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3D-Multiple Object Tracking training task improves passing decision-making accuracy in soccer players

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This publication shows the **benefits of 30 sessions of 3D-MOT training on passing accuracy in soccer** during a match (5x5 for 40min.).

Passing accuracy **increases** from **58%** (±3%) without 3D-MOT training to **73%** (±5%) after **30 sessions of 3D-MOT** training.

Neurofy relies on 3D-MOT principle and its variations allowing fully immersive training sessions.

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A R T I C L E I N F O

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A B S T R A C T

Objectives: The ability to perform a context-free 3-dimensional multiple object tracking (3D-MOT) task has been highly related to athletic performance. In the present study, we assessed the transferability of a perceptual-cognitive 3D-MOT training from a laboratory setting to a soccer field, a sport in which the capacity to correctly read the dynamic visual scene is a prerequisite to performance.
Design: Throughout pre- and post-training sessions, we looked at three essential skills (passing, dribbling, shooting) that are used to gain the upper hand over the opponent.
Method: We recorded decision-making accuracy during small-sided games in university-level soccer players ($n = 23$) before and after a training protocol. Experimental ($n = 9$) and active control ($n = 7$) groups were respectively trained during 10 sessions of 3D-MOT or 3D soccer videos. A passive control group ($n = 7$) did not received any particular training or instructions.
Results: Decision-making accuracy in passing, but not in dribbling and shooting, between pre- and post-sessions was superior for the 3D-MOT trained group compared to control groups. This result was correlated with the players' subjective decision-making accuracy, rated after pre- and post-sessions through a visual analogue scale questionnaire.
Conclusions: To our knowledge, this study represents the first evidence in which a non-contextual, perceptual-cognitive training exercise has a transfer effect onto the field in athletes.

Introduction

In dynamic sports such as soccer (Association Football), the ability to 'read the game' distinguishes skilled from less skilled players (Williams, 2000). However, athletes are not characterized by superior vision (Abernethy, 1987; Helsen & Starkes, 1999) and visual training programs have not shown any evidence of transfer to the field (Wood & Abernethy, 1997). Rather, sport scientists identified a number of abilities that are tightly related to superior anticipation and decision-making to better explain the ability to 'read the game'. Anticipation and decision-making represents the human brain's ability to extract meaningful contextual information from the visual scene and are essential for high-level performance in sports (Casanova, Oliveira, Williams, & Garganta, 2009). They are typically referred to as perceptual-cognitive skills, illustrating the role played by both perceptual and cognitive processes.

Two main approaches have been proposed to identify athletes' perceptual-cognitive superiority. The first and most common theory that supports athletic expertise relies on the expert performance approach. It reflects comparisons between elite, sub-elite and/or novice performers in tasks that are domain specific and, in some cases representative of the behavioral requirements of the competitive setting. In essence, experts have been shown to be superior to sub-elite and/or novices in sports-specific tasks including advance visual cue utilization (Abernethy, Gill, Parks, & Packer, 2001; Ward, Williams, & Bennett, 2002), pattern recall and recognition (Abernethy, Baker, & Côté, 2005; Smeeton, Ward, & Williams, 2004), visual search strategies (Vaeyens, Lenoir, Williams, & Philippaerts, 2007; Williams, 2000) and the knowledge of situational probabilities (North & Williams, 2008; Williams, Hodges, North, & Barton, 2006). Those abilities have been linked to game intelligence. On the other hand, the cognitive component skill approach examines whether sport expertise influences fundamental cognitive and perceptual functions outside the sport-

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specific domain (Nougier, Stein, & Bonnel, 1991). It relies on more fundamental, sport context-free, paradigms that confer a cognitive fidelity rather than a physical fidelity with the sport environment. In fact, it is well accepted that physical activity enhances brain plasticity and improves cognitive and executive functions (for recent reviews see Erickson, Gildengers, & Butters, 2013; Vivar, Potter, & van Praag, 2013). For example, a significant correlation has been demonstrated between the results from the executive functions tests (neuropsychological assessment tool) versus the number of goals and assists the players had scored two seasons later (Vestberg, Gustafson, Maurex, Ingvar, & Petrovic, 2012). The authors suggested that results in cognitive function tests predict the success of top-soccer players. Furthermore, higher order cognitive function has been suggested to be relevant for talent identification and development in youth soccer players (Verburgh, Scherder, van Lange, & Oosterlaan, 2014). In a recent meta-analysis, Voss and colleagues showed that expertise in sport was related to high levels of performance on measures of processing speed and visual attention (Voss, Kramer, Basak, Prakash, & Roberts, 2010). Moreover, Alves and colleagues found that volleyball players differed from non-athlete controls on two executive control tasks and one visuo-spatial attentional processing task (Alves et al., 2013). Furthermore, interesting significant differences have recently been found between athletes that outperformed non-athletes in socially realistic multitasking crowd scenes involving pedestrians crossing streets (Chaddock, Neider, Voss, Gaspar, & Kramer, 2011) or in learning complex and neutral dynamic visual scenes through a three dimensional multiple object tracking (3D-MOT) task (Faubert, 2013). These studies support the claim that the cognitive component approach captures a fundamental cognitive skill associated with competitive sport training (Voss et al., 2010).

Given the emerging evidence of brain plasticity following learning or injury (Draganski & May, 2008; Ptito, Kupers, Lomber, & Pietrini, 2012), Faubert and Sidebottom (2012) introduced a perceptual-cognitive training methodology for athletes (Faubert & Sidebottom, 2012). The technique used is a “highly leveled” 3D-MOT perceptual-cognitive task because it stimulates a high number of brain networks that have to work together during the exercise including complex motion integration, dynamic, sustained and distributed attention processing and working memory. In an earlier publication by Faubert (2013), the 3D-MOT training technique revealed striking superior skills in professional athletes compared to sub-elites and novices when rapidly learning complex and neutral dynamic visual scenes (Faubert, 2013). The results showed a clear distinction between the level of athletic performance and corresponding fundamental mental capacities for learning an abstract and demanding dynamic scene task. The author suggested that rapid learning in complex and unpredictable dynamic contexts is one of the critical components required for elite performance. Lately, a study revealed that 3D-MOT performance was most likely related to the athletes' ability to see and respond to various stimuli on the basketball court, however the simple visuo-motor reaction time that was not related to any of the basketball specific performance measures (Mangine et al., 2014). Furthermore, recent neurological evidence has demonstrated the role of 3D-MOT in enhancing cognitive function in healthy young adults (Parsons et al., 2014). In fact, 10 sessions of 3D-MOT training improved attention, visual information processing speed and working memory recorded through neuropsychological tests and quantitative electroencephalography. In addition, other evidence has demonstrated that 3D-MOT training can show transfer to socially relevant tasks such as biological motion perception in the elderly (Legault & Faubert, 2012).

In sport science and especially in perceptual-cognitive training studies, focus on transfer measures is essential to determine whether any improvements observed in the laboratory may transfer back to a live game situation. A common hypothesis suggests that transfer can occur if the trained and transfer tasks engage specific overlapping cognitive processes and brain networks (Dahlin, Neely, Larsson, Backman, & Nyberg, 2008). Studies supporting the expert performance approach have raised the question of perceptual-cognitive transfer in athletes (Caserta, Young, & Janelle, 2007; Gabbett, Carius, & Mulvey, 2008; Hopwood, Mann, Farrow, & Nielsen, 2011; Williams, Ward, & Chapman, 2003), however; to our knowledge, studies from the cognitive component approach have yet to demonstrate this transfer. For instance, Gabbett et al. (2008) investigated the effects of video-based perceptual training on decision-making skills during small-sided games (SSG) in elite women soccer players (Gabbett et al., 2008). Video-based training yielded on-field improvements in passing, dribbling and shooting decision-making skills. In addition, the use of SSG as a measure of transfer seemed to be an efficient strategy in capturing the dynamic and strategic components of soccer. In fact, a major challenge with transfer settings is to develop objective and sensitive measures of transfer. Soccer is an invasion game where the main goal is to invade an opponent's territory (offensive scenario) to score and/or to contain space and regain ball possession (defensive scenario) to avoid conceding goals (Mitchell, Oslin, & Griffin, 2013). Players have to make different decisions whether they have to defend or to attack. During the attack, the offensive aspect is to score a goal (e.g. shooting) while conservation of the ball (e.g. passing, dribbling) is the defensive aspect (Gréhaigne, Richard, & Griffin, 2012). Passing and shooting the ball have been recognized as important factors that contribute to the success or improvement of performance in invasion games (Hughes & Bartlett, 2002). On the other hand, recovering the ball or putting pressure (e.g. pressing) on the opposing team to regain possession of the ball is the offensive aspect of the defense. Defending one's goal (e.g. tackling) consists in the defensive aspect of the defense. Therefore, soccer presents a complex and rapidly changing environment where different decisions have to be made under pressure and time constraints. The quality of response to those decision-making situations is crucial in the success of the team and to improve performance. SSG allows players to experience similar situations that they encounter in competitive matches while optimizing training duration. It also reduces space and therefore the amount of time to respond. This process increases the number of opportunities for decision-making and thus increases the ratio of players' participation in decision-making (Aguiar, Botelho, Lago, Maças, & Sampaio, 2012).

In the present study, we assessed the transfer capability of perceptual-cognitive 3D-MOT training void of sports context on offensive decision-making with soccer players. In a dynamic sport environment such as soccer, players must be able to correctly read the key information from a visual scene to make accurate decisions. They are usually confronted with multiple choices. To score goals, players have to select the best options especially during an offensive scenario. For example, within a split second, players need to decide whether they protect the ball, when and where to pass or whether they should take a shot on net. The decision-making skill refers to the capability of individuals to make a choice and achieve a specific task goal from a set of possibilities (Bar-Eli, Plessner, & Raab, 2011). Becoming an expert in decision-making is thought to be acquired following sport-specific deliberate practice (10 000 hour rule) (Ericsson, Krampe, & Tesch-Römer, 1993) even if there is some speculation about the benefits of the involvement in non-sport-specific activities during the first years of practice (Baker, Cote, & Abernethy, 2003). This refers to the general benefits of involvement in any physical activities explained earlier (cognitive component approach). Decision-making in sport relies on three major cognitive components such as perception, knowledge and decision strategies (Bar-Eli et al., 2011). Expert decision-makers depend on advanced perceptual and memory processes to better execute short term decisions. In particular, they rely on advanced visual search strategies in their central and peripheral vision (Vaeyens et al., 2007) as well as selective, focused and divided attention (Bar-Eli et al., 2011). While general visual training programs hardly improve decision-making in sports, 3D-MOT includes dynamic visual information that has to be processed actively, which is a crucial part of the perceptual component involved in decision-making. The 3D-MOT selective attention and processing speed of multiple moving targets task may be a crucial skill to help execute decision-making. This is supported by studies showing that performance on multiple target tracking tasks is superior in different kinds of experts such as professional radar operators, video-gamers and athletes (Allen, McGeorge, Pearson, & Milne, 2004; Green & Bavelier, 2003; Zhang, Yan, & Yangang, 2009). To train perceptual and attentional processes involved in decision-making, we used a highly leveled perceptual-cognitive training task that includes complex motion integration, dynamic, sustained and distributed attention processing and working memory. Three-dimensional MOT training has already shown evidence in enhancing cognitive function by improving attention, visual information processing speed and working memory. Additionally, this is a task in which has previously highlighted athletes' impressive learning capabilities in complex and dynamic visual scenes. Recently, the technique has shown training transfer onto a perceptual-cognitive task, such as biological motion perception, within a laboratory setting. To assess the role of 3D-MOT in decision-making accuracy on the field, we looked at three essential skills that are used to gain the upper hand over the opponent throughout soccer offensive scenarios. We suggested that passing, dribbling and shooting could be improved in the 3D-MOT trained group compared to control groups between pre- and post-training sessions.

Method

Ethics statement

The experimental protocol and related ethical issues were evaluated and approved by the Comité d'Éthique de la Recherche en Santé of Université de Montréal. All subjects were given verbal and written information about the study and gave their verbal and written informed consent to participate.

Participants

Twenty-three young males from the Carabins soccer team of Université de Montréal participated (Table 1). All subjects reported normal or corrected-to-normal vision (6/6 or better) with normal stereoacuity (50 s of arc or better). None of the subjects had ever taken part in any previous 3D-MOT or perceptual-cognitive experiment.

Apparatus

Laboratory tests

The 3D-MOT experiment and 3D soccer videos (active control) were conducted using a fully immersive virtual environment thanks to a head-mounted display (Sony HMZ-T2) in a room with controlled lighting. The head-mounted display is a 3D-ready system that allows image projection on two OLED panels with a resolution of 1280 × 720 pixels and covering a maximal visual field of 45°. Inter-pupillary distance was adjusted for each subject. The 3D-MOT experiment was supported by a Hewlett-Packard ProBook 4530s with a Core i5 processor and an Intel HD Graphics 3000 graphic card. The 3D soccer videos, from the official 2010 FIFA world cup™ blu-ray, were played on a Sony PlayStation 3™ system. Both the computer (for 3D-MOT) and the Sony PlayStation 3™ (for 3D soccer videos) were connected to the head-mounted display to offer an immersive experience.

Field test

Decision-making assessment was conducted during standardized SSG before and after the training period. SSG consisted of standard 5 × 5 soccer matches on a 30 m × 40 m interior turf soccer field to avoid weather influence. Coaches were positioned on the side of the pitch to give their instructions as in a real game situation. Players were randomly distributed in five different teams composed of five players each including a keeper. The five teams were randomly facing each other two times during ten games of 5 min each. Every player was then taking part in eight games of 5 min for a total of 40 min during both pre- and post-sessions. Players who were waiting for the start of the next game were stretching or exercising with the ball. SSG were recorded using two video cameras (Sony, HDR-CX260VW). Cameras were positioned in the bleachers of the stadium, approximately 10 m above the field of play to cover the entire playing area. Players were identified by jerseys and numbers. The video recordings were analyzed using Dartfish Connect v6.0.

Decision-making coding

On-field decision making ability during SSG was coded using standardized coding criteria adapted from previous studies (French & Thomas, 1987; Gabbett et al., 2008). Passing, dribbling and shooting were the skills assessed (see Table 2). The coding instrument made it possible to separate the cognitive decision-making component of performance from the motor skill execution component of performance. When initially used by French and Thomas (1987) in basketball players, the coding instrument was built to evaluate three aspects of performance: control (e.g. a player catches the ball), decision (e.g. a player decides which action is appropriate), and execution (e.g. a player then executes the skill). In a recent study, Gabbett et al. (2008) adapted the instrument for coding decision-making in soccer. They assessed one aspect of performance, the decision, which is central in the context of our study. The decision component involves selection of the skill (e.g. pass, dribble, shoot), as well as which teammate to pass to, what direction to dribble, when to shoot, when to stop dribbling, and so

Table 1
Players' information (±SEM).

Group	n	Mean age (years)	Started to play soccer (age in years)	Playing soccer in a club (duration in years)	Hours of training by week (game-free)
3D-MOT	9	21.27 ± 0.81	6.56 ± 0.59	12.78 ± 1.63	8.67 ± 1.32
Active control	7	21.39 ± 1.03	6.00 ± 1.31	12.86 ± 1.79	11.14 ± 2.97
Passive control	7	22.48 ± 0.71	8.17 ± 2.12	11 ± 2.38	8.33 ± 1.09
All of the participants	23	21.67 ± 0.46	6.82 ± 0.71	12.32 ± 1.01	9.36 ± 1.04

Table 2
Decision-making coding instrument.

Decision criterion	1 point decision	0 point decision
Passing	The player made a good decision when the pass went to a teammate who was open and it: - directly or indirectly created a shot attempt, or - went to a teammate who was in a better position than the passer.	The player made a poor decision when the pass was: - made to a player who was closely guarded or when there was a defensive player positioned in the passing line, or - intercepted or turned over, or - made to an area of the field where no teammate was positioned, or - kicked out of the field of play.
Dribbling	The player made a good decision to dribble when dribbling if it created: - space for teammates, or - a scoring opportunity, or - space for the dribbler.	The player made a poor decision to dribble when he dribbled: - when the defenders were in good defensive position, or - into a supporting defender that was in good position, and this did not create space for the dribbler or teammates, or - out of the field of play, or - and the immediate defender was in a good position to defend the dribble, or - without a purpose (e.g. not going anywhere).
Shooting	The player made a good decision to shoot when he was open for the shot and it was uncontested.	The player made a poor decision to shoot when the shot: - was blocked, or - was taken off balance, or - was taken when one or more defensive players were in good position, or - was taken when it was contested.

Adapted from: French and Thomas (1987), Gabbett et al. (2008).

on. The quality of each decision was coded as 1 for an appropriate decision and 0 for an inappropriate decision according to the criteria (Table 2). Decisions that were neither appropriate nor inappropriate were not coded. For instance, when the player made a pass that did not: a) directly or indirectly created a shot attempt; b) went to a teammate who was in a better position than the passer; c) went to a player who was closely guarded; d) being intercepted or cause a turn over; e) reached an area of the field where no teammates was positioned or out of the field of play. Moreover, where the player did not have time to assess the options (e.g. player was tackled as soon as he received the ball) the disposal was not considered for assessment. Decision-making coding was assessed by an experienced soccer coach blinded to the experimental protocol and trained to use the instrument for coding. Then, the total score of each player by session was converted to percentage for analysis. Percentage accuracy values were established for each participant by dividing the number of points awarded by the total number available and then multiplying by 100.

Assessment of subjective judgements

To assess whether perceptual-cognitive learning was directly perceived or related to unconscious processes, we used participants' judgments in on-field decision-making. Players' confidence levels in decision-making accuracy were assessed promptly after pre- and post-sessions using the Sport Performance Scale application developed in our laboratory (http://vision.opto.umontreal.ca/english/technologies/apps_en.html). In the present study, we used a simple visual analog scale (rated from min [0%] to max [100%]) to assess players' confidence levels in decision-making. Measurements were performed on a ‘10′ Samsung Galaxy Tab II™’ tablet. The following instructions were individually given to the players: 1) to rate their ‘decision-making accuracy during the last play’ and to do so by 2) scrolling their finger on the visual analog scale of the touchscreen tablet until they had reached the appropriate score. Decision-making accuracy was described and contextualized on the scale as follows: ‘Your level of accuracy in anticipating teammate or opponent movements and to deliver a correct response (e.g. assist, shot)’. No time constraint was imposed and each player took approximately 15 s to both receive the instructions and give an answer.

Stimuli

3D-MOT

The 3D-MOT task (Fig. 1) was working under the NeuroTracker™ system licenced by the Université de Montréal to CogniSens Athletics, Inc. (Montreal, Canada). The CORE mode of the NeuroTracker™ system was used. During the exercise, four of eight projected spheres had to be tracked within a 3D virtual volumetric cube space with virtual light grey walls, subtending a visual angle of 42°. The spheres followed a linear trajectory in the 3D virtual space. Deviation occurred only when the balls collided against each other or the walls. In order to support an effective distribution of attention, a fixation spot was presented in the center of the cube throughout the experimentation. An instructed part of the training task was to focus on this green fixation square throughout the

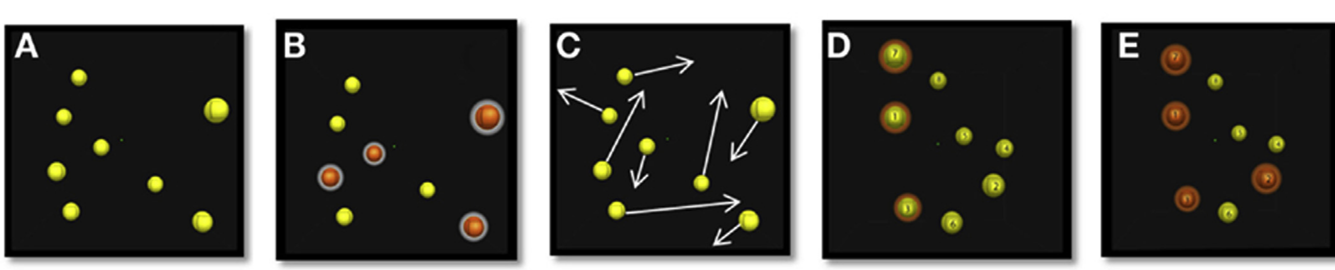

Fig. 1. 3D-MOT task. Illustration of the 5 critical phases: **A**) Presentation of randomly positioned spheres in a virtual volumetric space, **B**) Identification of the spheres to be tracked during the trial, **C**) Removal of identification and movement of all spheres with dynamic interactions, **D**) Observer's response by identifying the spheres, **E**) Feedback is given to the observer. If the observer correctly identifies all four spheres, the task is repeated at a faster speed. If, on the other hand, the observer makes a mistake, the task is repeated at a slower speed.

tracking phase which serves as an anchor point from which to extract information from the visual periphery (Ripoll, 1991). In other words, the anchor point is localized in a central position where the fovea could be directed while the relative movement of the spheres could be monitored using the peripheral visual field which is also able to detect movement (McKee & Nakayama, 1984). The effective use of such a strategy has already been demonstrated in experts through a variety of sports (e.g. Ripoll, Kerlirzin, Stein, & Reine, 1995; Savelsbergh, Williams, Van der Kamp, & Ward, 2002). Each session, based on a staircase procedure, lasted about 8 min. The staircase procedure consists of increasing speed if the subject got all the indexed targets or decreasing speed if at least one target was missed. Speed thresholds were then evaluated using a 1-up 1-down staircase procedure (Levitt, 1971). After each correct response, the dependent variable (speed ball displacement) was increased by 0.05 log and decreased by the same proportion after each incorrect response, resulting in a threshold criterion of 50%. The staircase was interrupted after eight inversions and the threshold was estimated by the mean of the speeds at the last four inversions.

3D soccer videos

The 3D soccer videos consisted of game replay from group and knock-out stages of the FIFA world cup 2010. Participants went through the whole blu-ray video once during the first four sessions of training. They were asked to watch soccer actions during approximately 25 min/session. During the last six sessions of training, participants would watch the 3D soccer videos for a second time (20 min/session) and were challenged by 5 min interviews during which questions about decision-making accuracy occurring throughout the soccer videos were raised (e.g. Did the scorer make the right decision on the first goal of Brazil against North Korea according to the situation? What would you have done in his place: pass, dribble, shoot?). The questions only ensured that the players were focusing on the videos and reinforced their belief that the training was effective. Importantly, no feedback was given to the players after they answered.

Procedure

We used a computer randomization script to allocate players into three separate groups including an experimental ($n = 9$), active ($n = 7$) and passive ($n = 7$) control group. All of them completed a pre- and post-on-field session during standardized SSG. Participants were constrained to not take part in any other training research activities throughout the duration of the testing period. In addition, the university athletes maintained a similar weekly routine, which was limited to their academic class schedule, training and soccer practice.

Experimental group

Players were actively trained ten times; twice a week for five consecutive weeks. During each evaluation, they participated in three CORE sessions of 3D-MOT. All of the observers reached a total of thirty sessions at the end of the training. Each participant followed the same standard procedure and completed each task while seated.

Active control

Participants focused on 3D soccer videos from the official 2010 FIFA world cup™ blu-ray twice a week for a five week period and a total of 10 sessions. Players were informed that this training was expected to have a positive effect on their decision-making performance during soccer games. This procedure was undertaken to provide an expectancy set for training benefits comparable to that of the perceptual-cognitive training group (cf Williams et al., 2003).

Passive control

No instruction or training was provided for this group.

Analysis

Due to injuries, two players from the experimental and the passive control groups were removed from the decision-making analysis. As the two (active–passive) control groups showed no statistical differences and small sample size, they were analyzed as a single control group. On-field decision-making accuracy in passing, dribbling and shooting was compared between the experimental and the active–passive control group. To find out whether the players' performance was different between pre- and post-sessions in the 3D-MOT group compared to the other group, we used a mixed-design analysis of variance (ANOVA; group × sessions). A Levene test yielded no significant differences in homogeneity between groups ($p > 0.05$). We conducted paired Student t-tests to compare pre- and post-evaluation of players' subjective decision-making accuracy, rated by the Sport Performance Scale, in the 3D-MOT and the active–passive control group. Athletes' 3D-MOT speed threshold means analysis between pre and post-training showed a comparable improvement as previously demonstrated in athletes (Faubert, 2013; Faubert & Sidebottom, 2012).

Results

Field assessment

Objective decision-making assessment

On-field decision-making analysis revealed a significant improvement in passing accuracy only for the 3D-MOT trained group between pre- and post-sessions compared to the other groups ($F(1, 17) = 4.708$, $p = 0.044$, $\eta^2 = 0.162$) (Fig. 2A). No significant difference was observed in decision-making accuracy for dribbling ($F(1, 14) = 3.628$, $p = 0.078$, $\eta^2 = 0.200$) and shooting ($F(1, 13) = 0.210$, $p = 0.654$, $\eta^2 = 0.015$) between pre- and post-sessions for the experimental compared to the other groups. However, there is a clear tendency for improvement in dribbling that did not reach the significance threshold ($p = 0.078$). We suggest that a high variance could explain those results. In fact, mean number of dribbles (5.1 ± 0.63 SEM) and shots (4.0 ± 0.52 SEM) during games were far too small compared to mean number of passes (15.5 ± 0.93 SEM) to reach a decisive conclusion on the impact of 3D-MOT training on the on-field performance for these abilities.

Subjective decision-making assessment

A general improvement in subjective confidence levels of decision-making accuracy between pre- and post-sessions was observed in the 3D-MOT group following a paired student t-test analysis ($t[6] = -3.547$, $p = 0.012$) while no difference was observed in the active–passive control group ($t[11] = -1.515$, $p = 0.158$) (Fig. 2B).

Discussion

This study was designed to assess the transferability of perceptual-cognitive training void of sports context on decision-making accuracy in soccer players. The main result demonstrates a significant 15% improvement in passing decision-making accuracy in soccer players trained with the 3D-MOT technique compared to active and passive controls. Furthermore, this result

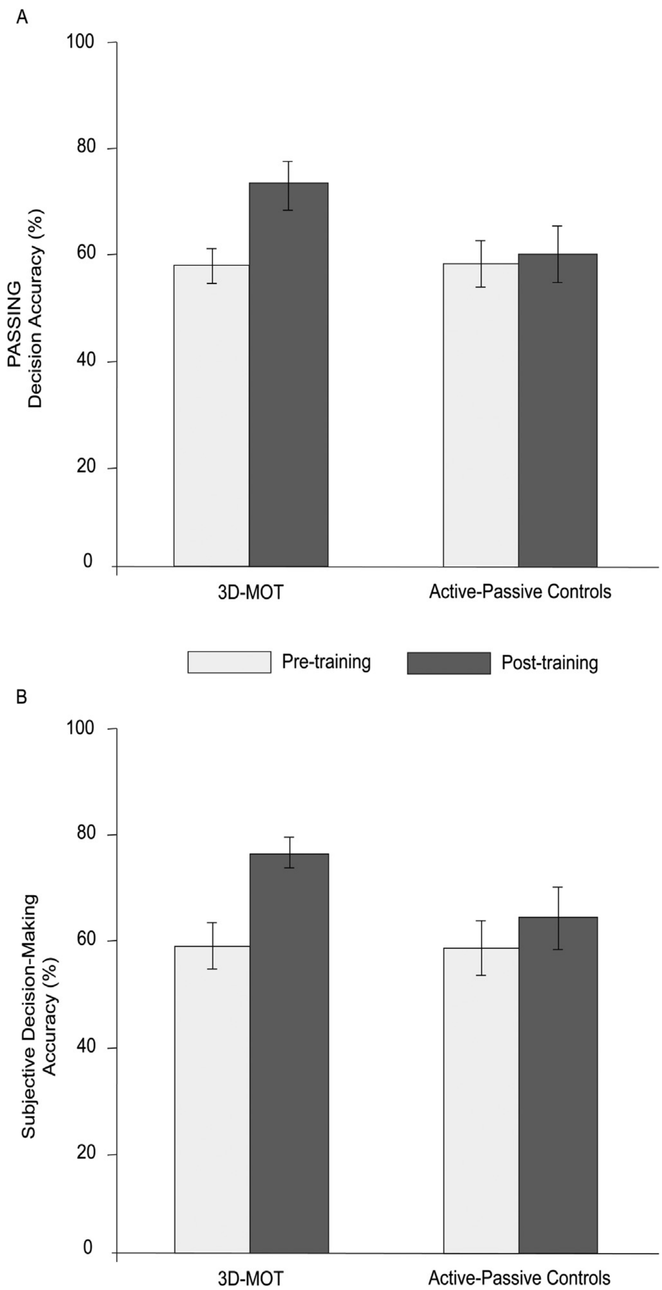

Fig. 2. A. Decision-making accuracy in passing of an experimental (3D-MOT training) and active–passive control groups during pre- and post-sessions of a SSG; **B**. Subjective decision-making accuracy of an experimental (3D-MOT training) and active–passive control groups during pre- and post-sessions of a SSG. Error bars represent SEM.

was corroborated with a proportional quantitative increase in subjective decision-making accuracy for the experimental group. Finally, players' 3D-MOT speed thresholds confirmed their superior capacity for processing a complex and dynamic visual scene task. It should be noted that even if we observed a trend ($p = 0.078$) in favor of an improvement in dribbling decision-making for the 3D-MOT group, no significant differences were found in dribbling and shooting abilities between groups. However, the low number of dribbles and shots attempted by the players restrict our ability to firmly conclude that the 3D-MOT training does not affect these decision-making abilities. For this reason, we will center the discussion on passing decision-making.

Decision-making improvement in passing

In the present study, we trained soccer players to track multiple elements through virtual, dynamic, complex and neutral (sport environment free) visual scenes using a perceptual-cognitive 3D-MOT technique. Ten training sessions in laboratory were sufficient to improve players' passing decision-making accuracy by 15% between pre- and post-sessions of SSG. Meanwhile, the active (10 sessions of 3D soccer matches) and passive control groups did not show any improvement. Considering 3D-MOT transferability has already been shown in a biological motion perception laboratory task (Legault & Faubert, 2012), this study represents the first evidence of 3D-MOT transfer from the laboratory to the field. Moreover, we argued in the introduction that expertise in athletes has been contextualized according to both the (sport specific) expert performance skills approach and the (sport environment free) cognitive component skills approach. While few studies have reported transfer following perceptual-cognitive training in specific sport contexts, the present study is, to our knowledge, the first evidence in favor of a non-contextual perceptual-cognitive training transfer on the sport-field. According to the most accepted theory, it is suggested that specific overlapping cognitive processes and brain networks were engaged for the laboratory 3D-MOT task and on-field decision-making process during SSG (Dahlin et al., 2008). Potential implications of 3D-MOT in decision-making improvement are discussed below.

Attentional tracking of multiple elements

One of the critical requirements to allow decision-making is to accurately extract meaningful information from the visual scene which is possible by using both perceptual and attentional processes. Attention and concentration are crucial abilities that affect the decision-making of athletes (Bar-Eli et al., 2011). During a soccer action, an athlete has to divide attention on the field (e.g. teammates, opponents, ball), to use selective attention (e.g. which player to give the ball to) and to focus attention (e.g. staring at the net to score). To this purpose, many benefits may arise from the highly leveled 3D-MOT technique. A core feature of the 3D-MOT technique relies on distributed attention on a number of separated dynamic elements (Cavanagh & Alvarez, 2005). The ability to track multiple elements has been reported to be superior with the involvement in sport activities in adults and youngsters during laboratory MOT tasks (Barker, Allen, & McGeorge, 2010; Trick, Jaspers-Fayer, & Sethi, 2005; Zhang et al., 2009). This result is not surprising knowing that the ability to maintain attention on multiple stimuli or locations for quite a prolonged period of time is important for sport (Memmert, 2009). Importantly the 3D-MOT technique includes speed thresholds as a dependent variable which is considered as a crucial part of MOT performance by requiring more attentional resources to track at higher speeds (Feria, 2012). Recently, neurological evidence has demonstrated the role of 3D-MOT in improving attention, visual information processing speed and working memory (Parsons et al., 2014). From other imagery studies, the MOT technique has reported activation of higher-level brain areas involved in attentional processes (Culham et al., 1998; Howe, Horowitz, Morocz, Wolfe, & Livingstone, 2009). These areas include parietal and frontal regions of the cortex and are believed to be responsible for attention shifts and eye movement. As well, the middle temporal complex has, not surprisingly, been implicated during MOT processing for motion perception (Culham et al., 1998). These brain pathways could potentially be involved during the action of reading the play in soccer players; a perception-in-action process which is known to activate both dorsal and ventral streams (Goodale & Milner, 1992). Training the brain to simultaneously activate those networks may possibly help to enhance perceptual-cognitive execution in athletes. In this sense, the attentional tracking of multiple elements during 3D-MOT could overlap brain networks required during decision-making. Training on 3D-MOT could serve as a tool to help automatize those networks and could lead to superior decision-makings abilities. Future imagery or electroencephalography study will help us to explain the neural process behind 3D-MOT improvements.

Engagement of visual search strategies in peripheral vision

Beyond the attentional tracking of multiple elements, the 3D-MOT technique engages wide visual field stimulation especially because peripheral vision has been suggested to play an important role in the performance of sports teams (Knudson & Kluka, 1997). With players spread all along a field of about 60 m in width, soccer utilizes a large amount of peripheral vision. Peripheral vision refers to the ability to detect and react to stimuli outside of foveal vision. In soccer referees, peripheral vision has been showed to be useful in decision-making accuracy (De Oliveira, Orbetelli, & De Barros Neto, 2011). To extract meaningful information from the visual scene, including the periphery, expert athletes rely on advanced visual search strategies (Vaeyens et al., 2007; Williams, 2000). There is evidence to support that relative motion information is picked up effectively via peripheral vision (Williams, Davids, & Williams, 1999). A common occurrence during a game is to use foveal and peripheral vision simultaneously. For instance, in 'time-constrained' situations (e.g. 5 vs 5 situation), skilled soccer players fixate the ball in foveal vision while using peripheral vision to monitor the positions of teammates and opponents in the periphery (Williams & Davids, 1997). A study by Vaeyens et al. (2007) showed that successful soccer decision-makers use the player in possession of the ball as the central point on which to fixate gaze to explore and pick up the key information underpinning decision making in offensive situations (Vaeyens et al., 2007). Researchers have reported the use of those 'visual pivots' in other sports (Ripoll et al., 1995; Savelsbergh et al., 2002) and is a reason why 3D-MOT includes such an anchor point. On the other hand, it has been proposed that athletes from visual demanding sports (e.g. netball) can generate more frequent (and shorter) eye movements therefore enabling information to be extracted for the visual field more rapidly (Morgan & Patterson, 2009). Research on eye movement during MOT experiments have identified viewing strategies exercised by observers. When multiple targets (e.g. 3 spheres) were presented, participants usually adopted a 'center-looking' strategy as if they were grouping the targets into a single object (e.g. triangle) and were looking closer to the center of the object formed by the targets (Fehd & Seiffert, 2008). This strategy is in contrast to a 'target-looking' strategy where participants would saccade from target to target. However, another study by Fehd and Seiffert (2010) demonstrated that participants often engaged in both 'target-looking' and 'center-looking' strategies by switching their gaze from the center to the targets and so on (Fehd & Seiffert, 2010). Visual search strategies involved during MOT could be closely linked to those engaged by sport experts during the process of extracting visual information from the action. By training those strategies, which are part of the perceptual component involved in decision-making, could help to improve in game decision-making.

Virtual reality (3D vision)

Another major asset of the 3D-MOT methodology is the involvement of virtual reality, a technology that is recognized as an important tool to potentially improve sport performance (Bideau et al., 2010; Carling, Reilly, & Williams, 2009). Immersive environments, such as those afforded by virtual reality, engender automaticity and therefore implicit learning — which yields decision-making that is robust under pressure (Patterson, Pierce, Bell, Andrews, & Winterbottom, 2009). Moreover, virtual reality involves stereoscopy (binocular disparity) which is required in situations where fast, complex and dynamic elements collide or overlap. For instance, stereoscopy has been shown to help in disambiguating object occlusions when processing dynamic visual scenes (Faubert & Allard, 2013). This is typically the kind of critical situation that can usually be found in soccer when players are close to each other (e.g. an attacker wants to make a deep run from behind the defender but needs to stay close until the last moment to avoid being called offside).

Whether it is fast attentional multiple element tracking, wide visual field stimulation or stereoscopy, all those components are involved during sport actions. Therefore, previous results revealing athletes' extraordinary skills for rapidly learning complex and neutral dynamic visual scenes using the 3D-MOT technique appear logical (Faubert, 2013). This non-contextual perceptual-cognitive training seems to involve higher-level cognitive abilities subserved by the central nervous system. Presumably, 3D-MOT may capture the dynamic components of soccer actions where players have to maintain focus and attention on teammates, opponents or the ball to make the best decisions. In summary, this paradigm, even if void of sports context, is in keeping with the complex and dynamic nature of strategic sport such as soccer. From a sport performance point of view, the result is of particular interest in regards to the implication of decision-making and passing in modern soccer. Today's elite soccer players require faster decision-making than ever mainly because as a competitive sport, the game of soccer is increasing in ball speed (15%) as well as the intensity of play and passing rate (35%) according to an analysis on world cup soccer final games from the last 40 years (Wallace & Norton, 2014). Whereas accurately passing the ball to a teammate is an essential and fundamental ability required by soccer players (Ali, 2011), it also represents the essence of keeping the ball and the source of scoring opportunities (Chassy, 2013). The 3D-MOT technique could play a crucial role in improving passing accuracy in elite soccer players and could be implemented in training centers.

Subjective decision-making assessment

Results of subjective decision-making assessment, collected from the Sport Performance Scale, support the on-field improvement observed in the 3D-MOT training group. One possible explanation is that it confirms that players who received the perceptual-cognitive training were conscious of their on-field improvement in decision-making after the training. Furthermore, confidence level improvement in decision-making accuracy of trained players was quantitatively proportional to the improvement in decision-making accuracy rated during video analysis. These results seem to demonstrate that passing decision-making accuracy improvement in the 3D-MOT group represents a meaningful training effect rather than the result of increased familiarity with the test environment or expectancy set for the training benefits.

Athlete skills for learning complex and neutral dynamic visual scenes

The 3D-MOT speed thresholds of soccer players were qualitatively similar to those previously obtained in professional and elite-amateurs athletes showing superior capacity for processing a complex and dynamic visual scene task (Faubert, 2013; Faubert & Sidebottom, 2012). This ability has been argued to be one of the critical components for elite performance and 3D-MOT performance has been shown to be highly associated with athletes' performance level (Faubert, 2013; Mangine et al., 2014).

Future requirements and limitations

To resolve the issue of whether this training can also transfer to better decision making in regards to dribbles and shooting decisions, we may have to use a different standardized SSG situation. For instance, we could reduce pitch size to favor 'one-on-one' situations (increase dribbling ratio) and direct 'goal-to-goal' actions (increase shooting ratio). To underline the potential of non-contextual 3D-MOT training, it will also be interesting to address the degree of transfer of the technique in other invasion (e.g. hockey) or net (e.g. tennis) games. Another important aspect is to evaluate perceptual-cognitive skills in youngsters with the 3D-MOT technique. Using memory recall and structured pattern of play, Ward and Williams (2003) have previously demonstrated superior perceptual-cognitive skills in elite compared to sub-elites soccer players as early as 9 years old (Ward & Williams, 2003). However, little or no studies have compared perceptual-cognitive skills of elite and novice youngsters using a perceptual-cognitive method void of sports context. One study has revealed better MOT performance in children involved in physical activity compared to more sedentary children (Trick et al., 2005). Knowing that rapid learning in complex and dynamic visual scenes is a critical component for sport performance (Faubert, 2013) and that 3D-MOT performance has been linked to sport specific performance measures (Mangine et al., 2014), 3D-MOT speed thresholds could serve as a tool to determine a player's ability. Non-contextual perceptual-cognitive techniques may also have implications in the screening or detection of new talent.

Conclusion

Expertise in athletes has been well characterized using specific as well as non-contextual perceptual-cognitive paradigms. However, the present study represents the first evidence of an on-field improvement (transfer) following a laboratory perceptual-cognitive training void of sports context. In fact, training to process complex and dynamic visual scenes has not only revealed superior learning ability in soccer players but has led to improvements in passing decision-making accuracy in the field as well. Future laboratory and in-field studies will be needed to evaluate the degree of transferability of such training on other dynamic sports.

Conflict of interest

One of the authors is director of Visual Psychophysics and Perception Laboratory at the University of Montreal and he is the Chief Science Officer of Cognisens Athletics Inc. who produces the commercial version of the NeuroTracker used in this study. In this capacity, he holds shares in the company. This does not alter our adherence to your journal policies on sharing data and materials.

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