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Research article

Effects of 6-Week Motor-Cognitive Agility Training on Football Test Performance in Adult Amateur Players – A Three-Armed Randomized Controlled Trial

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Abstract

Agility, defined as the ability to rapidly respond to unforeseen events, constitutes a central performance component in football. Existing agility training approaches often focus on change of direction that does not reflect the complex motor-cognitive demands on the pitch. The objective of this study is to examine the effects of a novel motor-cognitive dual-task agility training (Multiple-object tracking integrated into agility training) on agility and football-specific test performance parameters, compared to agility and a change of direction (COD) training. Adult male amateur football players (n = 42; age: 27±6; height: 181±7cm; weight: 80±12kg) were randomly allocated to one of the three intervention groups (COD, agility, agility + multiple object tracking). The Loughborough Soccer Passing Test (LSPT), a dribbling test with/without cognitive task as well as the Random Star Run (with/without ball) and the modified T-Test were assessed before and after a 6-week training period. Time effects within the T-Test ($F = 83.9$; $p < 0.001$; $\eta^2 = 0.68$) and dribbling test without cognitive task ($F = 23.9$; $p < 0.001$; $\eta^2 = 0.38$) with improvements of all intervention groups ($p < 0.05$) were found. Dribbling with cognitive task revealed a time effect ($F = 7.8$; $p = 0.008$; $\eta^2 = 0.17$), with improvements exclusively in the agility and dual-task agility groups ($p < 0.05$). Random Star Run with and without ball exhibited a time ($F = 38.8$; $p < 0.001$; $\eta^2 = 0.5$; $F = 82.7$; $p < 0.001$; $\eta^2 = 0.68$) and interaction effect ($F = 14.14$; $p < 0.001$; $\eta^2 = 0.42$; $F = 27.8$; $p < 0.001$; $\eta^2 = 0.59$), with improvements for the agility and dual-task agility groups. LSPT showed no time, group or interaction effect. The effects of change of direction training are limited to change of direction and dribbling test performance within preplanned scenarios. In contrast, motor-cognitive agility interventions result in notable enhancements in football-specific and agility tests, incorporating decision-making and multitasking components. No differences were observed between agility and agility + multiple object tracking. To achieve a transfer to game-relevant performance, coaches should focus on integrating cognitive challenges into motor training.

Key words: Cognition, dual task, multiple object tracking, soccer, athlete.

Introduction

Agility, defined as the ability to quickly respond to unpredictable stimuli and changing game situations through whole body movements (e.g. accelerations, cuttings; (Sheppard and Young, 2006)), is an important factor for performance and injury prevention in modern football (Mijatovic et al., 2022; Trajković et al., 2020; Kolodziej et al., 2022; Sheppard and Young, 2006). In addition to performing motor actions (e.g. dribbling or moving into free room), players must simultaneously track and process relevant information in their environment (opponents, teammates, ball) to monitor game situations and make appropriate decisions (Jordet et al., 2020). This puts players in constant dual/multi-task situations requiring efficient interaction of cognitive and motor functions (Büchel et al., 2022).

Nonetheless, the training of motor and cognitive components of agility and football performance is mostly performed and studied separately under single-task conditions (Padrón-Cabo et al., 2021; Scharfen and Memmert, 2021; Stankovic et al., 2023). To enhance sport-relevant motor abilities, training methods such as sprinting, cutting, or tempo dribbling are applied. Within these exercises, movements can be preplanned and players can concentrate on movement execution (Carvajal-Espinoza et al., 2023; Haugen et al., 2014). Computerized cognitive training methods such as choice reaction drills or multiple object tracking are employed to enhance cognitive abilities by addressing cognitive skills of decision making, working memory, attention and peripheral vision that are considered essential in football (Scharfen and Memmert, 2021; Schwab and Memmert, 2012). However, although these trainings set high demands on cognitive functions, there is only little to no integration of motor components which is often limited to a button press. (Ong, 2020; Scharfen and Memmert, 2021). Both isolated motor and cognitive approaches typically demonstrate task-specific training effects (i.e. athletes improve performance in the trained task), with very limited evidence of transfer to sports-related performance measures (Chaalali et al., 2016; Vater et al., 2021; Scharfen and Memmert, 2021). Researchers attribute this to low ecological validity (Young et al., 2015; Vater et al., 2021; Scharfen and Memmert, 2021; McNeil et al., 2021), i.e., the correspondence in stimulus and motor task between the conducted training and the actual sports-specific requirements (Schmuckler, 2001). Due to missing stimulus integration and cognitive processing, preplanned motor exercises exhibit low stimulus correspondence,

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while cognitive training with movements limited to upper extremity button presses lacks task correspondence (Vater et al., 2021; Hadlow et al., 2018). Based on these limitations recent research suggested combining sport-relevant motor and cognitive functions in dual-task approaches to enhance ecological validity and increase transfer effects (Scharfen and Memmert, 2021).

Initial evidence suggests that agility training, where players react to unpredictable stimuli, exhibits better transfer to a football-specific dribbling task with a decision-making component, compared to purely motor-based change of direction training (Chaalali et al., 2016). However, the exercises and testing methods used in this study required only a single cutting movement in response to a generic visual cue (Chaalali et al., 2016). This may not adequately represent game-related situations, in which agility on the court requires simultaneous tracking of multiple objects such as teammates, opponents, or the ball. Hence, integrating more complex cognitive tasks and moving visual cues (e.g., multiple object tracking) into agility training may bridge this gap and provide a better transfer to game situations (Romeas et al., 2019; Scharfen and Memmert, 2021).

The aim of this study was to assess the effects of a novel Dual-Task agility training (agility with integrated multiple object tracking, [DT-Agility]), compared to an agility training (multidirectional cuttings/runs with decision-making component) and a change of direction training [COD] on COD; agility and football-specific test performance in amateur players. The modified T-Test (Sassi et al., 2009) and Random Star Run (Friebe et al., 2023) were conducted to operationalize COD and agility performance. Tempo dribbling (dribbling test with and without cognitive task; (Höner et al., 2015) and multidirectional ball handling (assessed through Random Star Run with a ball and Loughborough Soccer Passing Test (Le Moal et al., 2014) were employed to evaluate football-specific performance.

It was hypothesized that (1) all training interventions would lead to enhanced COD and dribbling performance without cognitive task, whereas (2) the motor-cognitive interventions (agility and DT-Agility) would exhibit better transfer to agility and football-specific assessments. Furthermore, it was hypothesized (3) that the agility training with integrated multiple object tracking (DT-Agility) would excel in improving performance within football-specific tests that involve additional cognitive demands.

Methods

Trial design

We conducted a randomized-controlled parallel-group intervention study. The study was approved by the local Ethics Committee of the Faculty of the Faculty of Psychology and Sport Science, Goethe-University Frankfurt/Main, Germany (reference number: 2021 – 60). The study is registered at the Clinical Trial Register *(*ID: DRKS00027157*)*. The investigation was conducted according to the ethical standards set by the Declaration of Helsinki (*World Medical Association Declaration of Helsinki: ethical principles for medical research involving human subjects*, 2013). Before participation in the study, players were informed about the experimental protocol and signed a written consent.

Participants

We recruited healthy male amateur football players aged between 18 and 40 through football-related social media channels and information websites, bulletins as well as local football clubs. Participants were included in the study when actively playing football on amateur level with a minimum of ten years of experience and a frequency of at least two training sessions per week. Participants were excluded when they reported suffering from any performance-impairing acute or chronic disease or had surgeries of the lower extremities in the last three years as well as head injuries (e.g. concussion) in the last six months. Additional exclusion criteria were musculoskeletal injuries before pre- and post-measurements or within the intervention period that prohibited participation in the training sessions. Players who missed 3 (25%) or more training sessions were excluded from statistical analysis. All participants were refrained from intensive physical activities within 24 hours before the pre- and post-measurements. Participants were instructed to maintain their regular training and diet habits during the intervention period.

Randomization and sample size calculation

Required participant sample size was calculated with G*Power (Version 3.1.9.2; Germany). Based on the effect size of f = 0.51 reported by Romeas et al. (2019) for effects of reactive dual task training on sport-specific outcomes, an alpha error probability of 0.05 and a power of 0.9, a required sample size of 14 participants for each of the three groups was determined. Based on an estimated drop-out rate of up to 30% due to high chances of injuries within the football season, we aimed for a group sizes of 20 participants. Randomization sequence list was generated via block- randomization (non-stratified randomization; three blocks, each with a size of 20), using BiAS 10.0 (BiAS for Windows). The players were randomly assigned to the three groups based on a sequentially numbered list. Allocation was not blinded to participants or assessors, since the assessors simultaneously supervised the training interventions.

Experimental setup

Participants underwent a 6-week intervention performing either agility exercises with different cognitive components (Agility; DT-Agility (agility with integrated multiple-object tracking)) or change of direction training (COD). Two intervention sessions per week (at least 24h in-between; in total 12 sessions) with a duration of 30 to 40 minutes were performed in addition to the regular team football training. Since the players participated from various amateur clubs, the training load of regular football training could not be controlled but was assessed within the participant characteristics questionnaire in order to test for potential baseline differences. The study-related training was conducted independently of the club training. All training sessions were instructed and supervised by at least one sport scientist. The Agility and DT-Agility training sessions were conducted using the SKILLCOURT-system (5x5m; SKILLCOURT GmbH, Schweinfurt, Germany), which provides a variety of motor-cognitive agility assessments and trainings (Friebe et al., 2023). The agility and DT-agility training tasks are illustrated in Figure 1.

The SKILLCOURT presents the training task on a 65-inch screen and tracks the player's position on the 5x5m rubber mat court by a LiDAR system (see Friebe et al., 2023) for technical details). The COD training consisted of five different established COD protocols and was performed outside on hard ground to resemble the conditions of the SKILLCOURT training. The intervention-training volume of the three groups was matched based on the total distance covered per session (375 meters). Before each training session a standardized 5-minuite warm-up with runs and change of direction movements was performed to reduce risk of injury. Participants' subjective enjoyment as well as physical exertion were recorded after every training session.

Football-specific as well as agility and COD test performance was assessed before and after the intervention period. Prior to the pre-measurements, anthropometric data (age, height, weight), as well as weekly football training load (hours), and football-specific experience (years) were recorded.

Training Intervention

Change of Direction training (COD)

Within each COD training session, participants performed three trials each of the modified 505 (Taylor et al., 2019), the 3-cone test (Langley and Chetlin, 2017), the T-test (PAUOLE et al., 2000), the modified Illinois test (Hachana et al., 2014), and the ZigZag test (Rubajczyk and Rokita, 2020). Players were instructed to perform every run at maximal effort to ensure neuromuscular adaptation through a progressive increase in running and cutting speed (McBurnie et al., 2022). A 90-second rest was given between runs. Since the running paths were fixed, all runs and cuttings were preplanned. Accordingly, COD training addressed motor abilities without cognitive load.

Agility training

The agility sessions consisted of three exercises (Random Star Run, Random Run 25m, Random Run Plus 25m) with five runs each. All exercises were performed on the SKILLCOURT and required accelerations and changes of direction in response to visual stimuli (see Figure 1A). Within the first exercise (Random Star Run), the participant had to run to the highlighted outer field and return to the center before the next target field was indicated. Each trial consisted of eight unplanned runs/cuttings (each target field once), in a randomized sequence. In the second drill (Random Run), the players did not have to return to the center field after reaching the target fields. After stepping into the target field, the next field lit up in randomized order. Thus, every cutting/run could not be preplanned. The run ended when a distance of 25m was covered. Within the last agility exercise (Random Run plus), two fields were highlighted after the countdown expired. A yellow-colored field indicated the target field, whereas a blue highlighted field represented the target for the subsequent run. After the yellow field was reached, the previously blue field turned yellow and a new field was highlighted in blue. The trial ended with a distance of 25m covered. Participants rested for 90 seconds between each run. Participants were instructed to perform every run at maximal effort to ensure neuromuscular adaptation through a progressive increase in running and cutting speed (McBurnie et al., 2022).

Dual Task Agility training (DT-Agility)

To train agility in a dual task setting, a multiple object tracking task was integrated into an agility drill (see Figure 1B). This follows Scharfen and Memmert (2021) who suggested embedding multiple object tracking into a sport-specific tasks to increase ecological validity and transferability.

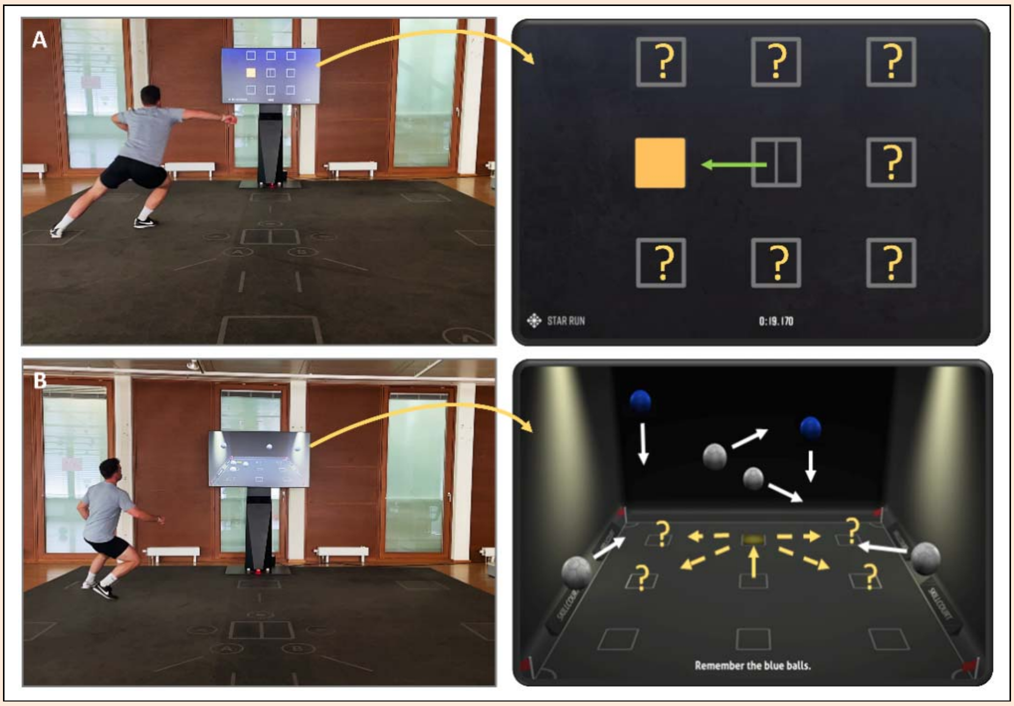

Figure 1. Exemplary illustration of the motor-cognitive agility interventions on the SKILLCOURT system (A: Agility; B: Dual Task Agility).

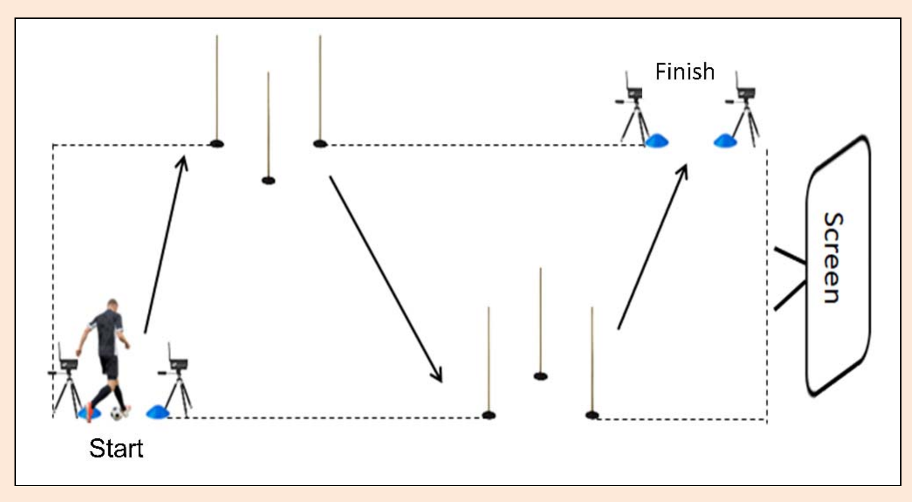

Figure 2. Exemplary Illustration of the modified dribbling test according to Hoener et al. (2015).

Participants started each trial from the center field. An illustration of six white balls in front of an of the 8 SKILLCOURT target fields was displayed on the screen (see Figure 1B). At the onset of each round, two balls to track during the trial were highlighted in blue for a duration of 3 seconds. Following this period, the two balls turned white, and all balls started moving within a three-dimensional space, in accordance with the principles of the 3D-multiple object tracking test proposed by Faubert and Sidebottom (2012). Concurrently, one out of five target fields (3 front fields and 2 middle fields) lit up in yellow color, indicating the field to run to. Once the player reached the target field, the next field was highlighted (in a randomized sequence). Balls stopped moving after 10 seconds, and each ball was assigned a number that was represented by one target field on the SKILLCOURT. To identify the balls that were initially shown in blue, the player needed to activate the corresponding field. Participants were instructed to run as fast as possible without losing the balls.

To assess daily performance level and ensure adequate progressive training load, each training session started with an adaptive testing version of the DT-Agility task. In 10 consecutive trials, ball speed was increased if both balls were correctly identified. If there was at least one ball missed the velocity was reduced. The highest motion speed at which both balls were correctly identified served as an indicator for daily performance level and threshold for the training settings. Three rounds with three trials each (total 9 trials) at 50% (agility focus), 75% (dual task focus), 100% (cognitive task focus) of the maximum velocity were performed. A rest period of 90 seconds was held between each round.

Testing procedure

Within 7 days prior to and after the intervention period the participant's performance was assessed in football-specific as well as agility and COD performance. To determine football-specific transfer effects, tempo dribbling with and without cognitive task (Höner et al., 2015), the LSPT (Ali et al., 2007) as well as Random Star Run with ball serve as primary outcome measures while agility (Random Star Run; Friebe et al., 2023) and COD (modified T-Test; Sassi et al., 2009) performance are considered as secondary outcomes. The sequence of the conducted assessments was randomized and maintained for pre- and post-assessments. Participants were asked to wear the same pair of indoor football shoes for both test days. All football-specific tests were performed using the "Bundesliga Brillant APS" ball (0,7 bar; Derbystar Sportartikelfabrik GmbH, Goch, Germany). Both pre- and post-measurements were conducted on the same weekday and time of the day in order to minimize the effects of circadian rhythm and daily routines (Facer-Childs et al., 2018). For all tests, a test run was performed to familiarize with the procedure, followed by three rated trials. The best out of the three trials was used for further analysis.

Tempo dribbling

The assessment of players' tempo dribbling speed and ball control was conducted through the dribbling test developed by Höner et al. (2015). To better replicate the motor-cognitive dual-task demands of football, a visual distractor stimulus was added using a 1.5x1.5m screen positioned in front of the dribbling course (Figure 2). This visual stimulus contained two football players with different jersey colors (white or red) who sequentially moved (timing randomized) from one side of a virtual playing field to the other, or vice versa, within a one-second timeframe each. While executing the dribbling task, participants were required to accurately recall both the running direction of the players and the color of their jerseys. Instances where participants failed to perceive the player or made incorrect recalls resulted in a penalty of one second. These forced participants to split their attention and constantly switch focus between the dribbling and the perception task, which might correspond better to on-field demands. Since prior research has demonstrated that adding a cognitive task can impair motor performance (Büchel et al., 2022), it is crucial to assess the applicability of training effects to the specific sport by investigating their transferability to a dual-task scenario. After the familiarization trials, players performed three trials each with and without visual distraction. Evaluation of performance was based on the total time taken to complete the dribbling course (including dribbling time and penalties).

A photoelectric timing gait system (Brower Timing Systems, Salt Lake City, Utah, USA) was used to assess test time. The dribbling task was performed on indoor floor.

Multidirectional ball handling

Multidirectional ball handling performance was assessed using the Random Star Run with Ball and the LSPT.

The basic procedure of the Random Star Run with ball is similar to the test version without ball (Friebe et al., 2023), with the difference that the players had to dribble the ball into the randomly displayed target field, change direction and return to the center field with the ball. As a result, this test demanded multidirectional ball control in reaction to a visual stimulus under time pressure. Performance was operationalized by the total time to complete the test (seconds).

The LSPT serves as a valid assessment tool for evaluating various football-related skills, such as passing, agility, ball control, and decision making while facing time constraints (Ali et al., 2007). In this test, participants respond to an unexpected auditory cue (color of the target) by passing the ball towards one of four rebound boards of corresponding colors. Following each bounce-back, the next color is announced, requiring rapid reorientation to accurately pass the ball to the designated target. Each trial comprises 16 consecutive passes. The main outcomes are the time taken to complete the test as well as the penalty time incurred due to errors (e.g. inaccurate passes, contact with cones). For a more comprehensive description of the test protocol and set up, please refer to. Ali et al. (2007). The LSPT trials were performed on indoor floor. Total test time as well as the error score of the best trial were used for further analysis.

Agility and COD

Agility and COD performance was evaluated using the the Random Star Run (Friebe et al., 2023) and the modified T-Test (Sassi et al., 2009), respectively.

The execution as well as distances of the modified T-test corresponded to the procedure according to Sassi et al. (2009). Instead of touching a cone players stepped into the corresponding fields on the SKILLCOURT. Players started in a split stance within the back central field of the court. The path to be covered was known to the players, so that the performance was only motor-determined. Performance was operationalized by the total time to complete the test.

The Random Star Run is a reliable agility test (ICC = 0.89) which incorporates relevant motor (sprint, COD; r = 0.73- 0.74; Hülsdünker et al., 2023) as well as a decision making component. Players began in an active stance positioned in the center field of the court. An illustration of the SKILLCOURT court, featuring eight outer target fields, was presented on the screen. Following a 3-second countdown, one of the eight target fields was presented in yellow. The participant's task was to run to the corresponding field and return to the center before the next target field was highlighted. Each trial consisted of eight runs, with each target field being indicated once (randomized order). Test Performance was operationalized by the total test time.

Training evaluation

Since the subjective perception of the training in terms of enjoyment and exertion are central elements of long-term adherence (Vella et al., 2017) and training load (Askow et al., 2021), these were surveyed after each training session. Enjoyment was assessed via the short form of the Physical Activity Enjoyment Scale (PACES–S; (Chen et al., 2021)). On a scale from 1 to 5 (full agreement to no agreement) participants had to rate the training session according to the items: “I enjoy it”, “I find it pleasurable”, “It is very pleasant”, and “It feels good”. Mean value of the four items was used for further analysis.

Subjective exertion was recorded using the Borg-Scale (Heath, 1998). The participants were asked to rate their average exertion level on a scale from 6 (very light) to 20 (maximum effort).

Statistical analysis

Following an initial plausibility check descriptive analysis was performed. Mean values as well as 95%-confidence intervals (95%-CI) were calculated. To ensure preconditions for parametric testing, Shapiro-Wilk test for normal distribution, Levene test for variance homogeneity and Mauchly test for sphericity were conducted. Group baseline characteristics (anthropometrics, training load, football-specific experience) were compared using analysis of variance (ANOVA). To analyze the data for potential training-induced differences in football, agility and COD test performance a two-factorial repeated measures ANOVA (two repeated measures: pre- / post assessments; 3 groups: COD, Agility, DT-Agility) was performed. Post-hoc tests with adaptations for multiple comparisons according to Bonferonni were used to identify the differences between measurements or groups. As several of the conducted tests were modified to better replicate the actual motor-cognitive requirements of football, the reliability of the three test trials from pre- and post-measurement was additionally calculated. The ICC was computed based on a 2-way mixed-effects model with absolute agreement and reported as single measures (ICC 3,1). According to (Koo and Li, 2016) values below 0.5 suggest poor reliability, those between 0.5 and 0.75 indicate moderate reliability, values falling between 0.75 and 0.9 suggest good reliability, and values exceeding 0.90 indicate excellent reliability.

Significance level was set at $p < 0.05$. Effect sizes were defined as small ($\eta^2 \leq 0.01$), medium ($0.01 < \eta^2 > 0.06$) and large ($\eta^2 \geq 0.14$) (Cohen, 1988). SPSS 28 (SPSS Inc., IBM, Chicago, IL, USA) was used to carry out the statistical analysis.

Results

In total, sixty adult male amateur football players were included into the study. Eighteen players dropped out of the study. Therefore, 42 participants were included in the statistical analysis. Study and participants flow including time and reason of drop outs can be seen in Figure 3. Participants baseline characteristics are shown in Table 1. Groups significantly differ in age ($F = 3.9$; $p = 0.03$). No further differences in anthropometrics or practice time as well as football-specific experience could be found ($p > 0.05$).

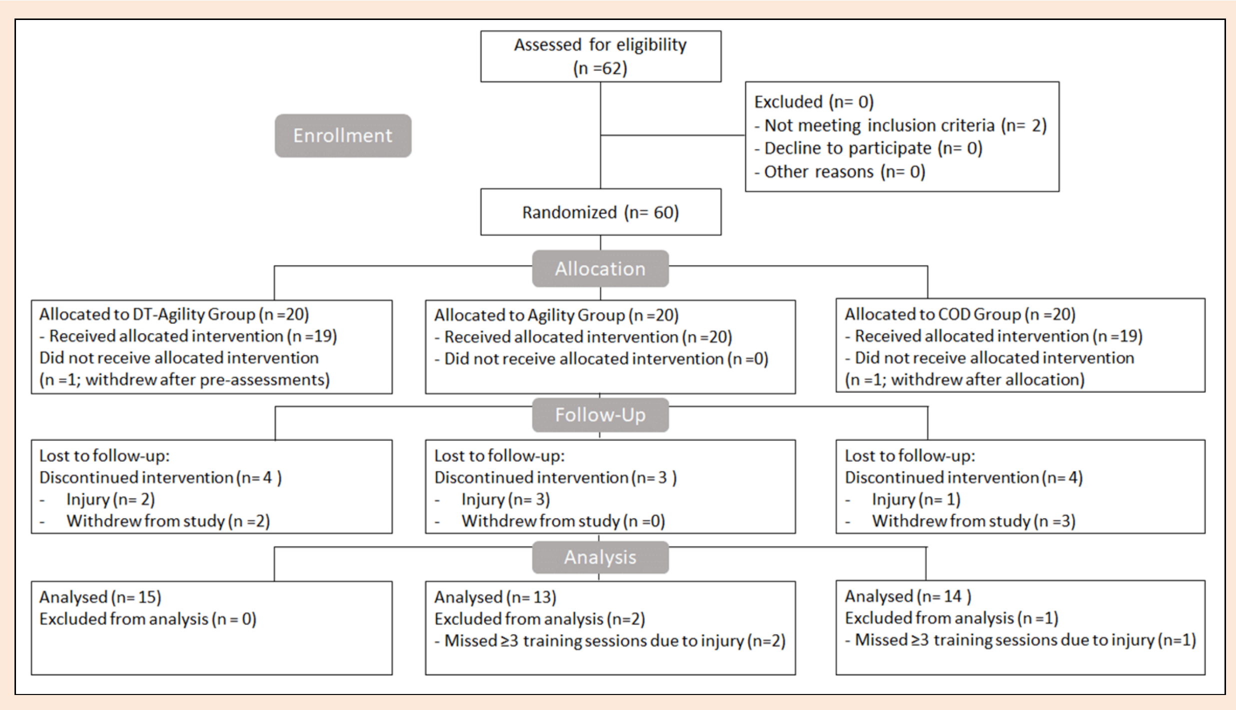

Figure 3. Study and participant flow according to the CONSORT guidelines (Schulz et al., 2010). n = absolute number.

Table 1. Anthropometrics and training volume/experience of the intervention groups. Data are means ± SD.

Outcomes	COD (n= 14)	Agility (n= 13)	DT-Agility (n= 15)	Between group Comparison (F-, p-value)
Age (Years)	24 ± 3*	28 ± 8*	26 ± 5	3.9; .03
Body height (cm)	181 ± 7	182 ± 6	181 ± 9	.1; .9
Body weigth (kg)	78 ± 9	82 ± 12	79 ± 13	.6; .57
BMI (kg/m²)	24 ± 2	25 ± 4	24 ± 3	.7; .51
Training volume (h/week)	3.8 ± .8	3.3 ± .6	3.4 ± .6	3.1; .07
Experience (years)	18 ± 6	20 ± 8	21 ± 6	1.4; .25

BMI = Body-Mass-Index; cm = centimeter, kg = kilogram; m² = square meters; h = hours; * marks significant differences ($p < 0.05$).

Table 2 presents the mean and 95% CI of the test results of the pre- and post-test measurements as well as the results of the repeated measures ANOVA.

Tempo dribbling

Mean values and 95%-CI of the pre- to post-differences in performance for the tempo dribbling tests are displayed in Figure 4A-B. Tempo dribbling performance without cognitive task showed a significant time but no group or interaction effect. Post-hoc analysis revealed significant improvements for all training groups ($p < 0.05$). Agility and DT-Agility groups differed in baseline performance ($p < 0.05$). Tempo dribbling with cognitive task displayed significant time but no group or interaction effects. Post-hoc tests revealed significant improvements for the agility and DT-Agility but not for the COD group. Tempo dribbling with visual distraction (ICC Pre: 0.74; Post: 0.65) and without (ICC Pre: 0.73; Post: 0.57) revealed moderate reliability values.

Multidirectional ball control

Mean values and 95%-CI of the test times within the LSPT and Random Star Run with Ball for pre- and post-measurements are shown in Figure 4C-D.

The LSPT showed no time, group or interaction effects for both test time and error score. LSPT test time revealed moderate to good reliability (ICC: Pre: 0.75; Post: 0.65) while reliability of the penalty score was poor (ICC: Pre: 0.43; Post: 0.38).

Performance within the Random Star Run with Ball displayed a and interaction but no group effect. Post-hoc, significant pre- to post differences could be found for the agility, DT-Agility but not for the COD group. Pre- to post-differences following the Agility ($p < 0.001$) and DT-Agility ($p = 0.003$) differed significantly from the COD group, but not from each other ($p > 0.05$). Baseline performance of the COD group differed significantly from Agility and DT-Agility ($p < 0.05$). The Random Star Run with Ball showed moderate reliability values (ICC: Pre: 0.73; Post: 0.55).

Agility and COD

Mean values as well as 95%-CI of the pre- to post-differences of the two agility tests can be seen in Figure 4E-F.

Performance within the T-test showed a significant time, but no group or interaction effect. Post-hoc tests showed significant pre- to post-differences for all three intervention groups ($p < 0.001$). Agility performance within

Table 2. Descriptive data and repeated measures ANOVA results of the of the pre- and post-measurements

Tests (measure)	Groups	Pre-Tests Mean, (95%-CI)	Post-Tests Mean (95 % CI)	Repeated Measures ANOVA Time effect	Group effect	Interaction effect
Tempo Dribbling (seconds)	COD	10.7 (10.2-11.2)	10.5 (10.0-10.9)	**p < 0.001**	p = 0.18	p = 0.55
	Agility	11.1 (10.7-11.5)	10.7 (10.4-11.0)	(F = 23.9;	(F = 1.8;	(F = .61;
	DT-Agility	10.6 (10.3-10.9)	10.3 (10.1-10.5)	η^2 = 0.38)	η^2 = 0.09)	η^2 = 0.03)
Tempo Dribbling with cognitive task (seconds)	COD	11.4 (10.8-11.9)	11.2 (10.9-11.6)	**p = 0.008**	p = 0.49	p = 0.48
	Agility	11.6 (11.2-12.0)	11.3 (10.9-11.6)	(F = 7.8;	(F = 0.73;	(F = .76;
	DT-Agility	11.4 (10.9-11.8)	10.9 (10.6-11.3)	η^2= 0.17)	η^2 = 0.04)	η^2 = 0.04)
LSPT Test Time (seconds)	COD	40.7 (39.1-42.7)	40.9 (39.1-42.7)	p = 0.11	p = 0.81	p = 0.26
	Agility	42.2 (41.0-43.4)	40.6 (39.4 – 41.7)	(F = 2.7;	(F = 0.22;	(F = 1.4;
	DT-Agility	41.7 (40.3-43.1)	40.7 (39.3-42.1)	η^2 = 0.07)	η^2 = 0.01)	η^2 = 0.07)
LSPT penalties (Error Score)	COD	0.1 (-2.9 – 3.2)	-1.9 (-4.1 - 0.2)	p = 0.19	p = 0.57	p = 0.47
	Agility	1.7 (-1.5-4.9)	-0.2 (-2.5-2.1)	(F = 1.8;	(F = 0.57;	F = 0.78;
	DT-Agility	- 0.4 (-3.5-2.6)	-0.1 (-2.2-2.1)	η^2 = 0.05)	η^2 = 0.03)	η^2 = 0.04
Random Star Run with ball (seconds)	COD	23.7 (22.9-24.5)	23.9 (23.2-24.5)	**p < 0.001**	p = 0.08	**p < .001**
	Agility	25.8 (25.2-26.5)	23.8 (23.2-24.4)	(F = 38.8;	(F = 2.7;	(F = 14.14;
	DT-Agility	25.1 (24.3-25.9)	23.7 (23.1-24.4)	η^2 = 0.5)	η^2 = 0.12)	η^2 = 0.42)
Modified T-Test (seconds)	COD	5.2 (4.9-5.5)	4.8 (4.6-5.1)	**p < 0.001**	p = 0.72	p = 0.11
	Agility	5.2 (5.0-5.4)	4.7 (4.5-4.8)	(F = 83.9;	(F = 0.33;	(F = 2.4;
	DT-Agility	5.1 (4.9-5.3)	4.8 (4.6-4.9)	η^2 = 0.68)	η^2 = 0.02)	η^2 = 0.11)
Random Star Run (seconds)	COD	16.7 (16.1-17.2)	16.5 (16.2-16.8)	**p < 0.001**	p = 0.26	**p < 0.001**
	Agility	17.2 (16.7-17.8)	14.8 (14.3-15.3)	(F= 82.7;	(F = 1.4;	(F = 27.8;
	DT-Agility	16.8 (16.4-17.2)	15.9 (15.5-16.4)	η^2 = 0.68)	η^2 = 0.07)	η^2 = 0.59)

CI: Confidence interval; s: seconds; η^2: eta squared.

the Random Star Run displayed a time, no group but an interaction. Post-hoc analysis revealed significant improvements in performance between pre- and post-measurements for the Agility ($p < 0.001$) and DT-Agility ($p < 0.001$) but not for the COD ($p = 0.48$), with highest improvements following the Agility training ($p < 0.001$). T-test (ICC: Pre: 0.83; Post: 0.8) as well as the Random Star Run (Pre: 0.75; Post: 0.87) showed good reliability values.

Intervention evaluation

Mean values and 95%-CI of the subjective enjoyment scale (PACES-S) and exertion (Borg Scale) over the course of the 12 intervention sessions can be seen in Figure 5A-B. The PACES-S showed a significant time ($F = 7.5$; $p = 0.01$; $\eta^2 = 0.17$) and group ($F = 11.8$; $p < 0.001$; $\eta^2 = 0.38$) but no interaction ($F = 1.8$; $p > 0.05$; $\eta^2 = 0.09$) effect between week 1 and week 6. Post-hoc tests indicated a significant reduction in subjective enjoyment within the COD ($p = 0.005$). In addition, in average enjoyment was rated significantly higher in the Agility-group compared to COD ($p < 0.001$) and DT-Agility ($p = 0.008$).

The repeated measures ANOVA revealed no time ($p = 0.39$; $F = 0.73$; $n^2 = 0.019$) but an interaction ($F = 18.1$; $p < 0.001$; $\eta^2 = 0.49$) and group ($F = 25.9$; $p < 0.001$; $\eta^2 = 0.58$) effect for the Borg-Scale. Post-hoc tests identified a significant increase in exertion within the Agility ($p < 0.001$) and DT-Agility ($p = 0.013$) groups and a decrease for COD group ($p < 0.001$). Mean exertion was rated higher for Agility and COD sessions compared to the DT-Agility training ($p < 0.05$). Agility and COD interventions did not differ in mean exertion ($p > 0.05$).

Discussion

This study evaluated the effects of 6-week dual task agility training on dribbling, multidirectional ball handling as well as agility and COD performance in adult amateur football players, comparing it to a conventional agility and a change of direction training. In accordance with our first hypothesis, all three interventions resulted in enhanced COD and dribbling performance without cognitive task. However, only the agility and DT-Agility training improved agility and dribbling performance with an integrated cognitive task which is in line with the second hypothesis. In contrast to the third hypothesis, there were no additional benefits of the DT-Agility when compared to agility training. The combined pattern of result indicates stronger performance gains following motor-cognitive agility when compared to change of direction training for football-associated skills.

Tempo dribbling

All three training interventions led to an improvement in dribbling performance without an additional cognitive task. However, a transfer to the dribbling in dual-task condition with an additional divided attention component was only evident following the agility and DT-Agility training.

The fact that dribbling speed in football can be improved through non-sport-specific speed and agility training is consistent with previous research. Among youth players, it has been demonstrated that several training approaches, such as ladder drills, change of direction runs (Padrón-Cabo et al., 2021; Formenti et al., 2021), and agility training (Chaalali et al., 2016), can enhance dribbling performance. However, to the best of the authors' knowledge, no previous studies have examined the transfer effects on game-related dribbling performance in a dual-task setting. Since previous research has shown that adding a cognitive task affects motor performance (Büchel et al., 2022), it is essential to assess the applicability of training effects to the specific sport by examining its transfer to a dual-task scenario.

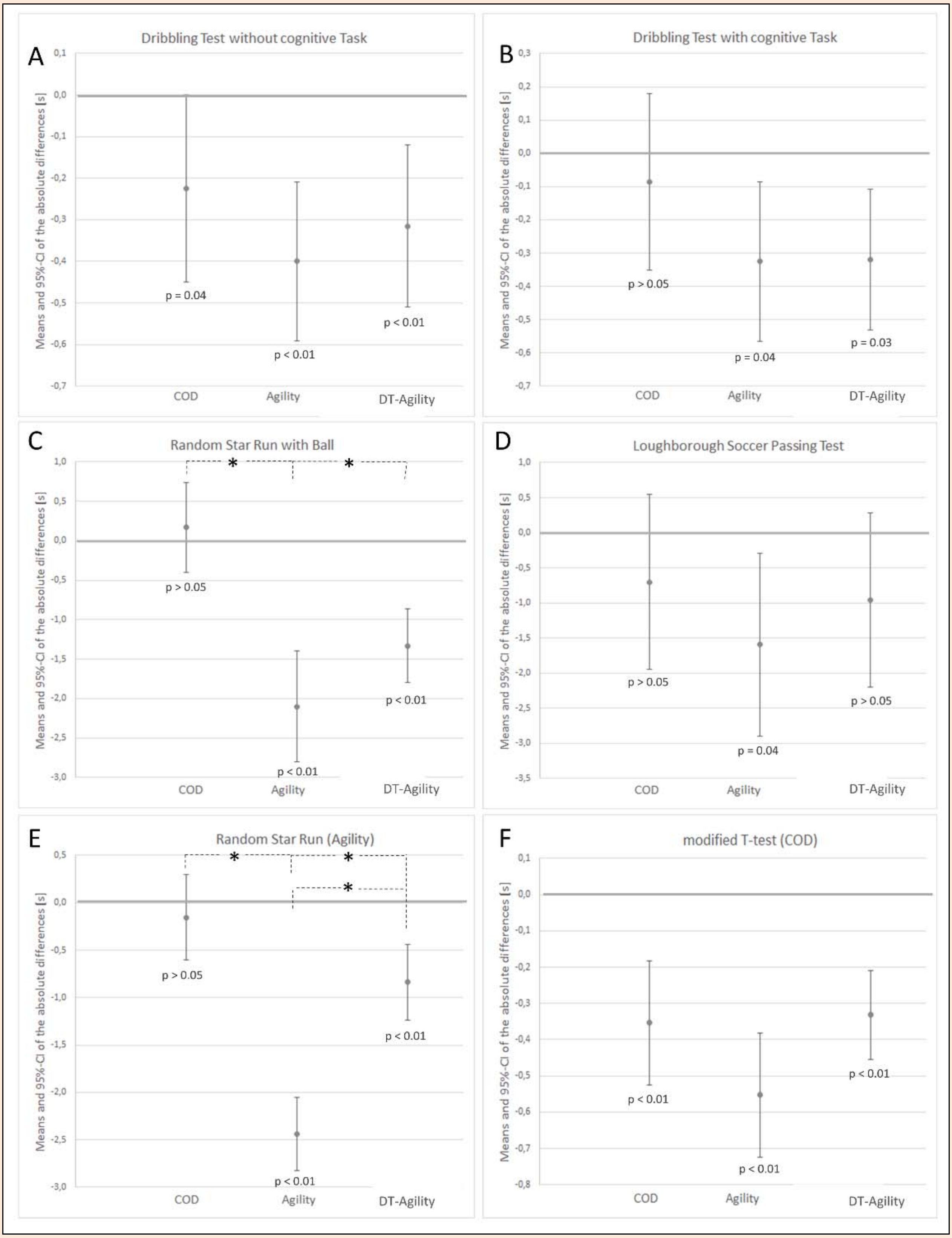

Figure 4. Means and 95% confidence-intervals (95%-CI) of the pre- and post-measurements (A: Tempo Dribbling; B: Tempo Dribbling with cognitive Task; C: Random Star Run with Ball; D: Loughborough Soccer Passing Test; E: Random Star Run; F: modified t-test). CI = Confidence Interval; s = seconds; * marks significant interaction effects; p values according to bonferoni post-hoc test (pre- to post-differences)

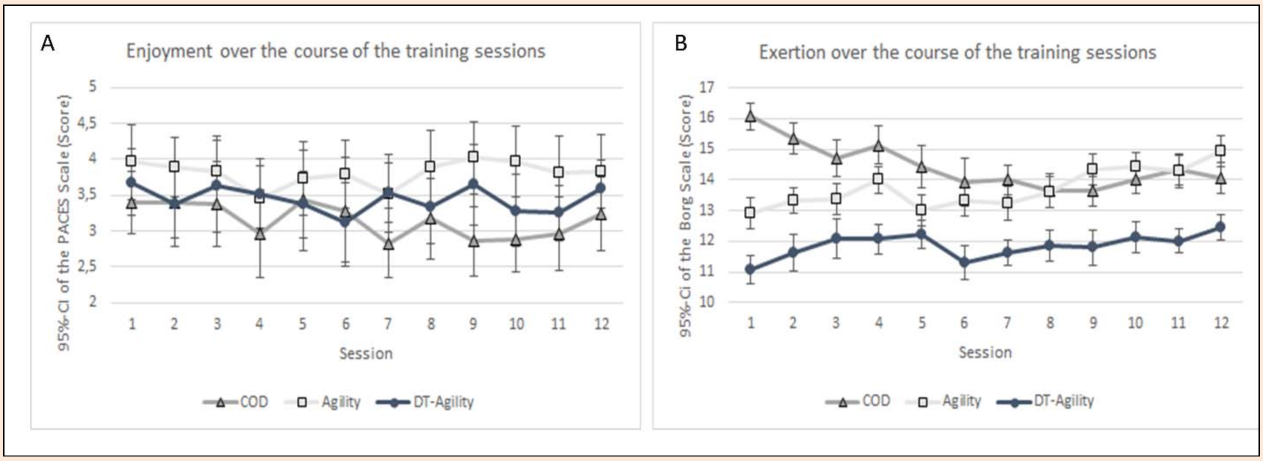

Figure 5. Enjoyment (A, PACES-S) and physical Exertion (B, Borg-Scale) over the course of the 12 training sessions.
CI = Confidence Interval.

This transfer, however, was only evident following agility and DT-Agility training. In contrast to the COD training, the agility and DT-Agility interventions required a constant external focus and divided attention to react quickly to external cues and perform the object tracking task. Therefore, it can be assumed that the agility and DT-agility trainings led to reduced interference effects of the cognitive supplementary task on motor performance, that manifests in improvements in dribbling speed for the dual-tasking setting.

It appears essential to incorporate cognitive challenges into change of direction training to compel the players to maintain an external focus during their own actions, thereby ensuring transfer to dribbling speed within cognitive challenging situations.

Multidirectional ball handling

For the Random Star Run with ball, performance gains were only observed for the agility and DT-agility groups. In context of the LSPT, no time or interaction effects were observed, although the 95% confidence intervals (Figure 4D) of the pre- and post-differences suggest performance improvement within the Agility group.

To our knowledge, there is currently only one study that examined the effects of agility training on a ball handling task with decision making component. In elite youth players, an agility training resulted in increased change of direction speed with ball in reaction to a visual stimulus, compared to a change-of-direction training (Chaalali et al., 2016). These findings, being in line with our results of improved performance within the agility test with ball, suggest that players can transfer their trained ability to react quickly to external stimuli to situations requiring ball control. The improved LSPT test times following the Agility intervention even indicate the transferability to more complex football-specific situations including multidirectional ball handling and passing.

As the dribbling and COD performance, both considered fundamental factors for multidirectional ball handling (Bekris et al., 2018), improved equally in all three groups, it can be assumed that performance gains in the Random Star Run with ball and the LSPT were likely driven by improved cognitive abilities or a more efficient interaction of motor-cognitive processes. Consequently, it appears that players following an agility or DT-agility training, seem to be able to react faster to unpredictable stimuli through multidirectional ball handling. The lack of significant time/interaction effects and the absence of improvement in error rates within the LSPT may be related to the skill level of the players and the resulting high variability in test results (ICC: 0.38-0.75). This aligns with the findings of Ali et al. (2007), which indicated that the reliability of the LSPT is lower in amateur players compared to elite players, particularly in terms of the error score attributed to technical mistakes. In our study, we observed that numerous players faced difficulties in controlling balls that rebounded from the passing boards. Consequently, the technical limitations may have reduced the influence of the trained abilities to react swiftly to external stimuli and perform under dual/multi-task conditions on test performance.

The combined pattern of results suggest that motor-cognitive training outperforms traditional COD training to improve football-associated skills. Only the motor-cognitive training approaches resulted in performance gains across change of direction, ball handling, dribbling and passing assessments while change of direction training does not show any transfer beyond preplanned actions.

Agility and COD

In congruence with the tempo dribbling test without cognitive task, all training groups improved change-of-direction performance in the T-test. In contrast, agility performance in the Random Star Run was only improved following the agility and DT-agility training.

These findings are consistent with previous research in youth football. It has been repeatedly shown that agility training with a decision-making component leads to improvements in both motor and agility performance, while the training effects of traditional COD trainings are limited to motor functions (Trecroci et al., 2016; Born et al., 2016; Chaalali et al., 2016). Cross-sectional studies support this conclusion, indicating that performance in preplanned change of direction drills and agility tasks share only limited common variance (Young et al., 2015; Trajković et al., 2020). Indeed, performance in agility tasks appears to be substantially determined by the cognitive decision-making component, which is not addressed in COD training (Scanlan et al., 2014; Young and Willey, 2010). The findings support that the players' agility performance and its transferability is highly context-specific, depending on both cognitive stimulus and motor task (Jeffreys, 2011; Schmuckler, 2001).

This also explains why the improvement in Random Star Runs was more pronounced after the agility training compared to the dual-task agility training. Within the agility drills, the rapid change of direction in response to the external stimuli was the main focus, while in DT-Agility training, players had to simultaneously handle the object tracking task. This shift towards more cognitive demands likely reduced the reactive decision-making component, contributing to the differences in training effects. Additionally, during the DT-Agility exercises, the players were consistently aligned frontally to be able to track the moving objects displayed on the screen. Therefore, unlike the requirements of the agility test, changes of directions were conducted through lateral shuffling or backwards running. This again, emphasizes the role of the correspondence between task and stimulus within the training and the targeted transfer performance.

Together, these results suggest that adding a cognitive component to change of direction training is crucial for its transferability to athletic movements with decision making component and does not negatively affect performance gains in change of direction ability.

Intervention evaluation

The analyses of the PACES-S scale indicated that training enjoyment was, on average, higher in the agility and DT-Agility groups compared to the COD training. Physical exertion levels following the COD and agility sessions tended to be higher than in the DT-Agility group.

This is consistent with previous studies that examined enjoyment within similar motor-cognitive approaches, such as exergaming or lifekinetic (Niederer et al., 2019; Moholdt et al., 2017; Garn et al., 2012). Farrow et al. (2019) and Moholdt et al. (2017) observed higher enjoyment in exergaming interval training compared to classical interval training while maintaining comparable training effects and intensities. The finding of more sustainable enjoyment through the course of the sessions is in line with Niederer's investigation (Niederer et al., 2019), who found the enjoyment of training with motor-cognitive demands to be maintained over a 6-week period. Since enjoyment of the training is one of the main drivers for long-term adherence and motivation to physical activity (Bauer et al., 2018), this could be one of the reasons why the exertion of training increased during motor-cognitive sessions and decreased during pure motor training.

Practical application

Overall, this investigation provides first evidence that the ecological validity and transferability of COD training can be enhanced through the integration of cognitive challenges. This should be taken into consideration in the design of training programs to improve agility performance in football. Incorporating components such as decision making under time pressure or divided attention can increase the difficulty, transferability and thus may be superior to COD training to ensure long-term progression and effectiveness of agility training in football. In addition, it is evident that motor-cognitive agility training surpasses COD training in terms of sustained training enjoyment and exertion levels. This could have important implications for long-term commitment and motivation in athletic training. In addition, increasing cognitive complexity of agility training could be utilized to regulate exertion and therefore physical training load.

Limitations and future research directions

One limitation of the study is that part of the tests of the pre- and post-measurements were also conducted on the SKILLCOURT training system. Therefore, it cannot be ruled out that familiarity with the SKILLCOURT system may have contributed to the performance gains in the agility and DT-Agility groups. However, a previous study on reliability of the SKILLCOURT suggests that that practice effects were not evident following an introductory familiarization of the testing procedure (Friebe et al., 2023). Furthermore, it contradicts the idea that, as a result of the COD training, comparable improvements occurred in the modified T-agility test conducted on the SKILLCOURT. In addition, the COD group exhibited superior reactive dribbling performance in the baseline measurement, potentially influencing the potential for improvements. While the employed tests are valid methods for assessing football-skill performance, they may not necessarily reflect full spectrum of on-field demands or effects on game-related performance measures (Serpiello et al., 2017). Therefore, future studies could investigate the impact of such training methods on game metrics (e.g., dribbling, pass accuracy, scorer) in small-sided games or in subsequent season matches. In addition, the ability to maintain high movement speed and quality in situations with high motor-cognitive demands (e.g. reaction under time constraints, divided attention) has been linked to the risk for non-contact injuries of the lower extremities (Mijatovic et al., 2022; Kolodziej et al., 2022). Future studies may use the results to evaluate injury-preventive effect of similar motor-cognitive training programs.

Conclusion

This study supports the importance of integrating cognitive tasks into COD training to achieve transfer effects on motor-cognitive football and agility performance. While the effects of COD training are limited to change of directions and dribbling under preplanned conditions, motor-cognitive agility interventions also led to significant performance improvements in agility and football tests with decision making and multitasking components. Within the conducted assessments, no additional benefit of integrating multiple-object tracking into agility training was observed.

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generated and analyzed during the current study are not publicly available, but are available from the corresponding author who was an organizer of the study. The experiments comply with the current laws of the country where they were performed.

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Key points

- This study compares the effects of a novel motor-cognitive dual-task agility training (combining agility and multiple object tracking) with an agility and change of direction training on football-specific test performance
- While effects of the change of direction training are confined to change of direction and dribbling performance under preplanned conditions, motor-cognitive agility interventions led to significant improvements in football-specific and agility tests with decision-making and multitasking components.
- No differences were observed between agility and agility training with integrated multiple object tracking.

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