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Research article

Computerized Cognitive Training with Minimal Motor Component Improves Lower Limb Choice-Reaction Time

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Abstract

The role of cognitive training in sports has experienced a recent surge in popularity. However, there is a paucity of longitudinal trials examining the effectiveness of related methods. This study aimed to investigate the impact of a cognitive training with minimal motor components on lower limb choice-reaction performance. A total of 44 healthy individuals (26.4 ± 3.7 years, 27 males) were randomly allocated to a cognitive training (CT) or an inactive control group (CON). The CT group participants, three times per week, engaged in a computerized exercise program targeting skills such as attention, reaction time, processing speed or inhibition control. Before and after the 6-week intervention period, lower limb choice-reaction time was assessed using the Quick Feet Board device. An ANCOVA of the post-intervention values, controlling for baseline data, demonstrated superior unilateral choice-reaction performance (stance on dominant leg) in the CT group ($p = 0.04$, $r = 0.31$). Conversely, no difference was found for the bilateral component of the test ($p > .05$). Off-court cognitive training may represent a suitable method to enhance reactive motor skills in athletes.

Key words: Neurocognition, reaction, athletes, computerized, inhibition control.

Introduction

Recent decades have brought dramatic changes to a variety of sports, rendering them more powerful and faster than before. Between 1966 and 2010, the passing rate of soccer increased by 35%, being accompanied by a 15%-raise in game speed and a 85%-surge in the number of sprints per match (Wallace et al., 2014; Barnes et al., 2014). Analyses in Australian football revealed that the ball velocity almost doubled between 1961 and 1997 (Norton et al., 1999) and for Rugby, substantial increases in points (39 vs. 55), passes (204 to 247) and tackles (160 to 270) were observed between 1995 and 2004 (Quarrie and Hopkins, 2007). A similar trend can be observed in racket sports. After analyzing data from the major Tennis Grand Slam tournaments, Cross and Pollard (2009) concluded that serve speeds were up to 25 km/h higher in 2008 when compared to 1999. These data impressively reflect the increased physical and mental affordances for athletes which, in turn, have become taller, stronger and faster (Gale-Watts and Nevill, 2016; Norton and Olds, 2001; Haugen et al., 2012).

Interestingly, for some Olympic disciplines of athletics, it has been suggested that further developments of performance may only be achievable by means of technological innovations (Balmer et al., 2011), which would mean that the physiological limits of the body are reached. However, reviews indicate that success in interactive (team/ball game) sports, besides physique, technique and equipment, is also dependent on cognitive skills (Herman et al., 2015; Zentgraf et al., 2017). For instance, when aiming to shoot, pass or dribble, a soccer player arguably needs exceptional visual perception to register approaching opponents and team mates, quick supraspinal processing of the resulting and other sensory information to choose the right action as well as fast decision-making and inhibition control to switch the motor plan if a defender impedes the execution of the current one. The potential relevance of cognitive function for sports performance is supported by compelling evidence. Voss et al. (2009) concluded based on their meta-analysis of 20 trials that athletes outperform non-athletes in processing speed and attention. A more recent meta-analysis, which pooled the results from 19 studies, confirmed this finding: Scharfen and Memmert (2019) detected a significant correlation ($r = 0.22$) between performance in cognitive tests (e.g. executive function or visual perception) and being an elite-level athlete.

Despite the intriguing cross-sectional data suggesting a possible association between cognition and sports activity, intervention studies examining the dependency of both factors, particularly the impact of cognitive training on motor performance, are scarce so far (Faubert and Sidebottom, 2012; Zentgraf et al., 2017; Harris et al., 2018; Walton et al., 2018). Two paradigms are often distinguished when investigating the relationship between sports and cognition. While the expert performance approach, aiming to achieve ecologically valid conditions, examines the athlete's cognitive skills in realistic game situations, the cognitive component approach, e.g. using pen & paper methods, focusses on sports-unspecific assessments and environments (Furley and Memmert, 2011). While both approaches doubtlessly have merit, the question arises if cognitive training for sports needs to be performed on the pitch or if a brain training intervention not including major or sport-specific movements would already suffice to enhance motor performance under time constraints. In fact, available literature reviews report evidence of a near transfer. Following non-motor cognitive training, improvements can occur in the same or a closely related skill (Harris et al., 2018, Renshaw et al., 2019). In contrast, the possibility of a far transfer from a brain training to a motor performance outcome has been doubted (Renshaw et al., 2019). However, this rather seems to be related to a paucity of experimental trials than to an unambiguous proof of ineffectiveness (Zentgraf et al., 2017; Harris et al., 2018).

The present study was designed to investigate the effect of a computerized cognitive training intervention

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with minimal motor component on lower extremity choice-reaction time. This outcome, defined as the time needed to register and adequately react to an external stimulus, was chosen because it, besides exhibiting a motor component, represents a functional correlate of many above-described cognitive skills, particularly attention, visual perception, processing speed and inhibition control (Burle et al., 2004; Tuch et al., 2005; Voss et al., 2009). It was hypothesized that a general improvement of cognitive function would translate to increased performance and hence, we expected higher gains of the training group when compared to an inactive cohort.

Methods

Ethical standards and study design

The study is part of the COINS (COgnition and INjury in Sports) network project. A randomized, controlled parallel group trial following the CONSORT (Consolidated Standards of Reporting Trials) guidelines was performed (Schulz et al., 2010). It was prospectively registered at the German Register of Clinical Trials (DRKS00017372) and conducted in accordance with the Declaration of Helsinki with its recent modification of Fortaleza (2013). Ethical approval was obtained from the local review board and each volunteer signed informed consent prior to study inclusion. Enrolled participants were randomly allocated to two groups: (1) cognitive training (CT) or (2) no-intervention control (CON). Prior to and after the 6-week intervention, motor performance (lower extremity choice-reaction speed) was assessed.

Participants

A sample of n = 44 healthy sports students (26.4 ± 3.7 years, 27 males) were recruited by means of personal contact and poster advertising. Exclusion criteria encompassed a) severe orthopaedic, cardiovascular, pulmonary, neurological, psychiatric or inflammatory rheumatic diseases, b) pregnancy or nursing period, c) analgesic intake during the trial or in the 48 hours prior to study enrollment, d) impairments in color vision, and e) history of surgery or trauma in the lower extremity.

Intervention

The CT group (n = 22, 15 males) performed a structured cognitive training program with three weekly 30-minute sessions for a period of six weeks. The intervention consisted of ten exercises performed under standardized (room size, temperature, daytime: mid-day) conditions using a personal computer with a 15 inch screen. The order of the tasks, which was performed in the sitting position, was randomized from session to session and between the respective exercises, breaks of 45 seconds were implemented. The intervention protocol detailing the aims and contents of the intervention parts are summarized in Table 1. All exercises required dominantly cognitive effort but minimal (clicking with the mouse or pressing a button) motor actions. They were selected based on their capacity to foster the abilities which may be of relevance for lower extremity choice reaction performance (attention, visual screening, reaction time, processing speed, short-term memory, inhibitory control, cognitive flexibility). Participants allocated to the CON group (n = 22, 12 males) did not receive an

Table 1. Exercises of the computerized cognitive training intervention

Task	Description	Skill
Stroop task	Color words (blue, red, yellow, green) shown in incongruent fonts (e.g. word yellow in red). Press correct pre-specified button for word (yellow) but not the color (red). 40 stimuli are presented.	Inhibitory control
Choice-Reaction task	Right/left arrows displayed for 500 ms. As fast as possible press “B” if left and “N” if right. 50 Stimuli are presented.	Attention, reaction time, processing speed
Fitt’s Law	A small yellow rectangle on the upper left corner of a black screen is shown. After clicking on it, a red rectangle with varying size appears somewhere on the screen and needs to be hit with the cursor as fast as possible. 20 stimuli are presented.	Awareness, hand-eye-coordination, visual search
Erikson Flanker task	Fiver letters (X,C,V,B) are presented on the screen, the first and last two are always identical. If the letter in the middle is an X or C, press A, if it is a V or B, press L. 50 stimuli are presented.	Attention, reaction time, inhibitory control.
Go/No-go task	Oval filled green or red is shown. If green, press “space” (go sign) as fast as possible, if red (shown only rarely), do not press anything (no-go sign). 25 stimuli are presented.	Inhibitory control
Corsi Block task	Nine squares are displayed and some of them light up in a random order. Click squares in correct order. 16 stimuli are presented.	Memory
Mackworth Clock task	A clock with an arrow is shown. The arrow moves at a slow and constant speed. Hit “space” if the arrow moves faster than normal as fast as possible. 50 stimuli are presented.	Attention, reaction time
Visual Search task	In a square, several “T”s are presented. They can have to forms (normal and upside down) and two colors (orange and blue). Hit “space” as fast as possible if a normal orange T appears. Position and number of correct and wrong T’s change constantly. 50 stimuli are presented.	Attention, visual search, reaction time, cognitive flexibility
Simon task	The words left or right are shown either right or left to a central fixation cross. If left, press A, if right, press L. Due to the different positions of the word, congruent (left shown on left side) and incongruent (left shown on right side) conditions occur. 50 stimuli are presented.	Reaction time, inhibitory control, cognitive flexibility
Cueing /Posner task	The screen shows a central fixation cross as well as small square boxes on the left and right side. One of the boxes randomly shows “go”. If signal appears left, press A, if right, press L.	Visual search, attention, choice-reaction, processing speed

intervention and, identically to the CT group, they were instructed to maintain their habitual physical activity routines.

Outcomes

Before and after the intervention, following a standardized warm-up (5 minutes of cycling on an ergometer), lower extremity choice-reaction time was assessed using the Quick Feet Board (The Quick Board, LLC, Memphis, USA). It consists of a flat pad of black color, positioned on the ground. Five yellow circles with implemented pressure sensors are located in the four edges and in the center of the pad. A small control box with five identically arranged diodes, which can light up red, is connected to the board. If the top right diode lights up, the participant has to touch the top right yellow sensor of the board with his foot.

Two tests (Figure 1) were performed. To determine unilateral choice-reaction speed, the participants, with the corresponding foot, stood on the right or left side of the pad, taking care not to be in contact with any of the sensors. With the free leg, they were instructed to as quickly as possible deactivate the sensors indicated on the control box. Both sides were tested. As a second test, capturing bilateral choice reaction speed, the participants, with both legs on the ground, stood between the lower left and right sensor. They were allowed to use both feet to deactivate the sensors indicated on the control box. For all tests, three trials were performed. To reduce the occurrence of learning effects, all participants performed a separate familiarization session prior to randomized group allocation. High reliability (ICC: 0.89) of the Quick Feet Board and the used test drills has been demonstrated (Galpin et al., 2008). All measurements were conducted between morning and midday.

Data processing and statistics

For both unilateral and bilateral lower extremity choice reaction time, the best trial (minimum) was used for analysis. After checking the data for normal distribution of residuals and variance homogeneity, an ANCOVA of the post-intervention values with baseline performance as a covariate was performed (Vickers, 2001). In case of a systematic group difference, the effect size of the corrected comparison was computed as $r = \sqrt{(t^2 / t^2 + df)}$. According to Cohen (1988), it was interpreted as small (r = 0.1), medium (r = 0.3) or large (r > 0.5). For all calculations, p-values <.05 were considered to be significant. Calculations were made with "SPSS Statistics", version 24 (IBM, SPSS Inc., Chicago, IL, USA) and "BiAS for Windows", version 9.05 (Goethe-University Frankfurt, Germany).

Results

Both groups were similar with regard to their basic characteristics (age, sex, BMI, level of physical activity, p > .05). No adverse events or drop-outs occurred and all participants completed the allocated (no-) intervention protocol as planned.

Adjusted for baseline values ($F_{(1,41)} = 63.591$, $\eta_p^2 = 0.61$, $p > 0.01$), the intervention group outperformed the control group in unilateral choice-reaction time when standing on the dominant leg ($F_{(1,41)} = 4.475$, $\eta_p^2 = 0.10$, $p = 0.04$, $r = 0.31$, Figure 2). With regard to bilateral performance and unilateral performance standing on the non-dominant leg, no group differences were detected ($p > 0.05$).

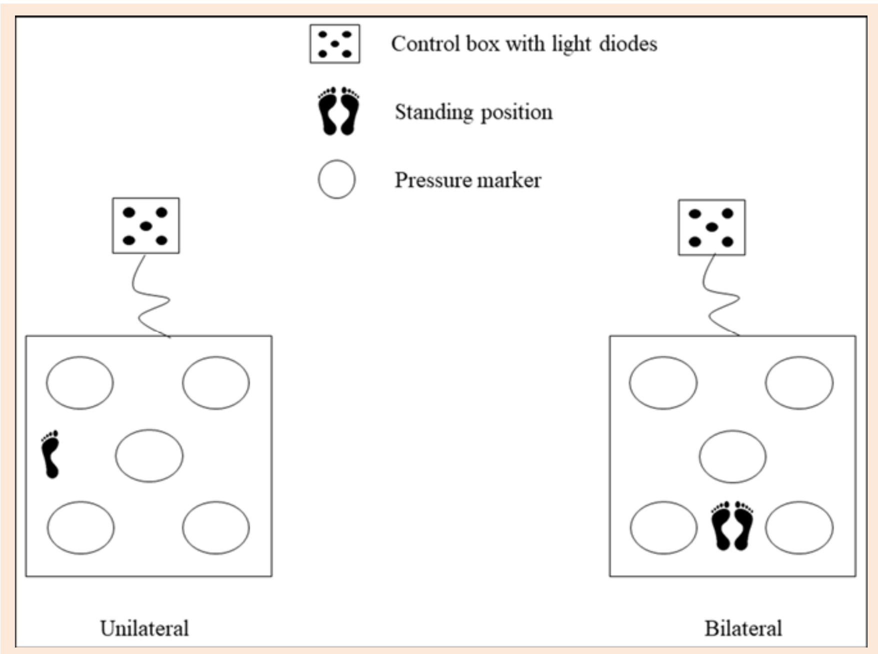

Figure 1. Schematic illustration of the testing interventions for the assessment of lower extremity choice-reaction time. The participants were standing on the testing device either on one (left) or both (right) legs and were required to as quickly as possible tap on the pressure markers indicated by the randomly lighting diodes of the control box.

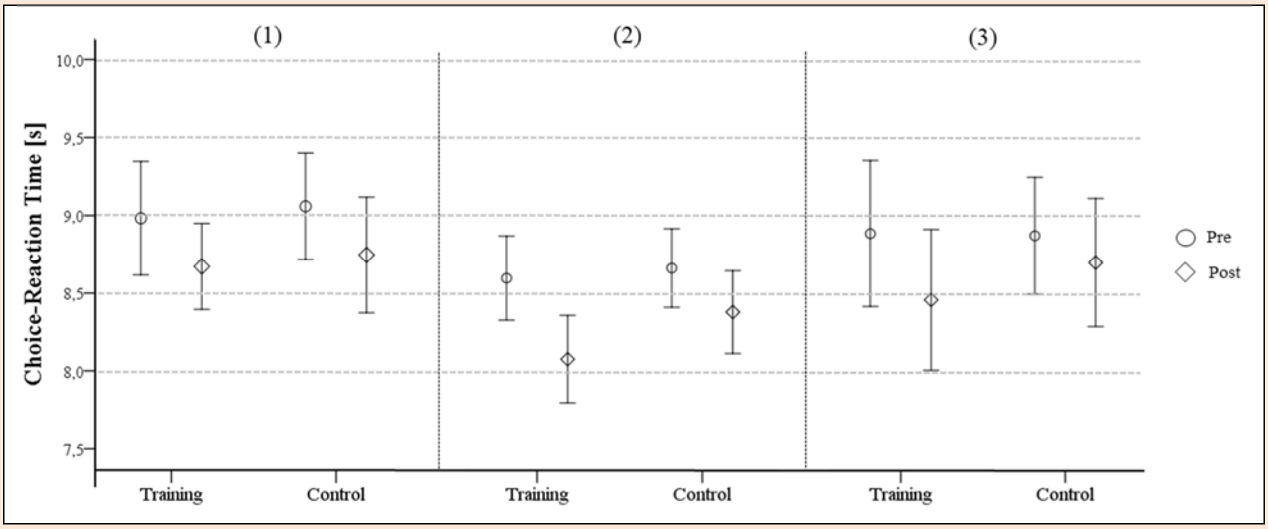

Figure 2. **Baseline and post-intervention values of lower extremity choice reaction time for the stance on the non-dominant (1), dominant (2) or both legs (3). Values are means with 95% confidence intervals.**

Discussion

The assessment and training of cognitive function represents a highly trending topic in sports and exercise (Walton et al., 2018). However, despite the recent surge in popularity, there is still a paucity of longitudinal studies investigating the effectiveness of interventions aiming to improve sport-specific cognitive skills (Faubert and Sidebottom, 2012; Walton et al., 2018). The present trial showed that a computerized cognitive training intervention with only minimal motor components might increase lower-limb choice reaction performance. According to the classification proposed by Cohen (1988), the improvement had a small to moderate effect size. This means that purely computerized cognitive training may help athletes during sports.

In volleyball players, Fleddermann et al. (2019) previously found a computerized perceptual-cognitive training to improve general skills such as sustained attention and processing speed. However, interestingly, besides these near-transfer effects, they did not observe a far-transfer impact on motor function. Also Formenti et al. (2019) performed a non-sport specific cognitive training program in volleyball players. As a result of the 6-week intervention, the accuracy of setting, serving and passing increased. Despite using off-court cognitive training, both studies were different to the present as their interventions included substantial amounts of physical exercise. To the best of our knowledge, only one other trial has examined the effect of purely non-motor cognitive training on aspects athletic performance. Romeas et al. (2016) demonstrated a generic multiple-object tracking intervention to increase passing accuracy in soccer players. Our results, indicating motor improvements following an off-court intervention, are in line with their findings.

While it has to be underlined that the outcome assessed by Romeas et al. (2016) showed a higher transfer level (sport-specific passing accuracy vs. general lower limb choice-reaction performance), we believe that the improvements found in our study may also have meaningful implications for athletes. One central hallmark ball game sports is the need to effectively couple perceptual-cognitive and motor skills when reacting to the actions of teammates and opponents. The tests performed in our study required effective visual scanning (identifying the hitting target), quick reaction and signal processing (initiating the limb movement) and inhibition control (limiting the amount of false hits). The here detected improvement in lower-extremity choice-reaction time could thus, for instance, be of value for the correct selection of the running path or the initiation of a sidestepping maneuver on the pitch. Interestingly, we found training-induced increases when the preferred/dominant leg was used for standing but none when it was used as the free leg. Rouissi et al. (2016) showed that the dominant leg allows better change of direction performance in young elite athletes. Arguably, athletes will try to use the dominant as often as possible when being force to alter the movement direction. Against this background, the detected training effect would be helpful during sports.

Some potential methodological aspects and shortcomings warrant careful consideration. We compared the effects of computerized cognitive training on motor function against an inactive control group. Although this is a generally viable approach, it would have been interesting to include a traditional exercise program. Strength training, for instance, leads to small improvements in choice-reaction time (Kauranen et al., 1998), which is possibly due to improved muscle activation. Similarly, future studies may want to include an intervention combining both cognitive affordances and sports-related movement in order to increase ecological validity. Both intervention and testing targeted lower limb choice reaction time. This is well grounded because in many sports, reactive explosive movements (e.g. when sidestepping defenders) are performed with the legs. However, for some athletes, related skills are also relevant in the upper extremity. It would hence be interesting to investigate the effectiveness of cognitive training in this regard as well. A second issue relates to potential effect modifiers. As this is one of the first studies examining the impact of purely cognitive training on motor function, we decided to focus on its general effects.

However, initial findings suggest men and women may react differently to cognitive exercise programs (Ingalhalikar et al., 2014; Jain et al., 2015). Also, as indicated, we observed an effect when standing on the dominant limb only. This finding points towards potential the existence of side differences and should be further explored in upcoming trials.

Conclusion

A computerized cognitive training intervention with minimal motor components can effectively enhance lower limb-choice reaction performance. Coaches and exercise professionals may thus consider adding similar off-court interventions in order to supplement their regular training programs.

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Key points

- There is a lack of evidence regarding the question as to whether cognitive training with minimal motor component has transfer effects for motor performance
- A six-week computerized cognitive training intervention enhances lower limb choice-reaction performance in healthy active adults
- The observed effects may help to increase sport-specific performance.

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