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Visual tracking of a moving target in 360-degree virtual reality: Analysis of the effects on attention and mood

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The training of attentional capacities is an important part of many rehabilitative efforts, for example, in the treatment of stroke. The Helix-Arena is an innovative virtual reality (VR) training device, which enables multimodal training in a 360-degree virtual environment. A pursuit training was developed for the Helix-Arena. In this study, we evaluate the effectiveness of the pursuit training in the Helix-Arena compared to a control group [CG, training on a personal computer (PC)] in 34 healthy participants. The experimental group (EG, N = 19) participated in four training sessions in the Helix-Arena over a period of 2 weeks. The control group (N = 15) completed similar training sessions in a non-VR environment on a PC. During each training session, changes in attention (Test of Attentional Performance battery, TAP) and general mood (Positive and Negative Affect Schedule, PANAS) were assessed pre- and post-training. A significantly higher pre-to-post improvement was observed in the EG for the TAP subtest attention shift in the subcategory invalid instructor (p = 0.04) than that in the CG. In addition, we found a higher positive affect after the training in the EG but not in the CG (p < 0.01). These results suggest advantages of the VR environment for attentional and affective processes. The VR training can thus improve not only cognitive abilities but also training motivation. In a next step, the training can be used with patients in a rehabilitation context, but it is also suitable for educational and gaming contexts.

KEYWORDS
pursuit training, virtual reality, Helix-Arena, attention, general affect

1 Introduction

Attention, as one of the central brain functions, has been the center of extensive research (Leclercq and Zimmermann, 2002; Sturm, 2005; Graf et al., 2011). Attention deficits often occur after a stroke (Loetscher et al., 2019). They comprise difficulty in concentration, higher distractibility, or faster tiring and can be present for several years (Loetscher et al., 2019). Furthermore, attention is a mediator for higher processes such as language and memory (Lezak et al., 2004). Training attentional functions is elementary as deficits can lead to problems not only in cognition but also in the quality of life (Nys et al., 2006), or they can hinder other rehabilitation processes (Hyndman and Ashburn, 2003).

The focus of research on attention in rehabilitation such as in stroke patients has been on neuropsychological processes (Posner and Boies, 1971; van Zomeren and Brouwer, 1994; Sturm, 1996) as well as on neurophysiological correlates (Graf et al., 2011). From a neurophysiological perspective, attention can be viewed as a top-down process, which influences the processing of information by a reinforcement of cortical responses and a modulation of neuronal activity. Attentional processes lead to a systematic and selective increase or decrease in neuronal associations. Thus, it may be possible that attention can influence the plasticity of the brain as a top-down process. This effect has been found in animals. In rats, expansions of cortical representations related to attentional processes were observed when different frequencies or loudness of auditory stimuli had to be detected; however, the sensory input was identical (Polley et al., 2006). These findings have also been supported in humans. For example, the imagination of finger movements led to an enlargement of the motor cortex area that is activated during actual movement (Pascual-Leone et al., 1995; Robertson and Murre, 1999). It can be concluded that systematic and targeted training can lead to the reactivation and functional recovery of damaged areas because the top-down input from attention circuits can improve connections in the non-damaged brain areas (Robertson et al., 1997). Several novel rehabilitation methods, such as imagination of movement or targeted directing of attention, have thus been shown to increase neuroplasticity (Jackson et al., 2001; Page, 2001; Stevens and Stoykov, 2003; Sharma et al., 2006; De Vries and Mulder, 2007). Therefore, improving attention may have positive effects by directing the attention to a targeted area, and thus, it increases the impact on beneficial neuroplasticity for treatments following brain damage.

The main aim of rehabilitation is to restore old functions or to compensate them by learning new functions (Cicerone et al., 2000). These methods are based on psychological, neuropsychological, and cognitive models and theories (Loetscher et al., 2019). The improvement of attention deficits can be trained via paper-pencil tasks or computer-based activities, all of which require attention (Loetscher et al., 2019). Additionally, one approach is to teach patients compensatory strategies for their impairment (Cicerone et al., 2005). A literature review concluded that there is no evidence for long-term improvement; however, in some cases, training is directly followed by a positive effect (Loetscher et al., 2019). For example, one study found an improvement in the Test of Attentional Performance battery (TAP) divided attention subtest in comparison to a control group (Röhring et al., 2004), but these effects are often not sustained. However, the sustainability of the effect is important to ensure a transfer to daily-life activities. Realistic training situations, such as those used in virtual reality (VR), could help improve sustainability because the realistic training situation might improve transfer into real-life situations.

VR has already been used in rehabilitation, for example, in stroke patients. Compared to patients who only received standard computerized cognitive rehabilitation, several studies have shown that patients who participate in VR training seem to have an advantage. For example, one study reported significantly more improvement in general cognitive functions, attention, and executive functions for a VR training than for conventional rehabilitation in stroke patients (Faria et al., 2016). In a meta-analysis of randomized controlled trials of stroke patients who received VR-based versus conventional treatment, a small-to-moderate additional effect of VR on cognition was reported (Aminov et al., 2018). Therefore, the use of VR in addition to conventional therapy was recommended. A further meta-analysis could not find an advantage of improvements in attention with VR; however, they observed a higher improvement in general cognitive functions (Zhong et al., 2021). In addition, there are already first findings regarding the Helix-Arena. In general, current studies did not unanimously find an advantage of VR training over standard therapies, but this approach appears promising (Khan et al., 2021; Bourgeois et al., 2023). A recent study found that the use of immersive VR led to an improvement in brain connectivity when used in addition to standard therapy (Huang et al., 2024). The Helix-Arena is a novel tool that allows VR training in a 360-degree environment, and first results show a small but significant correlation between multiple object-tracking performance and visuospatial attention (Ehmann et al., 2021). Thus, studies that explore the utility of the VR-based Helix training in attentional tasks used in neurological rehabilitation seem justified.

VR also improves affect (Schutte, 2020), especially in people who suffer from neurological impairments (Chan et al., 2020). In general, affect has a significant impact on cognition, social interaction, as well as psychological well-being, improving function in everyday life (Carver et al., 2014). Positive affect shows positive correlations with social activity, satisfaction, and a number of pleasant events. Regarding negative affect, positive correlations have been found with stress, health problems, and a number of unpleasant outcomes (Crawford and Henry, 2004). Thus, affect can have large influences on rehabilitation. Findings related to momentary affect and VR showed increased enjoyment of exercise (Bauer and Andringa, 2020; Brimelow et al., 2020; Zhong et al., 2021), restorative mood elevation (Chan et al., 2020; Schutte, 2020; Liszio, 2021), and increased curiosity and interest (Rupp et al., 2019; Schutte, 2020). Other findings suggest that the VR experience is perceived as positive, enjoyable, and relaxing (Anderson et al., 2017; Riches et al., 2021). In relation to an older sample, cognitive VR training was found to increase positive affect and decrease negative affect (Chan et al., 2020). The 360-degree environment can especially boost motivation and positive affect (Parong and Mayer, 2018; Roche et al., 2019; Chan et al., 2020; Liszio, 2021).

In general, VR appears to have a positive impact on psychological well-being (Roche et al., 2019). VR offers other benefits, such as direct feedback on performance, which can have a positive impact on motivation (Domínguez-Téllez et al., 2020). In addition, adaptive training can be perfectly implemented, which enables a constant challenge; hereby, an increased training effect can be expected, and motivation is maintained (Ryan et al., 2006; Sutcliffe et al., 2019). Immersion in a different environment is provided (Schutte, 2020). The higher the perceived immersion level, the higher the degree of presence. This resulted in pronounced relaxation and mood elevation effects (Bayyari and Tudoreanu, 2006; Liszio, 2021). Thus, the significance of the level of immersion is clarified.

Another advantage of VR is that it represents a new method in terms of learning processes. The immersive experience can lead to a much better understanding. The more realistic design indicates that connections can be made more quickly and effectively (Schott and Marshall, 2018; Shah et al., 2024). The inclusion of learning theories in VR applications offers additional advantages (Squire, 2003; Shah et al., 2024).

In summary, the use of VR may be promising for cognitive training (Roche et al., 2019; Park et al., 2020). The utilization of VR to enhance cognitive functions appears to be a rational approach. A salient factor that has emerged as a subject of interest is the nature of the VR intervention used (Moulaei et al., 2024). However, the current studies also show that there is still a need for further research to obtain a clearer picture. For example, studies are needed to examine possible long-term effects (Zhong et al., 2021), their sustainability, and their transfer into everyday life (Bauer and Andringa, 2020). There are also few comparisons with alternative training methods, which is where the current study should make a contribution.

The current project is based on the idea to train attentional functions with a special pursuit training. In pursuit training, a target is presented with five distractors. The participant's task is to pursue the target item. After a specific time, the participant has to tag the correct item. A relevant ability to practice the pursuit training is to place the fovea on the target item. This process needs a prediction to compensate the inherent neuronal gap, which is present in the visual processing stream (Barnes and Asselman, 1991). The performance of pursuit training was shown to occur in a top-down manner (Keller et al., 2009). As a consequence of neurological problems such as stroke, lesions of the parietal and frontal lobes are frequent, which may lead to deficits of the ocular motor system involved in the pursuit of objects (Heide et al., 1996). These and further brain areas (e.g., cerebellum and medial superior temporal areas) are involved in the processing, prediction, and transmission of visual information (Krauzlis, 2004). It was shown that the functionality of the ocular motor system can be a marker for cognitive and motor rehabilitation (Dong et al., 2013) and that pursuit training leads to an improvement for patients with subcortical lesions (Baumann and Greenlee, 2009). If the target is fast enough, only one target can exhaust pursuit and attention resources (Holcombe and Chen, 2012). Furthermore, pursuit training improves the ability to suppress distractors and focus on high velocity (Wu et al., 2013).

The aim of this study was to investigate the efficacy of a pursuit training in a VR environment (Helix-Arena) compared to a pursuit training on a personal computer (PC). In this project, the Helix-Arena generates the virtual environment. The Helix-Arena is a circular room that is entered through a door. VR is created on a screen with the help of projectors. Because of the 360-degree environment, the participants are shielded from the outside world and experience a high level on immersion (Ehmann et al., 2021). Compared to other VR devices, participants stand in the Helix-Arena and thus enter virtual reality without any other equipment. In contrast to an HMD, this can be an advantage, especially in educational setting or in gaming. In a first step, the study was carried out with healthy people using a procedure that would also be feasible for rehabilitation. We tested effects on visual and spatial attention and general mood, and hypothesized that the VR training would be superior to a normal training on a PC in these respects.

2 Methods

2.1 Participants

The composition of the study sample is presented in Table 1. The total sample size of the study was 34 participants, consisting of 19 participants in the experimental group (EG) and 15 participants in the control group (CG). Of these, there were 9 women and 10 men in the EG, with a mean age of 49.47 years (SD: 15.97). In the CG, there were seven women and eight men, with a mean age of 44.87 years (SD: 15.89). There were no significant differences between the groups for age or gender ($p > 0.05$). Nineteen participants had at least 12–13 years of education (level of high school diploma) and 15 had less than 12–13 years. The level of education was not significantly different between the groups ($p > 0.05$). Participants were only included if they were free of any major health problems. For the Helix-score (post), along with the visual scanning subtest of the TAP (pre), one participant had to be removed because of headache ($n = 33$). There were no dropouts, but two participants were excluded from the evaluation of the TAP subtest "Visual Scanning" due to incorrect execution. All participants signed informed consent, and the study was approved by the Ethics Committee of the Medical Faculty Mannheim of Heidelberg University.

2.2 Experimental design

An experimental control group design with a pre- and post-measurement was applied. The EG received a pursuit training in a 360° room (Helix-Arena), and the CG was trained with a computerized version of a pursuit training. The assignment of participants to either the EG or the CG was random. The intervention included a pre-measurement session, four training sessions, and a post-measurement session. The six appointments for each participant were carried out within 2 weeks (Figure 1).

The study took place at the TSG ResearchLab of the Bundesliga club TSG Hoffenheim in Zuzenhausen (Germany). It was designed as a pilot study to test the viability of a VR-based attention training compared to a standard computer-based training for potential later use with stroke patients.

2.3 Material

2.3.1 Helix-Arena

The Helix-Arena (skills.lab, Graz, Austria) is a circular room with a diameter of 6 m and a projection height of 2.44 m (Figure 2A). It is equipped with five projectors (1920 × 1,200, 6300 ANSI Lumen), which enable a continuous image (360-degree) of the training setup. The lighthouse systems ensure an interaction with the hand controller (Figure 2B) (HTC Vive Controller, HTC, New Taipei City, Taiwan).

TABLE 1 Composition of the study sample.

Variable	Statistical details	Experimental group	Control group	Total	t-Test/χ2-test
		N = 19	N = 15	N = 34	
Age	*M* (*SD*)	49.47 (15.97)	44.87 (15.89)	47.44 (15.86)	$t(32) = -0.84; p = 0.41$
	Min	27	24	24	
	Max	73	71	73	
Gender	Female (N)	9	7	16	χ^2 (1) < 0.01; p = 0.97
	Male (N)	10	8	18	

Note. M, mean; SD, standard deviation; Min, minimum; Max, maximum.

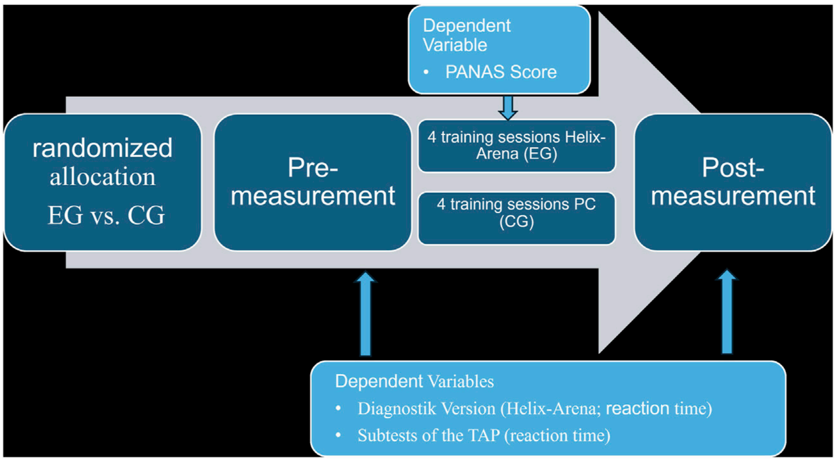

FIGURE 1
Experimental design and dependent variables. EG, experimental group; CG, control group; TAP, "Testbatterie zur Aufmerksamkeitsprüfung."

2.3.2 Pursuit training Helix-Arena

During the pursuit training, six red-colored avatars are presented on a 360-degree screen. The virtual environment is based on a virtual circular room (50 m diameter) and was designed in a neutral gray (Figures 2A,C). The avatars look like persons with a height of 1.80 m (Figure 2C). While the participants stand in a circular zone of 1 m diameter located in the middle of the room (Figure 2C), they pass several trials. Each trial starts with a presentation of the six avatars. The starting positions of the avatars are standardized with respect to the depth level of the virtual room. The presentation is followed by a marking phase, in which one of the six avatars is marked as the one to be tracked with a blinking circle presented on the ground below the respective avatar for a duration of 5 s (Figure 3A). When the blinking circle disappears, the avatars move through the 360° virtual environment [moving phase (Figure 3B)]. The participant has to pursue the target avatar. The avatars can run from a depth position of 4 m to a maximum depth of 53 m. The avatars move freely around the room, so their trajectories can cross each other, for example. After 10 s, all avatars return to a depth of 4.4 m, where they remain distributed in the 360-degree virtual environment [selection phase (Figure 3C)]. The task for the participants is to select the previously marked target avatar. Using the provided controller, the person presses a button to make their choice on one of the avatars. There is no time restriction regarding this choice. After the selection phase, the avatars start moving into a new position, and a new trial begins.

In the training version, the trajectories of the avatars are randomly distributed for every participant and trial; it is an adaptive training version. The starting speed level of the avatars is 10 km/h. After a correct trial, the auditory feedback announces success ("next level"). In the next level, the speed of the avatars increases by 1.5 km/h. If the trial was not correct, the Helix gives the feedback "step down." In this case, the speed of the avatars decreases by 1.5 km/h. After the training, the participant receives the feedback on how many trials were answered correctly (percentage correct).

In the diagnostic version, the target avatars, the trajectories, and the speed of the avatars are the same for every participant. Each trial is equal for each participant to ensure a standardized procedure. The diagnostic version consists of 30 trials, starting with the same speed level as the avatars in the training version (10 km/h). After three trials, the speed increases by 3 km/h until it reaches a maximum speed level of 40 km/h. The duration of the diagnostic version is circa 10 min. In contrast to the training version, the participants do not receive any feedback after any trial. Once the diagnostic version has been completed, the number of correct trials is presented to the participant. In case of a perfect performance with 30 of 30 correct trials, the value of 100% is shown. The diagnostic version was used for the pre- and post-measurements.

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FIGURE 2
(A) Helix-Arena, **(B)** hand-controller, and **(C)** pursuit training in the Helix-Arena.

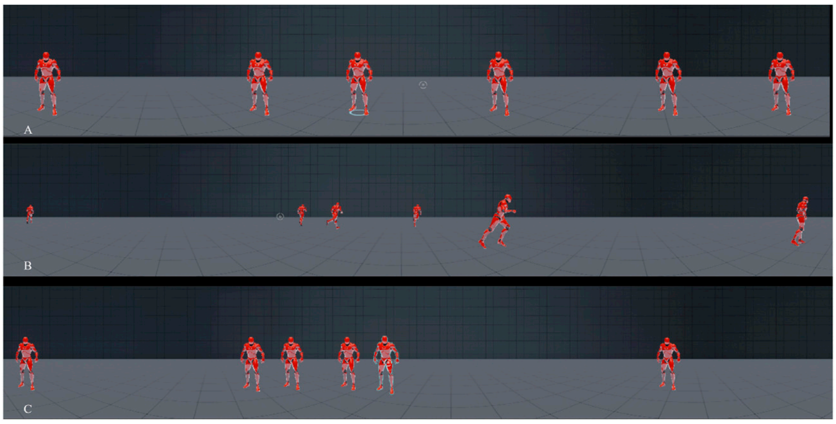

FIGURE 3
Phases of the pursuit training in the Helix-Arena: **(A)** marking phase, **(B)** moving phase, and **(C)** selection phase.

2.3.3 Pursuit training on the personal computer

The pursuit training on the PC (43.18 cm diameter) was designed using MATLAB [MATLAB. (2021). *version 9.10.0 (R2021a)*. Natick, MA, USA]. In this version, six white-framed squares are presented on a black background to the participant. Each trial starts with a marking phase, in which one square turns completely white for 0.7 s (Figure 4A). Once changed back to the original white frame, all squares are moving across the screen in different and randomized trajectories, with a speed of 6.35 cm/s (Figure 4B). After 5 s, the squares stop moving, and one random square is displayed, which is completely white. The participant is asked to decide whether this white-colored square is identical to the target square shown in the beginning. Depending on the decision, an arrow button either pointing to the left ("Yes") or to the right ("No") has to be selected. Without receiving any feedback, the participant starts a new trial. In the end, the experimenter receives the participants' results. We modified this from a multiple object tracking—PC training, which was used in several studies, also encompassing neurological patients (Merkel et al., 2017; Lesch et al., 2020).

2.3.4 Test battery for the evaluation of attention

A standard test battery was used to test changes in attention. The "Testbatterie zur Aufmerksamkeitsprüfung" [TAP (Zimmermann and Fimm, 2021)] is testing several attentional parameters and is frequently used in neurological rehabilitation (Zoccolotti et al.,

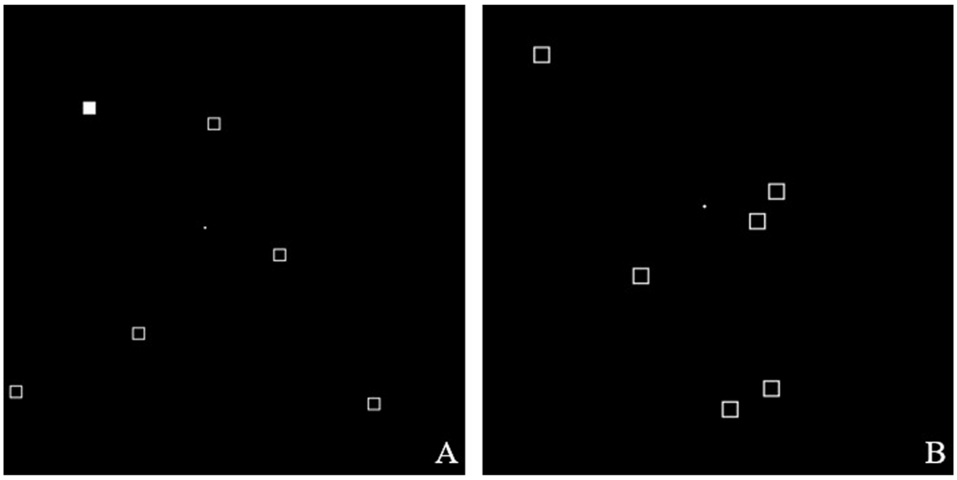

FIGURE 4
(A) Marking phase of the pursuit training on the PC and **(B)** moving phase on the pursuit training on the PC.

2000). The instrument was used to describe the level of attentional capacity of the participants and the training-associated change. It was decided to use this instrument because of the overall aim to work with patients in neurological rehabilitation.

The following four subtests were used.

- Alertness: alertness is the prerequisite for adequate actions; thus, it is the basis for any attentional performance. In this test, participants are asked to respond as quickly as possible to a cross presented to them on the screen. The aim is the measurement of the ability to maintain reaction time—in anticipation of a stimulus—as long as possible. Two versions were used: one without sound and one with a sound announcing the cross. Anticipated reactions in the subcategory with sound were counted as a further variable.
- Divided attention: in everyday life, the ability to concentrate on several things at the same time is needed. In the divided attention test, participants are presented with two stimuli simultaneously, one visually and the other one auditorily. Therefore, in this dual task, two stimuli have to be observed at the same time. Depending on the task, the participant should respond to either the visual or the auditory stimulus. As a further variable, the outliers for each subcategory (auditory and visual) and the errors in both categories were calculated.
- Attentional shift: attentional shift tests the ability to maintain visual attention to a specific stimulus without changing the direction of gaze. This shift can occur endogenously, that is, voluntarily to an expected stimulus in space. In this test, the participant is shown a central cue stimulus in the form of an arrow pointing either to the right or to the left. This is supposed to indicate the presumed side of the following stimulus. Thus, the endogenous attentional shift is tested. In the case of the invalid cue stimulus, the focus is initially on the indicated side, and after the target stimulus is shown on the other side, a shift is made to the side of the target stimulus that appears. Two values are reported: the speed of the response when the cue stimulus was valid and the speed of the response when the stimulus was invalid. As a further variable, the anticipate reactions in both categories were counted.
- Visual scanning: orientation and exploration of space is elementary for safe movement in it. In the visual scanning task, the participant must search a 5 × 5 matrix for a critical stimulus. The goal is to determine whether the critical stimulus is present or not. This is answered with the corresponding key for "contained" and "not contained." Two values are reported: the speed of the response when the stimulus was included (critical) and the speed of the response when the stimulus was not included (noncritical). As further variables, the outliers were counted for the critical value, and the errors were counted for the noncritical value.

2.3.5 Positive and Negative Affect Schedule

The "Positive and Negative Affect Schedule" [PANAS (Breyer and Bluemke, 2016)] is used to measure positive and negative affective states. The questionnaire contains a total of 20 adjectives, by which various feelings and sensations of the participant are queried. Ten words are connoted with a positive and 10 with a negative affective status. The reliability of the PANAS can be described as very high because of a Cronbachs $\alpha = 0.86$ and a Raykovs $\rho = 0.93$ for both scales (Breyer and Bluemke, 2016). It also has good validity.

2.4 Procedure

2.4.1 Pre- and post-measurement

The pre- and post-measurements consisted of the following procedures: subtests of the TAP. This was followed with questions about the general affective state (PANAS) and motivation (one item: "How motivated are you today?" answered with a 5-point Likert Scale from "Not at all" to "Extremely"). After that, the diagnostic version of the pursuit training in the Helix-Arena started (duration of approximately 10 min). To compare the pre- and post-general affective state after the training in the Helix-Arena, the PANAS had to be completed again.

TABLE 2 Dependent variables for the testing.

Variable	Subtest	Subcategory	Subcategory	Subcategory	Subcategory	Subcategory
Helix	Helix score	Reaction time				
TAP	Alertness	Without sound	With sound	Anticipate reactions		
	Divided attention	Auditory	Visual	Outlier (auditory)	Outlier (visual)	Error
	Attention shift	Valid instructor	Invalid instructor	Anticipate reactions		
	Visual scanning	Critical value	Noncritical value	Outlier (critical)	Error (noncritical)	
PANAS		Positive	Negative			

Note: TAP, "Testbatterie zur Aufmerksamkeitsprüfung"; PANAS, "Positive and Negative Affect Schedule."

TABLE 3 Descriptive statistics for the Helix score and the reaction time (sec) in the Helix compared to the PC.

Variable	Time	Experimental group		Control group	
		N = 19		*N* = 14	
		M	*SD*	*M*	*SD*
Helix score	Pre	29.53	0.77	29.57	0.76
	Post	29.95	0.23	29.64	0.63
Helix(rt)	Pre	2.21	0.51	2.11	0.09
	Post	1.96	0.48	2.09	0.44

Note: M, mean; SD, standard error; rt, reaction time.

The procedure of pre- and post-measurement was identical. Additionally, participants were asked to answer a questionnaire about demographic variables at the pre-measurement and a feedback questionnaire after the post-measurement. All questionnaires were answered *via* the online platform Microsoft Forms (version 2022) on the PC.

2.4.2 Training sessions

During the four intervention sessions, the EG received the pursuit training version in the Helix-Arena (see 1.3.2), whereas the CG received a parallel computerized version of the pursuit training (see 1.3.3). Training sessions also started and ended with the PANAS, followed by two rounds of interventions with a duration of 5 min and a break of approximately 1–2 min between them. As the diagnostic version of the pre-measurements was already carried out in the Helix-Arena by all participants, an adaptation to the training was provided.

2.5 Data analysis

2.5.1 Preparation of the data

A 2 measurement (pre vs post) × 2 condition (EG vs CG) design was used in the present study. Measurement was the group factor, whereas condition served as the between-group factor. For the testing of the hypotheses, an analysis of variance (ANOVA) with repeated measures for each dependent variable was conducted (Table 2). Due to the nature of the data and the high statistical power, this measurement method was chosen. In addition, age was included as a covariate for further calculations in a separate ANCOVA as it can be assumed that age plays a major role in the parameters studied. This ANCOVA was not calculated for the TAP-subtest parameters anticipated reactions, outlier, and error. The prerequisites for the application of the ANOVA with repeated measures were checked. The normal distribution assumption could not be confirmed for all the categories (Kolmogorov–Smirnov test). As variance homogeneity (Levene test) and sphericity (not more than two measurements) were given, this violation could be neglected (Berkovits et al., 2000). To test for baseline differences, a univariate ANOVA with the pre-measurement results was calculated. For none of the parameters, the group difference was statistically significant ($p \geq 0.11$).

For the results in the diagnostic version of the pursuit training in the Helix-Arena, the number of the correct trials was used. Here, the maximum value was 30. The ANOVAs, ANCOVAs, and t-tests were performed, with the mean values of the pre- and post-measurements. In addition, the reaction time per trial was averaged across all participants and compared between pre- and post-measurement. For the subtests of the TAP, the mean of the reaction time at the pre- and post-measurement was used. Thus, alertness (without and with sound), divided attention (auditory and visual), attention shift (valid and invalid instructors), and visual scanning (critical and noncritical values) were tested. For the other parameters of the individual TAP subtests, the mean values of the number of anticipate reactions, errors, or outliers were used.

For the PANAS, a mean of all results from the surveys during the training sessions was calculated. Therefore, two values for the pre- and post-training measurement were calculated. Furthermore, the

TABLE 4 Results of the TAP subtests.

Variable	Time	Experimental group N = 19	Control group N = 15	F-value (df) (group*time), p-value
Alertness				
Without sound	Pre	270.05 (69.85)	249.27 (44.24)	F (1,32) = 1.30, p = 0.26
	Post	260.00 (50.03)	258.13 (72.43)	
With sound	Pre	277.16 (72.17)	259.13 (46.68)	F (1,32) = 0.60, p = 0.44
	Post	261.48 (55.65)	255.67 (62.53)	
Shared attention				
Auditory	Pre	603.58 (85.32)	560.53 (83.75)	F (1,32) = 0.68, p = 0.42
	Post	581.79 (72.40)	554.47 (77.62)	
Visual	Pre	794.37 (91.55)	775.40 (101.91)	F (1,32) = 1.43, p = 0.24
	Post	786.79 (123.77)	740.80 (95.57)	
Attention shift				
Valid instructor	Pre	313.95 (79.99)	275.20 (54.45)	F (1,32) = 2.40, p = 0.13
	Post	296.00 (69.10)	278.27 (69.70)	
Invalid instructor	Pre	352.63 (91.08)	305.60 (71.83)	F (1,32) = 4.45, p = 0.04
	Post	321.00 (73.53)	308.67 (77.37)	
Visual scanning				
Critical	Pre	2597.11 (621.90)	2348.79 (1,266.77)	F (1,30) = 0.08, p = 0.79
	Post	2330.00 (581.86)	2105.14 (835.66)	
Noncritical	Pre	4711.79 (1,120.59)	4534.50 (3029.03)	F (1,30) = 0.40, p = 0.84
	Post	4439.06 (1,026.00)	4147.92 (1885.53)	

ms, mean reaction time; SD in brackets.

PANAS was split into the positive and negative scales. Because of this, it is possible to go into more detail about the effects in terms of positive and negative affect.

All calculations were carried out using the statistical analysis software SPSS (version 28.0.1.0, IBM Corporation, Chicago, IL, USA). The analyses included ANOVAs, ANCOVAs, and *t*-tests for dependent samples and t-tests for independent samples (one-sided), as well as linear regression. For the report of a significant result, p <0.05 was adopted. A listing of the original degrees of freedom is provided. Furthermore, as a measure of effect size, partial Eta squared (η^2) is reported for the calculated ANOVAs. Graphs include the standard error of the mean.

3 Results

3.1 Helix score: diagnostic version of pursuit training

3.1.1 Helix score

The ANOVA with repeated measures for the diagnostic version of the pursuit training revealed no significant interaction effect of group and time for the Helix score [F (1, 31) = 1.11; p = 0.30; η^2 = 0.04; Table 3]. No main effect of time [F (1, 31) = 2.20; p = 0.15; η^2 = 0.07] and group [F (1, 31) = 0.80; p = 0.43; η^2 = 0.03] could be found.

The ANCOVA with the covariate age revealed an almost significant interaction effect of time with the covariate age [F (1, 30) = 4.29; p = 0.05; η^2 = 0.13]. Additionally, there was a significant main effect of age [F (1, 30) = 12.17; p < 0.01; η^2 = 0.30]. Based on this, a linear regression was calculated to examine the influence of age on the dependent variable (Helix score (pre and post)). At the pre-measurement, age was found to be a significant predictor [β = −0.02; t (32) = −2.55; p = 0.02]. Age explained a significant proportion of the variance at the pre-measurement [R^2 = 0.17; F (1, 32) = 6.49; p = 0.02]; the older the participants, the worse the Helix score. At the post-measurement, we no longer observed a significant effect (β < −0.01, t (31) = −0.39, p = 0.70; R^2 = 0.07, F (1, 31) = 0.15, p = 0.70).

3.1.2 Helix score reaction time

For the ANOVA with repeated measures that compared the mean reaction time in the Helix-Arena between the groups, no significant interaction effect of group and time was found [F (1, 31) = 2.29; p = 0.14; η^2 = 0.07; Table 3]. Furthermore, no significant main effect of time [F (1, 31) = 3.05; p = 0.09; η^2 = 0.09] or group [F (1, 31) = 0.01; p = 0.92; η^2 <0 .01] was observed.

The ANCOVA with the covariate age revealed no significant interaction effect of time with the covariate age [F (1, 30) = 0.02; p = 0.89; η^2 <. 01]. However, there was a significant main effect of age [F (1, 30) = 12.93; p < 0.01; η^2 = 0.30]. The linear regression yielded age as a significant predictor at both the pre-measurement [β =0 .01, t (31) = 3.34, p < 0.01; R^2 = 0.52, F (1, 31) = 11.16, p < 0.01] and post-measurement [β =0 .01, t (31) = 2.57, p = 0.02; R^2 = 0.42, F (1, 31) = 6.61, p = 0.02] performance. The older the participants, the higher the reaction time in the Helix-Arena.

3.2 TAP

For the TAP, separate analyses were performed for each subtest.

3.2.1 Alertness

For the subtest alertness with the subcategories with or without sound, no significant interaction effect of group and time could be found (Table 4). A main effect of neither time [with sound: F (1, 32) = 1.51, p = 0.23, η^2 = 0.05; without sound: F (1, 32) = 0.01, p = 0.94, η^2 <0 .01] nor group [with sound: F (1, 32) = 0.39, p = 0.54, η^2 = 0.01; without sound: F (1, 32) = 0.35, p = 0.56, η^2 =0 .01] was significant.

The ANCOVA with the covariate age revealed no interaction effect of time and covariate age [with sound: F (1, 31) = 0.10, p = 0.75, η^2 <0 .01; without sound: F (1, 31) = 1.45, p = 0.24, η^2 = 0.05]. However, there was a significant main effect of age [with sound: F (1, 31) = 7.61, p = 0.01, η² = 0.20; without sound: F (1, 31) = 15.91, p < 0.01, η^2 = 0.34]. Therefore, the linear regression showed significant results for age as a predictor at pre-measurement [with sound: β = 1.7, t (32) = 2.73, p = 0.01; R^2 = 0.43, F (1,32) = 7.44, p = 0.01; without sound: β = 2.39, t (32) = 4.62, p < 0.01; R^2 = 0.63, F (1,32) = 21.3, p < 0.01] and post-measurement [with sound: β = 1.49, t (32) = 2.52, p = 0.02; R^2 = 0.40, F (1,32) = 6.37, p = 0.02; without sound: β = 1.68, t (32) = 2.81, p = 0.01; R^2 = 0.45, F (1,32) = 7.89, p = 0.01]. The older the participants, the higher the reaction time.

The ANOVA for the anticipate reaction parameter in the with-sound subcategory found a significant interaction effect of group and time [F (1, 32) = 5.46, p = 0.03, η^2 = 0.15]. At the pre-measurement, significantly more anticipated reactions were found in the EG than in the CG [t (32) = −2.99, p < 0.01 (CG: M = 0, SD = 0; EG: M = 0.47, SD = 0.61)]. At post-measurement, this difference could no longer be detected [t (32) = 0.07, p = 0.47 (CG: M = 0.33, SD = 0.62; EG: M = 0.32, SD = 0.75)]. In the CG, a significant decrease from pre- to post-measurement was found [t (14) = −2.09; p = 0.03]. No significant change was found in the EG [t (18) = 1.14, p =0 .13]. There was no main effect of time [F (1, 32) = 0.70; p = 0.41; η^2 = 0.02] and group [F (1, 32) = 1.72; p = 0.20; η^2 = 0.05].

3.2.2 Shared attention

In addition, the subtest shared attention with the subcategories auditory and visual was applied. No significant interaction effect of group and time was found, neither for auditory nor for visual (Table 4).

For the auditory subtest, a significant main effect of neither time [F (1, 32) = 2.13; p = 0.15; η^2 = 0.06] nor group [F (1, 32) = 1.85; p = 0.18; η^2 = 0.06] could be found.

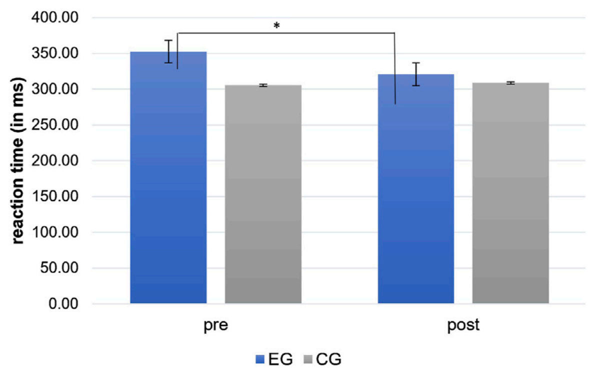

FIGURE 5
Significant interaction effect of group and time for the invalid instructor subcategory in the subtest attention shift (p <0 .05). The experimental group (EG) has a faster reaction time at post-measurement than at pre-measurement. In the control group (CG), no significant difference was observed between pre- and post-measurement.

An interaction effect of time with the covariate age could not be found [F (1, 31) < 0.01; p = 0.93; η^2 <0 .01]. Nevertheless, there was a significant main effect of age [F (1, 31) = 8.18; p < 0.01; η^2 = 0.21]. The linear regression revealed age as a significant predictor at pre-measurement (β = 2.3, t (32) = 2.69, p = 0.01; R^2 = 0.43, F (1,32) = 7.23, p = 0.01) and post-measurement (β = 2.20, t (32) = 2.98, p < 0.01; R^2 = 0.47, F (1,32) = 8.89, p < 0.01). The older the participants, the worse the reaction time.

The ANOVA for the auditory subtest with regard to the outlier parameter revealed no significant interaction effect of group and time [F (1, 32) = 2.17; p = 0.15; η^2 = 0.06]. In addition, no main effect of time [F (1,32) = 0.23; p = 0.63; η^2 <0 .01] and group was found [F (1, 32) = 1.17; p = 0.29; η^2 = 0.04].

In the visual subtest, no significant main effect of time [F (1, 32) = 3.48; p = 0.07; η^2 = 0.10] and group [F (1, 32) = 0.90, p = 0.35, η^2 = 0.03] could be found.

The ANCOVA with the covariate age revealed an interaction effect of age and time [F (1, 31) = 7.99; p = 0.01; η^2 = 0.21]. Additionally, there was a significant main effect of age [F (1, 31) = 46.67; p < 0.01; η² = 0.60]. The further results for the interaction effect with age, along with the main effect of age, revealed that there were significant linear regressions at both the pre-measurement [β = 3.91, t (32) = 4.84, p < 0.01; R^2 = 0.65, F (1,32) = 23.45, p < 0.01] and the post-measurement [β = 5.85, t (32) = 8.15, p < 0.01; R^2 = 0.82, F (1,32) = 66.45, p < 0.01]. That is, the older the participants, the worse the reaction time in the visual divided attention task.

The ANOVA for the visual subtest with regard to the outlier parameter revealed no significant interaction effect of group and time [F (1, 32) = 1.04; p = 0.32; η^2 = 0.03]. In addition, no main effect of time [F (1, 32) < 0.01; p = 0.98; η^2 <0 .01] and group was found [F (1,32) = 2.36; p = 0.13; η^2 = 0.07].

For both auditory and visual subcategories, no significant differences could be found in the ANOVA with the common parameter error. No significant interaction effect of group and time could be found [F (1, 32) = 0.31; p = 0.58; η^2 = 0.01]. No main effect of time [F (1, 32) = 0.31; p = 0.58; η^2 = 0.01] and group [F (1, 32) = 0.82; p = 0.37; η^2 = 0.03] was found.

TABLE 5 Descriptive statistics PANAS.

Variable	Time	Experimental group		Control group	
		N = 19		*N* = 15	
		M	*SD*	*M*	*SD*
Positive affect	Pre	3.39	0.73	3.08	0.74
	Post	3.97	0.71	3.13	0.88
Negative affect	Pre	1.10	0.17	1.22	0.31
	Post	1.07	0.13	1.13	0.26

Note. M, mean; SD, standard deviation.

3.2.3 Attention shift

For attention shift, the subcategories valid and invalid instructors were analyzed. For the valid instructor, no significant interaction effect of group and time could be found (Table 4).

However, a significant interaction effect of group and time was found for the invalid instructor [F (1, 32) = 4.45; $p = 0.04$; $\eta^2 = 0.12$]. Further analyses of the interaction effect of the time (invalid instructor) and the group revealed a significant improvement in reaction time between pre- and post-measurement (Figure 5). This effect was found in the EG [t (18) = -2.9; $p <.01$], but not in the CG [t (14) = --0.25; $p = 0.40$; Table 4]. EG participants were faster at post-measurement than at pre-measurement.

No significant results were observed for the main effect time [valid: F (1, 32) = 1.20, $p = 0.28$, $\eta^2 = 0.04$; invalid: F (1, 32) = 3.02, $p = 0.09$, η^2 =0 .09] or group [valid: F (1, 32) = 1.50, $p = 0.23$, $\eta^2 = 0.05$; invalid: F (1, 32) = 1.29, $p = 0.26$, η^2 =0 .04].

The ANCOVA with the covariate age revealed no significant interaction effect of the covariate age and time [valid: F (1, 31) = 0.17, $p = 0.69$, $\eta^2 = 0.01$; invalid: F (1, 31) = 1.29, $p = 0.27$, $\eta^2 = 0.04$]. However, there was a significant main effect of age [valid: F (1, 31) = 27.74, $p < 0.01$, $\eta^2 = 0.47$; invalid: F (1, 31) = 34.77, p < 0.01, $\eta^2 = 0.53$]. The further calculations revealed significant linear regressions for age as a predictor at pre-measurement [valid: $\beta = 3.09$, t (32) = 5.31, $p < 0.01$; $R^2 = 0.68$, F (1,32) = 28.16, $p < 0.01$; invalid: $\beta = 3.89$, t (32) = 5.93, $p < 0.01$; $R^2 = 0.72$, F (1,32) = 35.11, $p < 0.01$] and post-measurement [valid: $\beta = 2.82$, t (32) = 4.82, $p < 0.01$; $R^2 = 0.65$, F (1,32) = 23.22, $p < 0.01$; invalid: $\beta = 3.15$, t (32) = 5.12, $p < 0.01$; $R^2 = 0.67$, F (1,32) = 26.18, $p < 0.01$]. The older the participants, the worse the reaction time in both the valid and invalid instructors of the attention shift task.

For both subcategories, that is, valid and invalid, no significant differences could be found at the ANOVA with the common parameter anticipate reactions. No significant interaction effect of group and time could be found [F (1, 32) = 0.67; $p = 0.42$; $\eta^2 = 0.02$]. No main effect of group [F (1, 31) = 0.42; $p = 0.52$; $\eta^2 = 0.01$] was found. Nevertheless, there was a main effect of time [F (1, 32) = 4.89; $p = 0.03$; $\eta^2 = 0.13$]. There were more anticipate reactions at the pre-measurement than at the post-measurement (pre: $M = 2.34$, $SD = 3.48$; post: $M = 1.24$, $SD = 1.10$).

3.2.4 Visual scanning

The last subtest of the TAP that was applied was visual scanning. The critical and noncritical subcategories were examined. No significant interaction effect of group and time was found, for both critical and noncritical values (Table 4).

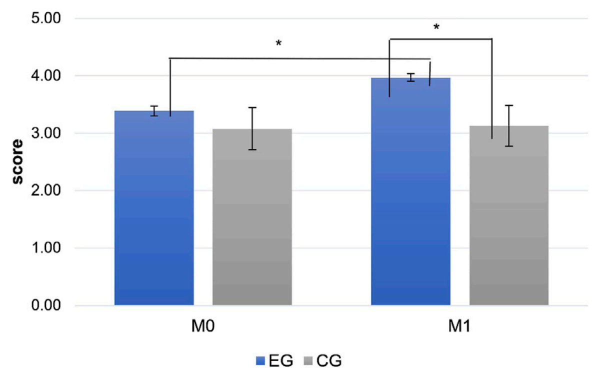

FIGURE 6
Significant interaction effect of group and time for the positive PANAS subscale (p <0 .05), including the means and the standard deviation. A significant improvement from before (M0) to after the training (M1) was detected for the positive affect. After the training, there were significant differences between the experimental group (EG) and the control group (CG).

With regard to the main effect of time, a significant result was found for the critical value [F (1, 30) = 11.28; $p < 0.01$; $\eta^2 = 0.27$]. The total sample was faster at post-measurement ($M = 2231.63$; $SD = 700.96$) than at pre-measurement ($M = 2499.53$; $SD = 954.72$). There was no significant main effect of the group [F (1, 30) = 0.73; $p = 0.40$; $\eta^2 = 0.02$].

For the noncritical value, no significant main effect of time was found [F (1, 30) = 3.51; $p = 0.07$; $\eta^2 = 0.11$]. The same occurred for the main effect of the group; no significant result was found [F (1, 30) = 0.16; $p = 0.96$; $\eta^2 = 0.01$].

The ANCOVA with the covariate age revealed a nonsignificant interaction effect of the covariate age and time for the critical value [F (1, 29) = 3.94; $p = 0.06$; $\eta^2 = 0.12$]. Furthermore, there was a significant main effect of age [F (1, 29) = 21.26; $p < 0.01$; $\eta^2 = 0.42$]. For both pre- and post-measurement, a significant linear regression with age as a predictor was determined. Older participants had a slower reaction time at pre-measurement [$\beta = 38.06$, t (31) = 4.57, $p < 0.01$; $R^2 = 0.63$, F (1, 31) = 20.86, $p < 0.01$] and post-measurement [$\beta = 28.80$, t (31) = 4.72, $p < 0.01$; $R^2 = 0.65$, F (1, 31) = 22.32, $p <$

0.01]. The interaction effect with age [F (1, 29) = 6.81; p = 0.01; η^2 = 0.19] and the main effect of age (F (1, 29) = 16.68; p < 0.01; η^2 = 0.37) was also found for the noncritical value. At pre-measurement [β = 79.59, t (31) = 4.09, p < 0.01; R^2 = 0.59, F (1,31) = 16.72, p < 0.01] and post-measurement [β = 53.04, t (30) = 3.93, p < 0.01; R^2 = 0.58, F (1,30) = 15.48, p < 0.01], older participants were slower.

For the subcategory critical value and the parameter outlier, ANOVA revealed a significant interaction effect of group and time [F (1, 30) = 4.02; p = 0.05; η^2 = 0.12]. At the pre-measurement, a significant difference between the groups was found [t (31) = 1.75, p = 0.05; CG: M = 7.57, SD = 6.21; EG M = 4.33, SD = 4.04]. No significant difference was found at post-measurement (t (30) = 0.12, p = 0.45; CG: [= 4.29, SD = 4.41; EG: M = 4.11, SD = 3.92]. In the CG, a significant improvement from pre- to post-measurement was found [t (13) = 2.22; p = 0.02] but not in the EG [t (17) = 0.31; p = 0.38]. Furthermore, there was a significant main effect of time [F (1, 30) = 5.27; p = 0.03; η^2 = 0.15]. There were more outlier at the pre- than at the post-measurement [pre: M = 5.75, SD = 5.27; post: M = 4.19, SD = 4.08]. There was no significant main effect of the group [F (1, 30) = 1.35; p = 0.25; η^2 = 0.04].

With regard to the error parameter in the noncritical subtest, ANOVA revealed no significant interaction effect of group and time [F (1, 30) < 0.01; p = 1; η^2 <0 .01]. No main effect of time [F (1, 30) < 0.01; p = 1; η^2 <0 .01] and no main effect of group (F (1, 30) = 2.28, p = 0.14, η^2 = 0.07) were found.

3.3 PANAS

The ANOVA with repeated measures for the PANAS results were calculated separately for each scale (positive and negative).

3.3.1 Positive subscale

The positive scale revealed a significant interaction effect of group and time [F (1, 32) = 14.86, p < 0.01, η^2 = 0.32]. It shows a higher score in the EG than in the CG [t (32) = −3.09; p < 0.01; Table 5 and Figure 6] post-training (M1). At pre-training (M0), no significant difference could be observed [t (32) = −1.22; p = 0.12]. In addition, a significantly higher PANAS score was found in the EG at post-training than at pre-training [t (18) = −5.68; p < 0.01; Table 4]. This effect was not found in the CG [t (14) = −0.5; p = 0.31]. Additionally, there was a main effect of group [F (1, 32) = 5.14; p = 0.03; η^2 = 0.14] and time [F (1, 32) = 20.09; p < 0.01; η^2 = 0.39]. The positive PANAS score was (M = 3.60; SD = 0.88) higher at post-training than at pre-training [M = 3.26; SD = 0.74].

The ANCOVA with age revealed no interaction effect of the covariate age and time [F (1, 31) = 0.06; p = 0.81; η^2 <0 .01]. However, there was a significant main effect of age [F (1, 31) = 4.76; p = 0.04; η^2 = 0.13]. Further tests revealed a significant linear regression with age as a predictor at pre-measurement [β = 0.02, t (32) = 2.28, p = 0.03; R^2 = 0.37, F (1, 32) = 5.18, p = 0.03] and post-measurement [β = 0.02, t (32) = 2.28, p = 0.03; R^2 = 0.37, F (1, 32) = 5.22, p = 0.03]. The older the participants, the higher the score of the positive PANAS subscale.

3.3.2 Negative subscale

The negative scale revealed no significant interaction effect of group and time [F (1, 32) = 2.16; p = 0.15; Table 5]. Moreover, there was a significant main effect of time [F (1, 32) = 7.87; p < 0.01; η^2 = 0.20]. The negative PANAS score was (M = 1.10; SD = 0.20) lower at post-training than at pre-training (M = 1.15; SD = 0.25).

No significant main effect of group [F (1, 32) = 1.42; p = 0.24; η^2 = 0.04] could be found.

The ANCOVA with age revealed no significant interaction effect with age [F (1, 31) = 0.03; p = 0.87; η^2 <0 .01] and no main effect of age [F (1, 31) = 3.71; p = 0.06; η^2 = 0.11].

4 Discussion

4.1 Main findings

In this study, we aimed at evaluating the feasibility of a pursuit training in the Helix-Arena as a potential part of treatment for stroke patients in the neurological rehabilitation process. This study was conducted only with healthy people in order to evaluate the feasibility of the 2-week pursuit training version in the Helix-Arena compared to a training on a PC. Pre- and post-measurements involved subtests of the TAP and a diagnostic version of the pursuit training in the Helix-Arena. In addition, the mood of the participants was assessed before and after every training session.

For a better comparability with stroke patients, a number of participants in an older age group were included because the prevalence of stroke increases with age (Asplund et al., 2009; Katan and Luft, 2018). Therefore, the age range was large enough to also assess the relationship between performance and age.

The results of the TAP, the diagnostic version of the pursuit training in the Helix-Arena, and the results of the PANAS yielded differential results. Age was included in the analysis with respect to the influence of age in attention processes (Der and Deary, 2006).

For the TAP, participants of the EG showed a higher improvement under the Helix condition than under the PC condition in the subtest attention shift with the subcategory invalid instructor, where they displayed a significantly faster reaction time at the post-measurement than at the pre-measurement. This task has great similarity to the skills that are required in the pursuit training. One explanation why the significant effect appears with the invalid instructor could be that the participants obtain greater certainty through the training in the helix when something does not correspond to the correct stimulus. Possibly, the training in the Helix-Arena conveys larger confidence in one's decision and leads to a faster and more confident categorization of invalid information. In addition, the phenomena explained in the theory section, such as the natural environment, the fun factor, and the game factor (Karamians et al., 2020), could play a role. All these points are present in the Helix-Arena compared to the PC.

In the visual scanning subtest, a main effect of time was found for the parameter critical value. We observed that the entire sample was faster in the post-measurement than in the pre-measurement. As there was no interaction with the group, this effect is independent of the group allocation. This effect can probably be explained by a greater familiarity with the task and thus more courage to speed up. As a main effect of the associated parameter "outlier" could also be found, this did not take place at the expense of incorrect responses. Fewer outliers at post-measurement were found here. Thus, the entire sample improved in this TAP subtest.

The significant main effects of the time factor (critical value—outlier, valid, and invalid—anticipate reactions) and the significant interaction of group and time (critical value—outlier) show that both interventions seem to lead to an improvement; only the improvement in the EG was not significant. With regard to this TAP subtest, an improvement in the parameters could be found in the entire sample, which gives an indication of the care taken in the work. The worsening of the CG in relation to the parameter anticipate reactions in the alertness subtest with sound cannot easily be explained.

The results of the PANAS revealed an improvement in positive affect in the EG compared to the CG. After the training sessions, people who trained in the Helix-Arena reported a much higher value at the positive PANAS scale than those who trained on the PC. This result suggests that the Helix training is well suited for cognitive training and that it might also be useful for patients in the neurological rehabilitation. Many studies report effects of a positive mood for neurological rehabilitation (Choe and Kim, 2021). It can be a motivating factor not only for the rehabilitation but also for the everyday life (Rapport et al., 2020). For the negative subscale, no significant effect was found. For both subscales, no significant interaction effect with age could be found. However, a significant main effect of age was found for the positive subscale. This effect could not be confirmed in the literature so far (Lawton et al., 1993; Isaacowitz and Smith, 2003).

Both groups showed a small but nonsignificant improvement in the diagnostic version of the pursuit training in the Helix-Arena. This result can be attributed to the fact that the versions of pursuit training in the Helix were designed for rehabilitation purposes. Because of this, it can be assumed that both the training and the diagnostic verification are too simple for a healthy sample. Thus, the CG was already able to achieve an improvement in the diagnostic version from pre- to post-measurement; however, they trained on the PC and not in the Helix like the EG.

The significant interaction effect of age in some subtests and the significant main effect of age in almost all subtests of the TAP supported the addition of age in the analysis. This effect is the result of a normal abuse of attention functions in case of the reaction time (Der and Deary, 2006; Kosinski, 2012). Age as a significant predictor for the Helix score appears to be particularly exciting; here, the significance could only be found for pre-measurement. At pre-measurement, a worse Helix score with increasing age was observed. This effect was no longer present at the post-measurement. Thus, there is no significant decrease in the Helix score with increased age. Therefore, the intervention seems to work also for elderly people. Interestingly, it occurred independently of the group so that even a single training in the Helix-Arena (for participants in the CG) was sufficient. The independence of age for the Helix task is important because in neurological rehabilitation, training must work for any age group.

4.2 Limitations

This study has the following limitations. First, a small sample was used with participants at a high level of performance. The small effects of the TAP may be related to this as a ceiling effect might have been reached. The pursuit training in the Helix and that on the PC were constructed for stroke patients in neurological rehabilitation; therefore, the task was at a level that may have been extremely easy for our sample. In addition, some compromises had to be made in terms of speed and the number of avatars to be tracked. Looking at the diagnostic version in the Helix-Arena, all participants were at a very high level. Furthermore, due to the good status of the participants' attentional functions, the frequency of four training sessions could have been too few to achieve an effect. It should also be noted that the reaction times in the Helix-Arena are subject to variation as no instructions were given regarding the speed of execution.

For the comparability of the PC training and the Helix training, the results are limited by the fact that the pursuit training on the PC had no adaptive mode. In addition, squares were tracked during PC training and not avatars. However, the PC training has already been used with patients in neurological rehabilitation (Lesch et al., 2020) and has been shown to be effective. With regard to statistical analysis, the use of multiple tests must be taken into account. Due to the special nature of the Helix-Arena, we did not assess prior VR experiences.

4.3 Conclusion

In summary, it can be said that the selected pursuit training works in the Helix-Arena. The participants were able to achieve an improvement in their attention performance in a TAP subtest from pre- to post-measurement. In addition, an influence on the positive affect in the EG could be determined. A significant improvement in positive affect was observed from before to after the training. This effect could not be found in participants of the CG. The Helix-Arena appears to be a good tool for promoting attention functions and affective components such as fun and motivation. With further adaptations, the Helix-Arena could become an exciting tool in the world of VR in the future.

4.4 Future work

In general, the feasibility of the Helix approach was confirmed. The use of the task in a group of healthy people was successful. Although the pursuit training at the Helix-Arena is not a challenging task for healthy people, positive effects were nevertheless reported. In particular, the result of the positive subtest of the PANAS is promising for the study with patients in neurological rehabilitation. Furthermore, the implementation of the adaptive training version in the Helix seems to be very effective. Thus, every patient can train on their own level. It is to be assumed that patients from neurological rehabilitation start from a lower level than healthy people. For them, the combination of moving around in 360-degree space and paying attention to the avatars can add real-world value to their attentional functions. Additionally, the report of positive emotions and the improvement in the positive actual state after the training can be a motivating factor within the rehabilitation. Almost all participants were able to complete the study (excluding one due to headache). Concerns about the feasibility of the training for older and thus more limited patients could be counteracted as older participants also participated successfully. Due to the success of this study, the Helix-Arena can be tested on a neurological sample in a future study.

4.5 Practical implications

The Helix-Arena is currently used primarily in a sports context. More and more research is also being carried out in other areas. The characteristics of the Helix-Arena offer a wide range of possible applications in various areas, for example, in neurological rehabilitation or in educational contexts (Shah et al., 2024).

Data availability statement

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

Ethics statement

The studies involving humans were approved by the Ethics Committee of the Medical Faculty Mannheim of Heidelberg University. The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study.

Author contributions

TS: conceptualization, data curation, formal analysis, investigation, methodology, project administration, writing – original draft, writing – review and editing, resources, validation, and visualization. PE: methodology, software, and writing – review and editing. JS: conceptualization, methodology, software, and writing – review and editing. FG: software, writing – review and editing, investigation, and methodology. AR: software, writing – review and editing, investigation, and methodology. JM: writing – review and editing, conceptualization, and software. MS: methodology, supervision, writing – review and editing, and conceptualization. HF: conceptualization, methodology, supervision, writing – review and editing, and funding acquisition.

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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.

Generative AI statement

The author(s) declare that no Generative AI was used in the creation of this manuscript.

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