Assessment and training of football academy students' cognitive functions with computerized psychometric tests

Abstract of PhD Thesis

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1. Introduction

The participants of sport sciences, including researchers, teachers and coaches, collaborate in the selection and training of talented young athletes, emphasizing the importance of the major components of talent selection and the entire training process (Williams & Reilly, 2000). Talented athletes start to develop their performance-related abilities as early as during childhood and adolescence in order to reach peak performance in a multidimensional system of expectations (Elferink-Gemser et al., 2011). The most recent empirical findings focusing on the importance of cognitive functions suggest that success in football depends on the efficiency of complex and rapid information processing in a constantly changing environment (Vestberg et al., 2012). A good team player possesses excellent spatial orientation, distributed attention, working memory and mentalization ability, and quickly adapts their strategy to altered situations requiring inhibition of previous motor and emotional responses. These abilities are collectively referred to in sport as *game intelligence* (Stratton et al., 2004), while the term *executive functions* is used in neuropsychology (Strauss et al., 2006). This latter umbrella term includes all cognitive processes regulating thinking and action, particularly in non-routinized situations (Friedman et al., 2008).

The present doctoral dissertation focuses on the applicability of laboratory-based computerized assessment and training techniques in improving the cognitive components of sport performance in young athletes.

Players of team sports face serious demands in terms of physical, physiological and mental workload (Baur et al., 2006). Most experts in sport psychology recognize now the importance of cognitive processes in sport performance (Starkes & Ericsson, 2003; Sternberg & Grigorenko, 2003; Williams & Hodges, 2004; Ericsson et al., 2006). Furthermore, Vestberg and colleagues (2012) point out that the baseline levels of cognitive abilities predict future sport performance. The vital cognitive abilities in sport are sorted into two broad categories such as tactical knowledge and perceptual abilities. Tactical knowledge includes the combination ability required to adequately judge whether the optimal course of action in a given situation is feasible. Perceptual abilities such as anticipation, execution, visual search strategies and cues, and stimulus detection contribute to effective pattern recognition essentially involved in peak performance. Further abilities required from athletes include adequate attentional focus in critical situations, well-timed information retrieval, adaptive problem solving, and last but not least, adequate decision making within the given time limit (Baláková et al., 2015). Cognitive abilities are improvable by means of adaptive training, whose outcomes are distinctly reflected in the activity patterns of the involved neural networks (Bherer et al., 2005; Erickson et al., 2005). Vestberg and colleagues (2012) likewise draw attention to the importance of executive function training. Harris and colleagues (2018) promote efforts at obtaining more reliable empirical findings in the field by means of systematic assessment of athletes, which requires athletic rather than cognitively impaired control samples.

1.1. Assessment in Sport Psychology

Baumeister and colleagues (2007) point out that self-report measures are more economical in terms of time demand, financial costs, and workload as compared to behavioral measures, for example. However, the authors warn that exclusively relying on self-report data may produce biased findings due to the limitations of respondents' subjective perspective. In this regard, Donaldson and Grant-Vallone (2002) previously called attention to the social desirability effect, that is, respondents' tendency to present themselves in a favorable light. A relatively recent meta-analysis of studies published in psychology journals revealed that 60% of the studies were based on self-report data (Haeffel & Howard, 2010), which is in line with another observation pertaining to sport psychology, pointing out that the principal measurement method in the field is introspective and subjective in nature (Tenenbaum et al., 2012). Any objective measure of athletes' abilities and psychological states essentially requires an adequate technological background (Zhu, 2012). Computerized assessment methods are widely used to obtain empirical data on athletes' characteristics (e.g., ImPACT, CogSport; Ong, 2015). Ali (2011) gives a comprehensive and structured overview of the cognitive and motor ability tests used in the assessment of football players (the cognitive tests assessing mental concentration, perception and anticipation, and psychomotor abilities).

Although exceptionally talented players are easily recognized by their motor parameters and performance measures, practitioners who choose to use such tests need to be aware of the less obvious technical and ability differences across athletes to adequately evaluate the obtained results (Fózer-Selmeci et al., 2019a).

1.2. The VTS in Sport

The Vienna Test System (VTS) offers a variety of computerized psychometric tests, which enable researchers to assess differences on the measured performance dimensions between athletes and non-athletes, across sports, and across different levels of sport participation. The VTS provides measures of both the abilities and personality characteristics of athletes, which are computed automatically (Schuhfried, 2009). These measures enables researchers to establish cross-sport differences and help practitioners explore the various demands posed to all athletes irrespective of the pursued sport (Ong, 2015). Poliszczuk and Mosakowska (2009) used two VTS measures to assess interactions between peripheral perception (PP) and time-movement anticipation (Zeit- und Bewegungsantizipation; ZBA), which provided accurate and reliable data on motor coordination. Csáki and colleagues (2016) used the Determination Test (DT) to assess football players' reactive stress tolerance by position, which required the participants to give specific responses to rapidly changing stimuli (colors, sounds, a light randomly appearing on the right or left side of the visual field). The authors found similar reaction times across positions, but forwards showed relatively low overall error rates, while goalkeepers and midfielders showed relatively low miss rates. In a review paper, Ong (2015) addresses the question whether different authors have the same understanding of the various measures provided by the VTS. The measure obtained with the DT, for example, has simultaneously been defined as reactive capacity (Baur et al., 2006), psychomotor speed and reaction time (Nederhof et al., 2007, 2008), choice reaction time (Jiménez-Pavón et al., 2011), and complex reaction time (Gierczuk & Ljach, 2012; Gierczuk et al., 2012; Sadowski et al., 2012; Zisi et al., 2009). Kiss and colleagues (2018) VTS measures to assess junior female handball players (aged 16.7 years on average) for their abilities to cope with increased competitive pressure as measured with the DT, to make quick and adequate decisions as measured with the Cognitrone (COG) and the Reaction Test (RT), to adequately realize opportunities as measured with the Visual Pursuit Test (Linienverfolgungstest; LVT), and to anticipate movements and courses of actions as measured with the ZBA. In a subsequent study, Kiss and Balogh (2019) employed VTS measures to carry out a targeted sport-specific assessment of handball players' abilities. The COG and DT were used to explore differences across age groups, positions, and genders in a sample of 92 players aged 14 to 37 years (M = 19.3). As Pucsok and colleagues (2018) note, the VTS measures provide valuable information for athletes and coaches on several factors that potentially contribute to performance improvement. The authors point out that future research should clarify the sport-specific information value of each VTS measure.

1.3. The Importance of Cognitive Functions in Football

The real advantage of elite athletes compared to those sporting at a lower level of participation lies not in faster tactical decision making but in the essentially higher accuracy of their decisions (Kioumourtzoglou et al., 1998). Individual differences in the basic cognitive abilities (e.g., intelligence, memory capacity, perceptual functions) do not predict elite performance on most dimensions (Ericsson at al., 2007). Most related findings generally show that the individual levels of basic cognitive abilities do not distinguish elite athletes from others. Other findings, however, point to important differences in certain basic abilities such as attention, for example (Furley & Memmert, 2010). Dubecz (2009) found that psychological factors such as attention, anticipation, decision making, and executive functions all largely contributed to sport success. In a study specifically focusing on football players' performance (N = 600, aged 11 to 19), Ljach and Witkowski (2010) revealed that spatial orientation, reaction speed, and rhythmic ability were the most important factors in coordination.

Open-skill sports such as football, among others, require players to react in a dynamically changing, unpredictable and externally paced environment. As a consequence, players need to more flexibly improve their visual attention, decision making and execution compared to those pursuing close-skill sports. Players have to continuously find and realize the best options according to the available information about the given situational context of the game (working memory), whether they are intercepting, possessing, passing, dribbling, and moving the ball (cognitive flexibility), or to stop a planned pass to a player who is guarded by a defender (inhibition control). Players have to make quick and adequate decisions in a continuously changing situational context (Huijgen et al., 2015).

1.4. The importance of cognitive training

The theoretical background of cognitive training is largely based on the concept of *neuroplasticity*, that is, the hypothetical structural and functional capacity of the human brain to flexibly adapt to new environmental challenges, which is manifested in permanently increased size and/or improved functionality of the involved regions, similarly to skeletal muscles exposed to changing demands (Draganski et al., 2004). The available computerized training programs are particularly effective in treating attention disorders. These programs operate adaptively, that is, they are automatically adjusted to individual clients' current ability levels so that clients are neither over- nor understimulated. A training program requires a relatively long period of regular practice to be effective. It is recommended to gradually increase the difficulty level in alignment with performance fluctuations. The training program should be continued as long as there is prospect for further progress, which period usually spans several weeks (Robertson, 1990; Cicerone et al., 2000). Cognitive training enables targeted improvement of a wide variety of basic cognitive functions such as those involved in attentional and decision making processes, for example. In addition to improving the overall quality of basic functions (e.g., selective attention), cognitive training also enables transference of context-specific abilities (e.g., movement anticipation) to various domains (e.g., opponent perception; Harris et al., 2018). Cognitive training programs consist of computerized exercises that train targeted cognitive functions by means of repetitive tasks. Importantly, complexity levels and reaction time limits should be frequently changed during and across practice sessions in order to avoid over- and understimulation (Walton et al., 2018). In a comparative assessment of various commercial cognitive training programs such as Cogmed, Lumosity, Posit Science, Cognifit, Neurotracker, Nintendo Brain Age, and Dynavision, Harris and colleagues (2018) found that these programs provided only limited support for the transference benefits of sport-specific tasks, since they were not targeted at a sporting environment.

2. Research Aims

The present studies were primarily aimed at a comparative assessment of athletes pursuing various individual and team sports on objective measures of the cognitive functions most frequently assessed in related studies by means of the computerized Vienna Test System.

Furthermore, the studies tested the capacity of computerized cognitive training programs for improving football academy students' cognitive functions.

Although the CogniPlus programs have primarily been used in neuropsychological and clinical assessment, they are also suitable for athletic training purposes due to their adaptive operation, that is, they are automatically adjusted to individual clients' current ability levels. Finally, an effectiveness study was conducted in order to assess the impact of the cognitive training programs on football academy students' cognitive performance (Fózer-Selmeci et al., 2019a).

2.1. Hypotheses

The selection of the VTS measures used in the cross-sectional comparative assessments was based on the related literature and on the professional considerations contributed by the participants' coaches.

H1: Significant cross-sport differences in concentration were expected between football players and athletes pursuing other sports.

H2: Significant cross-sport differences in reactive stress tolerance were expected between football players and athletes pursuing other sports.

H3: Significant cross-sport differences in visual orientation were expected between football players and athletes pursuing other sports.

H4: Significant cross-sport differences in time and movement anticipation were expected between football players and athletes pursuing other sports.

The CogniPlus computerized training battery was used to improve football academy students' targeted cognitive functions, while the effectiveness of the training was assessed with relevant VTS measures.

H5: Football academy students were expected to show significant improvement in the speed and quality of information processing as a result of the cognitive training.

H6: Football academy students were expected to show significant improvement in the speed and accuracy of performance under pressure as a result of the cognitive training.

H7: Football academy students were expected to show significant improvement in response inhibition as a result of the cognitive training.

H8: Football academy students were expected to show a significantly reduced amount of sequencing errors as a result of the cognitive training.

3. Method

3.1. Sample

The participants of both the cross-sectional comparative assessments and the effectiveness study were recruited via convenience sampling. The cross-sectional comparative assessments conducted in 2013 involved 153 participants pursuing an individual sport (fencing; n = 49, M_{age} = 26±6.23) or one of three team sports (football: n = 77, M_{age} = 17±1.19; handball: n = 14, M_{age} = 23±2.65; ice hockey: n = 13, M_{age} = 19±0.28).

All participating football players were students of the Bozsik Football Academy, Hungary. All students of the academy participated in the studies, except three who reported illness at the time of data collection. By position, the 77 participating football players included 9 goalkeepers, 28 defenders, 19 midfielders (including both defensive and offensive midfielders, which were not separated in order to keep an adequate subsample size for comparative purposes), and 21 forwards. By age group, 16 participants qualified as U16, 22 as U17, 18 as U18, and 21 as U21 at the time of data collection.

The subsample of fencers included all athletes who were national team members or qualified as talented athletes in 2013. All participating handballers were members of the Budaörs team, while the involved ice hockey players were members of the U19 national team.

Each participant was assessed at a previously agreed time, at a testing facility temporarily installed in their respective regular sporting environments (dressing rooms of the fencing center, footballers' residence hall, handballers' dressing rooms, medical room at the ice rink). Prior to participation, each adult athlete signed a declaration of informed consent, while those under 18 years of age each submitted a certificate of parental consent.

The effectiveness study conducted in January 2017 involved 60 students of the Puskás Football Academy, Felcsút, Hungary. Baseline measures of their concentration, reactive behavior, response inhibition and working memory were obtained with the VTS.

The assessments were carried out at the Puskás Football Academy. Taking account of the obtained baseline test scores, 30 participants were assigned to a training group and a control group each, in such a way that both groups included approximately equal numbers of participants with below-average, average and above-average results. Participants in the training group completed a cognitive training, while no intervention was administered to those in the control group. The cognitive training lasted three months with two 15-minutes sessions per week. Directly after the end of the training, both the training group and the control group were reassessed for the targeted cognitive functions.

All participants were assessed in an in-person setting. Two participants were simultaneously assessed at a time, during a 48-minute session. The accuracy and reliability of the assessment were supported with adequate input and output devices such as panels, pedals and earphones.

3.2. Instruments

Table 1: Instrumental methods (Schuhfried, 2015, 2019)

	Cross-sectional comparative assessments	Effectiveness Study	CogniPlus training
Concentration	**COG** S8 (´9; r=0,95)	**COG** S8 (´9; r=0,95)	**SELECT** (selective attention)
Anticipation	**ZBA** S1 (´20; r=0,92-0,98)		
Memory	**CORSI** S2 (´15; r=0,81-0,89)	**CORSI** S2 (´15; r=0,81-0,89)	VISP (spatial working memory)
Response Inhibition	**STROOP** S7 (´15; r=85-0,99)	**STROOP** S7 (´15; r=85-0,99)	HIBIT-R (response inhibition)
Reactive stress tolerance	**DT** S1 (´6; r=0,98-0,99)	**DT** S1 (´6; r=0,98-0,99)	ALERT (attention - alertness) SELECT (selective attention)
Reaction Time	**RT** S3 (´5; r=0,84-0,95)		
Visual orientation	**LVT** S2 (´13; r=0,92)		

3.3. Statistical Data Analysis

The obtained raw data (raw frequencies, seconds) were converted into percentile ranks (PR) based on the results of a representative norm sample on each VTS measure. Each PR scale ranges from 0 to 100, on which below-average performance is represented by the interval 0 to 24, average performance by 25 to 75, and above average performance by 76 to 100. The descriptive statistics obtained for performance included means, standard deviations, and frequencies (number of participants, percentages). Cross-sectional comparisons for each assessed cognitive function were carried out by means of one-way analyses of covariance (ANCOVA) with each VTS measure as the dependent variable, the pursued sport as a factor, and participants' age as a covariate (significant age differences were found between the tested sport groups). Comparisons for the targeted cognitive functions within the footballer sample across age groups (U16, U17, U18, U21) and positions (forwards, midfielders, goalkeepers, defenders) were conducted with one-way ANOVA tests. In the effectiveness study, repeated measures ANCOVA tests were conducted to assess the main effects of, and interactions between the time of assessment (baseline, post-intervention) as the within-subjects factor and group (training group, control group) as the between-subjects factor at the $\alpha = .05$ level of significance. The statistical data analysis was carried out with the IBM SPSS Statistics for Windows, Version 22.0 software package (IBM Corp. Released 2013., Armonk, NY: IBM Corp.).

4. Results

Cross-Sectional Comparative Assessments

4.1.1. Concentration

Norm-Based Assessment of Football Players

Footballers showed above-average performance on four of the five employed measures of concentration including *mean reaction time for correct reactions*, *total number of correct and incorrect reactions*, *number of correct reactions*, and *mean reaction time for incorrect reactions*. They achieved the best performance on the *mean reaction time for correct reactions* (*M* = 87.39, *SD* = 16.45) and on the *total number of correct and incorrect reactions* (*M* = 87.39, *SD* = 16.36). Lower but still above-average performance was shown by footballers on the *number of correct reactions* (*M* = 84.84, *SD* = 17.49) and on the *mean reaction time for incorrect reactions* (*M* = 77.71, *SD* = 19.60). By contrast, they reached below-average performance on the *percentage of incorrect reactions* (*M* = 18.00, *SD* = 18.18).

Cross-Sport Comparisons between Players of Football and Other Sports (Fencing, Ice Hockey, Handball)

No significant difference was found across sports on four of the above five measures. Irrespective of the pursued sport, athletes achieved the highest levels of above-average performance (PR > 75%) on the *mean reaction time for correct reactions* and on the *total number of reactions*. Likewise, above-average performance was shown by athletes on the *number of correct reactions,* whereas fencers, ice hockey players and handballers as opposed to footballers only achieved average performance on the *mean reaction time for incorrect reactions*. Compared to other sports, handballers showed the most balanced overall performance on concentration, while their results were relatively low among those in the above-average range.

4.1.2. Reactive Stress Tolerance

Norm-Based Assessment of Football Players

Footballers showed average performance on the *number of correct reactions* measure of reactive stress tolerance (*M* = 49.17, *SD* = 20.03). By contrast, their performance was below average (PR < 25%) on the *number of incorrect responses* (*M* = 11.36, *SD* = 10.99) and *number of omitted stimuli* measures (*M* = 19.12, *SD* = 16.76).

Cross-Sport Comparisons between Players of Football and Other Sports (Ice Hockey)

Footballers and ice hockey players significantly differed from each other on one of the six measures of reactive stress tolerance (*total number of reactions*; $F(1,86)=4,804$; $p< 0,031$; $\eta^2_p = 0,053$). Footballers achieved average performance on the *number of correct reactions* and below-average performance on the *number of incorrect reactions* and *number of omitted stimuli*.

Ice hockey players also showed average, albeit lower, performance on the *number of correct reactions*, while their below-average results were somewhat higher than those of footballers. A significant difference was found between the two groups in the *total number of reactions*, footballers scoring higher on this measure.

4.1.3. Reaction Time

Norm-Based Assessment of Football Players

Football players showed average performance on *mean reaction time* (*M* = 68.90, *SD* = 23.07) and above-average performance on *mean motor time* (*M* = 83.65, *SD* = 18.05).

4.1.4. Visual Orientation

Norm-Based Assessment of Football Players

Football players showed average performance on all three employed measures of visual orientation. That is, footballers showed average speed and accuracy in processing situational cues to find an unguarded player in the field.

Cross-Sport Comparisons between Players of Football and Other Sports (Handball)

No significant difference was found between footballers and handballers on the employed measures of visual orientation.

4.1.5. Time-Movement Anticipation

Norm-Based Assessment of Football Players

Footballers showed average performance on both employed measures of time and movement anticipation.

They performed better on *median deviation time* assessing the temporal accuracy of passing than on *median direction deviation* assessing spatial accuracy.

Cross-Sport Comparisons between Players of Football and Other Sports (Fencing, Handball)

A significant cross-sport difference was found on *median deviation time* ($F(2,136)=4,482$; $p<0,013$; $\eta^2_p = 0,062$). All groups of athletes showed average performance on both measures of time and movement anticipation. Handballers scored lower on *median deviation time* than did footballers and fencers.

Cross-Sectional Comparisons Across Age Groups in Football

4.2.1. Concentration

No significant difference was found across the four sampled age groups on four of the five measures of concentration.

All age groups achieved above-average performance on the *mean reaction time for correct reactions*, *number of correct reactions*, and *total number of reactions*, U18 footballers showing the best results. All age groups showed below-average performance on the *percentage of incorrect reactions*.

4.2.2. Reactive Stress Tolerance

No significant difference was found across the four sampled age groups on any of the employed measures of concentration. The highest *number of correct reactions* was shown by U21 footballers (M = 54.9, SD = 24.73), while the poorest performance on the *number of incorrect reactions* by U17 players (M = 8.77, SD = 7.99), although these latter achieved the lowest *number of omitted stimuli*, scoring in the below-average range.

4.2.3. Reaction Time

Significant differences across age groups were found on *mean motor time* ($F(3,73)=3,465$; $p<0,026$). All age groups reached average or above-average performance on the employed measures. The most balanced performance was shown by U16 players as reflected in their standard deviations.

4.2.4. Visual Orientation and Time-Movement Anticipation

No significant difference was found across the sampled age groups on the employed measures of visual orientation and time-movement anticipation. The best performance on the visual orientation measures was shown by U18 and U21 footballers. All age groups showed average performance on both measures of time and movement anticipation. U17 and U18 players performed better than others on *median deviation time* (M = 72.27, SD = 22.87) and on *median direction deviation* (M = 45, SD = 31.76), respectively.
No significant difference was found across the sampled age groups on visual orientation, that is, in terms of their ability to quickly and accurately find unguarded players in the field. In terms of time and movement anticipation, U17 and U18 players performed better than others on temporal and spatial accuracy of passing, respectively, both groups scoring in the average range.

Cross-Sectional Comparisons Across Positions in Football

4.3.1. Concentration

No significant difference was found across the sampled positions on the employed measures of concentration. Goalkeepers showed the highest overall performance, scoring in the above-average range, whereas they scored lowest on the *percentage of incorrect reactions*, showing below-average performance on this measure. No significant cross-position difference was found on the employed measures of concentration.

4.3.2. Reactive Stress Tolerance

No significant cross-position difference was found on the employed measures of reactive stress tolerance. Goalkeepers and defenders respectively performed better (M = 58.78, SD = 17.63) and worse than others (M = 45.64, SD = 21.62) on the *number of correct reactions*, while midfielders achieved the lowest *number of omitted stimuli* (M = 22.28, SD = 17.8).

4.3.3. Reaction Time

No significant cross-position difference was found on the employed measures of reaction time. Defenders achieved better *mean reaction time* than others (with average and lower standard deviations compared to goalkeepers). Forwards performed better than others on *mean motor time*, with relatively low standard deviations. Midfielders showed the most balanced overall performance as reflected in their standard deviations.

4.3.4. Visual Orientation

No significant cross-position difference was found on the employed measures of visual orientation.

4.3.5. Time-Movement Anticipation

A significant difference was found between goalkeepers and defenders on *median direction deviation* ($F(3,73)=3,417$; $p<0,028$).

Effectiveness Study

4.4.1. Concentration

Footballers in both the training group and the control group showed significant changes across the pre-intervention (baseline) and post-intervention (T1) assessments on all five measures of concentration. Irrespective of whether or not an intervention was administered, the athletes performed significantly better at T1 on the accuracy (*number of correct reactions*; $F(1,53)=59,614$; $p<0,001$; $\eta^2_p=0,53$), decision making (*mean reaction time for correct reactions*; $F(1,53)=47,263$; $p<0,001$; $\eta^2_p=0,47$), and processing speed (*total number of reactions*; $F(1,53)=51,968$; $p<0,001$; $\eta^2_p=0,50$) components of process observation under time pressure. By contrast, the under-pressure levels of adequate decision making (*number of incorrect reactions*; $F(1,53)=13,49$; $p<0,001$; $\eta^2_p=0,20$) and detail orientation (*percentage of correct reactions*; $F(1,53)=4,887$; $p<0,031$; $\eta^2_p=0,08$) significantly decreased, albeit remaining slightly below average.

In sum, football academy students performed significantly better on concentration at T1 both in qualitative (*number of correct reactions, mean reaction time for correct reactions*) and quantitative terms (*total number of reactions*), while they showed significantly reduced performance on the speed of adequate decision making (*number of incorrect reactions*) and on detail orientation (*percentage of correct reactions*).

4.4.2. Reactive Stress Tolerance

No post-intervention difference was found between the training group and the control group on the three measures of reactive stress tolerance including the *number of correct reactions*, *number of correct reactions*, and *number of omitted stimuli*. However, both groups showed a significant change across the baseline and T1 assessments on the *number of correct reactions* ($F(1,53)=21,404$; $p<0,001$; $\eta^2_p=0,29$).

A significant main effect was found for the *number of correct reactions*. Specifically, football academy students made faster and more accurate decisions under time pressure at T1, albeit still scoring in the average range.

Neither the main effect of the time of assessment nor the time by group interaction was significant for the *number of incorrect reactions*. It is worth noting, however, that lower scores were obtained at T1 (M = 15.73, SD = 16.70) as compared to the baseline assessment (M = 19.87, SD = 17.73).

4.4.3. Response Inhibition

The time of assessment had significant main effects on all employed measures of response inhibition including the *reading interference tendency* ($F(1,53)=9,865$; $p<0,003$; $\eta^2_p=0,16$), *naming interference tendency* ($F(1,53)=5,491$; $p<0,023$; $\eta^2_p=0,10$), *reading interference mean reaction time* ($F(1,53)=5,755$; $p<0,020$; $\eta^2_p=0,10$), and *naming interference mean reaction time* ($F(1,53)=9,510$; $p<0,003$; $\eta^2_p=0,15$).
Football academy students performed better on all four measures at T1, that is, it took less time for them to ignore irrelevant stimuli while processing relevant information.

4.4.4. Spatial Working Memory

The time of assessment had significant main effects on the *immediate bloc span* ($F(1,46)=5,644$; $p<0,022$; $\eta^2_p=0,11$) and on the *number of correctly tapped sequences* ($F(1,46)=4,283$; $p<0,044$; $\eta^2_p=0,09$).
Football academy students performed better on both measures at T1. At the same time, they made a slightly larger amount of *sequencing errors*.

5. Conclusions

5.1. Concentration

H1 was rejected, since no significant difference was found across the sampled sports on the employed measures of concentration (COG), except on the *proportion of incorrect reactions*, on which ice hockey players showed lower performance than footballers did.

H5 was rejected, since no significant difference was found on the speed and quality of information processing following the intervention. Importantly, however, both the training group and the control group performed significantly better at T1 on the accuracy, decision making, and processing speed components of process observation under time pressure, while the under-pressure levels of detail orientation significantly decreased.

5.2. Reactive Behavior and Visual Functions

H2 was rejected, since no significant difference was found across the sampled sports on the employed measures of reactive stress tolerance (DT), except on the *total number of reactions*, on which footballers scored significantly higher than ice hockey players did, that is, the former gave more responses under time pressure.

H6 was rejected, since no significant difference was found following the intervention. However, the time of assessment had a significant main effect on the *number of correct reactions*. Specifically, football academy students made faster and more accurate decisions under time pressure at T1.

H3 was rejected, since no significant difference was found between footballers and handballers on visual orientation (LVT).

5.3. Time-Movement Anticipation

H4 was rejected, since footballers showed no significant difference on time and movement anticipation (ZBA) from athletes pursuing either individual or team sports (fencing and handball, respectively). The anticipation of movement direction is the ability that coaches train with sport-specific drills focused on ball driving, dribbling, and dropping. As Somodi (2008) points out in a practice-oriented paper, motor coordination exercises without a ball train the harmony and speed of movement.

5.4. Response Inhibition

H7 was rejected, since the training group showed no significant improvement in response inhibition. However, the time of assessment had significant main effects on all employed measures of response inhibition including the reading interference tendency, naming interference tendency, reading interference mean reaction time, and naming interference mean reaction time.

Football academy students performed better on all four measures at T1, that is, it took less time for them to ignore irrelevant stimuli while processing relevant information.

5.5. Spatial Working Memory

H8 was rejected, since football academy students in the training group showed an increased rather than decreased amount of sequencing errors following the intervention.

Recommendations

Performance prediction is even more complicated in ball games than in other sports. Most previous studies of talent selection in football primarily focused on differences between elite and subelite athletes, on junior recreational athletes, and/or on homogeneous samples of players differing in biological maturation. Certain parameters such as perception and decision making may be useful in predicting sport performance (Pucsok et al., 2018).

The VTS is used by coaches and sport managers as a means of screening for those athletes and prospective team members who possess the psychological and cognitive abilities required for success in their pursued sports. The obtained data inform both practitioners' and coaches' efforts at supporting peak athletic performance (Ong, 2015). Obviously, the various VTS measures may provide a complex picture varying across individuals, and account should be taken of each measure for each individual rather than treating the employed set of measures as a single homogeneous construct (Ong, 2015). The VTS may also provide a valuable instrument for researchers in applied sport psychology, therefore future studies should focus on the selection of those measures that are useful for sport-specific performance prediction. The currently available test batteries include the TAKIDS enabling age-specific assessment of junior athletes aged 7 to 10 years, the TATEENS2 designed for those aged 11 to 14, and the SFTEAM for those above 15 years of age, which latter enables the assessment of cognitive functions, reactive behavior and visual functions by position (goalkeeper, forward, field player (Schuhfried, 2012; Fózer-Selmeci, 2020). The results of the cross-sectional assessments reflect differences in the preparation of goalkeepers and field players. Decision-making ability, speed and accuracy are the key areas in goalkeepers' training. The results on goalkeepers' readiness to make quick and adequate decisions underpin the importance of these requirements. In the sampled age groups, priority is given to quick decision making, which may be subsequently combined with low error rates in a training setting. However, decision-making speed may not be increased at the expense of goalkeepers' ability to efficiently intervene in the game. An interesting trend is reflected in midfielders' likewise outstanding performance on decision-making speed, which points out the need for them to efficiently support the team in shifting from offense to defense and vice versa as quickly as possible (Fózer-Selmeci et al., 2016).

At an adequately high level of participation, football may help adolescents train cognitive functions essential in academic performance, and it enables those having difficulties with response inhibition to improve both physical and cognitive functions according to sport-specific needs (Wang et al., 2013). Cognitive abilities may also be improved with personalized adaptive training, whose outcomes are primarily reflected in more efficient neural networks (Bherer et al., 2005; Erickson et al., 2007). The previous related studies involving sport experts and lab-based assessments revealed inconsistent findings on attention and other cognitive functions, in part due to small sample sizes and the heterogeneity of the employed methods. Assessments of small samples often produce results with low effect sizes even though the results are otherwise valid (Schmidt, 1992).

Addressing this difficulty, Lumsden and colleagues (2016) demonstrated that gamification may be efficiently used to increase participants' long-term motivation, which in turn results in commitment and increased ecological validity of the obtained findings. In a review paper, Slimani and colleagues (2016) point out important differences across age groups and positions in the most effective methods of cognitive training and interventions targeted at the improvement of positive psychological abilities. Younger footballers prefer visual techniques as compared to older players, while elite footballers and especially elite midfielders show a higher preference for goal setting, active imagination, and self-talk than their non-elite counterparts. As Walton and colleagues (2018) notes, much further research is needed to clarify how these methods may help athletes realize their full potentials, which requires cooperation between all participants in sport sciences including coaches and athletes.

List of publications

Publications related to the topic of the thesis

Kiss, Z., Fózer-Selmeci, B., Csáki, I., & Bognár, J. (2015). Bentlakó labdarúgó-korosztályok pszichés-mentális jellemzői. *Mentálhigiéné és Pszichoszomatika*, 16(4), 331–347. http://doi.org/10.1556/0406.16.2015.4.2

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