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The effects of perceptual-cognitive training with Neurotracker on executive brain functions among elite athletes

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Abstract: The current study tests possible transfer effects from NT 3D MOT training among elite athletes from dynamic sports on executive brain functions, such as alerting, orienting, executive control, inhibition, shifting and updating. Sixty athletes from different sports, such as martial arts (boxing and wrestling), handball, soccer, orienteering, biathlon, alpine skiing, and Paralympic sports (sled hockey, badminton and table tennis), participated in a cross-over experiment-control group design over a period of 10 weeks. The results in the current study show specific training effects on training measures used by the NT 3D MOT tool, but no significant transfer effects on the executive functioning tests. The results are discussed based on the importance of training specificity and the mental state at the moment of NT 3D MOT training.

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PUBLIC INTEREST STATEMENT

There is a growing marked for brain training tools, such as the Neurotracker. The main goal for such tools is to improve cognitive capacities, such as for example attention. Thus, a systematic training program with brain training tools should affect executive tests measuring executive functions of the brain. The current study could not find any such effects on executive brain tests.

Subjects: Elite Sports; Elite Sport Development; Cognitive Science

Keywords: elite sport; perceptual-cognitive training; attention; executive functioning

Attentional resources are claimed to be of high importance for elite athletes in dynamic sports, such as e.g. basketball, soccer, handball and ice hockey, because of the rapidly and constantly changing external environment (arena) during execution of their sports (Bernier, Thienot, Codron, & Fournier, 2009; Kaufman, Glass, & Arnkoff, 2009; Kee & Wang, 2008; Moen & Firing, 2015; Moen, Hrozanova, & Pensgaard, 2018). In typical dynamic team sports (e.g. basketball), athletes need to pay attention to the rapidly changing movements of teammates and opponents, and quickly perceive the most important information, interpret that information, decide needed actions and execute these actions to detect optimal choices for their movements and where to pass the ball (Appelbaum & Erickson, 2016; Mangine et al., 2014). In dynamic individual sports (e.g. orienteering), it is crucial to pay attention to a rapidly changing terrain and the map while running in high speed, and execute the necessary actions to choose the fastest path from one point on the map to the next. These attentional resources in dynamic sports constitute the perceptual-cognitive skills that athletes depend on to perform at their best.

Given the importance of perceptual-cognitive skills, especially in dynamic sports, it is not surprising that training programs aimed at improving such skills have a relatively long history in elite sports (Martin, 1984; Revien & Gabour, 1981; Seiderman & Schneider, 1983; Stine, Arterburn, & Stern, 1982). Recently, as several studies in the field of sport psychology claim that attentional resources are crucial for performance in elite sports (Mann, Williams, Ward, & Janelle, 2007), research has shown that programs training the perceptual-cognitive skills have the potential to improve athletic performance (Appelbaum & Erickson, 2016). Athletic experts were found to be both faster and more accurate in their decision-making than lesser skilled athletes (Mann et al., 2007). Therefore, the underlying functions in the brain that regulate athletes' abilities to quickly perceive and extract the most important information in the environment, interpret that information to decide what actions are needed, and then execute those actions to handle the situation optimally, are key to high level performances in dynamic sports (Mangine et al., 2014). Thus, perceptual-cognitive tools should have the potential to affect the executive functions (EF) of the brain. However, in general, the possible effects from perceptual-cognitive tools are claimed to lack empirical support (Owen et al., 2010). The aim of the current study is therefore to investigate if a perceptual-cognitive tool has the potential to affect the underlying functions in the brain that regulate the perceptual-cognitive process.

1. Executive functions of the brain

In the rapidly changing environments of dynamic sports, it is the EF linked to the prefrontal cortex in the brain that make the athletes capable of regulating the dynamics of perception, cognition and action (Miyake & Friedman, 2012), while collecting the environmental information needed for performance. Furthermore, EF make the collected information available for athletes' perception and enable the identification of actions that are most suitable in the situation (Welford, 1968). Athletes' attentional resources are therefore crucial in this perceptual-cognitive process that makes them capable of responding effectively to a situation.

According to Miyake and Friedman (2012), there are three important EFs related to this attentional regulation: updating, shifting and inhibition. Updating is the ability to constantly monitor the environment for essential information and to rapidly add or delete contents in working memory. Shifting is the ability to switch between different tasks or mental sets and use attention with flexibility. Inhibition is the ability to deliberately override dominant or prepotent responses to certain stimuli. The EFs are correlated, but they also show diversity with one another, and are all related to the attentional processes in the brain (Miyake & Friedman, 2012; Moran, 2012). Thus, the attentional processes involve the ability to focus on the task at hand while ignoring any irrelevant distractions, the ability to shift focus when it is needed and the ability to change one's mind according to suitable actions in the dynamic sporting environment (Moran, 2012).

1.1. Attentional resources

Perception and decision-making (cognition and action) are closely related processes where attentional resources are central. Accordingly, working memory is closely connected to attentional processes, wherein attention serves as a monitor and decides what content is placed in working memory (Fougnie, 2008; Moen, Firing, & Wells, 2016). Thus, working memory requires the monitoring that is executed by attention as part of completing goal-directed actions in the setting of interfering processes and distractions (Conway, Cowan, & Bunting, 2001; Moen et al., 2016). Attentional processes are therefore complex cognitive systems, containing three independent, but related network stages: orienting to sensory events, detecting signals for focal (conscious) processing, and maintaining information in a vigilant alert state (Moen et al., 2016; Posner & Petersen, 1990). The goal-directed actions are then executed as the result of a comparison of information stored in working memory and relevant experience that is stored in long-term memory. In this case, experience is the amount of training on skills and actions that are necessary to perform in sport-specific situations. Thus, attentional resources and experience operate close together to influence performance in dynamic sports.

1.2. Research on perceptual-cognitive training programs

Research has shown that perceptual-cognitive training has the potential to influence sport-specific tasks (Crist, Li, & Gilbert, 2001; Mangine et al., 2014; Moen et al., 2018; Romeas, Guldner, & Faubert, 2016) and that elite athletes have significantly better attentional resources than non-elite, less skilled athletes (Ericcson, 2003; Mann et al., 2007). Elite athletes also gain better improvements and have a higher learning rate from perceptual-cognitive training than less skilled athletes (Faubert, 2013; Romeas & Faubert, 2015; Zhang, Yan, & Yangang, 2009). However, the underlying idea of perceptual-cognitive training programs is that these programs are supposed to improve the mechanisms that regulate the dynamics of human perception, cognition and action (Miyake & Friedman, 2012). Therefore, these programs should improve the EFs related to attentional processes. To the authors' knowledge, there is only one study showing that perceptual-cognitive training has an effect on cognitive functions, such as attention, visual information processing speed and working memory, in a group of University students (Parsons et al., 2016). To our knowledge, no studies have investigated how perceptual-cognitive training tools are related to the general underlying mechanisms that regulate the dynamics in elite athletes' perception, cognition and action, such as the EFs (Miyake & Friedman, 2012). The perceptional-cognitive tool that is used in the current study is the Neurotracker (NT) 3-dimensional (3D) multiple object tracking (MOT) device (Parsons et al., 2016). The NT 3D MOT is a tool for non-contextual perceptual-cognitive training and is used among elite athletes in dynamic sports (Faubert, 2013).

1.3. The current study

The aim of this study is therefore to investigate if the NT 3D MOT training program improves the basal executive functions in the brain.

Hypothesis 1: Perceptual-cognitive training with NT 3D MOT will improve athletes' executive functioning.

2. Method

2.1. Participants

Sixty elite athletes from dynamic sports were randomly selected based on the group of sport they belonged to and invited to participate in the study. The dynamic sports included martial arts (boxing and wrestling), handball, soccer, orienteering, biathlon, alpine skiing and Paralympic sports (sled hockey, badminton and table tennis). Participants were randomly selected from a cohort of athletes who were previously involved in projects with the Norwegian Olympic center in mid-Norway, currently competing at elite level in the abovementioned dynamic sports. Data from the current study is a part of a bigger data set that is used in different theoretical approaches (Moen et al., 2018).

2.2. Materials

2.2.1. Executive functions tests

A web portal that required a two-factor identification key was used to administer a questionnaire measuring demographic data, such as age, gender and type of sport, and the EF tests. The four EF tests investigated in this study were the attention network test (ANT), the anti-saccade task (AST), the color shape task and the letter memory task (LMT).

2.2.1.1. Attention network test. The ANT is an experimental measure of the three attention networks: alerting, orienting and executive control (Fan, McCandliss, Sommer, Raz, & Posner, 2002). The alerting network is concerned with an individual's ability to achieve and maintain a state of increased sensitivity to incoming information, the orienting network manages the ability to select and focus on the to-be-attended stimulus, and the executive control network manages the ability to control our own behavior to achieve intended goals and resolve conflict among alternative responses. There are three types of target stimuli (neutral, congruent and incongruent) and four types of cues (no, center, double, spatial) (Fan et al., 2002).

The ANT involves a cued reaction time task and a flanker task. During the cued reaction time conditions, one of four cue types was provided: no cue, a center cue, a double cue, or a spatial cue to alert the participant to the possible location of an array of arrows (the flanker condition) that would subsequently appear on the screen. Next, an array of stimuli was presented consisting of a central stimulus (an arrow pointing either left or right) and flankers that were either congruent (two flanking arrows on either side of the central arrow all pointing in the same direction as the central arrow), incongruent (a set of flanking arrows which pointed in the opposite direction of the central arrow), or neutral (two horizontal lines on either side of the central arrow). Compared to the congruent flankers, the incongruent flankers introduce conflict likely to result in longer RTs (i.e., slower information processing speed) and the potential for reduced response accuracy.

2.2.1.2. Anti-saccade task. The AST is an inhibition task, investigating the voluntary and flexible cognitive control (Miyake & Friedman, 2012). In the AST, participants are required to make a decision based on the direction of an arrow, appearing either right or left from the fixation mark. On the right from the fixation mark, the arrow can either point to right or left, and similarly, on the left from the fixation mark, the arrow can point to either right or left. Two types of stimuli are presented in the task: congruent and incongruent. The congruent stimuli involve the arrow pointing in the same direction as to where it is placed (i.e. arrow on the right from fixation mark that points to the right), while the incongruent stimuli involve the arrow pointing in the opposite direction as to where it is placed (i.e. arrow on the right from fixation mark that points to the left). Incongruent trials have a longer latency than pro-saccades and subjects are more likely to make errors on anti-saccade trials (Friedman et al., 2008; Jamadar, Fielding, & Egan, 2013; Roberts, Hager, & Heron, 1994).

2.2.1.3. Color-shape-task. The color-shape-task (CST) is an experimental measure of shifting (Miyake & Friedman, 2012). During this test, a letter (either C or S) appear above a colored shape (outline of either a circle or triangle). The letter is a cue telling the participant what response to make. When the letter was C, it indicated for the participant to respond with whether the color of the shape was red or blue. When the letter was S, it indicated for the participant to respond with whether the shape was a triangle or a circle. Given that both colors and shapes are presented simultaneously, task switching requires participants to move visuospatial attention away from one set of features in order to selectively attend to the alternative feature set. Half of the trials were switch (different), the other half were no-switch (same) (Miyake, Emerson, Padilla, & Ahn, 2004).

2.2.1.4. Letter memory task. The LMT is an experimental task of updating (Miyake & Friedman, 2012). Participants view series of letters (5, 7, 9 letters long), one at a time in the middle of the computer screen. Whenever a new letter appears on the screen, the participants have to rehearse out loud the last three letters in the series. After the last letter disappears, they have to enter the last three letters by selecting the correct letters on the keyboard. There were 12 trials in total (Friedman et al., 2008; Morris & Jones, 1990).

In the current study, ANT executive functioning will be used to measure alerting, orienting and executive control, while the CST will be used to measure shifting, the LMT will be used to measure updating, and the AST will be used to measure inhibition (Posner & Rothbart, 2007).

2.3. The Neurotracker 3D multiple object tracking tool

An online version of NT 3D MOT was used, and athletes were instructed to sit upright on a stool in front of their computer with a pair of 3D glasses for each trial. The NT 3D MOT device uses a 3D transparent cube containing eight identical yellow balls that are presented on the screen. In the first stage of each trial, two of these balls were randomly illuminated for 2 s while marked with a red color, before returning to the baseline yellow color again. Athletes were instructed to track the two balls while all the eight balls were moving simultaneously and randomly in all areas of the cube for 8 s. The movement speed was adjusted according to the current level. After 8 s, the balls were frozen in their individual space and assigned a number from 1 to 8 by the computer. Athletes were instructed to identify the two balls they were originally asked to track by clicking on them in the cube with their mouse or keyboard. The movement speed of the balls depended on the score the athletes received on their previous session. If the athletes correctly selected both two balls, the speed was increased, if not, the speed was reduced. All athletes started their sessions with tracking two balls and increased up to maximum tracking of four balls.

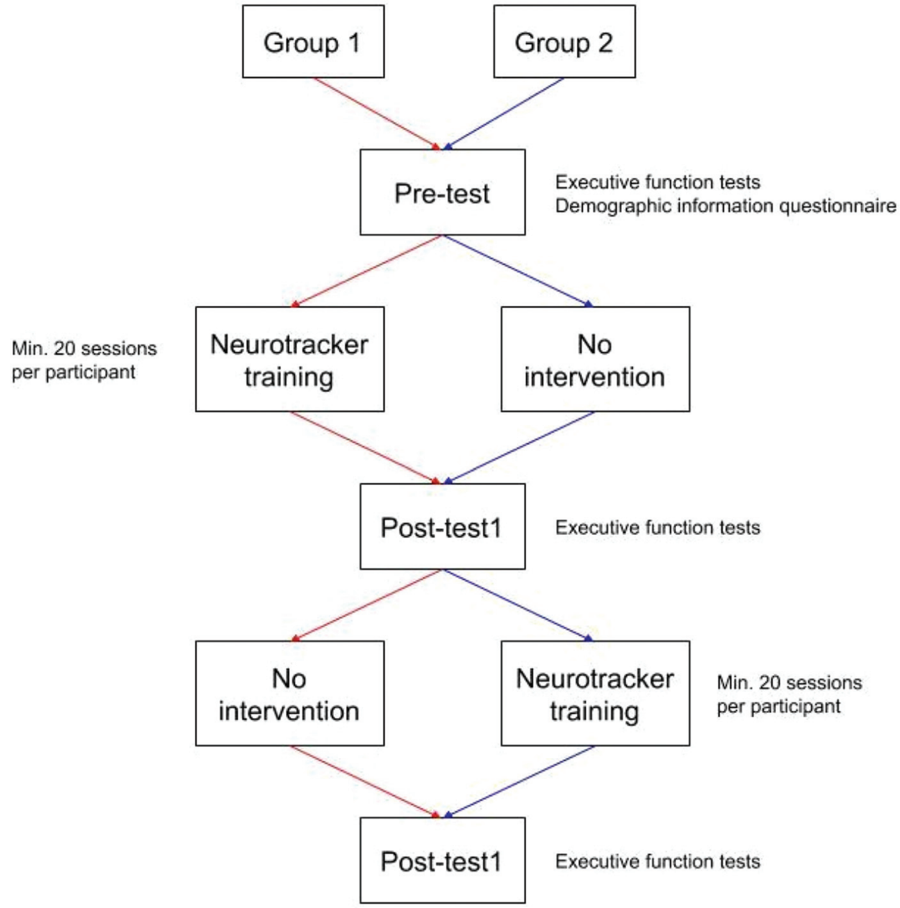
Relevant variables were detected as baseline scores in the beginning of the training and at the end of the 5th week of training. The 3 first sessions were used to compute the geometric mean defined as *the initial baseline*. The number of balls they were tracking was defined as number of *targets*. The variable *improvement rate* was calculated to measure if and how much the athletes had improved from when they started using NT 3D MOT. The following formula was used to calculate the improvement rate: (Baseline at 2 Targets—initial baseline)/initial baseline. *Learning rate* was defined by the athletes' score had they been tracking at two targets.

2.4. Procedure

Prior to the beginning of the study, an approval was granted by the Norwegian Social Science Data Services (NSD), which is the research ethic board for social sciences in Norway. The current study utilized a cross-over design involving two groups, with participants randomized based on the group of sport they belonged to and the timing of the competition season of the respective sports. The aim was to avoid clashes between the duration of the study and the competition season. Group 1 included wrestling, handball, biathlon, and alpine skiing. Group 2 included soccer, Paralympic sports, boxing and orienteering. Athletes belonging to these respective sports were randomly invited to participate. Prior to the beginning of the study, all invited athletes, their coaches and coaching staff received oral and written information about purpose, procedure, and requirements of the study.

Throughout the study, both groups underwent three testing sessions: pre-test, post-test 1 and post-test 2, in which they completed the EF tests. In addition, both groups completed the demographic information questionnaire at pre-test. An invitation to participate at each testing session was sent by email to each participant. At each testing point, athletes were given one week to complete the materials. Furthermore, all athletes trained with the NT 3D MOT. The NT 3D MOT license was sent to athletes immediately prior to the beginning of their training period, to ensure that athletes were completely unfamiliar with the tool to avoid possible training effects confounds (Faubert, 2013). Each athlete received instructions to perform at least 4 sessions per week, over a period of five consecutive weeks. The procedure is illustrated in Figure 1.

Figure 1. The implemented cross-over design with the procedure for the two respective groups (Group 1 in red arrows, Group 2 in blue arrows).



2.5. Data analysis procedures

Missing data were identified for six athletes, who had not completed the experiment in its full entirety. For these subjects, the SPSS function replace missing with series mean was used to replace missing values. Thus, data was analyzed for all 60 athletes. Then, NT data was examined with the use of descriptive statistics, such as statistical means, standard deviations, maximum and minimum values.

To test the hypothesis that perceptual-cognitive training with the NT 3D MOT improves EFs in elite athletes, data analysis procedure with the following variables were conducted: alerting, orienting and executive control (assessed with ANT) (Petersen & Posner, 2012), updating (assessed with LMT), shifting (assessed with CST) and inhibition (assessed with AST). Firstly, descriptive statistics including statistical means and standard deviations measuring the investigated EF variables were carried out for Group 1 and Group 2 respectively, at each testing time-point. Additionally, paired samples *t*-tests were applied to test for improvements between pre-test and post-test 1, and between post-test 1 and post-test 2, in each of the two groups respectively. To investigate whether Group 1, after receiving NT training, has significantly improved the EFs compared to athletes in Group 2, a series of seven separate hierarchical regression analyses were conducted. The EFs variables at post-test1 (ANT- alerting, orienting, executive, AST-inhibition incongruence and congruence, CST-shifting, and LMT-updating) were included as dependent variables. In the first step, age, sex and pre-scores of the EF variables were entered simultaneously as covariates to rule out their potential confounding effects. In the second step, the group variable was entered as a dichotomized variable.

Table 1. Descriptive statistics assessing the NT variables *n* = 60

	Group 1				Group 2			
Variables	**Mean**	**Std**	**Max**	**Min**	**Mean**	**Std**	**Max**	**Min**
Age	22	3.5	35	17	22	4.19	35	17
NT number of sessions	26.5	13.3	76	9	27.54	10.48	61	14
NT baseline	3.04	0.60	4.40	1.91	3.50	0.91	5.06	1.68
NT improvement*	45.45	50.64	213	−24.5	42.79	30.15	98.63	−8.70
NT learning rate	3.23	0.53	4.21	2.25	3.25	0.75	4.67	1.75
NT targets	3.8	0.41	4	3	3.83	0.48	4	2

* Values in percent.

To investigate whether Group 2, after receiving NT training between post-test 1 and post-test 2, has significantly improved the EF variables compared to athletes in Group 1, new series of seven hierarchical regression analyses were conducted. The analyses were set up in the same way as for Group 1, with the following exceptions: dependent variables scores were used from post-test2, and EFs scores from post-test1 were entered. All statistical analyses were carried out with IBM SPSS version 25. Statistical significance was established at alpha level <0.05.

3. Results

From the 60 participants, 48.3% were male and 51.7% were female. The sample had a mean age of 21.7 years (ranging from 17 to 35 years). Group 1 included 31 participants, 21 were from individual sports (alpine skiing 11, boxing 2, biathlon 8) and 10 from team sports (handball 8, football 1, ice hockey 1), and 16 were males and 15 were females. Group 2 included 29 participants, 16 were from individual sports (Orienteering 13, boxing 1, table tennis 1, badminton 1) and 13 from team sports (football 9, sledge hockey 4), and 13 were males and 16 were females.

3.1. NT training in Group 1 and Group 2

Descriptive statistics of participants' NT training, from groups 1 and 2, respectively, are shown in Table 1. Based on the NT improvement rate and learning rate variables, these results show that both groups experienced NT-specific improvements as a result of NT training (Faubert, 2013).

Table 2. Mean, standard deviation and *p*-values for Group 1 at pre-test, post-test 1 and post-test 2 (*n* = 31)

	Pre-test		Post-test 1			Post-test 2		
Variable	**Mean**	**Std**	**Mean**	**Std**	***p***	**Mean**	**Std**	***p***
ANT-alerting	−3.95	45	6.94	33	.16	11	23	.54
ANT-orienting	12.44	30	3.37	19	.08	6.42	23	.55
ANT-executive	117	90	79	36	**.02**	74	41	.38
AST-inhibition*	652	191	640	184	.79	604	144	.30
AST-inhibition**	635	197	609	134	.49	594	101	.56
CST-shifting	693	827	496	271	.18	486	482	.91
LMT-updating	64	24	72	17	**.02**	84	13	**.000**

* Congruence, ** incongruence.

Table 3. Mean, standard deviation and *p* values for Group 2 at pre-test, post-test 1 and post-test 2 (*n* = 29)

	Pre-test		Post-test 1			Post-test 2		
Variable	**Mean**	**Std**	**Mean**	**Std**	***p***	**Mean**	**Std**	***p***
ANT-alerting	19	64	11	37	.64	10	26	.93
ANT-orienting	17	35	14	23	.61	14	18	.99
ANT-executive	102	73	83	59	.08	72	18	.26
AST-inhibition*	937	1419	601	109	.19	579	84	.19
AST-inhibition**	637	198	602	136	.27	556	75	**.02**
CST-shifting	580	449	472	244	.18	474	207	.97
LMT-updating	76	17	80	16	.11	88	11	**.02**

*Congruence, ** incongruence.

Table 4. Summary of linear regression analysis for variables predicting the dependent variables specified as the executive test variables (*n* = 60)

Dependent variable	Predictors	*B*	*t*	*p*	R^2
ANT-alerting 2	Age	−.16	−1.21	.232	
	Gender	.07	.459	.648	
	ANT-alerting 1	−.07	−.51	.613	
	Group	.08	.60	.554	−.03
ANT-orienting 2	Age	.32	2.60	**.012**	
	Gender	−.05	−.44	.658	
	ANT-orienting 1	.32	2.61	**.012**	
	Group	.20	1.69	.096	17
ANT-executive 2	Age	−.04	−.31	.760	
	Gender	−.03	−.25	.805	
	ANT-executive 1	.46	3.81	**.000**	
	Group	.10	.79	.436	16
AST-inhibition* 2	Age	.06	.44	.665	
	Gender	.04	.29	.773	
	AST-inhibition* 1	.27	1.86	.068	
	Group	−.17	−1.35	.182	.05
AST-inhibition** 2	Age	.19	1.534	.131	
	Gender	.04	.28	.779	
	AST-inhibition** 1	.38	3.08	**.003**	
	Group	−.04	−.31	.761	13
CST-shifting 2	Age	.12	.89	.377	
	Gender	−.01	−.11	.911	
	CST-shifting 1	.34	2.58	**.012**	
	Group	−.02	−.19	.853	.05
LMT-updating 2	Age	−.00	−.03	.975	
	Gender	−.06	−.52	.607	
	LMT-updating 1	.56	4.76	**.000**	
	Group	.08	.68	.502	32

*Congruence, ** incongruence.

3.2. Effects of NT training on executive functions

Means, standard deviations and paired samples *t*-tests for the outcome variables at pre-test, post-test 1 and post-test 2 are given in Table 2 for Group 1 and Table 3 for Group 2. The paired samples *t*-tests compared values between pre-test vs. post-test 1 and post-test 1 vs. post-test 2. Overall, there has been a slight improvement on all tested variables in both groups, especially from pre-test to post-test 1. Analysis revealed a significant improvement in executive control function from pre-test to post-test 1 and a significant improvement in updating at both tested time points in Group 1, and a significant improvement in inhibition and updating from post-test 1 to post-test 2 in Group 2.

3.3. Effects of group differences in NT training on executive functions at post-test1

The hierarchical regression analyses did not reveal any significant effects of group on the EF measures, neither in Group 1 nor in Group 2. Consistently, the only variables that predicted the respective EF measures were the respective EF measures at pre-test. The results of step 2 of the regression analyses are summarized in Table 4.

3.4. Effects of group differences in NT training on executive functions at post-test2

In addition, results of the hierarchical regression analyses using EF scores at post-test 2 as dependent variables gave similar results, with no significant effect of group. For the sake of keeping this article concise, results of hierarchical analyses for Group 2 are not reported in full.

4. Discussion

The purpose of the present study was to examine possible effects from a 5-week experiment with a control group design with the NT 3D MOT tool on executive brain function tests, such as ANT-alerting, orienting and executive control, AST-inhibition congruence, AST-inhibition incongruence, CST-shifting and LMT-updating. After the 5-week intervention period the two groups changed positions in a cross-over design for another 5-week intervention period. Sixty elite athletes from different dynamic sports participated in the experiment. The analysis in the current study shows that there were significant improvements among the participants in both groups on the NT 3D MOT tool used in this study. The training effect on the perceptual-cognitive tool was comparable to other studies (Faubert, 2013). However, the results in the current study show that the specific benefits from NT training did not transfer to other more specific executive functioning regulating attentional processes. No significant effects from the NT 3D MOT tool were found on the EF tests used in the current study.

Possible explanations of the results in the current study are grounded on the importance of training specificity and the mental state at the moment of NT training.

4.1. The importance of training specificity

First of all, research claims that individual differences in EF are almost entirely genetic in origin (Friedman et al., 2008). However, the development of the brain is also claimed to be epigenetic (Edelman, 1992), which involves the idea that genes alone cannot explain the development of the brain, and that specific experiences from training on specific skills are needed to fully develop the potential of the brain. Edelman's "neural group selection" theory claims that it is the specific neural brain development that ultimately causes learning and development of that particular skill (Edelman, 1987, 1992; Moen et al., 2018; Sigmundsson, Trana, Polman, & Haga, 2017). Thus, to learn a skill implies the necessity to specific experience repeated executions of that skill, so that the specific neurons in the brain that are needed for that particular skill are activated (Edelman, 2006). In this process groups of activated neurons will establish networks that connect the different areas of the brain that are needed to execute that specific skills (Edelman, 1993). The "neural group selection" also involves the idea that neurons, group of neurons and networks that are not used in this process are not activated, and will therefore eventually disappear (Freberg, 2006). Such an explanation also find support in the theoretical framework behind neural plasticity (Hebb, 1949), which also claims that neurons or group of neurons that are active at the same time will strengthen their connections and fire simultaneously (Taya, Sun, Babiloni, Thakor, & Bezerianos, 2015). Thus, perceptual-cognitive training programs that are repeated will strengthen areas in the brain that work together to execute that particular brain-training actions, and build stronger associations between them. Interestingly, several studies confirm this and document effects on neural activity in the brain when using brain training (Jolles & Crone, 2012; Klingberg, 2010).

The general idea behind cognitive-perceptual training, such as the NT 3D MOT tool, is that when neurons and groups of neurons build stronger associations into networks in the brain, these networks can transfer to other tasks that need these same neurons and networks. It is therefore reason to believe that the NT tool used in the current study has not affected the neurons, groups of neurons and networks of groups of networks that are needed for completing the executive functioning tests used in the current study.

However, the results also indicate a specific training effect on the executive functioning tests, whereas both the experiment group and the control group improved their scores on the executive tests used in the current study (especially from test 1 to test 2). However, only ANT-executive and LMT-updating improved significantly and only in Group 1. The results in the current study therefore indicate that the brain networks that are engaged in the NT training tasks do not overlap with the brain networks related to the EF test tasks. The question is if the NT 3D MOT used in the current study is specific enough compared to the test used to measure executive functioning? The results in the current study indicate that it is not.

4.2. The mental state at the moment of training

Another possible explanation of the results in the current study can be that the mental state at the moment of training with the NT tool was not optimal. Research shows that if the task is too demanding or difficult it can be difficult to concentrate at the task, which can result in exhaustion from such workloads (Taya et al., 2015). Interestingly, the training difficulty level (NT targets) is found to explain effects from NT training on subjective performance (Moen et al., 2018). Future studies should include measurements of mental states during training with perceptual-cognitive tools, such as the NT 3D MOT.

5. Conclusion and limitations

The current study shows that training with the NT 3D MOT used in the current study results in specific benefits on skills used when training with this specific tool. However, the results in the current study show no significant general improvements on different aspects of executive functioning (ANT-alerting, orienting and executive, AST-inhibition, CST-shifting, LMT-updating). Thus, the specific benefits do not transfer to other brain tasks.

A possible limitation in the current study might be that the participants were not familiarized with the executive tests. However, other studies also used the first tests scores to analyze possible effects from brain training (Owen et al., 2010). Future studies should however consider using the mean from several executive tests to set the baseline score on the first test. Future studies also should consider using electroencephalography (EEG) to provide biomarkers that document brain networks when performing brain training and executive tests, to compare transferability. In the current study, only the CORE program was used, while there are a wide variety of different training protocols that can be utilized depending on what type of training one wants to emphasize. A variable that measures motivation and concentration should be included in future research to control for possible transfer effects from perceptual-cognitive tools. Experiments with a control group design and a larger number of participants are also called for in future research. Also, studies with a larger intervention period are called for in future studies, to control for possible effects related to time, since neural adaption in the brain takes time to develop.

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