detection and analysis (TPA) with the THEME™ software (patternvision.com) has been applied in many areas with studies published in two dedicated edited volumes (Anolli et al., 2005; Magnusson et al., 2016) and in many studies as already reviewed (Casarrubea et al., 2015; Consuelo et al., 2022; Anguera et al., 2023, and see related, Casarrubea et al., 2018, 2022).

1 https://www.nature.com/scitable/definition/ribosome-194/

2 See https://www.nobelprize.org/prizes/chemistry/2009/press-release/

3 See https://www.nobelprize.org/prizes/chemistry/2009/illustrated-information/

4 https://www.ncbi.nlm.nih.gov/books/NBK26876/

1.2. The T-pattern model and detection algorithm

The following sections describe essential aspects of the T-pattern model and detection algorithms while referring to recent free open-access online publications (for example, Magnusson, 1996, 2000, 2017, 2020a,b).

1.3. T-data

The type of data, called T-data, referred to by all T-system definitions is labeled series of positions on a single discrete dimension, 1 to T, here, in time or on strings. The series label specifies the type of event in time or element in a string (see Figure 1).

1.4. The T-pattern

The T-pattern, which is a self-similar binary tree, that is, has the same statistical relationship at each non-terminal node. It attempts to consider several structural aspects of behavior such as order (including concurrence), modularity, and hierarchy.

A T-pattern, Q, is defined as m ordered components, $X_{1..m}$, recurring on a single discrete dimension within [1, T], where each component is either a T-data series or a T-pattern, noted as follows:

$$Q: X_1 \approx dt_1 X_2 \approx dt_2 ... X_i \approx dt_i X_{i+1} \ldots X_{m-1} \approx dt_{m-1} X_m$$

(m = length), where the **≈dt** ($0 \leq dt$) terms stand for the approximate distances between the consecutive components X of the pattern when it occurs within T-data, each significantly invariant relative to a zero hypothesis of independent random distribution of each component with constant baseline probability per unit time given by its number of occurrences divided by T.

In terms of the intervals of variation of the **≈dt** terms, the definition comes closer to the currently used detection algorithms:

$$Q: X_1 [d_1, d_2]_1 X_2 [d_1, d_2]_2 ... X_i [d_1, d_2]_i X_{i+1} \ldots X_{m-1} [d_1, d_2]_{m-1} X_m$$

(m = length), where the intervals $[\ d_1, d_2\ ]_i$; $0 \leq d_1 \leq d_2$ are the intervals within which $\approx dt_i$ varies.

1.5. T-pattern detection and analysis (TPA)

This section describes the essentials of the T-pattern detection algorithm implemented in the Theme software.

The current binary-tree bottom-up search algorithm relies on finding in T-data one or more pairs of series related by so-called critical intervals and then adding their occurrence series to T-data, thus including them in the continued search for more pairs and possible pairs of pairs, etc.

An evolution algorithm gradually builds the patterns while removing redundancy. The binary tree approach has allowed the detection of numerous and complex T-patterns, but as shown elsewhere, this does not guarantee the detection of all T-patterns in the data requiring possibly trinary or higher trees (Magnusson, 2020a).

All the X terms, and especially in small data, can thus be simple events and the T-pattern may have no inherent modular, hierarchical, or self-similar structure as suggested by pattern diagrams, which may simply be artifacts of the binary tree detection procedure, but this can normally be seen in T-pattern diagrams with non-terminal nodes (sub-patterns) not being more frequent than the whole pattern.

Self-similarity, meaning that a part has the same structure as the whole (see, for example, dictionary.com), is a central aspect of fractal structures which in mathematics are infinite, but in nature, they do not have infinite levels "self-similarity over a range of scales is a hallmark of fractal geometry," (Kautz, 2011, p. 280) and "Physical fractals typically display statistical self-similarity over scales differing by just a few factors of 10. Nonetheless, as Mandelbrot first observed, it is extremely useful to recognize the fractal properties of natural shapes" (Kautz, 2011, p. 293).

In his book "The Fractal Geometry of Nature," Mandelbrot implicates self-similarity in many ways, for example:

> "Furthermore, most fractals in this Essay are invariant under certain transformations of scale. They are called scaling. A fractal invariant under ordinary geometric similarity is called self-similar" (Mandelbrot, 1983, p. 18).

The T-pattern is a self-similar tree structure, that is, with the same critical interval relationship (CIR) at each non-terminal node; moreover, it recurs with significant translation symmetry (as defined also by the critical interval relationship, CIR). It can thus also be seen as a particular kind of recurring semi-rigid CIR-based statistical fractal pattern (see Figure 2 and Magnusson, 2017, 2020a,b).

1.6. The T-string

The T-string is a material string of length T of elements 1..T, where some of the elements form T-patterns, for example, RNA, DNA, proteins, and text (see Magnusson, 2020b, section 5). The T-string is thus seen as a material version of a discrete-time scale (see T-data above) of the same length and containing T-patterns.

2. The RNA world hypothesis

According to the RNA World hypothesis (see, for example, Pressman et al., 2015), billions of years ago, a major evolutionary transition occurred from one polymer T-string world to another, from the RNA world, where RNA polymers took care of both information storage and work, to a DNA world, where inert DNA polymers only store information, while proteins do most of the work. Thus, DNA became an inert giant extra-individual purely informational storage polymer (string) outside the proteins (citizens) but defining their structure, behavioral potentials,

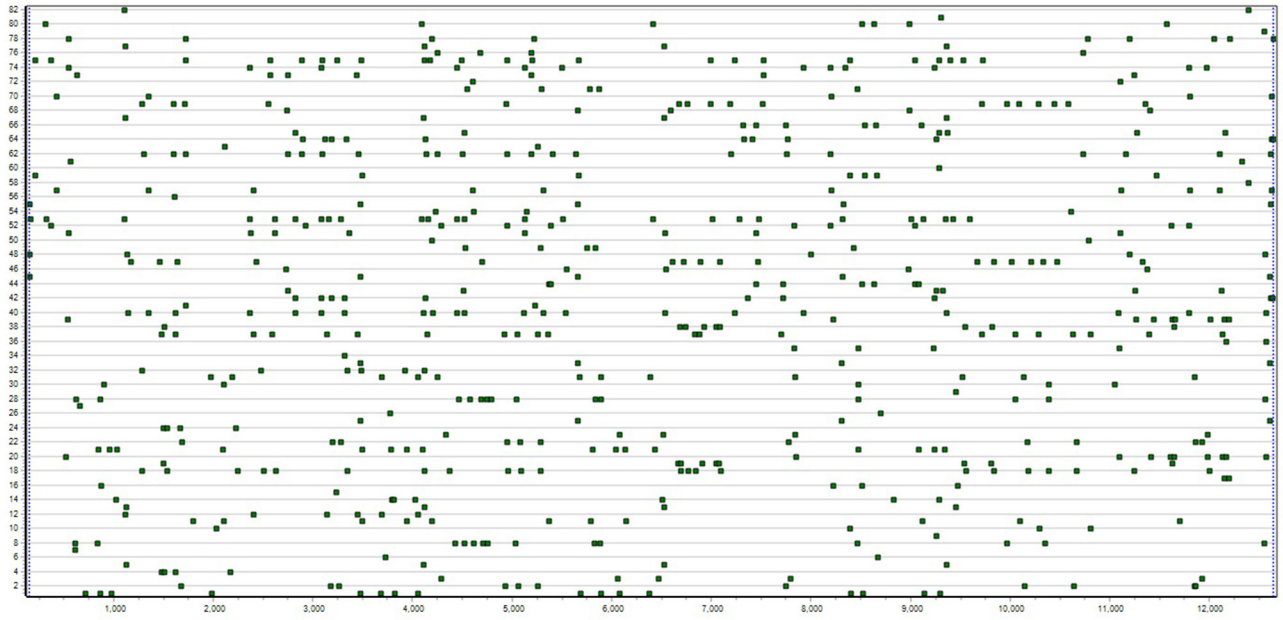

FIGURE 1
T-data example shows 82 occurrence series each for the different behavior of one of two children exchanging and playing with a toy for 13 and a half minutes [see for example, Magnusson (2020a)].

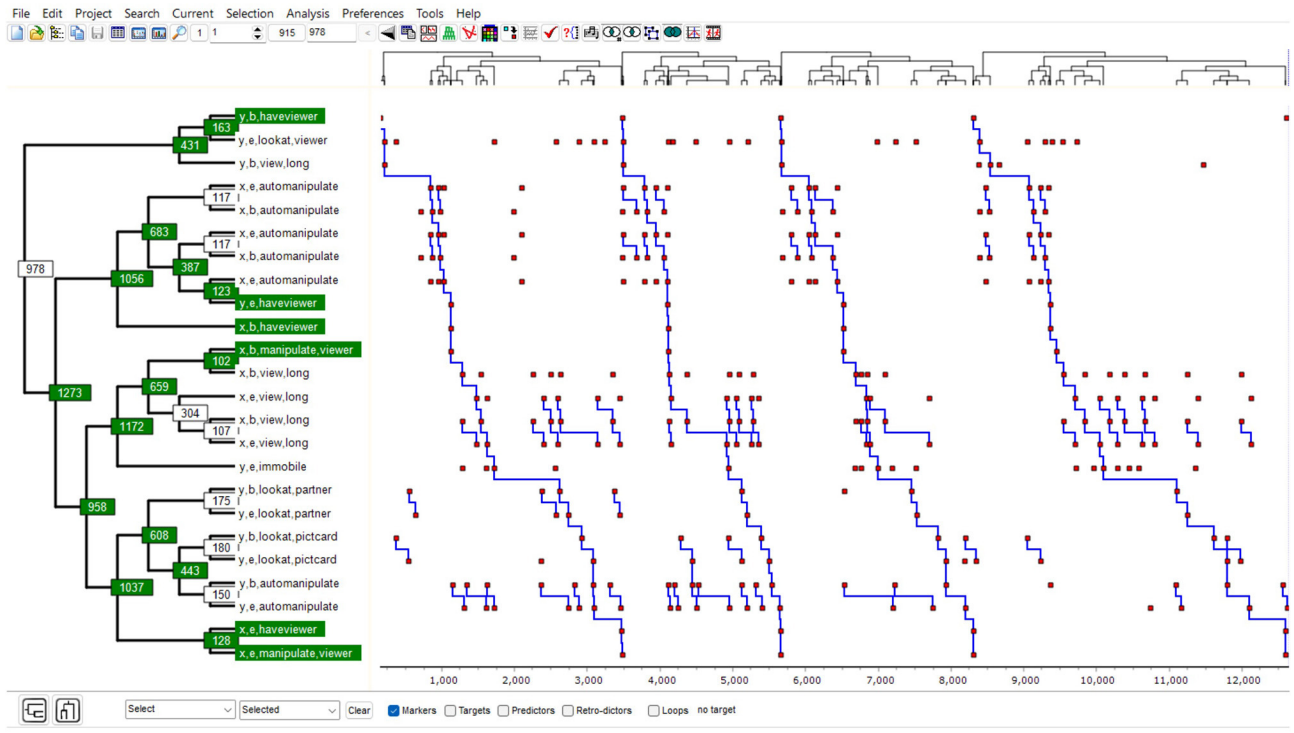

FIGURE 2
The t-pattern diagram example shows a T-pattern detected with THEME 6 in the data shown in Figure 1 [see, for example, Magnusson (2017)].

tendencies, and roles.[5] A social organization that emerges from interactions between citizens without such giant purely informational extra-individual strings is here called *Interactive Emergence Society (IES)* and is the only kind in the RNA world and in animals and preliterate human beings, see Figure 3.

3. The T-society

With the human invention of inert extra-individual purely informational memory, i.e., text, analogous separation happened between work and information determining numerous neuronal brain patterns in the citizens and, thus, much of their behavioral potentials, tendencies, and roles.

The detection of T-strings in DNA and proteins and in the letter strings of texts (Magnusson, 2020a,b) shows similarities in patterning across very different scales and levels of biological organization. The similarity between protein and literate human mass societies was thus recognized as each is based on what here is called *Giant Extra-Individual Purely Informational T-string* or *GEIPIT,* determining the characteristics of different types of individuals (members, citizens). The genome in the protein society and the textome (i.e., all text) in a literate human society are, thus, GEIPITs and here together called T-stringomes.

This has allowed the definition of the T-system concept *T-society*, as a T-stringome-based society, found only in proteins and literate humans but neither in non-human animals nor illiterate humans (see Wilson, 1975; Hölldobler and Wilson, 2008) (see Figure 4).

3.1. Social organization of two kinds and a human paradigm shift

In human T-societies, text segments, such as curricula, are to brain patterns what genes are to proteins, assuming that the behavior of literate humans is partly determined by brain patterns shaped by exposure to text. Thus, in protein T-societies: DNA → protein 3-D structure → protein behavior, while in human T-societies: text → brain patterns → human behavior. It has been suggested that T-patterns are involved: "because spike-timing is of such theoretical importance, analysis of temporal sequencing in multiple neuronal activity, using such techniques as T-pattern analysis, may be of great value in understanding the mechanisms whereby neuronal networks encode sensory information" (Nicol et al., 2005, p. 74) (see Figure 5).

Among the best-known segments for the forming of specialized citizens are the genes of the genome and the curricula used in educational institutions (Magnusson, 2020b). Most of the genome and the textome do not have a citizen-defining function, for example, "non-coding DNA."[6] (Figure 6).

The separation of information and action was, thus, essential when the RNA world invented the DNA world and preliterate humans invented the textual world.

Therefore, after billions of years of evolution, this unique self-similarity appeared, in a biological eyeblink but with considerable consequences, really leaving all living creatures behind. Humans, thus, became the **first and only species** to develop the same social organization *paradigm found in every biological cell,* including all those constituting all its citizens. Texts as precise unlimited extra-individual T-string memory suddenly allowed an explosive increase in the specialization of individuals and in human knowledge, science, technology, and law. This revolutionary increase in human abilities, and knowledge of nature and the universe, seems to belong among the very rare major evolutionary transitions (see, for example, Kun, 2021).

As human citizens are composed of protein T-societies (i.e., cells), human T-societies are T-societies of T-societies, here thus called *second-order T-societies*. Such T-society self-similarity is not found in proteins and is, thus, unique to humans (see Figures 7–9). Figure 7 shows protein and human T-societies, analogous structure.

3.2. T-societies and the invention of writing

While T-societies have existed in cells for billions of years, the invention of writing, only a few thousand years ago, was a necessary precondition for the development of human T-societies. Simple messaging and bookkeeping were insufficient as standardized texts, and their effective copying and distribution to form the many kinds of specialized individuals (citizens) were needed in complex societies. It would take a very long time to reach the level of protein T-societies as for most of the time since the beginning of writing it has been very different.

> "Literacy rates over most of human existence were insignificant. Estimates from the Middle Ages, which are primarily based on the proportion of people who could sign their name on various documents, point to rates below 10 per cent in countries such as China, France, Germany, Belgium and the Netherlands, and even lower levels elsewhere in Europe and across the globe" (Galor, 2022, pp. 63–64).

Only very recently, the now largely text-based educational system began to create countless different kinds of specialists:

> "education in pre-industrial Europe was still not geared toward the provision of skills to a mass workforce" (Galor, 2022, p. 65).

In the Industrial Revolution era, this finally changed:

> "In England. . . In 1841, for instance, only 5 per cent of male workers and only 2 per cent of female workers were employed in occupations in which literacy was required. Workers developed skills primarily through on-the-job training," (Galor, 2022, p. 67).
>
> "In the earliest phase of the Industrial Revolution, literacy and numeracy played a limited role in the production process, and thus the enhancement of these aspects of human capital would have had a limited effect on workers'

5 The use of the word "giant" is borrowed from the title of Grossberg and Alexei (1997).

6 See https://www.genome.gov/genetics-glossary/Non-Coding-DNA

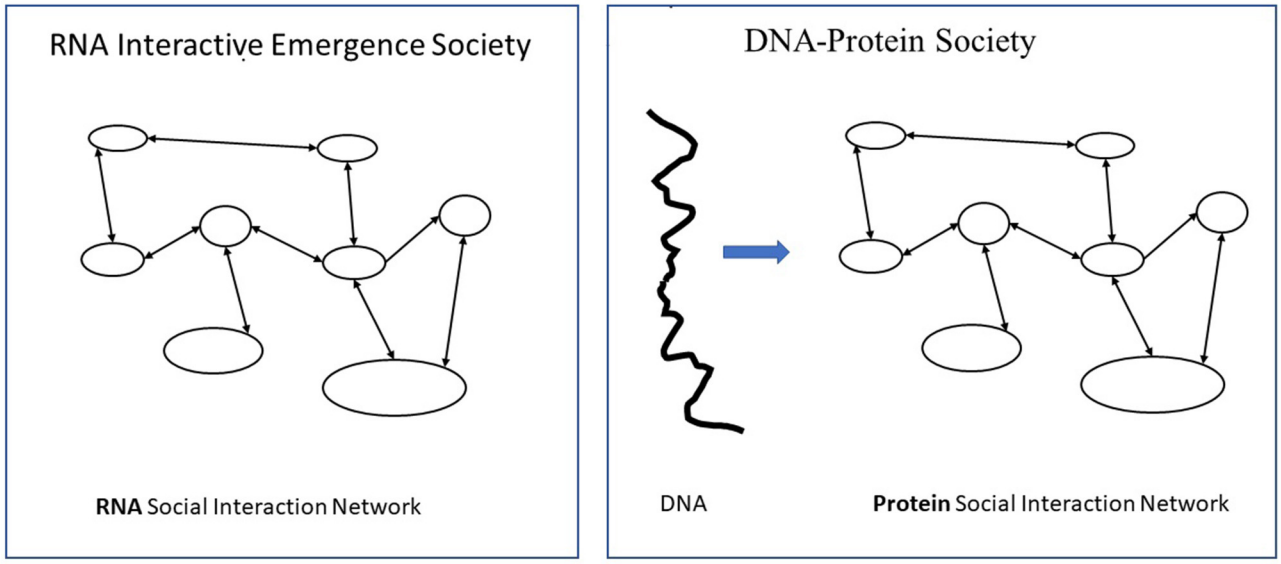

FIGURE 3
Interactive Emergence Society (IES) vs. T-society. These two figures, left and right, represent two types of societies. **(Left)** An Interactive Emergence Society where citizens interact, and a social structure emerges. **(Right)** An external string partly determines the characteristics of the interacting individuals. The first **(left)** describes the RNA world and animal (including illiterate humans) societies. The other **(right)** called a T-society is only found in the cells of the DNA world and in human modern mass societies.

> productivity. Although some workers, supervisory and office personnel in particular, were required to be able to read and perform elementary arithmetical operations, a large portion of the tasks in industry was successfully performed by people who were illiterate. During the subsequent phases of the Industrial Revolution, the demand for skilled labor in the growing industrial sector markedly increased. From here on, and for the first time in history, human capital formation—factors that influence worker productivity, such as education, training, skills, and health—was designed and undertaken with the primary purpose of satisfying the increasing requirements of industrialization for literacy and numeracy as well as mechanical skills among the workforce" (Galor, 2022, p. 67).

3.3. Slow spread of literacy

> "The global literacy rate currently stands at 87%, up from 12% in 1820. Most developed countries have achieved a 99% literacy rate" World Economic Forum.[7]

If the human invention of extra-individual T-string memory, i.e., text, was important, why did not it spread faster among all *Homo sapiens*? It seems this great tool was like so much else kept by and for ruling subgroups and was among others used to ascertain that order with T-strings sometimes set in stone:

> "Hammurabi's Code, for example, established a pecking order of superiors, commoners, and slaves. Superiors got all the good things in life. Commoners got what was left. Slaves got a beating if they complained" Harari (2014, p. 168).
>
> "For most of human history, formal education was available only to a small, privileged section of society" (Galor, 2022, p. 63).

4. Discussion

After billions of years of biological evolution, a shift in human social organization gradually became analogous with the protein T-societies in every biological cell, a self-similarity unique not only in the animal world but in all life. A transition that made possible the progress in science and technology that allowed its own discovery.

Human T-societies became gradually possible with the advent of writing (∼3500 BC) followed by the creation of texts and gradually more effective means of copying and distribution (recently, printing, and Internet) and, eventually, of standardized curricula used by schools to form the multitude of different brain patterns, and thus behavioral potentials, of the many specialized human citizens.

The mass societies of modern *Homo sapiens* thus seem to have adopted a new social organization paradigm analogous with every

7 See https://www.weforum.org/agenda/2022/09/reading-writing-global-literacy-rate-changed/.

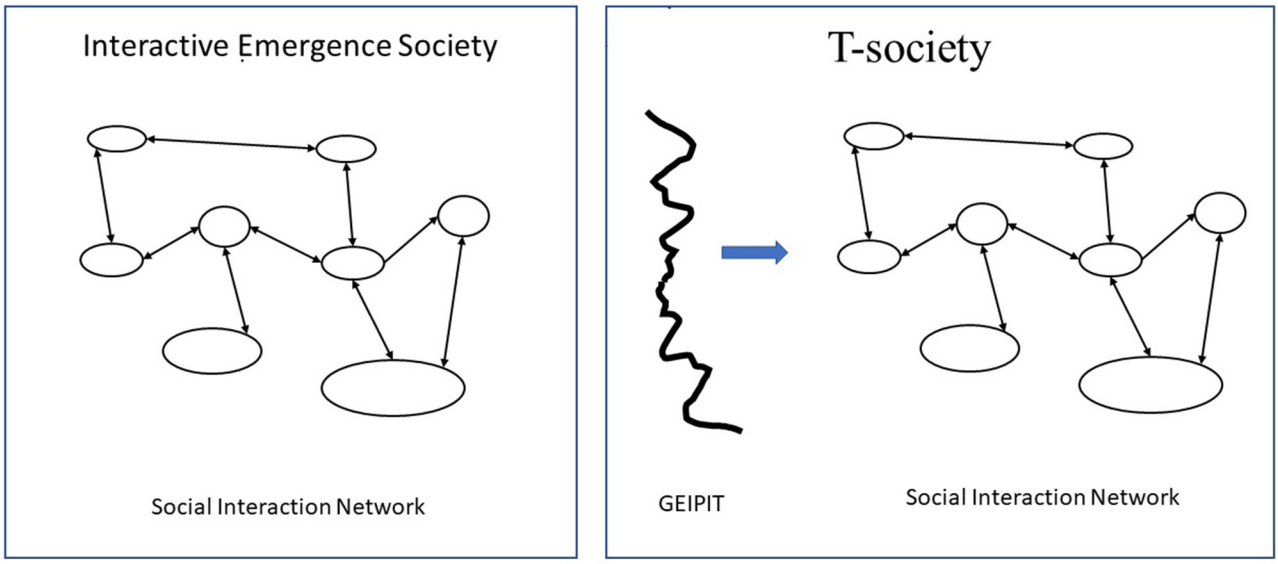

FIGURE 4
The similarity between protein and literate human mass societies, here called T-societies, was recognized as each is based on what here is called Giant Extra-Individual Purely Informational T-string or GEIPIT, determining the characteristics of different types of individuals (members, citizens). A social organization that emerges from interactions between citizens without GEIPIT is here called Interactive Emergence Society (IES).

cell in their bodies, while different from all other animals and earlier humans even of the same species. This seems to justify rethinking human mass society issues, but, apparently, this has not happened generally judging, for example, by the recent writings of highly esteemed and widely read authors as indicated below by a few glimpses into their writings.

4.1. Population sizes, citizen types, and social coherence

Tens of thousands of years after the advent of language, extra-individual T-string memory, i.e., text first appeared in humans. This unique evolutionary transition happening in an eyeblink has allowed a great increase in the number of different types of citizens and population sizes, with ever-faster growth of human mass-social potential and possibly even explaining the recent shrinking of the human brain (DeSilva et al., 2021). Billions of citizens of thousands of different types in some protein societies far exceed any animal society other than modern human mass societies, such as in China and India, each exceeding a billion individuals and with new texts and kinds of specialists constantly being created (Milo and Phillips, 2015, p.105). Moreover, manyfold the size of the largest non-human mass societies, those of social insects that are interactive emergence societies (IES), not T-societies (Hölldobler and Wilson, 2008), same as with animal bodies seen as societies of cells, which are IES, not T-societies.

"The world population tripled between 1500 and 1900, to an estimated 1564 million" (see https://worldmapper.org/maps/population-year-1900/). With the population of China and India, each now reaching nearly that size, how could such mass-social cohesion and collaboration be possible given the evolutionary history of the human species?

Among those who recently have posed this question and suggested answers are Dunbar (2022) and Harari (2014), but neither mentions the kind of nanoscale phenomena or self-similarity described above. While, of course, recognizing the considerable importance of writing, both, and especially Dunbar, treat human mass societies as primate interactive emergence societies (IES).

4.2. Robin Dunbar, brains, religion, and population size

After decades of study of relations between brain structure, social interaction, social organization, and population size in primates, both non-human and human, Robin Dunbar wrote the following part:

> "The core of the social brain hypothesis is a simple linear relationship between the typical social group size of a species and the size of its brain – or, more strictly, the size of its neocortex. The neocortex (literally, 'new cortex') is the part of the brain that supports all the clever thinking that we do. It has evolved out of all proportion to the size of the rest of the brain in the primate lineage. In mammals as a whole, it occupies 10–40 percent of brain volume, but in primates, it begins at 50 percent and rises to 80 percent in humans. This relationship between neocortex size and group size in primates allows us to estimate the equivalent "natural" group size for humans: it is simply a matter of plugging human neocortex size into the

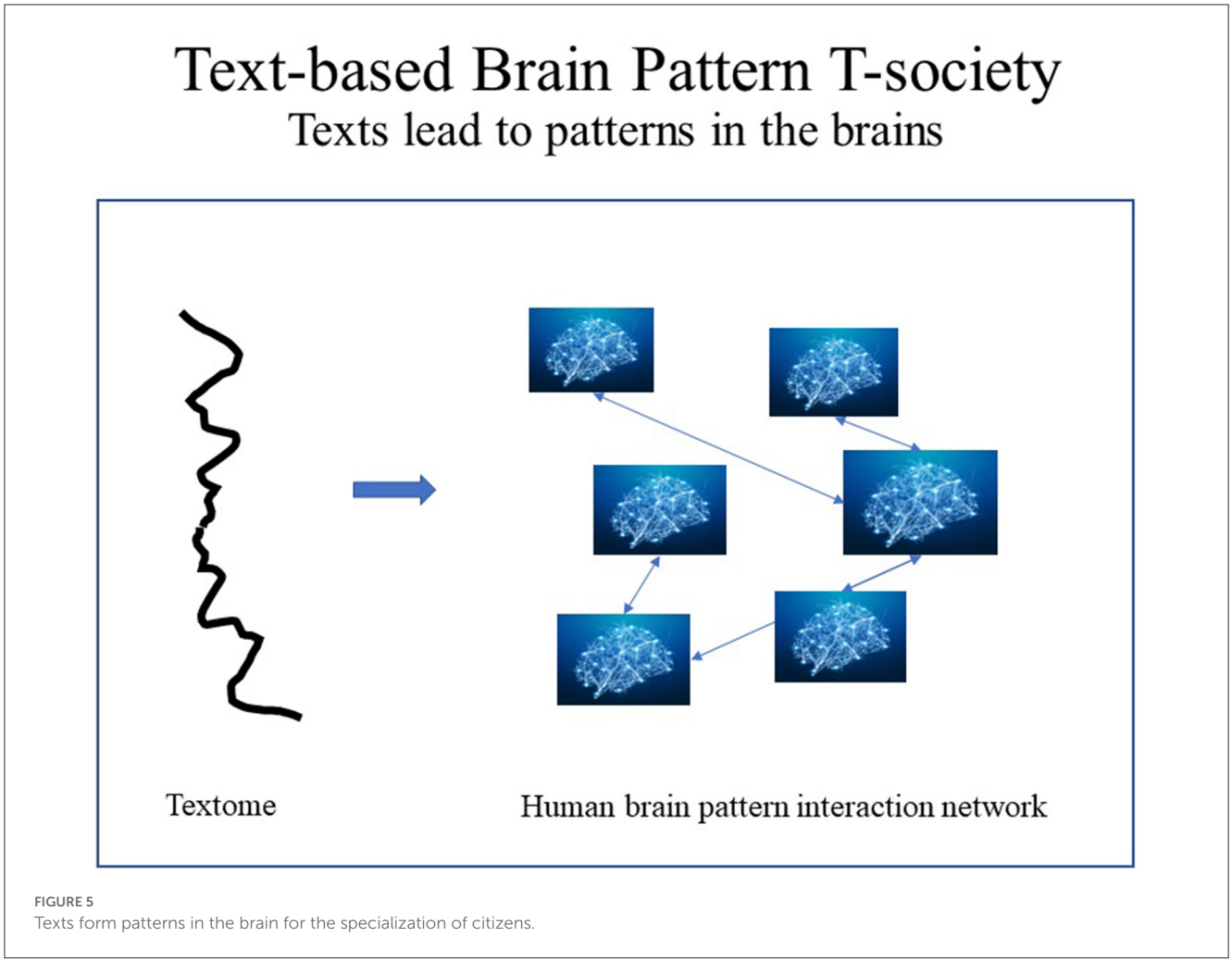

FIGURE 5
Texts form patterns in the brain for the specialization of citizens.

> equation for the monkeys and apes, and then reading off the corresponding group size. The group size for humans predicted by this equation is 150, to the nearest round number… The key point for us, perhaps, is that this is the typical size of hunter-gatherer communities, the form of society in which we have spent more than 95 percent of our existence as a species" (Dunbar, 2022, pp. 80–81).

Other group sizes of strikingly exact multiples of these basic numbers have been discovered (Dunbar, 2022, p. 87), and Dunbar has suggested that religions, and more specifically Doctrinal Religions, play a major role in maintaining cohesion in the current very large populations.

> "At some point, there was a transition to a more formal kind of religion marked by regular places of worship, gods (who sometimes actively intervene in human affairs), religious specialists or priests (who intervene between the community and the gods, in some cases via trance-based rituals), more formal theologies, and moral codes that have divine origins – Moses receiving the tablets with the Ten Commandments directly from God on Mount Sinai, the Prophet Muhammed receiving the dictation of the Koran from God, Joseph Smith receiving the golden plates of the Book of Mormon. Most of these doctrinal religions also have origin stories, often associated with the revelatory experiences of a specific individual as founder – Zoroaster in the case of the Zoroastrians of ancient Persia; Siddhārtha Gautama for the Buddhists; Jesus Christ for Christians; the Prophet Muhammed for Islam; Guru Nanak for Sikhism. Because these religions typically have quite explicit theological doctrines, they are often known as doctrinal religions. They are also known as world religions because most of them now have very large followings spread over most of the planet (notwithstanding the fact that this is actually a very recent phenomenon)" (Dunbar, 2022, pp. 8–9).

Dunbar ends his book about religion, where the line between religion and ideology is not sharp, with the following conclusion:

> "In short, it is difficult to see any convincing evidence for anything that will replace religion in human affairs. Religion is a deeply human trait. The content of religion will surely change over the longer term, but, for better or for worse, it is likely to remain with us" (Dunbar, 2022, p. 268)

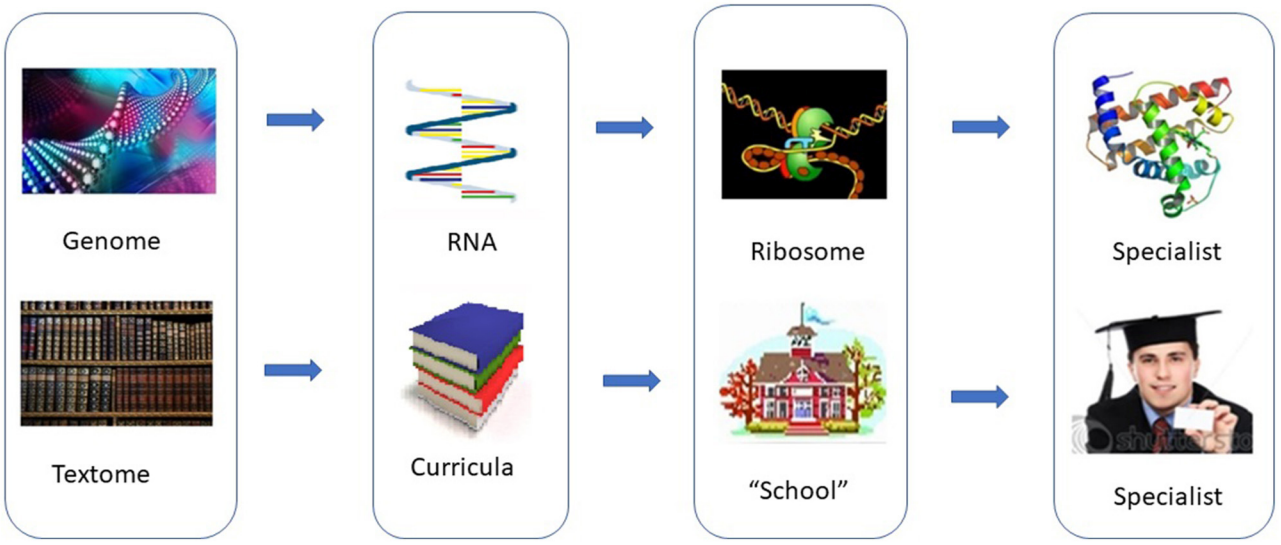

FIGURE 6
Forming of citizens in T-societies. Process (top) leading from the genome to a specialized protein citizen in an intracellular protein T-society and (bottom) the analogous process from the textome (i.e., all the text) of a human T-society *via* curricula and a "school" (educations system) to a specialized human citizen.

It should be noted that China, which has the largest population, does not have any important superstition-based religion, and the meaning of the word "religion" surely should not be stretched to consider Mao's Little Red Book or Karl Marx's Das Kapital as holy scriptures.

In human life, for example, greed, violence, deception, superstition, and religions, based on it, may be hard to erase from human existence, but much is done to reduce these tendencies. The irrationality and counterfactual content often found in holy scriptures seem risky for humanity on the brink of a global catastrophe, or, in the recent words of the UN general secretary, a "collective suicide" (The Guardian, 18 July 2022).

4.3. Yuval Noah Hariri, imagined order, and scripts

In his multimillion-copy bestseller Sapiens, Harari wrote the following:

> "UNDERSTANDING HUMAN HISTORY in the millennia following the Agricultural Revolution boils down to a single question: how did humans organize themselves in mass-cooperation networks when they lacked the biological instincts necessary to sustain such networks? The short answer is that humans created imagined orders and devised scripts. These two inventions filled the gaps left by our biological inheritance" Harari (2014, p. 168).

4.4. Doctrinal religions and scripted order

It seems obvious that spreading complex standardized stories and scripts, for example, the Bible and the Quran, among millions of individuals, was impossible before the advent of extra-individual memory (texts) and efficient copying and distribution technology. Such T-strings, i.e., sacred/holy scripture or books (each a T-string), when added to the texts (textome) of a society and thus become a part of its T-stringome, among others push for sometimes even evangelical spreading of the word (holy message) and thus for their own further copying and distribution, much like viruses in the DNA-based protein T-societies.

4.5. Textual viruses as T-strings to brain T-patterns

The similarity between textual T-strings and the temporal T-patterns in neuronal networks in brains may help to explain the powerful influence of textual T-strings on thinking and behavior, for example, by holy scriptures and misinformation, with their virus-like insertion into the T-stringoms of T-societies sometimes

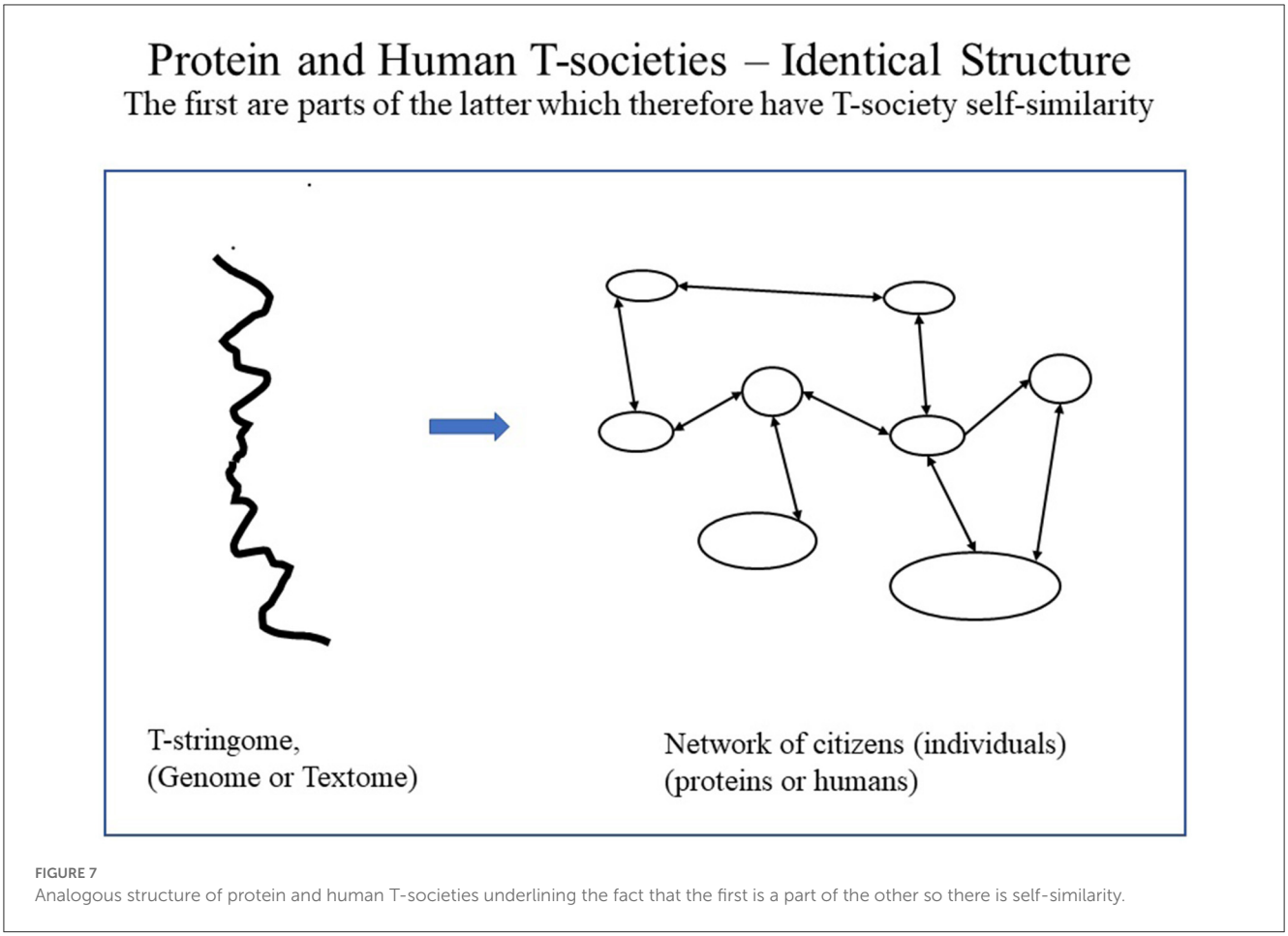

FIGURE 7
Analogous structure of protein and human T-societies underlining the fact that the first is a part of the other so there is self-similarity.

becoming a major threat (Magnusson, 2022). Misinformation during the viral epidemic COVID-19 has, thus, been considered a leading cause of death in the US.[8]

Billions of humans are greatly influenced by external T-string memory created during times of now unimaginable ignorance and brutality, but T-string memory is normally stored in countless copies of stable inert materials, so like DNA it may last for millennia, and any dangerous content can possibly be revived, copied, and distributed.

4.6. Medical vs. social use of DNA world information

While the medical use of genetic information typically identifies aspects of DNA or genes that influence the protein structure and/or function that correlate with medical symptoms, the present behavioral and social approach searches for analogies between the nanoscale DNA–protein mass societies and those of humans and has found the second-order T-society unique to humans. While the medical focus is mostly on intracellular polymer structures and functions, the focus here concerns analogous structures and functions (behavior) in human societies.

4.7. Proteomics as a source of ideas

Human modern T-societies ultimately descend from those of proteins, so proteomics may be a valuable source of ideas and insights into T-societies generally. Human T-societies have horizontal T-string transfer analogous to DNA transfer between cells. Questions also come up about money as an extremely powerful external memory, functioning somewhat like ATP in cells as little happens without it, and even about democracy in T-societies. Could the recently accessible nanoworld thus contain new keys to understanding the human exception and should modern humans, with their unique second-order T-societies, be considered almost like a new species, much as social insects vs. solitary insects?

4.8. Vaclav Smil and the exponential growth of knowledge

Similar to Dunbar, Harari, and Galor, that is, without any consideration of similarities or self-similarities between nano- and human-scale

8 See https://www.cnn.com/videos/health/2022/05/07/fda-robert-califf-intv-misinformation-death-sot-vpx.cnn.

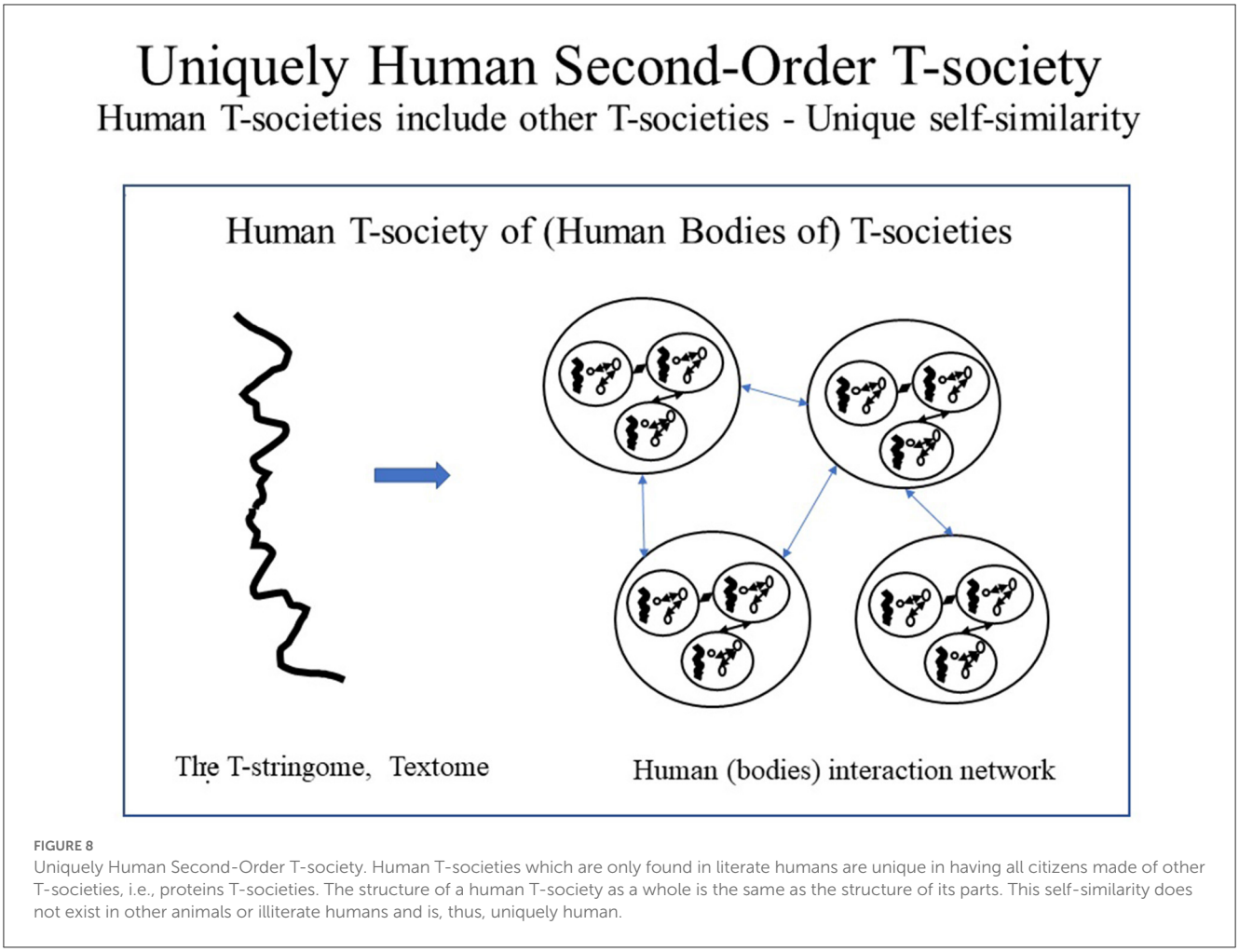

FIGURE 8
Uniquely Human Second-Order T-society. Human T-societies which are only found in literate humans are unique in having all citizens made of other T-societies, i.e., proteins T-societies. The structure of a human T-society as a whole is the same as the structure of its parts. This self-similarity does not exist in other animals or illiterate humans and is, thus, uniquely human.

phenomena, Smil (2022, pp. 1–2) wrote regarding the current situation of accumulated knowledge and individual specialization:

> "By the middle of the Eighteenth century two French savants, Denis Diderot and Jean le Rond d'Alembert could still gather a group of knowledgeable contributors, to sum up, the era's understanding in fairly exhaustive entries in their multi-volume Encyclopédie, ou Dictionnaire raisonné des sciences, des arts et des métiers.)… In 1872, a century after the appearance of the last volume of the Encyclopédie, any collection of knowledge had to resort to the superficial treatment of a rapidly expanding range of topics, and, one and a half centuries later, it is impossible, to sum up, our understanding even within narrowly circumscribed specialties: such terms as "physics" or "biology" are fairly meaningless labels, and experts in particle physics would find it very hard to understand even the first page of a new research paper in viral immunology. Obviously, this atomization of knowledge has not made any public decision-making easier. Highly specialized branches of modern science have become so arcane that many people employed in them are forced to train until their early or mid-thirties in order to join the new priesthood."

How easy will it be for such individuals to collaborate on current global issues? Therefore, analogous to the successful nanoscale transition from the RNA to the DNA world, the success of human T-societies has been decisive as in the year 1900 knowledge doubled once a century, but now it appears, closer to once a day[9] and with incomparably better public access to knowledge through new technology. But unfortunately, this may also be a cause for major human worries such as overpopulation and global warming.

The world of living creatures first switched from one polymer T-string world to another, from the all-RNA world to the current exclusively DNA world, thus separating information storage from work, then such separation happened in human mass societies, and a naked ape became a "text ape" or "string-ape" nearly everywhere enabled and controlled by texts.

The main conclusion here concerns the aim of this study. Beginning over half a century ago, there was an attempt to find something that clearly and non-trivially separates modern

9 See https://www.linkedin.com/pulse/human-knowledge-doubling-every-12-hours-amitabh-ray/.

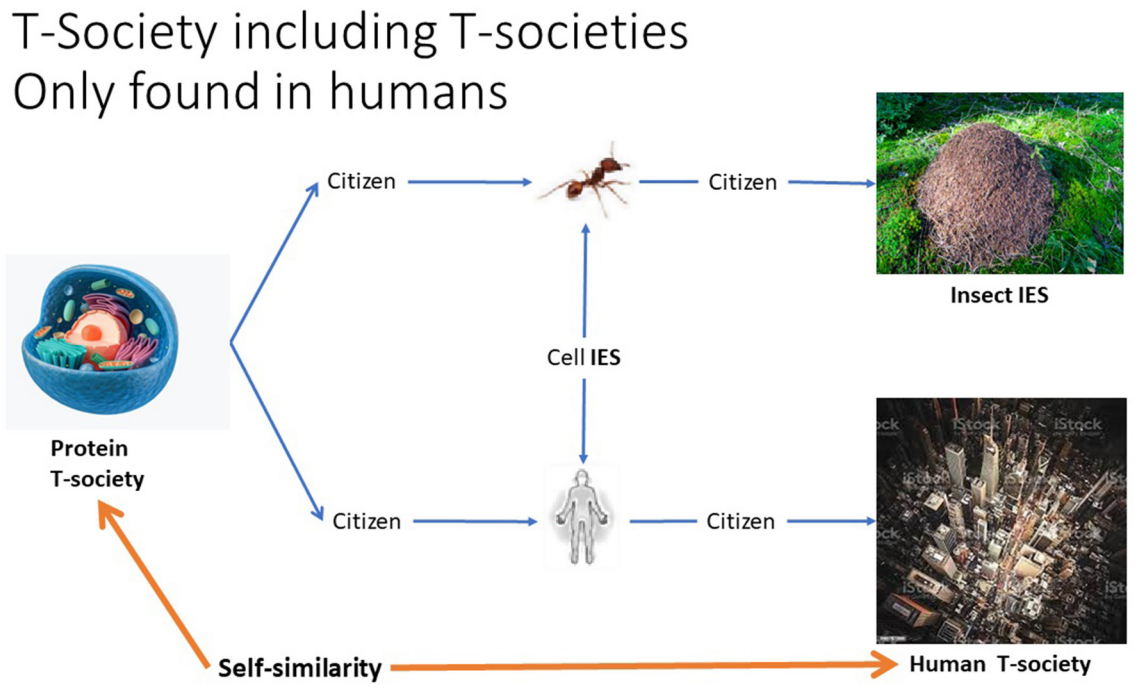

FIGURE 9
Relationships between Interactive Emergence Societies (IES) exemplified by two different kinds of IES of cells, that is, the bodies of an ant and a human. They make up two different kinds of mass societies, an ant hive (IES) and a human T-society. While a cell (protein T-society) on the left is a component in all the others, it has a self-similarity only with the human T-society, humans being the only species to have created such societies.

humans, and especially their modern mass societies, from all other animal species.

Surprises happened repeatedly on the way from the definition and detection of T-patterns and T-strings at multiple levels and scales to the definition of T-societies in proteins and humans. This allowed a biomathematical definition of human uniqueness, the human exception in life on earth: second-order T-societies. After the invention of human extra-individual unlimited and material memory (text), humans are the only species to have become conscious of vast areas of the universe from the innermost components of matter to the microscopic components of our own bodies but also of galaxies and galaxy clusters and other astronomical scale phenomena. Therefore, the species *Homo sapiens* seems to have finally earned its name.

It seems that a paradigm change in social organization occurred in a biological eyeblink in *Homo sapiens*, from Interactive Emergence Societies (IES), common to all non-human animals and illiterate humans, to second-order T-societies, i.e., T-societies of T-societies, never before appearing on Earth.

Where do T-patterns come from? Which came first; temporal or spatial? Can folded proteins and atoms with their electron orbits be seen as recurrent 3-D T-patterns?

This half-a-century search may eventually be elaborated and continued toward a proper T-pattern self-similarity theory, especially of mass societies, where biology and culture are one on the same biomathematical continuum.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Author contributions

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

Conflict of interest

MM is the sole author of the T-system and the sole programmer and copyright owner of its implementation as the THEME software, and is the principal owner and COB of PatternVision Ltd. (www.patternvision.com) responsible for the marketing of the THEME software.

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The Methodological Quality Scale (MQS) for intervention programs: validity evidence

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Introduction: A wide variety of instruments are used when assessing the methodological quality (MQ) of intervention programs. Nevertheless, studies on their metric quality are often not available. In order to address this shortcoming, the methodological quality scale (MQS) is presented as a simple and useful tool with adequate reliability, validity evidence, and metric properties.

Methods: Two coders independently applied the MQS to a set of primary studies. The number of MQ facets was determined in parallel analyses before performing factor analyses. For each facet of validity obtained, mean and standard deviation are presented jointly with reliability and average discrimination. Additionally, the validity facet scores are interpreted based on Shadish, Cook, and Campbell's validity model.

Results and discussion: An empirical validation of the three facets of the MQ (external, internal, and construct validity) and the interpretation of the scores were obtained based on a theoretical framework. Unlike other existing scales, MQS is easy to apply and presents adequate metric properties. In addition, MQ profiles can be obtained in different areas of intervention using different methodologies and proves useful for both researchers doing meta-analysis and for evaluators and professionals designing a new intervention.

KEYWORDS

methodological quality, scale, meta-analysis, program evaluation, reliability, validity

1. Introduction

The concept methodological quality (MQ) can be defined as the degree to which a study can avoid systematic errors (bias), and the degree to which we are sure that such study can be believed (Reitsma et al., 2009). Measuring MQ is important to foster accumulative knowledge given the relationship between MQ and effect size, where effect size is higher when MQ is low; i.e., low MQ studies tend to overestimate the effectiveness of interventions (Hempel et al., 2011). Thus, when multiple interventions lack MQ, it becomes difficult to reach trustworthy conclusions (Chacón-Moscoso et al., 2014).

In meta-analytical research, the results of different primary studies on a specific issue or research question are quantitatively integrated (Cooper et al., 2009). Generally, the MQ of primary studies is measured with the intent of evaluating the credibility of the results obtained in the meta-analysis (Luhnen et al., 2019). On some occasions, low MQ is an exclusion criterion.

Measuring MQ is not just useful for integrating finished interventions in meta-analysis. In the context of program evaluation, it is also fundamental to increase the MQ of the design, the implementation, and the evaluation of ongoing and future intervention programs. Finally, when several different interventions are feasible, it allows the most adequate to be chosen based on the target population, the aims, and the context (Cano-García et al., 2017).

Thus, a wide variety of professionals need to measure MQ. In most cases, these professionals are not experts in methodological issues, and when they seek out an instrument to gauge MQ, they encounter a wide variety of them (Higgins et al., 2013). There are two reasons why experts in methodology are unable to offer a simple way to assess quality.

First, a plethora of strategies for assessing the MQ of primary sources can be found in the literature (see, for example, www.equator-network.org). At present, we can affirm that around 100 quality scales have been identified (Conn and Rantz, 2003) as well as more than 550 different strategies to measure MQ (Chacón-Moscoso et al., 2016).

In some settings, such as medicine, a certain consensus has been reached on the use of individual quality components or items not combined into scales (Herbison et al., 2006), and researchers in the social sciences also appear to be increasingly forgoing scales (Littell et al., 2008). However, no empirical tests have been conducted in other areas such as psychology, which is problematic given how this decision affects the replicability of study results (Anvari and Lakens, 2018).

Second, discrepant results were found when applying several measurement strategies in the same sample of primary studies (Losilla et al., 2018). Depending on the instrument chosen, the assessment of MQ may vary. As a result, the choice of scale can lead us to treat a study differently, rely on its results to varying degrees, or even include/exclude it from a meta-analysis.

The discrepancies between the quality scales may be attributed to different causes: the scales measure different aspects of quality, have been constructed from different research contexts (Albanese et al., 2020), or present metric deficiencies (Sterne et al., 2016). This is because the makers of these scales did not follow the standards for developing measuring instruments, and their metric properties are generally unexplored.

This paper considers MQ based on its existing use and applications in the literature. Our approach, which draws on consequential validity (Brussow, 2018) and is centered on the descriptive theory of valuation, aims to describe values without evaluating whether any one is better than others (Shadish et al., 1991). For this purpose, we developed the 12-item MQ Scale (MQS) (Chacón-Moscoso et al., 2016). We did an exhaustive review of the literature (Nunnally and Bernstein, 1994) and compiled 550 different strategies to assess MQ (the list of bibliographic references is available in Supplementary material S1). Subsequently, we selected the most frequent indicators of MQ, obtaining 23 items. A content validity study was then carried out. Thirty experts in meta-analysis and/or methodology participated voluntarily. All were methods group members of the Campbell Collaboration and/or the European Association of Methodology. Participants (12 women and 18 men, 20 from Europe and 10 from the United States) were contacted by e-mail or face-to-face in the biannual congresses of the associations. Their mean age was 42, with an average of 14 years of experience on these issues. Participants evaluated the representativeness, utility, and feasibility of each item with respect to a hypothetical global construct of MQ. Finally, the 12 items that passed the cutoff point were selected and refined after an intercoder reliability study (the final version of the instrument, used as a coding manual for this work, is available in Supplementary material S2).

An advantage to this approach is that we specify the origin and reasons for the selection of these final items and, additionally, these were not limited to any particular intervention, methodology, or context. Furthermore, to bypass the common handicap of presenting a proposal without a thorough study of its metric properties, the aim of this paper was to analyze the metric properties of the scores obtained with the MQS in terms of reliability and validity evidence, as well as its dimensional structure.

As the concept of MQ is multidimensional, we hypothesized that we were not going to find a general factor that explained the set of 12 items. Instead, we approached the empirical study of the possible different facets (profiles) of the validity evidence of these 12 items based on a conceptual validity framework (Shadish et al., 2002), and the structural dimensions that form the acronym UTOSTi; Units, Treatment, Output, Setting and Time (Chacón-Moscoso et al., 2014, 2021). Finally, we present an application in organizational training programs based on the interpretation of the scores obtained in such validity facets.

2. Methods

2.1. Participants

Studies on training programs for workers in organizations were selected as a topic that has attracted substantial research interest (Sanduvete-Chaves et al., 2009). A total of 299 full texts were selected. References from these studies are available in Supplementary material S3. Each study had to meet the following inclusion criteria: their research topic was training programs for workers at organizations; non-duplicated; written in English or Spanish; full text available; primary study; empirical study in which a training program was applied; and the training program was the aim of the study.

2.2. Instruments

MQS, available in Supplementary material S2, was applied. This scale presented 12 items, each with three alternatives (0, 0.5, and 1) representing, respectively, the null, medium, or total level of achievement of the criterion presented in the item.

2.3. Procedure

The search cut-off date for the primary studies was June 2020. The following databases were included because of the relevant issues they cover: Web of Science, SCOPUS, Springer, EBSCO Online, Medline,

CINAHL, Econlit, MathSci Net, Current Contents, ERIC, and PsycINFO. The combined keywords were "evaluation" AND "work" AND "training programs," with a search in title, abstract, keywords, and complete article. Additionally, authors who published most frequently on training programs for workers were contacted by e-mail to ask if they could share any other work, published or unpublished, on this topic.

During the initial screening, the inclusion criteria were applied to title, keywords, and abstract. The included studies were evaluated at a second stage, applying the inclusion criteria to the full texts. Two coders (SSC and FPHT) applied the criteria independently. In case of disagreements, a third coder (SCM) mediated to reach a consensus.

For the data extraction, the same two coders participated in 2 months of training sessions until the appropriate inter-coder reliability was met, with κ agreement greater than 0.7 in a pilot study. Subsequently, they coded the entire sample of selected studies. Finally, the discrepancies between coders were resolved by involving a third researcher (SCM) to reach a consensus.

2.4. Data analyses

Using SPSS v.26, we conducted an intercoder reliability analysis after the selection phase and data extraction phase. Kappa (κ) coefficient, a statistic specifically created to value inter-rater agreement which corrects the probability of concordance due to hazard (McHugh, 2012), was computed for each item and 95% confidence intervals. κ between 0.61 and 0.80 was considered substantial; and above 0.80, very good (Landis and Koch, 1977). We then performed descriptive analyses of item scores, calculating the mean, the standard deviation, skewness, and kurtosis coefficients.

To obtain the validity facets that were implicit in the tool, the FACTOR software (Ferrando and Lorenzo-Seva, 2017) was used. First, a parallel analysis was done using optimal implementation to determine the number of dimensions (Timmerman and Lorenzo-Seva, 2011; Yang and Xia, 2015); second, Exploratory Factor Analyses (EFA) were performed to extract the main dimensions (Ferrando and Lorenzo-Seva, 2018). The polychoric correlation matrix (Holgado-Tello et al., 2010) was used because of the ordinal metric of the variables and the non-normal data distribution. Unweighted least squares were applied as the estimation method and varimax rotation (Sanduvete-Chaves et al., 2013, 2018).

Using the JASP version 0.16 software (JASP Team, 2021), the reliability of the test scores was examined for each dimension obtained by calculating the McDonald's omega (ω) coefficient. For item discrimination, we computed corrected item-total correlation coefficients.

In addition, the theoretical interpretation of each extracted dimension was analyzed according to its items. Thus, the correlation between items, the factor solution, the metric features of the dimensions, and the theoretical congruence were considered to obtain the different dimensions.

Once the validity facets were obtained, we presented their descriptive statistics (mean, standard deviation, reliability, and average discrimination). Finally, a theoretical interpretation was performed for the primary studies analyzed.

3. Results

3.1. Selection of the studies

Figure 1 summarizes the selection process. A total of 2,886 studies were found in database searches and 39 were sent by the authors contacted by e-mail. Of the 2,878 nonduplicated papers found, 887 met the inclusion criteria, 299 of which were selected at random.

3.2. Intercoder reliability

In the study search, intercoder reliability was $\kappa = 0.705$. $p < 0.001$, 95% CI [0.674, 0.736]. Table 1 presents κ values with their significance and confidence intervals that refer to the information extraction phase. κ in items varied between 0.651 and 0.949, with an average of $\kappa = 0.910$. $p < 0.001$, 95% CI (0.898, 0.922). All items obtained adequate results.

3.3. Descriptive analysis

The database used in this article is available in Supplementary material S4. Table 1 presents descriptive statistics for the 12 items. The distributions obtained for each of the items highlighted their skewness. The median was 1 for most items. The means ranged between 0.24 and 0.99, the standard deviations were between 0.04 and 0.48, and there was no normal distribution of the items.

Items 5 and 8 presented means over 0.9, which implies that they lack the capacity to discriminate. Items 1, 5, 8, 10, and 11 obtained low variability, with SD below 0.25 (for example, in item 5, 99% of the studies fell into the category 1). Skewness was negative and less than −2.3 for items 3, 5 and 8. Finally, kurtosis exceeded 4.3 for items 3, 5, and 8.

To analyze the relationship between items, Table 2 presents the bivariate polychoric correlation matrix. Based on the associations between items, the highest positive bivariate correlations were between items 6 and 7 ($r = 0.77$) and between items 9 and 11 ($r = 0.73$). Additionally, items 5 and 8 were related ($r = 0.47$) and behaved differently than the remaining items, since their correlations with the others were negative and/or low. This may be related to the small discrimination capacity and variability that items 5 and 8 presented in Table 1.

3.4. Study of dimensionality

A parallel analysis was conducted to obtain empirical evidence about the number of factors that the scale presented (see Table 3). The results suggested no unidimensionality.

Next, we set out to identify the relevant factors from the twelve items, based on the chosen validity framework. Based on the previous parallel analysis, the first EFA conducted to extract dimensions was set to five factors. The rotated loadings (see Table 4), interpreted from a theoretical point of view, led us to form a dimension composed of items 1 (inclusion and exclusion criteria for the units), 3 (attrition), 4 (attrition between groups), and 12 (statistical methods for imputing

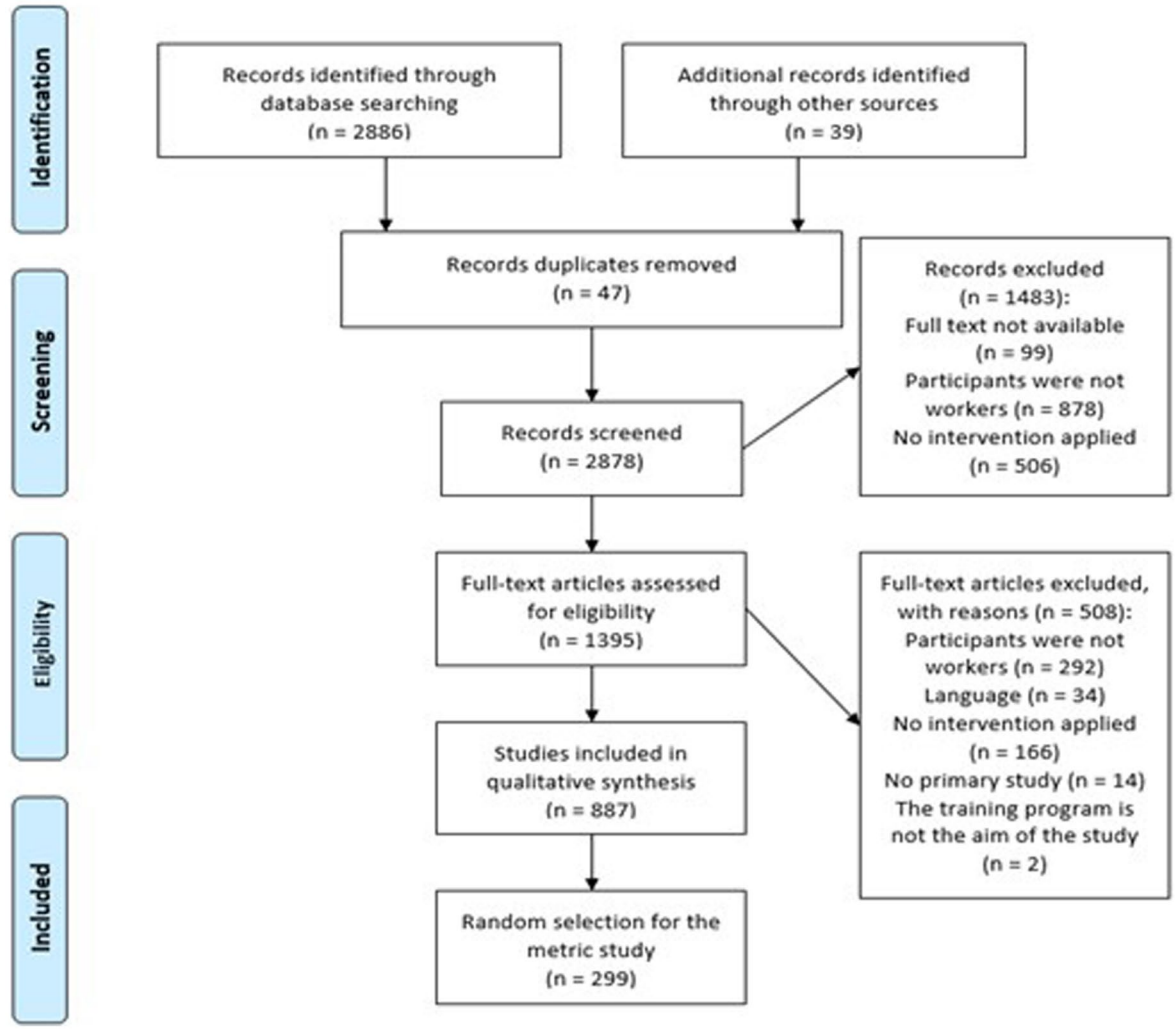


FIGURE 1
PRISMA Flow chart of the study selection process (Page et al., 2021).

TABLE 1 Intercoder reliability and descriptive statistics of the items.

	Intercoder reliability			Descriptive statistics					
Item	Kappa	*LL*	*UL*	*M*	*Mdn*	*SD*	S	K	SW
1	0.651	0.543	0.759	0.89	1	0.21	−1.53	0.77	0.51
2	0.912	0.869	0.955	0.27	0	0.35	0.90	−0.45	0.72
3	0.783	0.679	0.887	0.89	1	0.30	−2.46	4.32	0.4
4	0.784	0.633	0.935	0.78	1	0.41	−1.35	−0.08	0.55
5	0.798	0.412	1.184	0.99	1	0.04	−12.14	145.97	0.05
6	0.938	0.899	0.977	0.24	0	0.38	1.26	−0.13	0.63
7	0.949	0.918	0.980	0.52	0.5	0.39	−0.05	−1.32	0.81
8	0.86	0.768	0.952	0.91	1	0.22	−2.309	4.78	0.46
9	0.86	0.811	0.909	0.51	0.5	0.44	−0.04	−1.73	0.75
10	0.775	0.673	0.877	0.57	0.5	0.18	1.85	2.24	0.44
11	0.809	0.735	0.883	0.87	1	0.23	−1.52	1.25	0.55
12	0.884	0.829	0.939	0.36	0	0.48	0.60	−1.65	0.61

S, skewness; K, kurtosis; SW, shapiro-wilk normality test. All Kappa and SW obtained $p < 0.001$.

TABLE 2 Polychoric correlation matrix.

Item	1	2	3	4	5	6	7	8	9	10	11
1	1										
2	0.30	1									
3	0.41	0.32	1								
4	−0.20	−0.73	0.03	1							
5	−0.07	−0.33	−0.95	0.38	1						
6	0.01	0.58	0.22	−0.14	−0.07	1					
7	0.08	0.64	0.33	−0.29	−0.62	0.77	1				
8	−0.04	−0.33	−0.11	0.09	0.47	−0.35	−0.67	1			
9	0.29	0.42	0.25	−0.47	−0.32	0.21	0.42	−0.21	1		
10	0.48	0.41	0.14	−0.29	0.07	0.09	0.14	−0.01	0.21	1	
11	0.33	0.51	0.29	−0.66	−0.55	0.23	0.36	−0.07	0.73	0.21	1
12	0.35	−0.07	0.52	0.08	−0.22	−0.16	−0.15	0.19	0.04	0.06	0.19

TABLE 3 Parallel analysis.

Variable	% of S^2 in real data	Mean random % of S^2	95 *P* random % of S^2
1	19.91*	17.66	20.38
2	15.98*	15.35	17.31
3	13.54*	13.48	14.85
4	12.94*	11.74	12.82
5	10.25*	10.18	11.37
6	7.69	8.72	9.82
7	6.55	7.34	8.39
8	5.45	6.03	7.29
9	4.16	4.62	5.76
10	2.27	3.15	4.45

P, percentile.

TABLE 4 Rotated matrix (exploratory factor analysis) set to five factors.

Item	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5
1	0.48		−0.44		0.34
2		0.22			0.57
3	0.58	0.31	−0.21		−0.24
4	0.98				
5			0.97		
6		0.53			
7		0.97			
8			0.33		
9		0.31	0.23	0.45	
10					0.99
11				0.97	
12	0.63				0.63

Loadings lower than absolute 0.20 were omitted.

missing data). This dimension (factor 1 -F1-) could be interpreted as a measure of external validity, as items are focused on the representativeness of participants from a delimited population, selection criteria, the possible problem of a loss of participants during the study, and the method used to compute any missing data.

To guarantee that the four items mentioned (items 1, 3, 4, and 12) could be interpreted as a single dimension, a parallel analysis was conducted, introducing these four items exclusively. According to the results, a single dimension was recommended. The reliability of this dimension was $\omega = 0.60$, and the discrimination of the items was 0.21 for item 1, 0.45 for items 3 and 4, and 0.25 for item 12.

Once F1 was defined, the next step was to obtain empirical evidence that could statistically support other possible factors. Thus, a new EFA was conducted after omitting the items that formed F1 (items 1, 3, 4, and 12). The aim was to extract the next most relevant factor, avoiding redundant variability that could hamper its interpretation. Following this procedure, and after interpreting the results shown on Table 4, a second factor (F2) that could be interpreted as internal validity was obtained (Shadish et al., 2002). This second factor was formed by items 2 (methodology or design), 6 (follow-up period), 7 (measurement occasions for each dependent variable), and 10 (control techniques). These items focus on the level of manipulation, the number of groups, the measurements of relevant dependent variables to be measured, and the techniques applied to control for potential sources of error. As shown on Table 2, the bivariate correlations between items 2, 6 and 7 are high, between 0.58 and 0.77.

A parallel analysis conducted only with these items (items 2, 6, 7, and 10) yielded a single dimension. The reliability coefficient of F2 was $\omega = 0.70$. The inclusion of item 10 negatively affected the reliability of F2 ($\omega = 0.77$ without item 10); however, from a content validity perspective, it was considered that the information contained in item 10 was relevant to define this dimension, as it referred to control techniques directly related to internal validity. The discriminations of the items were 0.56 (item 2), 0.55 (item 6), 0.65 (item 7), and 0.17 (item 10).

Once F1 and F2 were defined, a third EFA was performed with the remaining items 5, 8, 9, and 11. The results, strongly supported

by the theory and according to results obtained in Table 4, showed a dimension defined by items 9 and 11. Additionally, they presented a high correlation in Table 2 ($r = 0.73$). These items measured the standardization of the dependent variables (item 9), and the construct definition (item 11). Therefore, this dimension (factor 3 -F3-) was interpreted as construct validity (Shadish et al., 2002), because it is focused on explaining the concept, model, or schematic idea measured as a dependent variable, the way the theoretical dimensions are empirically defined, and the standardization of the tool used to measure the dependent variable.

Based on the parallel analysis conducted after including items 9 and 11, a single dimension was recommended. The reliability of F3 was $\omega = 0.65$ and the discrimination of the two items was 0.48.

Based on the results obtained in Table 4, items 5 (exclusions after assignment) and 8 (measures in pretest appear in post-test) were difficult to integrate, though they appeared to be linked. If we hypothesize that, together, these items form a dimension, its metric indices would be very low, with a reliability coefficient of $\omega = 0.13$ and discrimination indexes of 0.07. These items were predicted to present problems, since they had no variability, did not discriminate between studies, and presented excessive skewness, as shown on Table 1. We decided to exclude these two items from the defined F3 because they did not fit items 9 and 11, and presented low theoretical congruence in this dimension.

3.5. Interpretation of the study scores in each validity facet and acquisition of possible profiles

Table 5 shows the descriptive statistics for each of the theoretical validity facets obtained. To interpret the items in the study, each received a score of 0 (low), 0.5 (medium) or 1 (high).

TABLE 5 Descriptive statistics for each facet.

	F1	F2	F3
Possible range	0–4	0–4	0–2
Mean	3.98	1.59	1.38
Standard deviation	0.89	0.96	0.59
McDonald's ω	0.60	0.70	0.65
Discrimination	0.34	0.48	0.48

F1, external validity facet; F2, internal validity facet; F3, construct validity facet.

Formed by items 1 (inclusion and exclusion criteria for units), 3 (attrition), 4 (attrition between groups), and 12 (statistical methods for imputing missing data), F1 assesses external validity. F1 answers the question: how accurately are the population and the selection criteria for units defined? Studies with high scores in F1 should be characterized by a well-defined reference population, explicit selection criteria for the units that form the sample, and the monitoring of possible unit losses over the course of the study that could compromise the representativeness of the results.

Formed by items 2 (methodology or design), 6 (follow-up period), 7 (measurement occasions for each dependent variable), and 10 (control techniques), F2 assesses internal validity. It answers the questions: What are the relevant variables of the study? How and when are they manipulated and measured? What is done to control for possible sources of error? Studies with a great capacity to manipulate variables and control for threats to validity (Holgado-Tello et al., 2016) would receive high scores in F2. Other factors that affect scores in F2 include clearly established criteria for assigning the units to study conditions and the quantity of measures before, during, and after the interventions.

Finally, F3 assesses construct validity. Formed by items 9 (standardization of the dependent variables) and 11 (construct definition of outcomes), it answers the question: How are dimensions empirically operationalized from their conceptual referents? Studies with high scores in F3 clearly present the referent or conceptual model, an empirical operationalization of its components, and standardized measurements.

Table 6 provides an example of how scores can be interpreted in each study based on the scores for each item, as well as an overall assessment of the study based on its mean per facet. The scores of the facets were obtained calculating the average of the items that comprised them. This average ranged from 0 to 1 (low if <0.5; medium if ranging from 0.5–75, both values included; and high for values >0.75). For example, study 3 had a score of 2 in F1 (average = 0.5; medium quality); in F2, 1.5 (average = 0.37; low quality); and in F3, 1.5 (average = 0.75, medium quality).

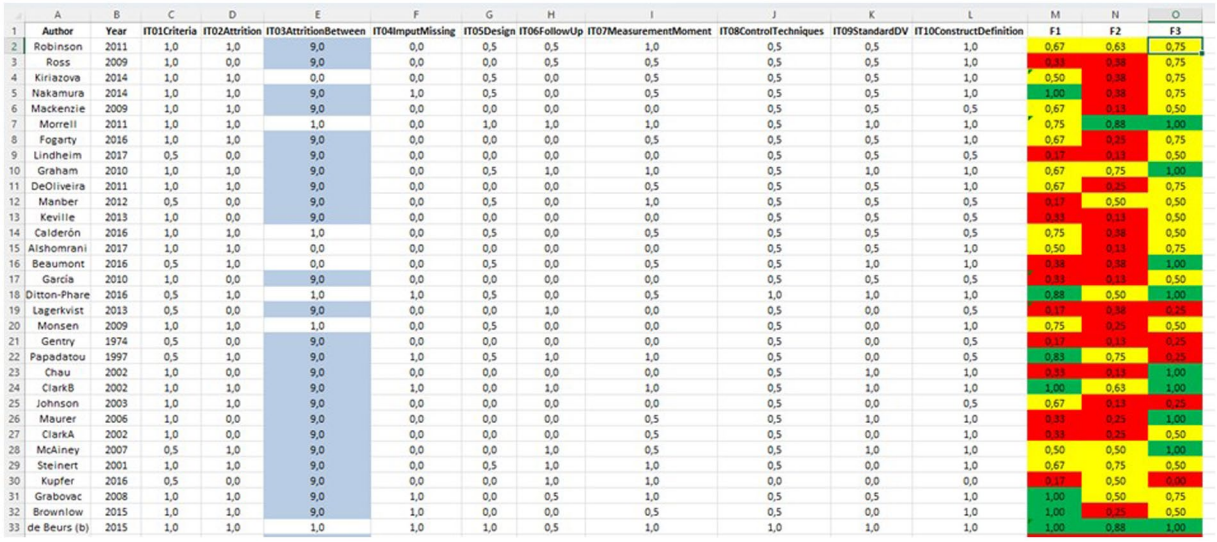
The evaluations of the 299 coded studies, by items and facets, are available in Supplementary material S4. Figure 2 represents part of this database, showing one line for each study, scores (0, 0.5 or 1) for each item, and the average score in each facet.

Table 7 presents the frequencies and percentages of studies of the sample that had a low, medium, and high level of quality in each facet. Based on the results obtained, most of the studies that

TABLE 6 Scores of four studies in each item, and average values in each facet.

Studies	Validity facets										Global		
	F1				F2				F3		Facets		
	I_1	I_3	I_4	I_{12}	I_2	I_6	I_7	I_{10}	I_9	I_{11}	F1	F2	F3
3	1	1	0	0	0.5	0	0.5	0.5	0.5	1	0.5	0.37	0.75
6	1	1	1	0	1	1	1	0.5	1	1	0.75	0.88	1
138	0.5	0.5	–	0	0	0	0	0.5	0	0.5	0.33	0.12	0.25
299	1	1	1	1	1	0	1	1	1	1	1	0.75	1

F1, external validity facet; F2, internal validity facet; F3, construct validity facet; I, item. Red, low level; yellow, medium level; green, high level of quality.



	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
1	Author	Year	IT01Criteria	IT02Attrition	IT03AttritionBetween	IT04ImputMissing	IT05Design	IT06FollowUp	IT07MeasurementMoment	IT08ControlTechniques	IT09StandardDV	IT10ConstructDefinition	F1	F2	F3
2	Robinson	2011	1,0	1,0	9,0	0,0	0,5	0,5	1,0	0,5	0,5	1,0	0,67	0,63	0,75
3	Ross	2009	1,0	0,0	9,0	0,0	0,0	0,5	0,5	0,5	0,5	1,0	0,33	0,38	0,75
4	Kiriazova	2014	1,0	1,0	0,0	0,0	0,5	0,0	0,5	0,5	0,5	1,0	0,50	0,38	0,75
5	Nakamura	2014	1,0	1,0	9,0	1,0	0,5	0,0	0,5	0,5	0,5	1,0	1,00	0,38	0,75
6	Mackenzie	2009	1,0	1,0	9,0	0,0	0,0	0,0	0,0	0,5	0,5	0,5	0,67	0,13	0,50
7	Morrell	2011	1,0	1,0	1,0	0,0	1,0	1,0	1,0	0,5	1,0	1,0	0,75	0,88	1,00
8	Fogarty	2016	1,0	1,0	9,0	0,0	0,0	0,0	0,5	0,5	0,5	1,0	0,67	0,25	0,75
9	Lindheim	2017	0,5	0,0	9,0	0,0	0,0	0,0	0,0	0,5	0,5	0,5	0,17	0,13	0,50
10	Graham	2010	1,0	1,0	9,0	0,0	0,5	1,0	1,0	0,5	1,0	1,0	0,67	0,75	1,00
11	DeOliveira	2011	1,0	1,0	9,0	0,0	0,0	0,0	0,5	0,5	0,5	1,0	0,67	0,25	0,75
12	Manber	2012	0,5	0,0	9,0	0,0	0,5	0,0	1,0	0,5	0,5	0,5	0,17	0,50	0,50
13	Keville	2013	1,0	0,0	9,0	0,0	0,0	0,0	0,0	0,5	0,5	0,5	0,33	0,13	0,50
14	Calderón	2016	1,0	1,0	1,0	0,0	0,5	0,0	0,5	0,5	0,5	0,5	0,75	0,38	0,50
15	Alshomrani	2017	1,0	1,0	0,0	0,0	0,0	0,0	0,0	0,5	0,5	1,0	0,50	0,13	0,75
16	Beaumont	2016	0,5	1,0	0,0	0,0	0,5	0,0	0,5	0,5	1,0	1,0	0,38	0,38	1,00
17	García	2010	1,0	0,0	9,0	0,0	0,0	0,0	0,0	0,5	0,5	0,5	0,33	0,13	0,50
18	Ditton-Phare	2016	0,5	1,0	1,0	1,0	0,5	0,0	0,5	1,0	1,0	1,0	0,88	0,50	1,00
19	Lagerkvist	2013	0,5	0,0	9,0	0,0	0,0	1,0	0,0	0,5	0,0	0,5	0,17	0,38	0,25
20	Monsen	2009	1,0	1,0	1,0	0,0	0,5	0,0	0,0	0,5	0,0	1,0	0,75	0,25	0,50
21	Gentry	1974	0,5	0,0	9,0	0,0	0,0	0,0	0,0	0,5	0,0	0,5	0,17	0,13	0,25
22	Papadatou	1997	0,5	1,0	9,0	1,0	0,5	1,0	1,0	0,5	0,0	0,5	0,83	0,75	0,25
23	Chau	2002	1,0	0,0	9,0	0,0	0,0	0,0	0,0	0,5	1,0	1,0	0,33	0,13	1,00
24	ClarkB	2002	1,0	1,0	9,0	1,0	0,0	1,0	1,0	0,5	1,0	1,0	1,00	0,63	1,00
25	Johnson	2003	1,0	1,0	9,0	0,0	0,0	0,0	0,0	0,5	0,0	0,5	0,67	0,13	0,25
26	Maurer	2006	1,0	0,0	9,0	0,0	0,0	0,0	0,5	0,5	1,0	1,0	0,33	0,25	1,00
27	ClarkA	2002	1,0	0,0	9,0	0,0	0,0	0,0	0,5	0,5	0,0	1,0	0,33	0,25	0,50
28	McAiney	2007	0,5	1,0	9,0	0,0	0,0	1,0	0,5	0,5	1,0	1,0	0,50	0,50	1,00
29	Steinert	2001	1,0	1,0	9,0	0,0	0,5	1,0	1,0	0,5	0,0	1,0	0,67	0,75	0,50
30	Kupfer	2016	0,5	0,0	9,0	0,0	0,0	1,0	1,0	0,0	0,0	0,0	0,17	0,50	0,00
31	Grabovac	2008	1,0	1,0	9,0	1,0	0,0	0,5	1,0	0,5	0,5	1,0	1,00	0,50	0,75
32	Brownlow	2015	1,0	1,0	9,0	1,0	0,0	0,0	0,5	0,5	0,0	1,0	1,00	0,25	0,50
33	de Beurs (b)	2015	1,0	1,0	1,0	1,0	1,0	0,5	1,0	1,0	1,0	1,0	1,00	0,88	1,00

FIGURE 2
Example of primary study coding. 9, not applicable. IT, item; F1, external validity facet; F2, internal validity facet; F3, construct validity facet. Red, low level; yellow, medium level; green, high level of quality. The complete items are available in Table 8.

TABLE 7 Distribution of studies by quality level in each facet (frequencies and %).

Level of quality	F1 External v.	F2 Internal v.	F3 Construct v.
Low	35 (11.7)	185 (61.9)	56 (18.7)
Medium	127 (42.5)	63 (21.1)	71 (23.8)
High	137 (45.8)	51 (17.0)	172 (57.5)
Total	*299 (100)*	*299 (100)*	*299 (100)*

F, facet; v., validity. Percentages are presented in brackets. For each facet (F1, F2, and F3), the most frequent level (low, medium, or high) is marked.

comprised the sample presented medium levels of quality in external validity, low levels in internal validity, and high levels in construct validity.

Table 8 presents the resulting MQS, ready to be used to measure the MQ in primary studies (MQS is also available in a printable version in Supplementary material S5).

4. Discussion

This work offers a practical approach to solve an existing problem, i.e., how to measure the varying quality levels of primary studies. It does so by analyzing the metric properties of a scale based on the standards for the constructions of measuring instruments that guarantee validity and reliability; not only analyzing content validity and intercoder reliability, but also including validity evidence based on the internal structure of the scale and metric properties of the tool (reliability based on internal coherence and discrimination). The proposed tool is available for researchers who are planning to carry out a meta-analysis. Additionally, it presents the basic elements to assess MQ of intervention programs, so professionals who are not experts in methodology can use the tool to design a new intervention or to evaluate an ongoing or completed intervention. Thus, this tool represents a first step toward guaranteeing that meta-analyses and interventions respond to replicability criteria.

In terms of other advantages, it is important to highlight that the inclusion criteria for the initial items of the MQS were specified. It not only considers the risk of bias associated with internal validity, but more broadly, that associated with external and construct validity. This yielded profiles with three facets, thus facilitating interpretation. It is a tool that can be applied to any type of intervention study (i.e., not only experimental methodology or randomized control trials). It is applicable in different areas of interest (not only in a specific setting). Moreover, it is easy to apply, as it is formed by ten items with three-point Likert scales.

A potential limitation of this study is that the MQS has only been applied to a set of studies in a specific field of intervention. However, regardless on the field of intervention, MQ varies between studies. For example, randomized studies with a high manipulation of variables can be found in in the field of health and in the social sciences too. MQ in itself is not related to the field of intervention. For this reason, we consider that MQ indicators can be studied in any context.

Additionally, the fact that the construct validity is comprised of only two items could be considered another limitation. However, one of the main ideas was to reduce the number of items in the scale as much as possible without lower its metric properties; this facet presents adequate validity and reliability indexes. Additionally, other tools (e.g., Valentine and Cooper, 2008), contain only one item on construct validity (i.e., face validity).

In relation to items 5 and 8, it was not possible to justify a single factor with adequate metric indexes, such as statistical conclusion validity, based on the results obtained. Nonetheless, the content of item 5 (exclusions after assignment) can be considered that is included in items referred to attrition (items 3 and 4 -external validity-). Moreover, the content of item 8 (measures in pretest appear in posttest) can be considered that is included in items referred to methodology and follow-up (items 2 and 6, respectively -internal validity-).

For further research, the same sample of primary studies will be coded using other tools available in the literature to compare the

TABLE 8 Methodological quality scale (final version).

Facet 1. External validity	
Item 1	**Inclusion and exclusion criteria for the units provided**: explicit reasons provided as to why certain units (usually people) were able to participate in the study and others were not: **0. No:** no explicit selection criteria for units AND with exceptions in their application; information unavailable. **0.5. Intermediate:** explicit selection criteria for units OR applied to all potential participants. **1. Yes (replicable):** explicit selection criteria for units AND applied to all potential participants.
Item 2	**Attrition:** loss of units. In randomized experiments, this refers to loss that occurred after the random assignment, i.e., the number of participants from the initial sample that did not conclude the study (e.g., N pre minus N post). **0. Unspecified:** information is not available and cannot be calculated AND reasons for loss of units are not specified. **0.5. Intermediate:** number of units lost is specified or can be calculated OR reasons for loss of units are specified. **1. Specified:** no units are lost, or number of units lost is specified or can be calculated AND reasons for loss of units are specified.
Item 3	**Attrition between groups:** this item evaluated the differences in attrition between two groups. **0. Unspecified:** information is not available and cannot be calculated AND reasons for attrition between groups are not specified. **0.5. Intermediate:** number of lost units is specified or can be calculated OR reasons for attrition between groups are specified. **1. Specified:** no units were lost, or number of lost units is specified or can be calculated AND reason/s for the attrition between groups is/are specified. **9. Not applicable:** no cross-group comparison.
Item 4	**Statistical methods for imputing missing data**: to estimate what the study would have yielded had there been no attrition: **0. High risk:** it is not clear if there was attrition, or there was attrition and calculations to estimate effects were carried out without imputing missing data. **0.5. Medium risk:** values for the missing data points were imputed so they could be included in the analyses. The method used was specified, i.e., sample mean substitution, last value forward method for longitudinal data sets, hot deck imputation, single imputation (e.g., imputation, regression imputation), or multiple imputation (e.g., likelihood ratio test after multiple imputation). The reasons for choosing the specific method were not specified. **1. Low risk:** there was no attrition or values for the missing data points were imputed so they could be included in the analyses; and the specific method used AND the reasons for choosing the specific method were specified.
Total facet 1	**External validity score:** Add the scores obtained in items 1–4 and divide by the number of items. If item 3 is not applicable, do not add a score for that item and divide the sum of items 1, 2 and 4 by 3.
Facet 2. Internal validity	
Item 5	**Methodology or design:** something an experimenter could manipulate or control in an experiment to help address a threat to validity: **0. Pre-experimental/others** (questionnaires/observational/naturalistic): a study with only one group and a maximum of two measurement occasions for the same dependent variable (e.g., pre-post design); or when there are two groups and only one measure (e.g., control-experimental design). **0.5. Quasi-experimental** (two groups without randomized assignment) non-equivalent control groups with pre-test and post-test; or one group with three or more measures of the same dependent variable (even without pretest): an experiment (exploration of the effects of manipulating a variable) in which units are not randomly assigned to conditions. **1. Experimental; randomized:** an experiment (exploration of the effects of manipulating a variable) in which units are randomly assigned to conditions.
Item 6	**Follow-up period**: the amount of time between the first post-intervention measurements and any additional measurements. When the study presented more than one follow-up period, the longest was considered. **0.** No follow-up or less than 2 months. **0.5.** Between two and 6 months (both included). **1.** More than 6 months.
Item 7	**Measurement occasions for each dependent variable**: this item specified when the measurements were taken. **0. Post-intervention only:** all measurements were taken after the intervention. **0.5. Pre- and post-intervention:** some measurements were taken before and immediately after the intervention. **1. Pre-, post-intervention and follow-up period:** some measurements were taken before, immediately after the intervention, and again at a later date.
Item 8	**Control techniques**: **0. None:** no control technique is specified or described. **0.5 Masking OR other/s:** masking, also known as double-blinding, refers to a procedure that prevented participants and/or experimenters from knowing the hypotheses; OR any other control technique was used (e.g., matching, stratifying, counterbalancing, constant, participant as own experimental control -longitudinal-). **1. Masking AND other:** masking AND at least one other control technique.
Total facet 2	**Internal validity score:** Add the scores obtained in items 5–8 and divide by the number of items (4).

(Continued)

TABLE 8 (Continued)

Facet 3. Construct validity		
Item 9	**Standardization of the dependent variables:** level of normalization of the tool to measure the variable that varied in response to the independent variable (also called effect or outcome). **0. Low standardization (self-reports and *post hoc* records)**: all measurements were taken using *ad hoc* tools, developed in a specific situation, and without any study of their psychometric properties. **0.5. Medium standardization**: at least one measurement was taken using structured tools with ONE study of their psychometric properties (reliability or one form of validity evidence). **1. High standardization**: at least one measurement was taken using structured tools. At least TWO studies of their psychometric properties (reliability, validity, construction of scaling) were carried out.	
Item 10	**Construct definition of outcome**: explanation of the concept, model, or schematic idea measured as a dependent variable: **0. No definition:** no concept treated as a dependent variable was measured in a conceptual or empirical way. **0.5. Vague definition:** at least one concept treated as a dependent variable was defined in a conceptual and/or empirical way. **1. Replicable by reader in own setting:** all concepts treated as dependent variables were defined in a conceptual and empirical way.	
Total facet 3	**Construct validity score:** Add the scores obtained in items 9 and 10 and divide by the number of items (2).	
INTERPRETATION for each type of validity (facet):		
<0.5 Low	[0.5–0.75] Medium	>0.75 High

results. The Risk of Bias version 2 (RoB 2) (Sterne et al., 2019) will be applied for experimental designs; and for quasi-experimental designs, the Risk Of Bias In Non-randomised Studies (ROBINS-I) (Sterne et al., 2016). Additionally, a cross-disciplinary guide will be drafted to inform practitioners of the design, implementation, and evaluation of intervention programs.

Data availability statement

The datasets presented in this study can be found in online repositories. The names of the repository/repositories and accession number(s) can be found in the article/Supplementary material.

Author contributions

SC-M conceived of and designed the study, analyzed and interpreted the data, and wrote the first draft and revised it. SS-C collaborated in the acquisition of data and critically reviewed the drafting for important intellectual content. JL-L contributed to the data acquisition, analysis, and interpretation and reviewed the paper. FH-T analyzed and interpreted the data and collaborated on the writing 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.

Publisher's note

Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpsyg.2023.1217661/full#supplementary-material

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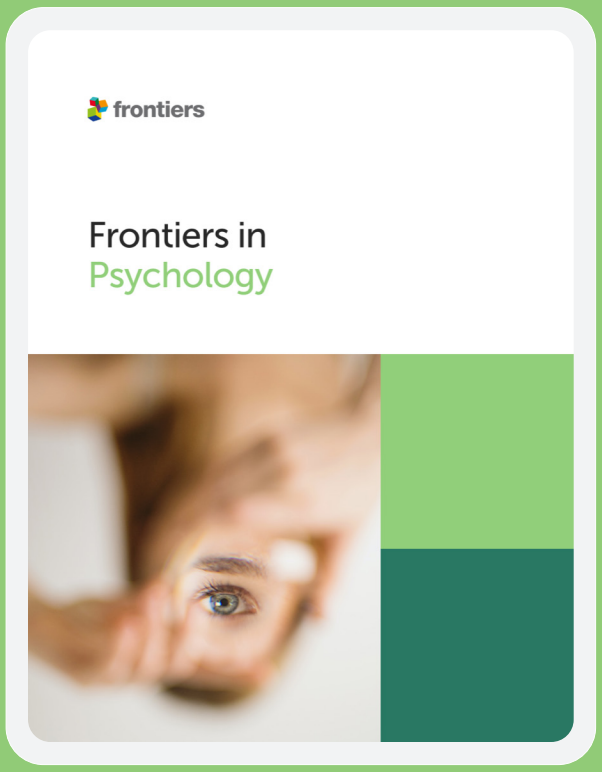

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