# Effects of task-specific strategy on attentional control game training: preliminary data from healthy adults

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## Abstract

Although recent studies showed the beneficial effect of video game training, it is still unclear whether the used strategy plays an important role in enhancing performance in the trained cognitive ability and in promoting transfers to other cognitive domains. We investigated behaviourally the effect of strategy on the outcomes of visual attentional control game training and both behaviourally and in terms of EEG-based event-related potentials (ERPs), the effect on other cognitive domains. We recruited 21 healthy young adults (M = 24.33, SD = 3.23), and randomly divided them into three groups: a strategy-training group (STG) instructed to use a specific strategy, a non-strategy training group (NSTG) that self-developed their strategy, and a passive control group (PCG) that underwent only pre- and post-tests (Oxford Cognitive Screen test, Buschke Selective Reminding Test, D2 test of Attention, Digit span test, BADS test, Bells test, Oddball and N-Back tests). Our results showed that the use of a specific strategy made the STG participants respond faster to the trained contrast level task, but not on the contour exercises task. Furthermore, both STG and NSTG showed pre- and post-transfers, however no significant differences were found when comparing the groups, for both behaviour and ERP responses. In conclusion, we believe these preliminary results provide evidence for the importance of strategy choice in cognitive training protocols.

Keywords; video game training, strategy, transfer effects, ERP, behavior

## Statements and Declarations

Competing Interests: The authors declare that there is no conflict of interest directly or indirectly related to the work submitted for publication.

## Introduction

An increasing number of research studies have shown the impact of video games on a large variety of cognitive abilities. Compared to a computerized-controlled game, where players interact with objects displayed on a screen, a video game is played, besides on a computer, also on a console or an arcade machine and it requires the processing of considerably more visual information under attention-demanding conditions (Bediou et al., 2018). It has been shown that are differences in recruited brain regions and pathways between expert video game players compared to non-video game players. For example, Gan et al. (2020) studied the fundamental role of the temporal brain area in visual selective attention. Using both behavioral and electrophysiological measures, the authors showed that, compared to non-experts, action real-time strategy gaming experts achieved a superior temporal visual selective attention performance in an attentional blink (AB) task as indicated by earlier P3 peak latencies, had more attentional resources distributed to targets as indicated by stronger P3 amplitudes, and exhibited a more flexible deployment of attentional resources. These results suggest the long-term benefits related to temporal visual selective attention improvements. Another example is the study of Bavelier et al. (2012 where differences were observed in the frontoparietal brain network that controls the allocation of top-down attention. While non-video game players showed increased activation in the frontoparietal network, as attention demand increased, video game players hardly engaged this network even with an increase in attentional demand. Both studies provide evidence that there are differences in resource allocation between expert video game players and non-gamers. Furthermore, a growing body of evidence suggests that video game training enhances performance, not just in the games themselves, but also in a large range of cognitive tasks, as it forces users to stay actively engaged during gameplay (Bediou et al., 2018). Evidence suggests that video games enhance top-down attentional control, peripheral target identification, and visual search speed (Blacker et al., 2014; Chisholm & Kingstone, 2015; Wu & Spence, 2013). Furthermore, it has been shown that playing video-games, specifically action video games, leads to performance enhancements noted in domains as varied as visual perception, top-down attention, visuo-spatial cognition, and multi-tasking and task switching (Bavelier et al., 2018; Bavelier et al., 2012) as well as allocation of attentional resources and attentional control (Chisholm & Kingstone, 2015). A possible mechanism behind the observed enhancements is ‘learning to learn’, evidenced by enhanced learning rates in new tasks (Bejjanki et al., 2012). According to this view, action video game training produces cognitive enhancements partially by enhancing the players’ ability to learn new tasks and, more specifically, by achieving improvements in the ability to quickly extract task-relevant characteristics (Bavalier et al., 2012). Increased longevity is often associated with a decline in several cognitive abilities, which eventually can impact on independent living, such as attention and executive functions (Craik and Salthouse, 2000). It has been shown that, besides genetic and biological dispositions, several factors can affect an individual’s decline in cognitive abilities such as environmental-, educational-, and even behavioral ones such as nutrition, physical activity, and cognitive engagement (Greenwood and Parasuraman, 2010; Ballesteros et al., 2014; Gajewski and Falkenstein, 2016). One method for improving cognitive functions is cognitive training, and it is increasingly utilized to improve the performance of older adults in cognitive functions essential for their activities of daily life and to maintain self-reliance. Indeed, many studies have shown beneficial effects of computer-based cognitive training on attention (Schubert et al., 2015; Strobach and Karbach, 2016; Bavelier and Green, 2019), executive functions (Strobach et al., 2012; Anguera et al., 2013), and working memory (Salminen et al., 2016; Strobach and Huestegge, 2017). An important aspect of cognitive training research is the transfer effect, referring to the ability to use the knowledge and skills learned in one scenario to achieve different goals in other scenarios (Wenig et al., 2019). It can be differentiated into near- (i.e. to tasks that are similar to the training tasks) and far-transfer effects (i.e., to tasks that are different from the training tasks; Barnett and Ceci, 2002). Recent work suggested that cognitive training leads to improvements of the trained cognitive functions (near transfer) and transfers to untrained cognitive tasks (far transfer) in healthy older adults (Karbach and Verhaeghen, 2014; Kelly et al., 2014; Strobach and Karbach, 2016; Chiu et al., 2017; Strobach and Huestegge, 2017; Pergher et al., 2020).

The idea behind cognitive and attentional control video game training is that, when achieving the maximum difficulty level one can manage, plasticity changes occur in support of increased cognitive performance, possibly underpinned by alterations in intracortical connections and synaptic plasticity (Lövdén et al., 2010). However, despite improved results observed for the trained task in many studies, it is still unclear whether there are any transfers to other cognitive functions (Green, & Bavelier, 2012). This specificity represents a limitation for the development of many real-world training or rehabilitation paradigms. In the last decade, it has been shown that training on ‘action video games’ produces learning that transfers beyond the training task. However, while some studies showed successful transfers to untrained cognitive domains (Anguera et al., 2013; Basak et al., 2008; Föcker et al., 2019; Zhang et al., 2020), others failed to show any transfer or found transfers limited to cognitive functions similar to the trained one (near-transfers) (Melby-Lervåg et al., 2016; Zinke et al., 2012; Owen et al., 2010). The controversy is explained by several factors, including the adopted strategy. It has been shown that the latter can influence cognitive task performances, such as for working memory (WM) (Soveri et al., 2017; Melby-Lervåg et al., 2016), and can even lead to changes in gray matter volume (Kühn et al., 2014). However, only a limited number of studies investigated the effect of adopted strategy on cognitive and video game training outcome in the case of older adults. For instance, from a video-game training perspective, when comparing older individuals trained on a real-time strategy-based videogame vs. non-trained ones (control group), Basak et al. (2008) showed that for the group that used a specific strategy, transfers were achieved to executive control tasks. Also, experience with action video games is known to be associated with improvements in several cognitive tasks. Chisholm & Kingstone (2015) showed that action video game players have greater control over the allocation of attentional resources compared to non-video game players, suggesting both perceptual and cognitive improvements. Similarly, from a cognitive training perspective, the study of Carretti et al. (2007) indicated that when adopting an imagery strategy for word lists improved word list recall performance compared to the non-instructed strategy group, and the study of Bailey et al. (2008) reported improvements in a complex span task when adopting a strategy for word list learning in comparison to no strategy, suggesting an improvement in cognitive constructs overlapping with the trained tasks. Furthermore, cognitive training that instructed one group of participants to follow a specific strategy (external strategy) while others developed their own (internal strategy) (McNamara et al., 2001; Dunlosky et al., 2007; Dunning, 2014; Pergher et al., 2018) showed beneficial effects in terms of transfers. For instance, the study of Laine et al. (2018) reported gains in healthy young adults for both the instructed strategy- (external) and non-instructed strategy (internal) groups, compared to passive control, for a trained letter N-Back task, and found transfers to an untrained color N-Back task only for the instructed strategy group, after a single session of the N-Back task.

The video games used in experimental settings are predominantly action games, a type of video game that requires participants to attend to disparate multiple in-game objects, within complex visual environments (Latham et al., 2013). Furthermore, it improves the spatial and temporal resolution of vision as well as its sensitivity (Green et al., 2010). For example, when asked to determine the orientation of a T flanked by distracting shapes above and below, video game players can tolerate distractors that are nearer to the T while maintaining a high level of accuracy (Green & Bavelier, 2007). This capacity, called crowding acuity, is often compromised in low-vision patients that struggle reading the small print used in newspapers (Legge et al., 1985). Additionally, evidence suggests that video game players perform better compared to non-gamers on several aspects of cognition, such as visual short-term memory (Anderson et al., 2011), spatial cognition (Greenfield, 2009), and some executive functions (Anderson & Bavelier, 2011, Chisholm & Kingstone, 2011). For example, the beneficial effects on daily life activities of adults can be seen in the task-switching abilities of expert video game players, as they can effortlessly switch from one task to another (Cain et al., 2012, Green et al., 2012, Strobach et al., 2012). Moreover, also in children, game play has shown to enhance mental rotation abilities (Feng et al. 2007), positively correlating with mathematical achievements in school (Halpern et al. 2007). Another cognitive function that can be enhanced is attention, more specifically, several aspects of top-down attentional control such as selective attention, divided attention, and sustained attention (Dye et al. 2009, Hubert-Wallander et al. 2011). Besides action video games, there exist other, albeit less often used types of video games, such as adventure video games, puzzle, strategy, platform, simulation, etc.

Besides behavioral enhancements, Föcker et al. (2018) could shed light on the neural correlates of perceptual and attentional control changes in terms of changes in visual event-related potentials (ERPs), stereotypical sequences of positive and negative amplitude deflections in response to stimulation. They recruited action- and non-action video game players for a target discrimination task that required attending to rapid sequences of Gabor patches –sinewaves windowed by a 2D Gaussian– under focused or divided attention conditions. The results showed faster reaction time (RT) to targets in the focused attention condition, and more pronounced ERP responses, especially for the P2 and anterior N1 components, for the action video game players compared to the non-action ones, suggesting an enhancement of perceptual and attentional control functions. However, contrary what could be predicted, they did not observe any group difference in attention-modulated occipital components, such as P1 and posterior N1. Moreover, several studies focused on both video game effects and age-related cognitive and neural changes, demonstrating that repeated sessions of video game practice lead to improvements in cognitive performance, visual perception and attentional control in healthy young (Kurylo et al., 2017) and older adults (Mishra et al., 2015; Berry et al., 2010; Anguera et al., 2013). For instance, using a discrimination judgement task where Gabor patches were either expanding or contracting, Berry et al. (2010) observed that older adults improved their discrimination abilities and found evidence for transfer to an untrained working memory task in both accuracy and changes in the N1 component. Using Berry et al.'s stimuli, Mishra et al. (2015) investigated neural (ERP) differences pre- and post-visual perception training compared to a control group. The results showed after training changes in N1 and N2, early visual ERP components and a higher behavior accuracy, suggesting an enhancement in allocating attention to stimuli presented in rapid sequence.

In the current study, we adopted an integrative approach where the goal was to assess the effect of strategy use during video game training, thereby also verifying possible transfers to other cognitive domains, in terms of behavioral- (accuracy and RT) and ERP responses (amplitudes and latencies of five ERPs components – P1, N1, P2, N2, and P3). Given the study of Deveau et al. (2014), which showed improved vision after perceptual game training and real-world transferable benefits by using a perceptual learning training program, as well as the study of Green and Bavelier (2003), which showed the efficacy of video games as a tool to induce perceptual learning improvements, we used a similar video game task. However, differently from the cited studies, we assessed the effect of instructed strategy over a self-chosen one. We considered older individuals but, although considered healthy, they could still exhibit a decline in several cognitive functions fundamental to independent living (Craik and Salthouse, 2000). Two groups of healthy adults underwent six training sessions. The Strategy-Training Group (STG) was instructed to use as a specific strategy to focus on the center of the screen during all sessions, while the Non-Strategy-Training Group (NSTG), was not instructed to use any specific strategy. Moreover, a passive control group was used to investigate test/re-test effects. For all three groups, a battery of cognitive tests was administered before and after training intervention to assess any transfers to untrained cognitive domains. Several studies have identified improvements in perception of elementary features (e.g. luminance contrast; Adini et al., 2002, Furmanski et al., 2004), global scene processing (Chun, 2000) and image recognition (Gold et al., 1999, Lin et al., 2010). However, not many studies have assessed possible transfer effects beyond the trained task or to real-world conditions. Deveau et al. (2014), using the same paradigm as we did, validated and reported the results of a novel integrative perceptual learning program that combines different perceptual learning approaches, such as training with a set of stimuli, optimized stimulus presentation, and reinforced training with the aim to generalize achieved benefits to real-world tasks. The results showed improved vision after training as well as real-world transferable benefits. Furthermore, a few studies have shown the efficacy of video games as a tool to promote perceptual learning enhancements. For example, Green and Bavelier (2003) showed that action video game training positively impacted on several visual skills including field of view, multiple object tracking, attentional blink, and performance in flanker tasks. Our study aims to shed light on transfers to untrained tasks using perceptual game training, which has been shown (Deveau et al., 2014; Deveau et al., 2014) to significantly impact on several visual skills as well as attentional abilities. We expected improvements in the trained task for both the instructed and non-instructed strategy groups, in accordance with Laine et al. (2018), but we hypothesized that STG may achieve larger transfer effects compared to NSTG, similarly to Bailey et al. (2008) who suggested transfers to untrained tasks for their instructed strategy groups only. Furthermore, we hypothesized to find more pronounced N1 and P2 ERP responses after training for STG compared to NSTG, reflecting an enhancement of attentional functions and perceptual processing. Additionally, referring to the study of Mishra and colleagues (2015), we hypothesized to find changes in N2 early visual ERP component after training together with a higher accuracy to allocate attention to the Gabor patches. Lastly, referring to the P3 ERP component, we hypothesized to observe significant changes in amplitude and latency after training, suggesting a far-transfer effect to working memory (Berry et al., 2010).

## Methods

### Participants and procedure

We recruited, as paid volunteers, 21 healthy undergraduate students from KU Leuven University and employers from the Gasthuisberg University Hospital in Leuven (*M* = 24.33, *SD* = 3.23, see Table 1 for their demographics). Participants were randomly assigned into three groups, a strategy-training group (STG, *N* = 7), a non-strategy training group (NSTG, *N* = 7) and a passive control group (PCG, *N* = 7). Participants of the STG were instructed to use as specific strategy to ‘focus on the center of the screen’ before each training session, which was monitored with an eye-tracker, while participants of the NSTG did not follow any specific instructions; participants of the PCG performed only pre- and post-tests. Participants from the training groups performed 6 training sessions at an average rate of three sessions per week, each one taking approximately 30 minutes. Before and after the six training sessions, participants completed a battery of cognitive tests to assess possible transfer effects. Participants were told that they could quit the experiment at any time. Before engaging in the experiments, we explained the experimental design to our recruitees, and when they agreed to participate, we invited them to sign the informed consent that was prior approved by our university’s Ethics Committee.

*Table 1*. Demographics

| | STG (N=7) | NSTG (N=7) | PCG (N=7) |
|---|---|---|---|
| Age | 24.57 (3.26) | 24.83 (4.07) | 23.86 (3.08) |
| Gender | 3 M/4 F | 3 M/4 F | 3M/4 F |
| Education | 10.14 (1.07) | 10.33 (1.03) | 9.86 (1.07) |

## Cognitive test battery

A battery of cognitive tests was administered twice (pre- and post-tests) to all participants of the 3 groups to assess test-retest reliability of the control group and possible transfers to other cognitive functions after training for the strategy and non-strategy groups. For two of those tests, namely N-Back and Oddball task (Figures 1 and 2; for details see Pergher et al., 2020), EEG was also recorded. The battery included:

(1) the Oxford Cognitive Screen test (Huygelier et al., 2019) to assess general cognitive functioning, as an alternative to the Mini Mental State Examination (MMSE). It consists of 10 tasks spanning 5 cognitive domains: attention and executive function, language, memory, number processing, and praxis. Furthermore, it also includes a brief evaluation of visual field defects. Administration is simple and takes around 15 minutes.

(2) the Buschke Selective Reminding Test (BSRT; Thielen et al., 2019) to measure verbal learning and memory through the use of a list-learning procedure. This paradigm is believed to separate verbal memory into distinct processes. It involves read aloud by the examiner a list of 12 unrelated words after which the subject should immediately recall as many of them as possible.

(3) the D2 test of Attention (Bates & Lemay, 2004) to evaluate selective and sustained attention and visual scanning speed. It is a paper-and-pencil test where participants are asked to cross out any letter "d" that has two dashes, which can be above or below the letter "d", in any order. The surrounding distractors are usually similar to the target stimulus, for example a "p" with two dashes.

(4) the Digit span forward and backward test (Kessels et al., 2008) to measure working memory. The Digit Span Forward requires the subject to repeat numbers in the same order as read aloud

by the examiner; the Digit Span Backward requires the subject to repeat the numbers in reverse order.

(5) the Behavioral Assessment of the Dysexecutive Syndrome (BADS; Canali et al., 2007) as alternative to FAB (Dubois et al., 2000) to evaluate executive functions mainly localized in the frontal lobes of the brain, where high-level tasks such as planning, organizing, initiating, monitoring and adapting behavior take place. It comprises 6 tests and 2 questionnaires and takes around 40 minutes.

(6) the Bells Test (de Yébenes et al., 2003) to measure quantitatively and qualitatively visual neglect in the near extrapersonal space. Specifically, the subject is asked to circle with a pencil all 35 bells embedded within 280 distractors (houses, horses, etc.) on the same page. All drawings are in black.

(7) the Oddball Task (García-Larrea et al., 1992) to measure attention. Presentations of sequences of repetitive stimuli are infrequently interrupted by a deviant stimulus. The reaction time f the participant to this ‘oddball’ stimulus is recorded.

(8) the N-Back task (Jaeggi et al., 2008) to assess working memory. Participants are required to manually press a button on the keyboard whenever one of the presented stimuli (target) matches the one presented n positions back in the sequence. The level of difficulty increases with increasing n and is varied during the test. No responses were required for non-targets.

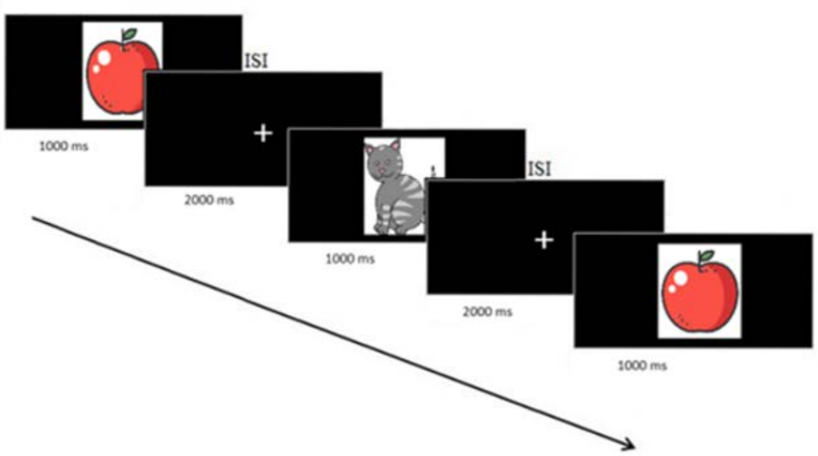

**Fig 1.** Example stimulus sequence during 2-Back task with stimulus durations of 1000ms and interstimulus interval (ISI) of 2000ms.

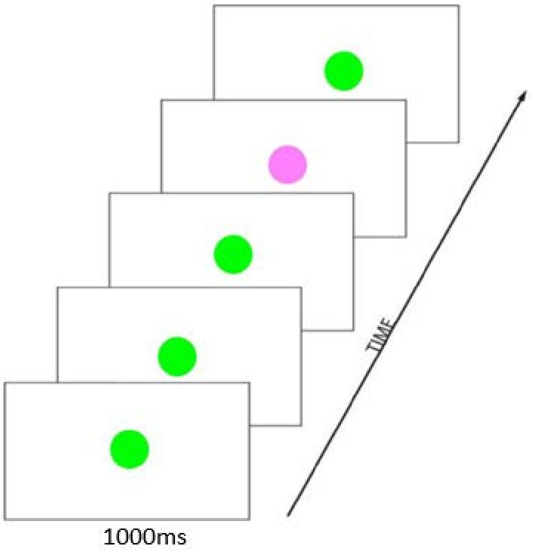

**Fig 2.** Example of a visual oddball task with stimulus duration of 1000ms and ISI of 1500ms.

### Experimental design - Attentional control video game

During the training sessions, participants were instructed to play the visual attentional control game "Sightseeing" developed by the Brain Game Center for Mental Fitness and Well-being of the University of California, Riverside (UCR). This reward-based game reinforces adherence and maintains training efficacy, and was previously used in a perceptual learning program to investigate transfers beyond the trained task and to real world conditions, with the aim to achieve general improvements to vision (Deveau et al., 2014; Deveau et al., 2014). Participants were expected to move through several training conditions and difficulty levels, ranging from detecting low-contrast Gabor patches to locating virtual circular contours in Gabor fields (Figure 3). The game runs on an iPad that displays the stimuli and records the participant's behavioral responses (RT and accuracy).

The Gabor patches (targets) adopted 6 spatial frequencies (1.56, 3.13, 6.25, 12.5, 25, 50 cpd) and 8 orientations (0°, 22.5°, 45°, 67.5°, 90°, 112.5°, 135°, 157.5°). The stimuli differed in contrast and contour integration, and the difficulty level was adapted based on subject performance (accuracy). Participants were asked to tap on the Gabor patches as quickly as possible when a target was presented on the screen. Accuracies and RTs were recorded on the iPad. The stimuli stayed on the screen until the subject responded, with a maximum of 5s to consider it correct. When a non-target (e.g., distractor) was selected, accuracy went down. At the end of each round, participants saw a summary of their performance: gold feedback means responses given in 2s, silver in 5s and bronze slower than 5s (which will be removed). Difficulty level was based on type of distractor, stimuli size, total number of elements (targets and distractors). The parameters that could be adapted were contrast, spatial frequency of the Gabors, number of stimuli displayed, and rate of stimulus presentation. At the beginning of each session, a calibration procedure was performed to set these parameters. Each trial took around 2 minutes, and alternated between static (simultaneous) and dynamic (sequential) exercises. When a target was selected, a sound was played. It changed based on the position of the target on the screen: lower tones for stimuli at the bottom of the screen and higher ones for stimuli at the top of the screen. The sounds provided an important cue for the location of the visual stimuli and were intended to enhance learning performance (Shams & Seitz, 2008). Additionally, eye-tracking using the EyeLink 1000 Plus (SR Research, Canada) was used during all training sessions to confirm reliance on the instructed strategy.

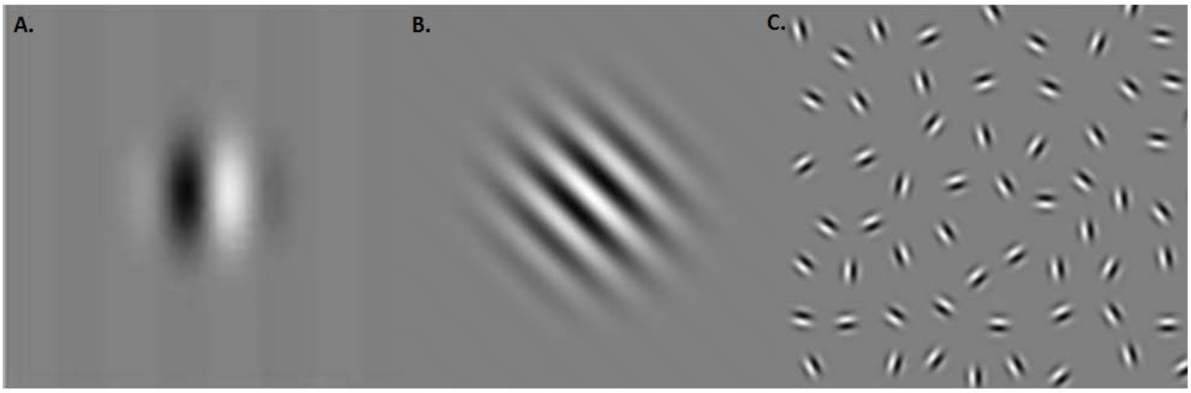

**Fig. 3** Summary of the training task stimuli. A) and B) Two spatial frequencies and orientations of a Gabor patch used in the contrast exercise. C) Gabor fields with some patches forming a virtual contour

## EEG recordings

During the N-Back and Oddball tasks, EEG was recorded with a Neuroscan SynampsRT device (Compumedics, Australia) at 2 kHz using 32 scalp electrodes, according to the 10-20 international system, and two additional electrodes were placed on the right and left mastoids. The recorded EEG signal was re-referenced offline from the original common mode sense reference (CMS, positioned next to electrode Pz) of the available EEG equipment to the average of two mastoid electrodes (average mastoid reference, TP9 & TP10), band-pass filtered in the range of 0.1 – 30 Hz, and cut into epochs starting from 200 ms pre- till 1000 ms post-stimulus onset. Baseline correction was performed by subtracting the average of the 200 ms pre-stimulus onset activity from the 1000 ms post-stimulus onset activity. Finally, the epochs were downsampled to 100 Hz and stored for ERP detection. Eye-blinking artifacts were removed using Independent Component Analysis (ICA) from four different electrodes placed around the subject's eyes. Epochs with incorrect behavioral responses were excluded from further analysis. In addition, epochs with EEG signals greater than 50µV were also excluded as they could be motion artifacts. The electrodes were placed at the scalp locations shown in Figure 4. Considering the N-back and Oddball tasks with joint EEG recording, we selected only the midline electrodes (Fz, Cz, Pz) and PO3 and PO4 for analysis. However, as Oz showed many artifacts, we looked at the adjacent electrodes O1 and O2, for which we selected O1 as it exhibited a cleaner EEG signal. For further details about the used EEG setup, preprocessing pipeline and analysis, we refer to Pergher et al. (2018; 2019; 2020).

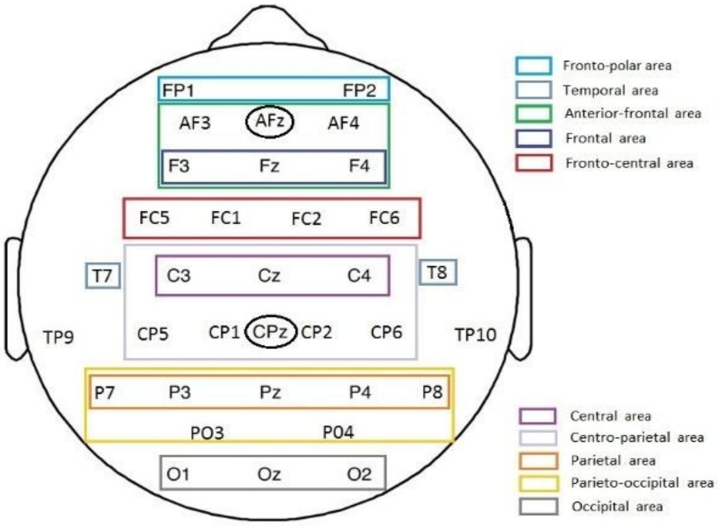

**Fig. 4** Scalp plot representing the electrodes' location. CPz and AFz are marked as reference electrodes

Amplitudes and latencies of six ERPs components – P1, N1, P2, N2, and P3 – were measured at each scalp location, for each stimulus and condition. They were defined as follows: P1 as a positive ERP component between 60 and 100 ms post-stimulus (Luck et al., 2000), N1 as a negative component between 150 and 200 ms (Mangun et al., 1991), P2 as a positive component between 150 and 250 ms (Luck et al., 1994), N2 as a negative component between 200 and 350 ms (Folstein et al., 2008), and P3 as a positive component between 250 and 500 ms (Polich et al., 2007).

## Statistical analyses

To assess possible transfer effects, statistical analyses were performed using a mixed ANOVA test with one within-subject factor (pre-post) and one between-subject factor (group) to investigate the interaction of training effects and groups. Furthermore, to account for any possible pre-post effects in terms of ERP components, peak- and average amplitude and latency were extracted, using repeated two-way ANOVA measures for target responses to detect the interaction between electrode site and differences between pre- and post-cognitive testing. Post-hoc Tukey tests were used when performing multiple comparisons of the means of the extracted ERP parameters. Bonferroni correction was used to correct for multiple comparisons.

Training data was analyzed using a mixed ANOVA (Group x Session) for contrast and contour exercises separately to assess behavioral differences over training sessions.

## Results

## Pre- and post-tests (Transfer effects)

### *Behavioral outcomes*

We observed significant pre-post differences for selective and sustained attention (D2-correct responses: F(1,18) = 46.104, p < 0.001, ηp2 = 0.719; D2- skipped targets: *F*(1,18) = 6.572, *p* = 0.02, ηp2 = 0.267), WM (Digit Span Forward: *F*(1,18) = 8.451, *p* = 0.009, ηp2 = 0.319; Digit Span Backward: *F*(1,18) = 4.609, *p* = 0.046, ηp2 = 0.204; N-Back (*F*(1,18) = 7.760, *p* = 0.012, ηp2 = 0.301), and general cognitive functioning (OCS-Subtask Attention: (*F*(1,18) = 4.673, *p* = 0.044, ηp2 = 0.206) (for details see Figure 5 and Table 2). However, no significant main effects for groups were found, suggesting that there were no significant pre-post differences between the training groups as well as the passive control group.

Furthermore, we investigated the experimental groups separately using post-hoc comparisons. The STG showed a significant pre-post difference for selective and sustained attention, specifically for D2-correct responses (p = 0.016) indicating a significant better performance on the post-tests (M = 76.68) compared to the pre-tests (M = 69.18), and for the Oddball task (p = 0.039), indicating a significant better performance on the post-tests (M = 100) compared to the pre-tests (M = 92.86). Furthermore, post-hoc comparisons showed a significant pre-post difference for memory span, specifically for Digit Span Forward (p = 0.039), suggesting a significant better performance on the post-tests (M = 84.26) compared to the pre-tests (M = 75.71), and for Digit Span Backward (p = 0.032), suggesting a significant better performance on the post-tests (M = 82.86) compared to the pre-tests (M = 70).

Additionally, the NSTG showed significant pre-post differences for sustained attention (Dd2-correct responses, p = 0.005) suggesting a significant better performance on the post-tests (M = 82.66) compared to the pre-tests (M = 72.58), and also for WM (N-Back, p = 0.010), suggesting a significantly better performance on the post-tests (M = 97.43) compared to the pre-tests (M = 96.38).

However, when investigating test-retest reliability using the PCG we observed significant pre-post differences for sustained attention, specifically for D2-correct responses (p < 0.001), suggesting a significantly better performance on the post-tests (M = 76.40) compared to the pre-tests (M = 67.13), and also for D2-skipped (p = 0.007), indicating a significantly better performance on the post-tests (M = 8.71) compared to the pre-tests (M = 14.14). Therefore, we excluded both D2 sub-tasks (correct responses and skipped) for all groups as they showed significant test-retest differences.

Last, we investigated whether there were significant differences between the 3 groups in all pre-tests as well as in age and education at baseline. In all conditions, we did not find any significant differences between the groups (p>0.05).

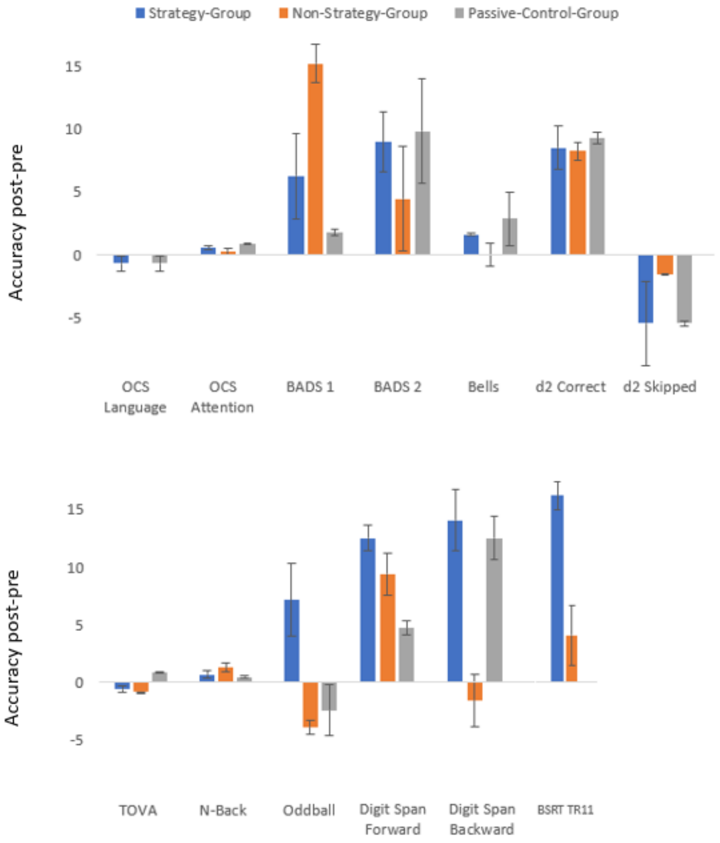

**Fig. 5** Mean accuracy for pre- and post- cognitive test differences for strategy, non-strategy and passive control groups. For the BSRT task, only one sub-category was reported (see the Data Sharing link for the full dataset)

*Table 2.* Behavioral data shown in percentage for correct answers of the pre- and post-tests.

| | STG | | NSTG | | PCG | |
|---|---|---|---|---|---|---|
| | Pre | Post | Pre | Post | Pre | Post |
| OCS Language | 100 | 99,4 | 100 | 100 | 100 | 99.4 |
| OCS Attention | 98.6 | | 98.0 | 99.1 | 97.7 | 98.6 |
| | 82.1 | 99.1 | 98.2 | 98.2 | 83.9 | 85.7 |
| BADS 1 | | | | | | |
| | | 90.2 | | | | |
| BADS 2 | 81.3 | 95.5 | 95.5 | 94.6 | 84.8 | 94.6 |
| BELLS | 95.1 | 96.7 | 95.1 | 95.1 | 95.5 | 98.4 |

| | | | | | | |
|---|---|---|---|---|---|---|
| d2 Correct | 69.2* | 76.7* | 72.6* | 82.7* | 67.1* | 76.4* |
| d2 Skipped | 12 | 6.9 | 9.1 | 7.6 | 14.1* | 8.7* |
| TOVA | 97.4 | 96.4 | 95.0 | 94.5 | 95.4 | 96.2 |
| N-Back | 96.0 | 97.0 | 96.4* | 94.5* | 96.9 | 97.4 |
| Oddball | 92.9* | 100* | 97.6 | 95.2 | 100 | 97.6 |
| Digit Span Forward | 75.7* | 84.3* | 81.4 | 92.9 | 71.4 | 80.0 |
| Digit Span Backward | 70.0* | 82.3* | 81,4 | 75.7 | 65.7 | 85.7 |
| BSRT TR 11 | 91.6 | 97.4 | 88.6 | 98.0 | 86.9 | 97.7 |

### *EEG- ERP outcomes*

We verified whether we could observe significant pre-post differences in several ERP components using a two-way ANOVA. The N-Back task for the STG showed significant differences in amplitude for N=2, mainly in P1 (PO4: $F(1,717) = 5.030$, $p = 0.025$), N2 (Fz: $F(1,717) = 8.989$, $p = 0.003$) and P300 (Fz: $F(1,717) = 8.798$, $p = 0.003$) ERP components, specifically in the frontal and parieto-occipital areas, and significant differences in latency for N=3 in P1 (O1: $F(1,456) = 4.618$, $p = 0.032$), and N1 (O1: $F(1,456) = 4.245$, $p = 0.040$; PO4 ($F(1,456) = 7.182$, $p = 0.008$). These results suggest that participants experienced the 2-Back as easier after training. For the STG, the Oddball task showed significant differences in amplitude in P100 (Cz: $F(1,2899) = 7.927$, $p = 0.005$, Pz: $F(1,2899) = 6.373$, $p = 0.012$, PO3: $F(1,2899) = 8.848$, $p = 0.003$, PO4: $F(1,2899) = 6.866$, $p = 0.009$) and N100 (Cz: $F(1,2899) = 9.036$, $p = 0.003$, Pz: $F(1,2899) = 7.747$, $p = 0.005$, PO3: $F(1,2899) = 5.906$, $p = 0.015$, PO4: $F(1,2899) = 5.222$, $p = 0.022$), in the central, parietal and parieto-occipital areas (Figure 6).

Moreover, for the NSTG, the N-Back task showed significant amplitude differences for N=1 in N1 (Fz: $F(1,403) = 4.152$, $p = 0.042$; Cz: $F(1,403) = 5.337$, $p = 0.021$) and P2 (Cz: $F(1,403) = 9.303$, $p = 0.002$, PO4: $F(1,403) = 5.008$, $p = 0.026$) for the NSTG, and we observed significant differences in amplitude for the Oddball task in P1 ($F(1,2441) = 9.792$, $p = 0.002$) and N1 ($F(1,2441) = 6.232$, $p = 0.013$), for occipital regions (Figure 7). We believe that these results are suggesting an overall easier effort in performing the 1-Back task in the post-tests compared to the pre-tests. Correlations analyses will be performed in a further manuscript to confirm our hypotheses.

However, looking at group differences, no significant results were found, indicating that STG and NSTG did not differ significantly between the first and last session.

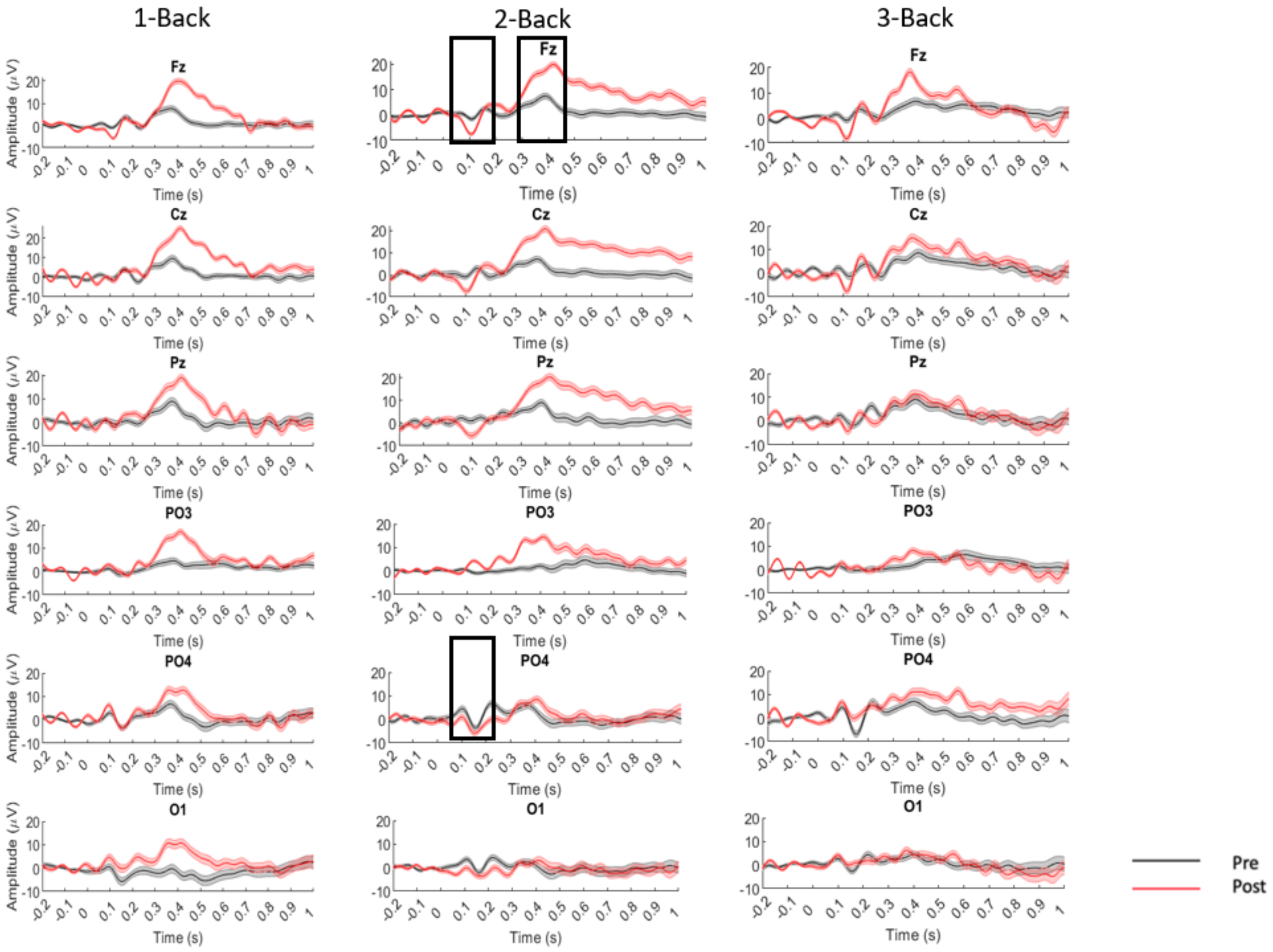

**Fig. 6** ERPs differences between pre- and post-training for N-Back for STG. *Significant differences in ERP components are marked by the black boxes

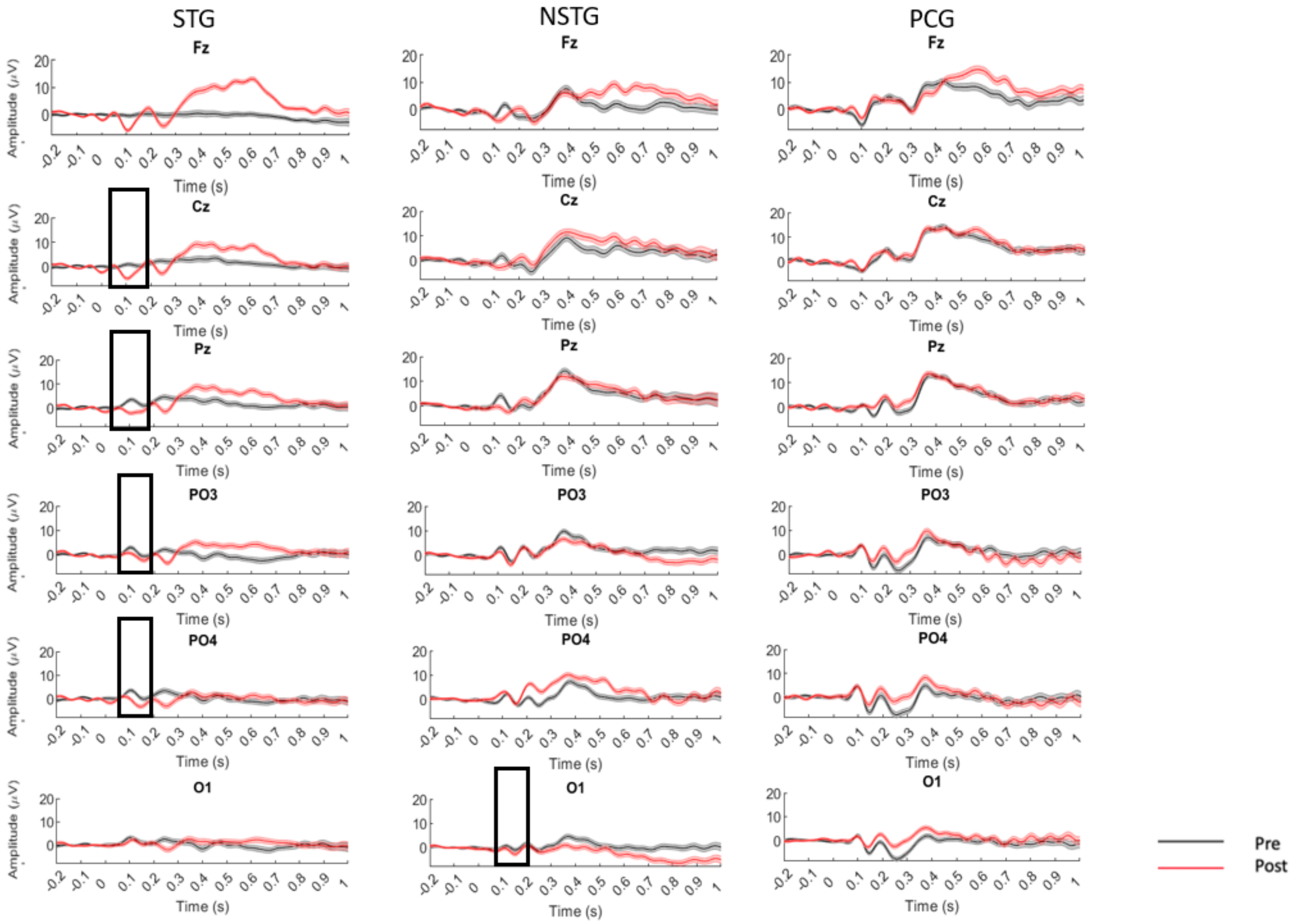

**Fig. 7** ERPs differences between pre- and post-training for Oddball. *Significant differences in ERP components are marked by the black boxes

## Training task

### Behavioral data

We applied a mixed ANOVA (Group x Session) to distinguish significant changes over training sessions considering RT and contrast level. Our results on the contrast exercises showed a significant difference in RT ($F(2.77,33.25) = 40.85$, $p < 0.001$), suggesting that participants became faster in responding over training sessions. Furthermore, we found a main effect of group ($F(1,12) = 5.19$, $p = 0.042$) suggesting that RT differed significantly between STG and NSTG over training sessions, and a significant decrease in contrast level ($F(1.715,20.577) = 254.20$, $p < 0.001$), indicating that participants became better at correctly responding to lower contrast levels over training sessions. Specifically, when looking at the post-hoc comparisons, we observed that the STG (M = 2.12) became significantly faster over sessions (p = 0.042) compared to the NSTG (M = 2.35). However, compared to the baseline (first session), we now observe a significant difference between the two training groups ($F(1, 13) = 7.07$, $p = 0.026$, ηp2 = 0.371), suggesting that the NSTG (*M* = 2.69) performed significantly better during the pre-tests than the STG (*M* = 2.39) (Figure 8).

Additionally, our results on the contour exercises showed significant differences for RT over training sessions (*F*(2.480,29.762) = 207.75, *p* < 0.001), suggesting a significant increase in RT with increasing difficulty level. However, no significant group differences were found when considering the contour exercises. No significant effects were found between group x time (Figure 8).

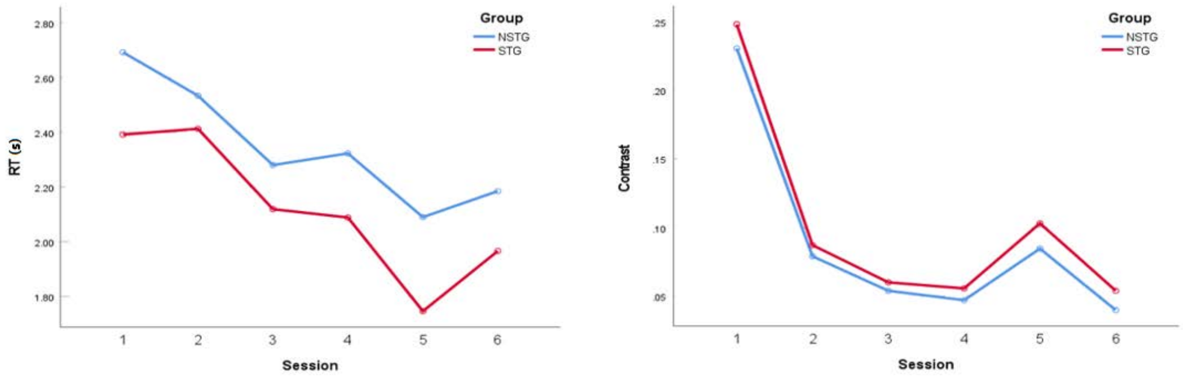

**Fig. 8** RT (s) and contrast outcomes of the training task. Left panel shows RT (s) over session during the contrast exercises. Right panel shows contrast levels (representing difficulty level) over sessions

## Discussion

In this study, we assessed the effect of strategy use on attentional control video game training and transfers to other cognitive domains, using both behavioral and EEG recording. While recent studies showed the beneficial impact of video game training on a large variety of cognitive functions (Strobach & Huestegge, 2017; Waris et al., 2019; Anguera et al., 2021), it is still unclear whether the strategy used during training plays an important role in enhancing both trained and untrained cognitive abilities. Similarly to previous literature studies (Laine et al., 2018), we did not observe any significant difference in improved trained task performance between the two training groups, although we did for RT for the contrast exercise. Moreover, although our results did not show significant differences between groups in transfer effects, when we considered the three groups separately, the STG showed transfers to four different tasks (D2-correct responses, digit span forward, digit span backward and oddball task), while NSTG to one transfer task only (D2-correct responses), and PCG to two transfer tasks (2-correct responses and D2-skipped), which is in accordance with Bailey et al. (2008) as they reported transfers for the trained group only. However, as the PCG exhibited significant test-retest differences in two sub-tasks of attention (D2-correct responses and D2-skipped), we did not further consider those tests in our analysis. Accordingly, the STG was the only group to show significant transfer effects with higher accuracy level in two memory tasks (digit span forward and backward) and one attention task (oddball). Furthermore, when investigating neural responses, the STG showed significant differences in ERP amplitudes for the intermediate difficult N-Back level (N=2) compared to the NSTG that showed significant differences in ERP amplitudes for the easier N-Back level (N=1). However, we did not find significant differences comparing the two training groups, probably due to the small sample size.

Interestingly, the behavioral outcomes of the training task revealed that participants in the STG became significantly faster in responding compared to the NSTG, while both groups performed better in correctly responding to lower contrast levels over training sessions. However, when considering baseline differences (first session) between groups, we found a significant difference between the two training groups, with the NSTG performing significantly better during the pre-tests than the STG. Furthermore, our results showed a faster RT over training sessions when looking at the contour exercises but, again, there were no group differences.

Several recent studies reported on beneficial effects of video game training interventions in healthy adults (Strobach & Huestegge, 2017; Waris et al., 2019; Anguera et al., 2021), especially when using a specific strategy compared to no-strategy (McNamara et al., 2001; Dunlosky et al., 2007; Pergher et al., 2018). In the study of Dunning and Holmes (2014), participants completed four working memory tasks. The results showed that the adaptive training group improved in several untrained WM tasks, by using a grouping strategy for visuospatial short-term memory and for verbal working memory tasks, indicating that the use of strategies mediates changes in memory task performance by exploiting the overlap with those used during training. However, it is still unclear whether there is transfer in case the used strategy does not overlap with that of the trained task (far-transfer). Similarly, when comparing older individuals, Basak et al. (2008) showed that specific strategy group (real-time strategy-based videogame), achieved transfers to executive control tasks compared to the non-strategy control group. However, a few other studies found improvements in the trained task for both strategy and non-strategy groups (Laine et al., 2018). Considering this controversy about the role played by strategy use in both trained and untrained tasks, our results shed light on this disagreement and, differently from Laine et al. (2018), provided supportive evidence for the role play by the strategy in the trained task but not in the untrained tasks, as reported by Dunning and Holmes (2014).

In this regard, several studies investigated the impact of training on numerous untrained cognitive domains, showing both successes (Anguera et al., 2013; Jaeggi et al., 2010; Basak et al., 2008) and failures or limited transfers to cognitive functions similar to the trained one (Melby-Lervåg et al., 2016; Zinke et al., 2012). For instance, Anguera et al. (2013) showed that by playing an adaptive version of NeuroRacer in multitasking training mode, older adults reduced multitasking effort compared to both an active control group and a passive control group, suggesting performance benefits extended to untrained cognitive control abilities (enhanced sustained attention and WM), while Melby-Lervåg et al. (2016) showed that WM training interventions appear to produce specific and short-term effects that do not generalize to far-transfer tasks and "real-world" cognitive skills. Therefore, in our study we decided to use a variety of cognitive tests for several cognitive domains to see whether the task type could have been an important variable as well. However, as highlighted in the review by Pergher et al. (2020), there is a substantial variability between protocols and tasks used in different training studies rendering it factually impossible to reach strong conclusions. Although the underlying mechanisms of transferability are still unclear, we believe that strategy use can have a considerable impact on both trained and untrained outcomes.

Finally, as only few studies used EEG recording to investigate the impact of cognitive intervention (Mishra et al., 2015; Berry et al., 2010; Pergher et al., 2018), and no EEG studies investigated the role of strategy use, we gauged ERP components of two cognitive tasks (N-Back and Oddball), pre- and post-intervention, and observed that there were no significant differences between the groups that did or did not use a specific strategy. However, in line with previous studies (Mishra et al., 2015), we found significant differences in both groups for N1, N2 and P1 ERP components. Additionally, we also observed changes in P2 and P3 ERP components between pre- and post- intervention in the N-Back task. A notable limitation of this study is its small sample size as, according to our power analysis, a sample size of 16 participants should have been used per group to achieve 80% accuracy. Hence, given our three groups fall short in this, we refrain from generalizing our conclusions. Furthermore, we did not statistically process our eye-tracking data, only to verify strategy-use, which could be a topic of further research.

## Conclusion

Our results showed that the use of a specific strategy improved RT for one of the trained tasks (contrast level), but not for the other (contour exercises) and improved performance in several transfer tasks. Despite individual pre- and post- differences, there were no significant differences when comparing groups for both behavioral and ERP responses. However, given the limited sample size of our three groups we refrain from generalizing our conclusions. In spite of this limitation, we believe that our preliminary results can guide the development of cognitive training protocols. An increased knowledge of factors that could have an impact on cognitive training outcome, such as strategy use, could be relevant for patients suffering from cognitive impairments to improve their cognition and eventually their quality of life.

## Data sharing

The data of this study are available via this link: https://drive.google.com/drive/folders/1nU8f1_CClZLSHYGak46KhxwZtfIgiQFg?usp=sharing

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## Author contributions

NV collected the data and performed the analyses; VP designed the experiment and wrote the manuscript. All authors discussed the results and contributed to the final manuscript.

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