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The Difference of Sport-related Cognitive Function according to Athletic Status and Type of Sport

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체육학과

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Doctor of Philosophy

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Abstract

Cognitive function has been recently accepted to be an essential factor along with physiological, physical, technical, and psychological factors for peak performance in sports. The present dissertation consists of two studies; study 1: the role of cognitive function in sports: a systematic review; and study 2: the difference of cognitive ability according to athletic status and type of sport.

Study 1: the purpose of the primary research was to systematically determine the existing evidence on the topics of cognition and sports performance. This systematic review was conducted following the guideline of the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA). Relevant studies were initially discovered via electronic sources, namely PubMed, Web of Science, Science Direct, Wiley Online Library, and Taylor & Francis Online databases. Additional searches were performed using Google scholar and the reference lists of relevant articles. The final search was completed on April 2018. The inclusion criteria were English written studies, healthy participants who were 8-35 years old, and study investigating cognitive function corresponding to athletic status or sport expertise or sport type. Of 192 initially retrieval articles, thirty-seven eligible studies meet inclusion criteria were finally included. In the process of data extraction, relevant information was extracted including first author, year of publication, participants' sample size, gender, age, sports experience, athletic status, sport expertise, type of sport, cognitive measurement, and result. The findings revealed the association between various aspects of cognitive function and athletic status, sports expertise, talented athlete, and sport type. Exceptional sports players were superior to sub-elite, amateur player, and ordinary people on several cognitive abilities utilizing measurements of simple and choice reaction time, go/no-go reaction time test, design fluency test, switching task, stop-signal task, flanker test, mental rotation test, tower test, stroop test, attention network test, trail making test, and digit span forward & backward test. Moreover, young talented athletes outperformed sub-talented and non-talented youth players on executive functioning. With regard to types of sport, there were significant effects on cognitive functions indicating; 1) strategic sport athletes had superior executive controls than those from interceptive sports, static sports, and non-athletes; 2) open skill athletes displayed better on inhibition, visual-spatial skills, and cognitive flexibility than closed skill athletes and non-athletes; 3) externally-paced players exhibited higher planning and problem-solving abilities in comparison to self-paced players and non-athletes; 4) self-paced athletes did more effective on response inhibition than externally-paced athletes and non-athletes. Based on preliminary results, the cognitive functions corresponding to peak performance in sports could be determined as executive function (inhibition, working memory, and cognitive flexibility), information processing (reaction time and processing speed), and spatial skill (mental rotation ability). Superior performance seems to be associated with cognitive abilities which could be utilized to predict the athletic achievements. However, the differences in multiple cognitive functions depending upon type of sport and athletic skill level were reported, but the components of cognitive function critical to each sports type are not fully clarified.

Therefore, further investigation is needed to be conducted proving the sport-related cognitive functions distinguished depending upon athletic status and type of sport.

Study 2 is a cross-sectional study to determine the sport-related cognitive function across athletic status (athlete and non-athlete) and type of sport (interceptive, static, and strategic sports). There were 120 male participants including 30 boxers (interceptive sport), 30 shooters (static sport), 30 soccer players (strategic sport), and 30 non-athletes who were young adults (age range 20-30 years). According to the theoretical model of sport-related cognitive functions in study 1, the cognitive performances were examined employing five computerized tests including simple (SRT) and choice reaction time (CRT) test, flanker test (FKT), trail making test (TMT), mental rotation test (MRT), and one paper-pencil test, which is design fluency test (DFT). The results show that athletes outperformed non-athletes on simple and choice reaction time test, trail making test (TMT-A), and design fluency test, suggesting athletes were superior in speed of cognitive processing and multiple executive aspects consisting action inhibition, working memory, cognitive flexibility, and creativity. Regarding sports disciplines, interceptive and static sports athletes yielded significantly faster responding on simple reaction time as compared to strategic sport athletes and non-athletes. The shorter reaction time of choice reaction time test were observed in three sport types athletes in comparison to non-athletes, and only interceptive sport athletes did statistically higher in accuracy rate of choice reaction time test. The result of trail making test, as compared to non-athlete group, static sport athletes did significantly faster on trail making test - part A. There was significant effect of sport type on mental rotation test, indicating interceptive athletes

performed better than static sport and strategic sport players, whereas non-athletes were found to be superior to strategic sport athletes. Concerning design fluency test, athletes from strategic sport could create more total unique figures than static sport athletes and non-athletes, and the higher total unique figures was also observed in interceptive sport athletes relative to non-athletes. However, no significant difference of flanker test was reported for athletic status and type of sport.

The results obtained in this study indicated that the superior cognitive abilities (i.e., information processing and executive function) were associated with participation in competitive sport training regardless of sports typology. The sport type differences were related to specific cognitive components, interceptive sport favoring on cognitive processing speed and visual-spatial skills, whereas executive functions (i.e., working memory and cognitive flexibility) could be benefited from the extensive training of strategic sport. Furthermore, visual processing speed may be essential for sports performances in the static sport such as shooting.

Key words: athletic status, type of sport, cognitive function, executive function, information processing, mental rotation ability

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I. Introduction

The elite sport's success has been considered to be a critical issue of the nations that the government should be concerned with regard to international reputation diplomatic relation, and ideological competition. It would also help to accomplish in indirect purposes such as national spiritual (pride) and socio-economic development (Bergsgard, Houlihan, Mangset, Nodland, & Rommetvedt, 2007; Green & Houlihan, 2005; Grix & Carmichael, 2012; Houlihan, & Green, 2007, 2008). The achievement in significant sporting competitions (e.g., Olympics games or Asian games, etc.) can be created by making a strategic investment in the elite sports system (Oakley & Green, 2001). In the past decade, the governments of several nations have attempted to find effective ways to achieve and maintain sustainable success of elite sporting competition by investing budget, supporting, and developing the elite sport system (Bergsgard et al., 2007; De Bosscher, Bingham, Shibli, van Bottenburg, & De Knop, 2008; Green & Houlihan, 2005). Besides, opportunity of country in sporting success would be increased if the young gifted athletes could be detected early (Vaeyens, Güllich, Warr, & Philippaerts, 2009). In recent international comparative studies, the talent identification and development system (TID) has been respected to be a significant factor influencing the international sporting success (Brouwers, De Bosscher, & Sotiriadou, 2012; De Bosscher, De Knop, Van Bottenburg, & Shibli, 2006; De Bosscher, Shibil, Westerbeek, & Van Bottenburg, 2015). Australia is an excellent example of prosperous nation applying talent identification and developmental process that showed an impressive development by reaching 58 medals at the Olympics games in 2000 after had poor performance (5 medals) in the 1976 Olympics games. Base on the developmental progression of Australia in major competition, sport talent identification and development program would be an essential foundation contributing the efficient elite sports system.

The talent identification and development system have been defined as an integration of exercise and sports scientific knowledge exploring a variety of gifted sporting characteristics of youngsters who have a potential to be the world-class players. The TID has been generally operated to detect the sport-specific talent, define a proper sport, predict prospective sports performance, and discriminate the athletic level (professional, amateur, and non-athlete). However, the assessment processes of identifying gifted performance are commonly focused on multidimensional components of genetics, physiological, anthropometrical, psychological, technical, and sociological aspects (Abbott & Collins, 2004; Mohamed et al., 2009; Reilly, Williams, Nevill, & Franks, 2000). Recently, in competitive sports, athletes need to prepare not only physical abilities, but also cognitive functions which has been associated to success in sports (Belling & Ward, 2015; Vestberg, Gustafson, Maurex, Ingvar, & Petrovic, 2012; Vestberg, Reinebo, Maurex, Ingvar, & Petrovic, 2017). Additionally, executive control has been proved to be one of the predictor of sports performances (Vestberg et al., 2012). Sport scientists have pointed out the importance of cognition in sport like soccer; players are required high-level cognitions (i.e., intelligence, perception, anticipation, working memory, reaction time, shifting, pattern recognition, and spatial ability) to maximize their physical and technical performances throughout the competition (Pruna & Bahdur, 2016). Importantly, greater cognitive performance has been discovered in talented athletes. A study in young soccer players (Verburgh, Scherder, van Lange, & Oosterlaan, 2014), the highly gifted young athletes who participated in the talent development program of the professional soccer club had better inhibition and attention relative to youth amateur soccer players. As well as, the study of Huijgen et al. (2015) has also reported that elite youth soccer players performed better than less-skilled players on executive functions. Thus, cognitive functioning may critically contribute to the successful process of elite sport development which could specify young potential athletes to be systematically nurtured and trained to reach the peak performance.

As previous evidence has observed the association between sport expertise and cognitive performances, athletes were mostly found to perform with higher proficiency on a wide range of laboratory-based cognitive tasks relative to non-athletes (Chueh et al., 2017; Jansen & Lehmann, 2013; Lundgren, Högman, Näslund, & Parling, 2016; Nakamoto & Mori, 2008; Schmidt, Egger, Kieliger, Rubeli, & Schüler, 2016; Voss, Kramer, Basak, Prakash, & Roberts, 2010; Wang, Guo, & Zhou, 2016; Yu, Chan, Chau, & Fu, 2017). Apart from this, empirical evidences using cognitive component skill approach showed that in comparison to less-performance athletes, exceptional athletes from various sports (e.g., baseball, marathon, soccer, and volleyball) had superior cognitive performances including executive attention, response inhibition, working memory, cognitive flexibility, planning, processing speed, and mental rotation ability (Alves et al., 2013; Cona et al., 2015; Liao, Meng, & Chen, 2017; Mann, Williams, Ward,

& Janelle, 2007; Mori, Ohtani, & Imanaka, 2002; Verburgh, Scherder, van Lange, & Oosterlaan, 2016; Vestberg et al., 2012; Voss et al., 2010; Wang et al., 2013). In this regard, it could assume that athletic skill differences are related to cognitive skills which experts are superior to novices and non-athletes.

Furthering the relationship between cognitive functions and particular sports types has been explored. Several finding revealed the individual with participating in a specific sport could benefit certain sub-aspect of cognition. For example, Di Russo et al. (2010) reported that the executive skills of disabled basketball players were better than swimmers. Participating in strategic or open skill or externally-pace sport events (e.g., basketball) that players are required to react to a consistent changing situation could enhance cognitive flexibility, while swimmers (static or closed-skill or self-paced sports) would not improve their executive skills due to they do not require creative ability or stimuli time pressured of responding skill during training and competition. With regard to interceptive sport, the sport that athletes need to response to an unexpected opponent's movement or object in the competitive environment by using parts of body (e.g., badminton, tennis, and boxing) (Davids, Savelsbergh, Bennet, & Van der Kamp, 2002). A study revealed that athletes from interceptive sports type performed quicker on reaction time relative to static sports athletes (Mann et al., 2007). Additionally, meta-analytic research has found that athletes in interceptive (e.g., tennis) and strategic sports (e.g., soccer) athletes had a faster response on processing speed task, as compared to static sports (e.g., shooting) athletes (Voss et al., 2010). Besides, compared with closed skill sports, open skill sports athletes were revealed to have superior inhibitory control, visual attention, and making decision (Taddei, Bultrini, Spinelli, & Di Russo, 2012; Wang et al., 2013). A study of Jacobson and Matthaeus (2014) showed that athletes in self-paced sports (e.g., bowling or running) could perform significantly better on action inhibition task relative to externally-paced sports athletes (interceptive and strategic sports) and sedentary, but externally-paced sports athletes were better on problem-solving ability. Emerging evidence by Yongtawee and Woo (2017) also demonstrate that accumulating training in interceptive sports (e.g., badminton or tennis) may facilitate the better information processing ability, whereas athletes in static sports (e.g., shooting or running) tend to display worse performance even their sports experience increase. According to the previous findings, there may be beneficial effects of regular training across various sports domains on specific sport-related cognitive performances.

However, the inconsistent findings have been found, it is likely impacted by differences in sport expertise, athletic status, and sport categories (Jacobson & Matthaeus, 2014; Wang et al., 2013). Furthermore, some sub-aspects of cognitive functions (e.g., executive control, processing speed, and spatial performances), there has been questionable due to lack of investigations conducted in the different sports like boxing (interceptive sport), shooting (static sport), and soccer (strategic sports). Therefore, the first study is a review literature aiming at to explore and systematically determine the extant evidence of sport-related cognition. Base on the primary findings, the objectives of secondary study is to gain an insight understanding of the relationship between sport-related cognitive functions, athletic status, and type of sport.

Purpose of the Study

There are three purposes of this study;

1. The primary objective was to determine the cognitive function related to sport performances by conducting the systematic literature review.

2. The secondary objective was to investigate the difference in sport-related cognitive functions according to athletic status (athletes and non-athletes).

3. The third objective was to investigate the difference in sport-related cognitive functions according to types of sports including interceptive, static, and strategic sports.

Hypothesis

Based on the previous finding, the hypotheses of this study are as follows;

1. There will be cognitive functions related to sport performance.

2. There will be significant difference in cognitive functions according to athletic status.

2.1 Athletes will exhibit better cognitive performances than non-athletes (Alves et al., 2013; Bianco, Di Russo, Perri, & Berchicci, 2017; Jacobson & Matthaeus, 2014; Liao et al., 2017; Schmidt et al., 2016; Vestberg et al., 2017; Wang et al., 2016).

3. There will be significant difference in cognitive performance according to type of sport (Jacobson & Matthaeus, 2014; Wang et al., 2013; Yao, 2016).

3.1 Interceptive sport athletes will exhibit better mental rotation ability than static sport athletes (Moreau, Clerc, Mansy-Dannay, & Guerrien, 2012).

3.2 Interceptive and strategic sport athletes will perform better on information processing in comparison to static sport athletes (Voss et al., 2010; Yongtawee & Woo, 2017).

Definition of Terms

1. Cognitive functions

Cognitive function is a complex mental process including perception, memory attention, executive functioning, information processing, spatial ability, and intelligence (Tomporowski, Davis, Miller, & Naglieri, 2008).

2. Executive functions

Executive functions refer to a set of cognitive processes such as inhibition, working memory, and mental flexibility, which regulate goal-directed behaviors, flexible respond, and quickly changing situations (Diamond, 2013).

1) Inhibition

Inhibition (inhibitory control or action inhibition) is defined as abilities controlling attention, behavior, thoughts, and emotions, which suppress to inappropriate response action (Diamond, 2013).

2) Working memory

Working memory refer to an ability to maintain, monitor, and update on-going information in mind for a brief moment of time and response using relevant data (Miyake et al., 2000).

3) Cognitive flexibility

Cognitive flexibility (mental flexibility or shifting) is defined as the ability to flexible mentally adaptation of new changing situations (Diamond, 2013).

3. Reaction time

Reaction time refers to the processing time of central nervous system between the onset of stimulus and onset of reaction (Donders, 1969; Sternberg, 1969).

4. Mental rotation

Mental rotation is a sub-domain of spatial ability that involves the mentally rotating process of two- or three-dimensional stimulus in unexpected-direction (Shepard & Metzler, 1971).

5. Interceptive sport

Interceptive sports is defined as the sport that athletes are required quickly dominant-response to the stimuli or objects in environment, or opponent's attacking in combat sports by coordinating individual's body, parts of the body or sport equipment (e.g., tennis, fencing, and boxing) (Davids et al., 2002).

6. Static sport

Static sports refers to the sports that players involved in strongly consistent environment or self-paced events (e.g., running, swimming, and shooting) (Davids et al., 2002).

7. Strategic sport

Strategic sports is defined as the sports that associated to plenty information processing regarding tactical formation, team-mate players, rival players, position, sport equipment (e.g., ball) and frequently engage in extremely diverse situation (e.g., basketball, soccer, and hockey) (Mann et al., 2007).

II. Review of literature

1. Cognitive function

Cognitive function has been referred to a complex mental process including perception, attention, memory, executive functioning, information processing, spatial ability, and intelligence (Tomporowski et al., 2008), which influence to various performances of the human throughout lifespan such as academic achievement (Visu-Petra, Cheie, Benga, & Miclea, 2011), driving performance (Jongen, Brijs, Komlos, Brijs, & Wets, 2011), physical fitness (Dupuy et al., 2015), and sports abilities (Mann et al., 2007; Voss et al., 2010).

Attention is multiple conceptual terms for various psychological phenomena (Styles, 2006), which has been determined into three sub-domains as alerting, orienting and the executive attention. Alerting attention is an ability to accomplish and maintain an appropriate alert state. Orienting attention is an ability to select relevant information from varieties of sensory stimuli (Raz & Buhle, 2006). Executive attention (also called selective or focused attention) refers to the ability to selectively allocate attention to relevant information and to neglect irrelevant information for the further proper response (Posner & Rothbart, 2007).

Memory is maintaining representative information reflected in thought, previous experience, or behavioral action. It is consisting of short-term and long-term memory. Short-term memory refers to temporary storage, which is limited to a certain number of chunks of information. Long-term memory is defined as informative knowledge which can be stored for long periods of time (Atkinson & Shiffrin, 1968).

Executive functions (also called executive control, the central executive, or cognitive control) has been conceptualized as a collective higher-order cognitive functioning including inhibition, self-regulation, working memory, cognitive flexibility, selective attention, decision making, and problem-solving. Generally, the components of executive functions have been identified into three sub-domains including inhibition, working memory, and cognitive flexibility (Baggetta & Alexander, 2016; Diamond, 2013; Lezak, Howieson, Bigler, & Tranel, 2012; Miyake et al., 2000). Inhibition (also called inhibitory control, action inhibition, response inhibition and impulse control) refers to the ability to suppress inappropriate response under control of attention, behavior, thoughts, and emotions (Diamond, 2013). Working memory (updating) is an ability to maintain, monitor, update, and assess the on-going information in mind for a brief moment of time, and response using relevant data (Miyake et al., 2000). Cognitive flexibility (also called mental flexibility, shifting, set shifting, switching) is the ability of perspective changing, flexible adjusting, and shifting between several mental tasks. These functions are firmly connected to another executive control such as reasoning, solving problem, planning, and making the decision (Best, Miller & Jones 2009; Diamond 2013).

According to several neuropsychological studies, there has been another sub-domain of executive control commonly utilizing tower task, mental planning, and Problem-solving. Planning is determined by organizing cognitive skill regarding time and space. (Owen, 1997). Problem-solving refers to “the process by which individuals attempt to overcome difficulties, achieve plans that move them from a starting situation to the desired goal, or reach conclusions through the use of higher mental functions, such as reasoning and creative thinking" (VandenBos, 2006, p. 735).

Information processing ability, which is an elementary cognitive task, refers to the ability to quickly automatic process and response that can be measured by processing speed and responding reaction tasks using single or multiple stimulus tasks or different speeded tasks. Reaction time has been defined as the central processing time between the onset presentation and the onset of reaction (Donders, 1969; Sternberg, 1969). It is determined as the amount of time elapsed between onset of stimulus and the onset of response. The response time reflects the time between onset of the stimulus and the completion of the related movement. Movement time is the duration of the movement phase of a response (Janssen, 2015).

Spatial ability is defined as the ability to retrieve, retain, and transform the visual information in the spatial surrounding (Halpern, 2000). It has been characterized as spatial perception, spatial visualization, and mental rotation ability. Spatial perception refers to an individual ability to determine prevalent horizontal and vertical directions in the area where distracting stimuli are showed. Spatial visualization is the ability to recognize and quantify the orientation changes in a scene (Velez, Silver, & Tremaine, 2005). Mental rotation refers to the ability to mentally rotate two- or three-dimensional stimulus in unexpected-direction (Shepard & Metzler, 1971), which is involved in problem-solving capability (Geary, Saults, Liu, & Hoard, 2000), acquisition of mathematical skill (Hegarty & Kozhevnikov, 1999), and academic knowledge (Peters, Chisholm, & Laeng, 1995).

Considering to mentioned previously, there is internally related between sub-aspect of cognition (e.g., working memory and selective attention) (Figure 1). Generally, in the process to examine the cognitions, a cognitive test assesses specifically cognitive aspects. However, cognitive function is a dynamic interactive system of multiple functions. For instance, to pay attention to sensory or internal information is controlled by selective attention, after which information becomes available for working memory. Working memory can manage data, while inhibition interrupts internal and external distractions. In working memory, the information is determined by targets and existing information which is stored in long-term memory and attending to the selective character of the environment. Information, which is manipulated, is encoded into long-term memory and learning takes place (Baars & Gage, 2010). Therefore, this would be beneficial for our understanding that one cognitive test could possibly evaluate multiple aspects of cognitive function as well.

et al., 2008).

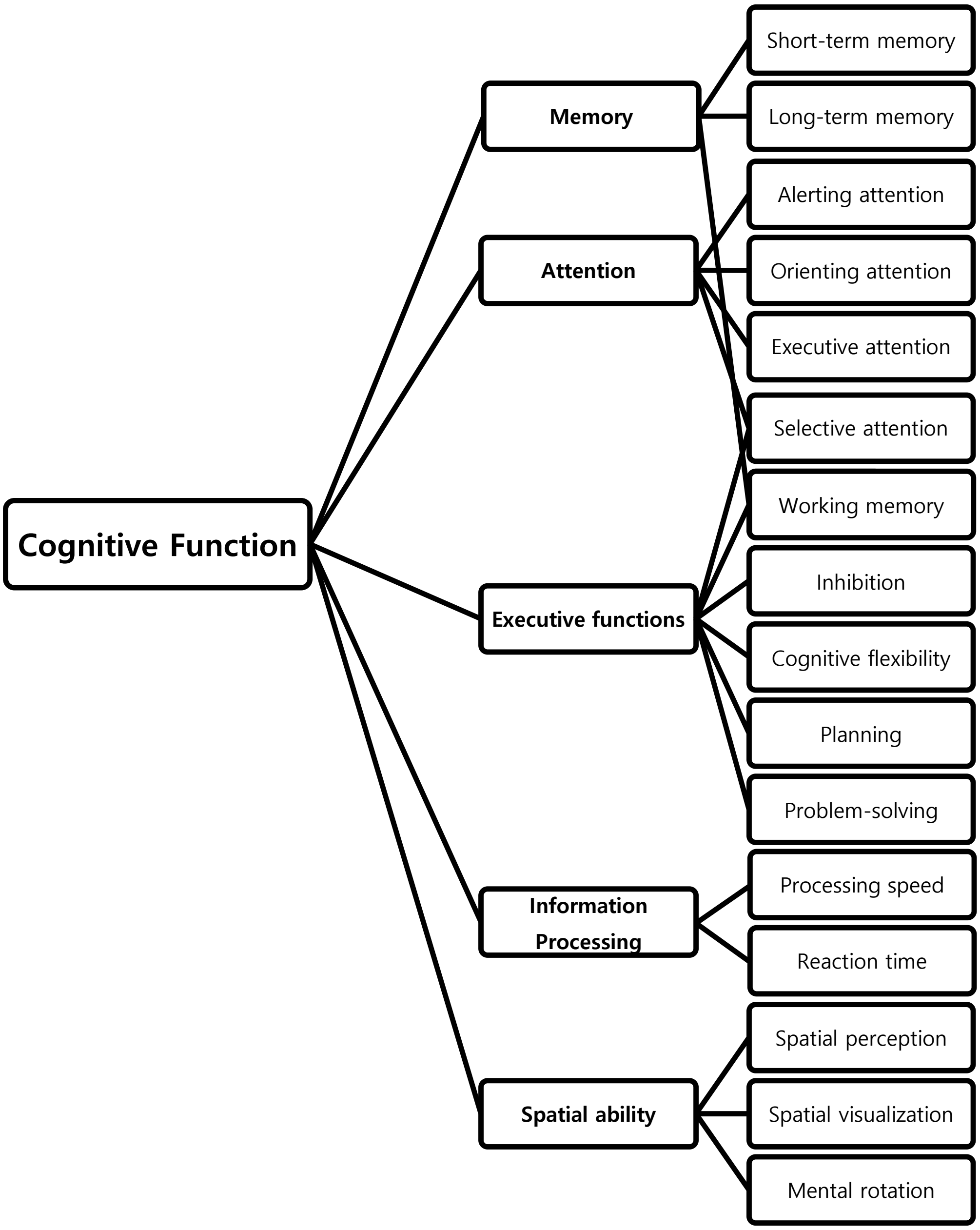

Figure 1. Model of cognitive function components (developed based on Baggetta & Alexander, 2016; Diamond, 2013; Lezak et al., 2012; Miyake et al., 2000; Tomporowski et al., 2008).

2. Cognitive function and sport performance

To reach peak performance in sports, it has been originally considered that athletes need to develop multidimensional elements including biological, physiological, psychological, technical, tactical, anthropometrical, and sociological aspects (Abbott & Collins, 2004; Baker, Horton, Robertson-Wilson, & Wall, 2003; Mohamed et al., 2009; Reilly et al., 2000). Recently, athletes have not required only excellent physical performance but also cognitive performance (Belling & Ward, 2015). Cognitive functions (executive function, cognitive flexibility, and working memory) has been identified to be related with successful performance in sports (Vestberg et al., 2012, 2017)

In sport context, the players have to perform effectively under complex mental processes (Mann et al., 2007). Empirical evidence has reported the positive links between cognitive abilities across various sports performance e.g., soccer (Huijgen et al., 2015; Vestberg et al., 2012; Verburgh et al., 2014, 2016), tennis (Wang et al., 2013), volleyball (Alves, et al., 2013), marathon (Cona et al., 2015), fencing (Bianco et al., 2017), ice hockey (Lundgren et al., 2016), gymnastics (Schmidt et al., 2016), and table tennis (Wang et al., 2016). Top-level athletes were found to display superior than novice or non-athletes across various cognitive tasks such as executive control, inhibition, working memory, mental flexibility, problem-solving, cognitive planning, decision-making, reaction time, and mental rotation ability (Cona et al., 2015; Huijgen et al., 2015; Jacobson, & Matthaeus, 2014; Lundgren et al., 2016; Vestberg et al., 2012, 2017; Wang et al., 2013). However, each sub-domain of cognitive abilities may play different role corresponding particular sports due to the differential characteristics of each sports (e.g., activity profiles, sports specific skills, environment, technical skill, type, intensity, duration of game, movement pattern, and danger from the collision) (Mitchell, Haskell, Snell, & Van Camp, 2005). For example, in strategic sports, athletes have to make the decision as rapidly and accurately that they can under complicate and unpredictable situations (Royal et al., 2006) by using relevant information such as ball position, teammates, team tactic, and opponents (Williams, Davids, Burwitz, & Williams, 1994). Whereas, boxing and fencing (interceptive or open-skill sport) athletes are required attentional skill (sustained attention or vigilance), adaptability and fast decision making in response to external cues in the unpredictable and constantly changing the environment. As well as, boxers and fencers were often in the situation requiring rapid reactions while dealing with cues or fakes intended to misdirect their attention (Bianco et al., 2017). Another sports type, shooting sport (static or closed-skill sport), which shooters are required visuomotor functions (spatial attention, scanning, and resilience to fatigue). Elite shooters can strike targets subtending less than 0.1° of visual angle, with 33 m/s beginning speed of and, in trap event, starting from unpredictable portions of space and in unpredictable directions (Di Russo, Pitzalis, & Spinelli, 2003).

As previously mentioned, there is growing evidence highlighting the importance of cognitive performances in sports. Therefore, it seems feasible that cognitive performances might be an essential factor contributing peak performance in sports.

3. Type of sport in cognitive psychological literature

Sports categories approach in perceptual-cognitive studies has been employed to examine cognitive performances in athlete participating in different type of sport. According to previous literature, type of sport can be categorized as; 1) open-closed skill sport; 2) externally paced sport and self-paced sport; and 3) interceptive, static, and strategic sports.

1. Open skill and closed-skill sports

The sports like soccer, basketball, tennis, and boxing, were classified as open skill sports because athletes are required to respond in a dynamically switching, unpredictable, and externally-paced environment (Di Russo et al., 2010). The sports like shooting, golf, running, and swimming, which players involved in the sporting events such as extremely stable, predictable pattern, and self-paced control, are determined as closed-skill sports (Di Russo et al., 2010; Voss et al., 2010,). These defined sport types were used in several studies regarding exercise and sport cognitive such as tennis and swimming (Wang et al., 2013), table tennis and bike riding or walking/jogging (Tsai, Pan, Chen, & Tseng, 2017), and badminton or table tennis, swimming or triathlon, and distance running (Chueh et al., 2017).

2. Externally paced and self-paced sports

Sports were defined as externally paced if athletes need to rapidly make the decision and adapt for reacting to external stimuli or cues in the environment (e.g., soccer, basketball, and volleyball). While, self-paced sports refer to the sports that athletes can exhibit for crucial sports performance under controllable pace without limited-time pressure (e.g., bowling, golf, and running) (Singer, 2000). A study applying these sports terminologies is Jacobson and Matthaeus (2014).

3. Interceptive, static, and strategic sports

Interceptive sports refer to the sports that athlete are required dominant-response quickly to the stimuli or objects in the environment, or opponent's attacking in combat sport by coordinating individual's body, parts of the body with holding sports equipment such racquet sport (e.g., tennis, fencing, and boxing). By contrast, static sports refers to the sports that players involved in the strongly consistent environment or self-paced events (e.g., running, swimming, and shooting) (Davids et al., 2002). Strategic sports is defined into the sports that associated to plenty information regarding tactical planning, team-mate players, rival players, position, sports equipment (e.g., ball) and frequently engage in the incredibly diverse situation (e.g., basketball, soccer, and hockey) (Mann et al., 2007). Previous researches exploring cognitive skills according to this sports types definitions are studies of Mann et al. (2007), Voss et al. (2010), Yao (2016), and Yongtawee and Woo (2017).

4. Cognitive function, athletic status, and sport expertise

Based on past findings, outstanding athletes could be determined by superior cognitive performances such as attention, executive function, and visuo-spatial ability (mental rotation ability) (Alves et al., 2013; Jansen, Lehmann, & Van doren, 2012; Voss et al., 2010). According to Singer and Janelle (1999), they summarized the cognitive aspects distinguishing expert from novice athletes, as followed.

1. Elite athletes have better knowledge on the particular task.
2. Elite athletes can determine the better meaning of extant information.
3. Elite athletes can effectively store and access information
4. Elite athletes can better identify and recall the formation of playing.
5. Elite athletes can better anticipate and predict the upcoming situation
6. Elite athletes decide more proper and faster.

Empirically, last decade literatures have accumulated to reveal that elite athletes have been found to perform superior than less-skilled athletes and non-athletes on various cognitive abilities. Mann et al. (2007) reviewed 42 studies that investigated perceptual-cognitive abilities in relation to expertise in sport. The analyses observed that elite athletes were superior to novice athletes on speed and accuracy tasks of decision-making, anticipation, spatial memory and visual search. A quantitative meta-analytic literature by reviewing 20 studies of Voss et al. (2010) examined a variety of cognitive performances between athletes and non-athletes. The cognitive functions were classified as; 1) attentional cuing; 2) processing speed; and 3) a category of varied attention paradigm.

They found that athletes exhibited significantly better on processing speed and varied attentional paradigms tasks relative to non-athletes. Vestberg et al. (2012) conducted two studies included cross-sectional and perspective designed research, primary purpose was to examine the creativity, response inhibition, and cognitive flexibility in male and female soccer players from high and low division and general population, and secondary objective was to explore if cognitive function could predict the success of sporting performance. The participants were tested by employing a design fluency test of Delis–Kaplan Executive Function System: D-KEFS (Delis, Kaplan, & Kramer, 2001) and two additional tests; color-word interference test (i.e. stroop test) and trail making test were used for confirmation of primary measurement. An analysis of variance (ANOVA) indicated a significant different on the scores of design fluency test. Both groups of soccer players had significantly better mental flexibility compared to a standardized norm group. In addition, they found that the players in the high division have superior scores compared with soccer players in the low division for both male and female athletes. Moreover, another prospective study showed positive correlation between executive functioning and soccer performances measured in goal scoring and assisting. It can conclude that cognitive function tests have a predictive property to success in team sport. Other studies, such as that by Jacobson and Matthaeus (2014) aimed at investigating the association between athletic status (athletes and non-athletes) and sub-components of executive functioning (i.e., inhibition, decision making, mental processing speed, and intelligence) using color–word interference test, tower test of D-KEFS (Delis et al., 2001), digit symbol substitution test (DSST; Wechsler, 1997), and vocabulary tests: WAIS-III (Davis, Pierson,

& Finch, 2011). The authors found that the athletes were better than non-athlete controls on inhibition and problem-solving, but there was no statistically significant difference on decision making, mental processing speed and intelligent abilities. In a study exploring sport and perceptual-cognition relationship performed by Alves et al. (2013), the professional volleyball players exhibited faster responding of two inhibition tasks, switching and stopping task, and better visuo-spatial attention in comparison with non-athletes. Huijgen et al. (2015) conducted an neuropsychological research to examined the cognitive function in elite and sub-elite youth soccer by administrating seven tasks of executive processes which were grouped into higher-level (i.e., working memory, inhibitory control, cognitive flexibility, and metacognition) and lower-level (i.e., reaction time and visuo-perceptual abilities) of executive functions. The significant differences were only found in metacognition, inhibitory control, and cognitive flexibility (higher-level cognitive tasks), but not found on lower-level cognitive functions which elite youth soccer players were superior. However, two multivariate analysis of covariance (MANCOVA) which weekly training hours variable was taken into account as covariate revealed the remaining significant different between elite and sub-elite youth players was only on inhibitory control and cognitive flexibility, but was not metacognition. Cona et al. (2015) used a battery of computerized executive tests included inhibition task and dual-task paradigm, before an ultra-marathon competition. The finding revealed the running performance was significantly related to action inhibition skills which faster runners were greater to slower runners. A recent published finding investigated executive abilities in ice hockey players compared with norms of the standardized sample using design fluency and trail making task of D-KEFS test battery. Results showed that athletes scored significantly higher on executive performance as assessed by design fluency task, but not on trail making test. However, the different between expert players and lower-division hockey players was not found (Lundgren et al., 2016). The further evidence evaluated inhibitory control, attention and visuo-spatial working memory in youth soccer athletes, suggesting young highly talented soccer players performed faster and more efficient only on action inhibition and alerting attention than age-matched amateur soccer players (Verburgh et al., 2014).

Spatial ability has been proven to be one of crucial aspects of cognitive abilities in sports. A number of studies investigating spatial performance using mental rotation test revealed that athletes in various sports (e.g., fencers, gymnast, handball players, orienteers, and soccer players) had better mental rotation skill than non-athletes (Jansen & Lehmann, 2013; Ozel, Larue, & Molinaro, 2002, 2004; Schmidt et al., 2016).

One significant cognitive skill, along with others, is information processing abilities. Mori et al. (2002) examined the speed of mental processing measuring simple and choice reaction time tests in karate athletes. The significant difference was found on only choice reaction time between the karate athletes and novices. A study using simple and Go/Nogo reaction time task showed that the athletes who involved in basketball and baseball were significantly faster on both tasks of reaction times relative to non-athletes (Nakamoto & Mori, 2008). Another study offered by Shadmehr, Padash, and Arsalan (2017) that explore reaction time and anticipation abilities in soccer players and non-athletes. The athletes were observed to respond shorter on auditory and visual choice reaction time as compared to sedentary.

5. Cognitive function and type of sport

Physical training has positively affected to development of cognitive abilities (Colcombe & Kramer, 2003; Hillman, Erickson, & Kramer, 2008). These improvements are due to the prolonged participating in fitness training which changing structure and functions of human brain (Colcombe & Kramer, 2003; Kramer & Erickson, 2007). Furley and Memmert (2011) also suggested that regular sport practicing could enhance general cognitive function, which is related to non-sport context. However, the differential effects of participation in various sports domain on cognitive abilities were shown in previous findings.

An interventional study of Moreau et al. (2012) examined the effect of a 10-month training program on spatial abilities in wrestlers and runners. Mental rotation test of Vandenberg and Kuse (1978) was administered at before and after participation of sport practicing. The posttest result indicated that the wrestling group exhibited more beneficial of mental rotation abilities to running group. The results of investigation regarding sport types-cognitive functioning paradigm seem to support Moreau et al. (2012)'s finding. A meta-analytic article by Voss et al. (2010) reported the difference in processing speed task across types of sport that athletes from interceptive and strategic sports (also referred to open skill sport) outperformed static sports athletes (closed skill sport). Other studies using different definition of sport types, externally-paced sports athletes performed more accurately on problem solving task compared to self-paced sports athletes and non-athletes, whereas the better in the task of inhibitory control was observed in athletes from self-paced sports events (Jacobson & Matthaeus, 2014). A finding of Wang et al. (2013) showed a statistically significant difference on inhibition task, as compared to swimmers (closed-skill sport), the tennis players (open skill sport) were superior. Nuri, Shadmehr, Ghotbi, and Moghadam (2013) investigated reaction time and anticipatory skill in open and closed skill-dominated sport. The volleyball (open skill sport) players and sprinters (closed-skill sport) performed computerized sensory-cognitive tasks consisting visual choice reaction time, visual complex choice reaction time, auditory choice reaction time, auditory complex choice reaction time, and anticipatory ability. The finding revealed that sprinters were faster on both auditory reaction times tests, whereas volleyball players were faster on anticipatory abilities tasks. Emerging cognitive research by Yongtawee and Woo (2017) demonstrated that the choice reaction time in male athletes involving interceptive sport was significantly accelerated as the training experience increases. In contrast to, long-term participating in static sport in men was statistically related to slower of mental processing speed ability, by performing digit symbol substitution task, as shown in Figure 2. These finding suggest that prolonged extensive training in certain sport could essentially develop the unique domain of the cognitive function.

However, there were some contradictory findings, a study of Jansen and Lehmann (2013) assessing mental rotation performance in soccer, gymnastics, and non-athletes. The significant difference was not observed between athletes form both sports, but only gymnasts showed superior mental rotation ability to non-athletes. As well as, the sport type’s differences between open skill (e.g., badminton and table tennis) and closed-

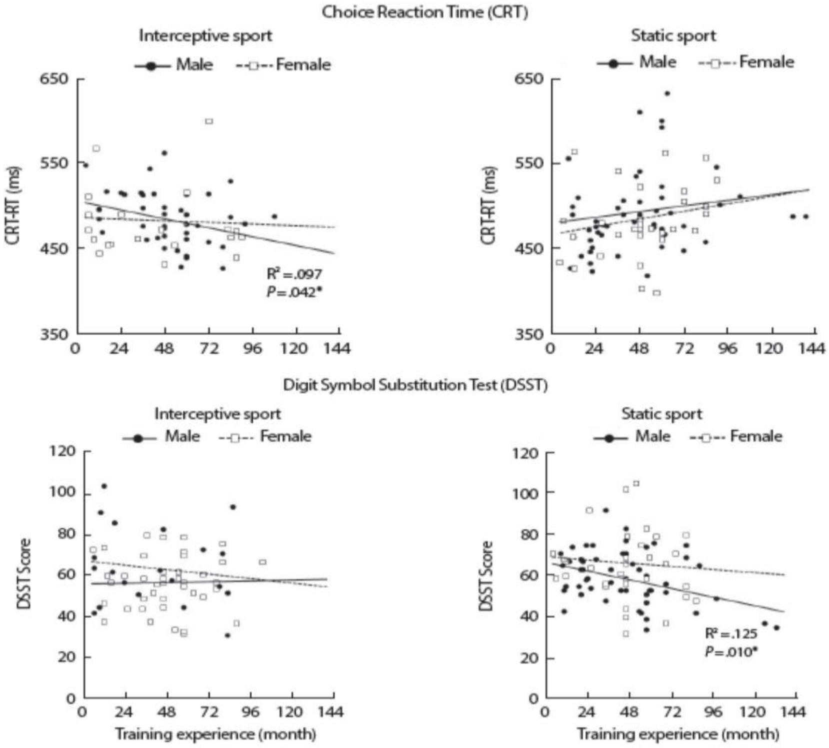

Figure 2. Scatter plot of training experience and information processing abilities of interceptive and static sport athletes (Yongtawee & Woo, 2017).

skill (e.g., swimming, triathlon, and running) athletes were not found on abilities of visuo-spatial attention and memory (Chueh et al., 2017). Although, previous research revealed inconsistent enhancements of cognitive abilities which were related to certain sport involvement. However, the study examining the association between a series cognitive function (motor inhibition, cognitive flexibility, mental processing and mental rotation ability) and three different types of sports including boxing (interceptive sport), shooting (static sport) and soccer (strategic sport), has not been investigated. Additionally, it is still unclear that which type of sport could perform better on mental rotation ability.

III. Study 1: The Role of Cognitive Function in Sports: A Systematic Review

Method

This systematic review literature was conducted in accordance with the Preferred Reporting Items for Systematic reviews and Meta-Analysis protocol: PRISMA (Moher et al., 2015).

1. Information sources and search strategy

The relevant literatures from 2008-2018 were explored through five electronics databases including PubMed, Web of Science, Science Direct, Wiley Online Library, and Taylor & Francis Online. For further potential studies, searches of reference lists and Google scholar were additionally conducted. The last search was performed on April 2018. The search terms were following these keywords: “cognition, cognitive function, cognitive performance, cognitive ability, attention, memory, executive function, executive functioning, executive control, inhibition, inhibitory control, working memory, cognitive flexibility, shifting, switching, planning, information processing, mental processing, processing speed, reaction time, spatial ability, visual-spatial ability, spatial visualization, spatial orientation, mental rotation" and "sport, sport expertise, sport performance, expert athlete, elite athlete, type of sport".

2. Selection criteria and study selection

The study selection was performed based on the following eligibility criteria; 1) study design criterion: observational (cross-sectional) or interventional studies; 2) language criterion: article was written in English; 3) participant criterion: the subjects were aged 8-35 years who had no any mental or brain problems and; 4) measurement criterion: studies examined at least one cognitive performance; 5) group comparison criterion: studies must compare cognitive ability between a minimum of two different groups according to athletic status or sport expertise or sport type (athletes and non-athletes, or expert and novice athletes, or talented and non-talented athletes, or closed-skill and open skill sport). The exclusion criteria: studies were excluded if they did not meet all inclusion criteria. Subsequently, eligibility evaluations of articles' title and abstract for final inclusion were screened by the reviewer.

3. Data Extraction

Relevant information was extracted including first author, year of publication, participants' demographics (sample size, gender, age, sports experience, athletic status or sports expertise or types of sport), cognitive measurement, cognitive domain, and key findings. With regard to the outcome of interest, cognitive function components were categorized into five aspects including attention, memory, executive function, information processing, and spatial ability. Sub-domain was generated within two domains of executive functions (i.e., inhibition, working memory, cognitive flexibility, and planning & problem-solving) and information processing (i.e., processing speed and reaction time). In addition, one author of the article was contacted for further information.

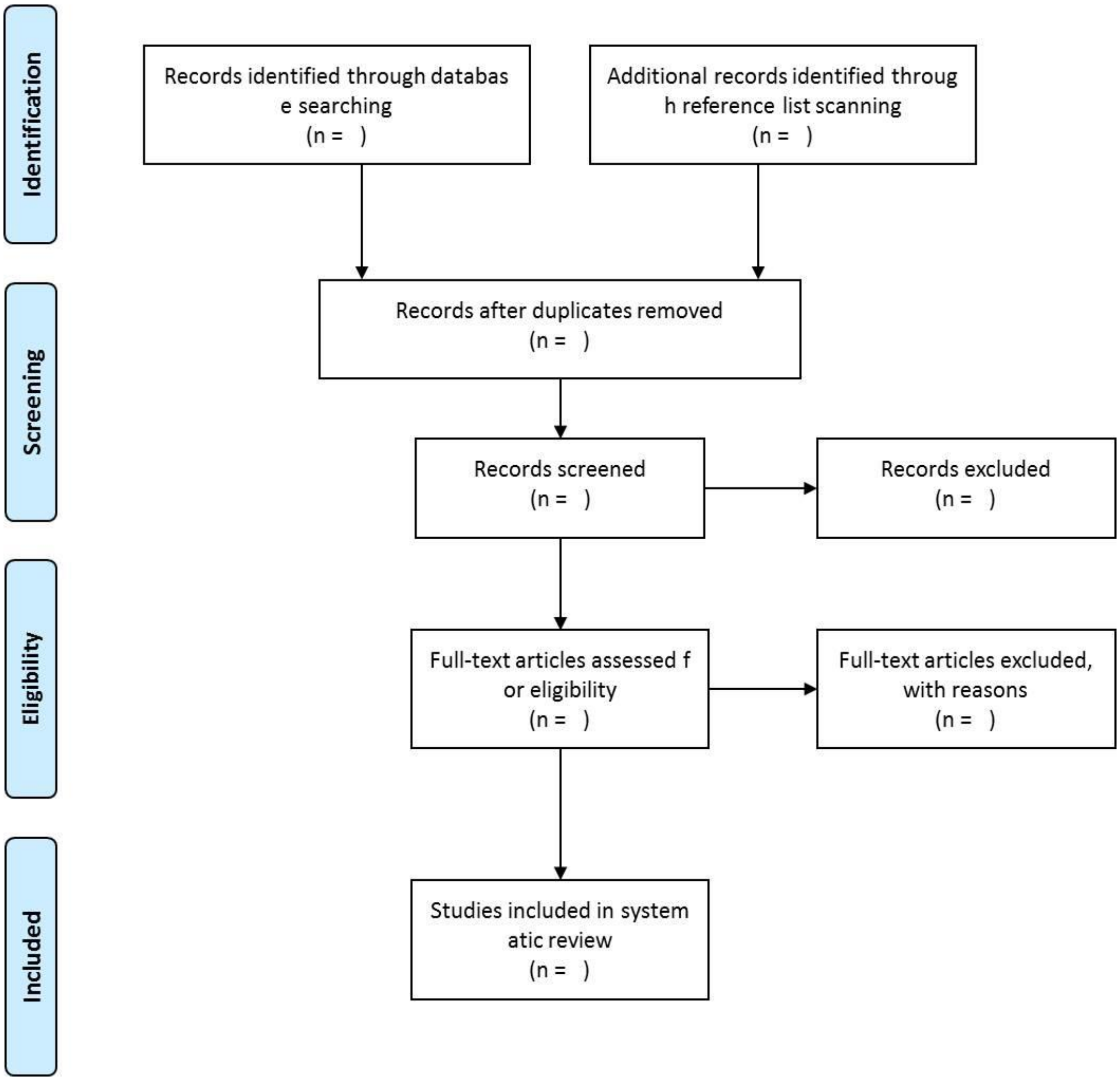

Figure 3. Schematic illustration of the flow diagram of systematic review.

4. Preliminary summary of literature review

This study has systematically reviewed the previous literature conducting the cognitive function in sport. The associated critical information(i.e., participants' characteristics, sample size, athletic status or sport expertise or types of sport, outcome(s) of interest, and measurements of cognitive functioning and results of studies) were extracted (Table 1).

Table 1. *The summary of preliminary literature review.*

Author (year & study no.)	**Participant, sample size, gender**	**Age** (mean or range)	**Skill level**	**Sport experience** (year)	**Measurements (Outcome of interest)**	**Summary results**
Nakamoto(2008) [1]	N = 57 Basketball (n=20; M) Baseball (n=24; M) Non-athletes (n=13; M)	 20.80 20.17 21.46	 Collegiate Collegiate -	 9.20 8.96 -	1. Simple reaction time (information processing) 2. Go/NoGo reaction time (inhibition)	1. Basketball and baseball players outperformed non-athletes on simple RT and Go/NoGo RT. 2. No difference between basketball and baseball players.
Memmert (2009) [2]	N = 120 Team sport (n=40; M=20, F=20) Non-team sport (n=40; M=20, F=20) Novice athletes (n=40; M=20, F=20)	 24 25 23	 Elite Elite Novice	 > 10 > 10 < 2	1. Functional field of view (attention) 2. Multiple Object tracking task (attention) 3. Inattentional blindness (attention)	No significant difference between groups on three attention tasks.

Author (year & study no.)	**Participant, sample size, gender**	**Age** (mean or range)	**Skill level**	**Sport experience** (year)	**Measurements (Outcome of interest)**	**Summary results**
Furley (2010) [3]	N = 112 Basketball players (n=54; M) Non-athletes (n=58; M)	24.8 - -	 Collegiate -	 > 10 -	Corsi block-tapping Task (working memory)	No significant difference between groups.
Chaddock (2011) [4]	N = 36 Athletes (n=18; M=8, F=10) Non-athletes (n=18; M=5, F=13)	 20.6 21.5	 Collegiate -	 - -	Simple reaction time (information processing)	Athletes responded faster than non-athletes
Chan (2011) [5]	N= 60 Fencing (n=30; M=15, F=15) - High-fit & Averagely-fit fencers Non-fencing (n=30; M=15, F=15) - High-fit & Averagely-fit non-fencers	(M, F) 21.07, 20.53 20.07, 20.87	 Experienced -	 ≥ 5 -	1. Simple reaction time (information processing) 2. Go/no-go reaction time (inhibition)	1. High-fit fencers had lower commission errors of go/no-go RT in comparison to high-fit non-fencers 2. No significant differences between fencers and non-fencers on SRT and go/no-go RT.
Cojocariu (2011) [6]	N = 73; Qwan Ki Do National athletes (n=8; M) Beginner athletes (n=18; M) Non-athletes (n=47; M)	(Range) 24-33 18-27 20-24	 Elite Novice -	 10 < 1 -	1. Simple RT (information processing) 2. Choice RT using dominant, non-dominant, and both hands (information processing)	1. Elite athletes had faster on choice RT than novice and non-athletes. 2. No significant difference on simple RT between 3 groups.

Author (year & study no.)	**Participant, sample size, gender**	**Age** (mean or range)	**Skill level**	**Sport experience** (year)	**Measurements (Outcome of interest)**	**Summary results**
Jansen (2012) [7]	N = 40 Soccer (n=20; M) Non-athletes (n=20; M)	 23.70 25.25	 Collegiate -	 - -	Mental rotation test (spatial ability) using abstract stimuli (cubes figures), and embodied stimuli (human figures and body postures)	Soccer players showed faster response time of mental rotation ability using embodied stimuli than non-athletes.
Moreau (2012) [8]	N = 62 Wrestlers (n=31; M=18, F=13) Runners (n=31; M=18, F=13)	 20.60 20.90	 Novice -	 - -	Mental rotation test (spatial ability)	Wrestlers were better than runners on mental rotation ability at after 10 months of specific sport involvement.
Vestberg (2012) [9]	N=57; Soccer High division (n=29; M=14, F=15) Low division (n=28; M=17, F=11)	 25.30 22.80	 Elite Sub-elite	 - -	1. Design fluency task (cognitive flexibility) 2. Color-word interference test (inhibition) 3. Trail making test (cognitive flexibility)	High division soccer players performed better than lower division soccer players on executive functions.
Alves (2013) [10]	N = 154 Volleyball (n=87) - Adult athletes (n=30; M=21, F=9) - Junior athletes (n=57; M=24, F=33)	(M, F) 24.85, 20.55 17.58, 16.27	 - -	(M, F) 11.61, 9.66 5.25, 5.43	1. Task switching task (switching) 2. Stopping task (response inhibition) 3. Flanker task (inhibition).	1. Athletes were better than controls on switching. 2. Athletes responded faster than controls on stopping task.

Author (year & study no.)	**Participant, sample size, gender**	**Age** (mean or range)	**Skill level**	**Sport experience** (year)	**Measurements (Outcome of interest)**	**Summary results**
	Non-athletes (n=67)				4. Change detection task (working memory)	3. Junior athletes responded faster than junior controls on stopping task.
	- Adult controls (n=27; M=18, F=9)	23.33, 21.55	-	-		4. Female athletes responded faster than female controls on flanker task.
	- Young controls (n=40; M=18, F=22)	17.33, 16.45	-	-		5. Athletes responded faster than non-athletes on change detection task. 6. Female athletes responded faster than female controls on change detection task.
Jansen (2013) [11]	N = 120	(M, F)		(M, F)	Mental rotation test using 2 stimulus (cubes figure and human figures)	1. Gymnasts performed better mental rotation performance than non-athletes 2. All participants performed higher accuracy rate on human stimuli compared to cubed stimuli.
	Soccer (n=40; M=20, F=20)	24, 23.55	-	16.15, 12.05		
	Gymnasts (n=40; M=20, F=20)	23.8, 21.8	-	13.5, 9.2		
	Non-athletes (n=40; M=20, F=20)	24.55,23.15	-	3, 1.85		
Lesiakowski (2013) [12]	N = 30				Visual stimulus discrimination (selective attention)	No significant difference between boxers and controls on visual stimulus discrimination task.
	Boxers (n=15; M=10, F=5)	20.40	Elite & novice	6.80		
	Non-athletes (n=15; M=10, F=5)	21.09	-	-		

Author (year & study no.)	**Participant, sample size, gender**	**Age** (mean or range)	**Skill level**	**Sport experience** (year)	**Measurements (Outcome of interest)**	**Summary results**
Nuri (2013) [13]	N = 22 Open skilled; Volleyball (n=11; F) Closed-skill; Sprinters (n=11; F)	 21.64 22.91	 Collegiate Collegiate	 4.31 4.27	1.Visual complex choice RT 2.Auditory and auditory complex choice RT (information processing)	1. Sprinters were better in auditory choice RT. 3. No significant differences between groups both choice RT.
Wang (2013) [14]	N = 60 Open skill; tennis (n=20; M) Closed-skill; Swimming (n=20; M) Non-athletes (n=20; M)	 20.70 19.31 20.40	 Collegiate Collegiate -	 5.50 4.85 -	Stop-signal task (inhibition)	Tennis players were superior to swimmers and non-athletes.
Cojocariu (2014) [15]	N = 28 Judo (n=8; M) Non-athletes (n=20; M)	 21-25 18-24	 Elite -	 >10 -	1. Simple RT (information processing) 2. Choice RT using dominant, non-dominant, and both hands (information processing)	No significant difference on simple and choice RT between judo athletes and controls.
Jacobson (2014) [16]	N = 54 Athletes (n = 39) - Externally paced sports (n=22; M=14,F=8)	 20.05	 High and less skilled	 -	1. Tower test (planning & problem-solving) 2. Color-Word interference test (inhibition)	1. Athletes were superior to non-athletes on inhibition, planning and problem solving.

Author (year & study no.)	**Participant, sample size, gender**	**Age** (mean or range)	**Skill level**	**Sport experience** (year)	**Measurements (Outcome of interest)**	**Summary results**
	- Self-paced sports (n=17; M=3, F=14)	20.18		-	3. Digit symbol substitution test (processing Speed)	2. Inhibition task Self-paced > externally paced > non-athletes.
	Non-athletes (n=15; M=6, F=9)	20.20	-	-	4. Vocabulary test (intelligence)	3. Planning & Problem-solving. Externally paced > self-paced > non-athletes.
Verburgh (2014) [17]	N = 126				1. Stop signal task (inhibition)	1.Talented players were better than amateur players on inhibition
	Talented soccer (n=84; M)	11.90	Talented	-	2. Visuo-spatial working memory (working memory)	2. Talented players were superior to amateur players on alerting attention.
	Amateur soccer (n=42; M)	11.80	Non-talent	-	3. Attention network test (attention)	
Huijgen (2015) [18]	N = 88				1. Trail making test (cognitive flexibility)	Elite soccer players were better than sub-elite soccer players on inhibition, and cognitive flexibility.
	Elite youth soccer (n=47; M)	15.48	Elite youth	9.80	2. Stop signal task (inhibition)	
	Sub-elite youth soccer (n=41; M)	15.15	Sub-elite youth	9.30	3. Backward visual memory span (working memory)	
					4. Design fluency test (cognitive flexibility)	

Author (year & study no.)	**Participant, sample size, gender**	**Age** (mean or range)	**Skill level**	**Sport experience** (year)	**Measurements (Outcome of interest)**	**Summary results**
Wang (2015) [19]	N = 25 Badminton (n=12; F) Non-athletes (n=13; F)	 20.58 19.07	 Elite -	 6.58 -	1. Visuo-spatial task: non-delay (attention) 2. Visuo-spatial task: delay (working memory)	Athletes responded faster than controls on visuo-spatial attention and working memory tasks.
Alesi (2016) [20]	N = 44 Young soccer players (n=24; M) Young non-athletes (n=20; M)	 8.78 9.25	 Novice -	 - -	1. Forward digit span tests (short-term memory) 2. Backward digit span tests (working memory) 3. Corsi block tapping test (working memory) 4. Visual discrimination task (attention) 5. Tower of London (planning & problem solving)	Young soccer players showed better cognitive abilities of working memory, attention, planning and problem solving, than non-athletes after 6 months of interventional soccer training program.
Heppe (2016) [21]	Study 1; N = 60 Elite handball & soccer (n=30; F) Recreational athletes (n=30; M=17, F=13)	 23.20 21.70	 Elite Recreational	(Range) 7-21 -	Mental rotation task using human figures (spatial ability)	No significant difference between two groups on accuracy and response time of mental rotation task.

Author (year & study no.)	**Participant, sample size, gender**	**Age** (mean or range)	**Skill level**	**Sport experience** (year)	**Measurements (Outcome of interest)**	**Summary results**
	Study 2; N = 54				Mental rotation task using three-dimensional human stimuli (spatial ability)	1. Elite athletes responded shorter on mental rotation task than novices. 2. No significant difference between groups on accuracy of mental rotation task.
	Elite volleyball & handball (n=27; M=15, F=12)	24.60	Elite	-		
	Recreational athletes (n=27; M=15, F=12)	23.90	Recreational	-		
	Study 3; N = 52				1. D2-R test (sustained attention) 2. Zahlen Verbindungs test (processing speed and divided attention) 3. KAI-N test: Memory span (intelligence)	Elite athletes performed better than recreational athletes on sustained attention.
	Elite volleyball & soccer (n=26; M=13, F=13)	21.90	Elite	-		
	Recreational athletes (n=26; M=15, F=11)	20.00	Recreational	-		
Lundgren (2016) [22]	N = 48	23.70			1. Design fluency task (cognitive flexibility) 2. Trail making test; number-letter switching (cognitive flexibility, visual scanning)	1. Level A players had higher scores of design fluency task compared with the standardized sample 2. No significant difference between level A and B players on DFT and TMT
	Ice hockey : Level A (n=29; M)	-	Elite	-		
	Ice hockey : Level B (n=19; M)	-	Sub-elite	-		

Author (year & study no.)	**Participant, sample size, gender**	**Age** (mean or range)	**Skill level**	**Sport experience** (year)	**Measurements (Outcome of interest)**	**Summary results**
Martin (2016) [23]	N = 20				A modified color-word stroop task (inhibition)	The professional cyclists performed better on accuracy rate of stroop task than recreational cyclists.
	Professional cyclists (n=11; M)	23.40	Elite	> 5		
	Recreational cyclists (n=9; M)	25.60	Novice	2		
Schmidt (2016) [24]	N = 80				Mental rotations test (spatial ability)	Orienteers and gymnasts were better than non-athletes.
	Gymnasts (n=20; M=10, F=10)	27.15	Collegiate	14.20		
	Orienteers (n=20; M=10, F=10)	26.20	Collegiate	10.80		
	Runners (n=20; M=10, F=10)	25.95	Collegiate	8.35		
	Non-athletes (n=20; M=10, F=10)	23.60	-	1.38		
Verburgh, (2016) [25]	N = 168				1. Stop signal task (motor inhibition) 2. Digit span forwards (memory) 3. Digit span backwards (working memory) 4. Attention network test (alerting, orienting, and executive attention)	1. Elite soccer players had better on inhibition than non-elite soccer players and non-athletes. 2. Elite soccer players had better on memory than non-athletes. 3. Elite and non-elite soccer players had better on working memory than non-athletes.
	Elite soccer (n=69; M)	10.60	Young elite	-		
	Non-elite soccer (n=48; M)	10.50	Young novice	-		
	Non-athletes (n=51; M)	10.40	-	-		

Author (year & study no.)	**Participant, sample size, gender**	**Age** (mean or range)	**Skill level**	**Sport experience** (year)	**Measurements (Outcome of interest)**	**Summary results**
Wang (2016) [26]	N = 65				Attention network test (alerting, orienting, and executive attention)	Table tennis athletes exhibited better on executive attention compared to non-athletes.
	Table tennis (n=31; M=20, F=11)	21.90	Elite	≥ 5		
	Non-athletes (n=34; M=20, F=14)	21.91	-	-		
Yao (2016) [27]	N = 64				1. Stop signal task (inhibition) 2. Task-switching (shifting) 3. Change detection task (working memory) 4. Iconic memory test (memory) 5. Attentional network test (attention)	1.Basketball athletes were better on inhibition than fencers, swimmers and non-athletes 2. Swimmers were more efficient on shifting ability than fencers. 3. Basketball athletes and fencers had higher accuracy rate of memory task than non-athletes. 4. Fencers and swimmers were superior to non-athletes on orienting attention task.
	Swimming; Static; (n=19; M=11, F=8)	20.00	Elite	8.20		
	Fencing; Interceptive, (n=14; M=8, F=6)	19.60	Elite	6.10		
	Basketball; Strategic (n=15; M=7, F=8)	20.10	Elite	8.60		
	Non-athletes (n=16; M=8, F=8)	20.20	-	-		
Bianco (2017) [28]	N = 39				Go/No-go task (response inhibition)	1. Elite fencers and boxers were faster than non-athletes. 2. Fencers were more accurate than boxers.
	Fencers (n=13; M=8, F=5)	29.40	Elite	11.70		
	Boxers (n=13; M=11, F=2)	25.50	Elite	11.20		
	Non-athletes (n=13; M=10, F=3)	28.50	-	-		

Author (year & study no.)	**Participant, sample size, gender**	**Age** (mean or range)	**Skill level**	**Sport experience** (year)	**Measurements (Outcome of interest)**	**Summary results**
Chang (2017) [29]	N = 60				1. Stroop test (inhibition)	No significant differences on any cognitive performances between three groups.
	Marathon (n=20; M=14, F=6)	21.20	Elite	7.75	2. Wisconsin card sorting test (shifting)	
	Wushu (n=20; M=15, F=5)	21.15	Elite	8.55		
	Non-athletes (n=20; M=13, F=7)	21.60	-	0.90	3. Tower of London task (planning and problem solving)	
Chiu (2017) [30]	N = 31				Flanker task (inhibition)	Volleyball players scored higher accurate rate of flanker task than athletes from running and swimming, and non-athletes.
	Volleyball (n=11; M=6, F=5)	23.36	Collegiate	-		
	Running & swimming (n=12; M=6, F=6)	21.50	Recreational	-		
	Non-athletes (n=8; M=3, F=5)	21.75	-	-		
Feng (2017) [31]	N = 47			(Range)	Mental rotation task (spatial ability)	Elite divers exhibited faster response time of mental rotation task than non-athletes
	Diving (n=24; M=11, F=13)	14.41	Elite	8-13		
	Non-athletes (n=23; M=11, F=12)	13.91	-	-		
Liao (2017) [32]	N = 57				Stop signal task (inhibition)	Badminton players were better than non-athletes on inhibition.
	Badminton (n=42; M=28, F=14)	22.70	Elite	11.2		
	Non-athletes (n=15; M=7, F=8)	26.10	-	-		

Author (year & study no.)	**Participant, sample size, gender**	**Age** (mean or range)	**Skill level**	**Sport experience** (year)	**Measurements (Outcome of interest)**	**Summary results**
Lesiakowsi (2017) [33]	N = 119				1. Simple RT (information processing) 2. Choice RT (information processing) 3. Visual stimulus discrimination (selective attention)	1. Volleyball and soccer players had shorter on simple RT and choice RT task compared to boxers, rowers, and non-athletes. 2. Volleyball players had higher accuracy rate of visual stimulus discrimination than boxers and non-athletes. 3. Soccer players and rowers had higher accuracy rate of visual stimulus discrimination than non-athletes 4. Volleyball and soccer players had shorter detection times of visual stimulus discrimination compared to boxers.
	Soccer (n=24; M)	20.25	Elite	6.54		
	Volleyball (n=22; M)	21.92	Elite	8.14		
	Boxing (n=26; M)	20.16	Elite	6.03		
	Rowing (n=23; M)	20.83	Elite	6.82		
	Non-athletes (n=24; M)	20.14	-	-		
Vestberg (2017) [34]	N = 30				1. demanding working memory (working memory) 2. Design fluency task (cognitive flexibility) 3. Colour-Word interference test (inhibition)	1. Young elite soccer players had higher ability of working memory and cognitive flexibility than normal population. 2. Significant correlation between demanding Working Memory and Design Fluency task and soccer performance
	Young soccer players (n=30; M)	14.93	Elite	-		
	* Compared with age-matched normative data					

Author (year & study no.)	**Participant, sample size, gender**	**Age** (mean or range)	**Skill level**	**Sport experience** (year)	**Measurements (Outcome of interest)**	**Summary results**
					4. Trail making test (scanning ability, shifting)	(Goals number and assisting during the season)
Wang (2017) [35]	N = 36 Open-skill; badminton (n=18; M) Closed-skill; track & field and dragon boat (n=18; M)	 20.77 20.61	 Collegiate Collegiate	 ≥ 6 ≥ 7	Flanker task (inhibition)	Badminton players (open skill sport) performed faster and less variable responses on the flanker task than closed skill athletes.
Yu (2017) [36]	N = 54 Open-skill; badminton (n=18; M=10, F=8) Closed-skill; track & field (n=18; M=11, F=7) Non-athletes (n=18; M=9, F=9)	 21.10 21.10 21.80	 Elite Elite -	 11.30 7.90 -	1. Task-switching: proactive and reactive control task (shifting) 2. Simple reaction task (information processing)	1. Open skill athletes performed better than closed-skill athletes and non-athletes on proactive control of task-switching task. 2. Open and closed-skilled athletes performed better than non-athletes on reactive control of task-switching.
Brevers (2018) [37]	N = 52 Fencing & taekwondo (n=27; M=23, F=4) Non-athletes (n=25; M=22, F=3)	 19.21 20.07	 Elite -	 10.64 -	Stop signal task (inhibition) - Proactive and reactive motor response inhibition	1. Athletes performed better reactive inhibition performance than non-athletes. 2. Athletes exhibited higher proactive inhibition than non-athletes.

Result

1. Overview of search results

As shown in PRISMA flow diagram (Figure 4), the overall search initially identified 251 articles and 59 duplicated studies were removed. After reviewing the titles and abstracts, there were 60 articles which were screened using full eligibility criteria. Finally, 37 full-text articles were retained for qualitative synthesis review. Twenty-three studies were excluded due to did not meet the inclusion criteria such as, participants had a history of mental disorder or brain injury (n = 11), review literature (n = 5), subjects were older than 35 years old (n = 4), no group comparison studies (n = 2), and non-English article (n = 1).

2. Study characteristics

Of 37 included studies, 22 studies examined the relationship between cognition and athletic status or sports expertise, 3 studies investigated the cognitive function across sports types, 12 studies explored both associations between cognition and sports expert, and between cognition and types of sport. Sample sizes have ranged from 22 to 168.

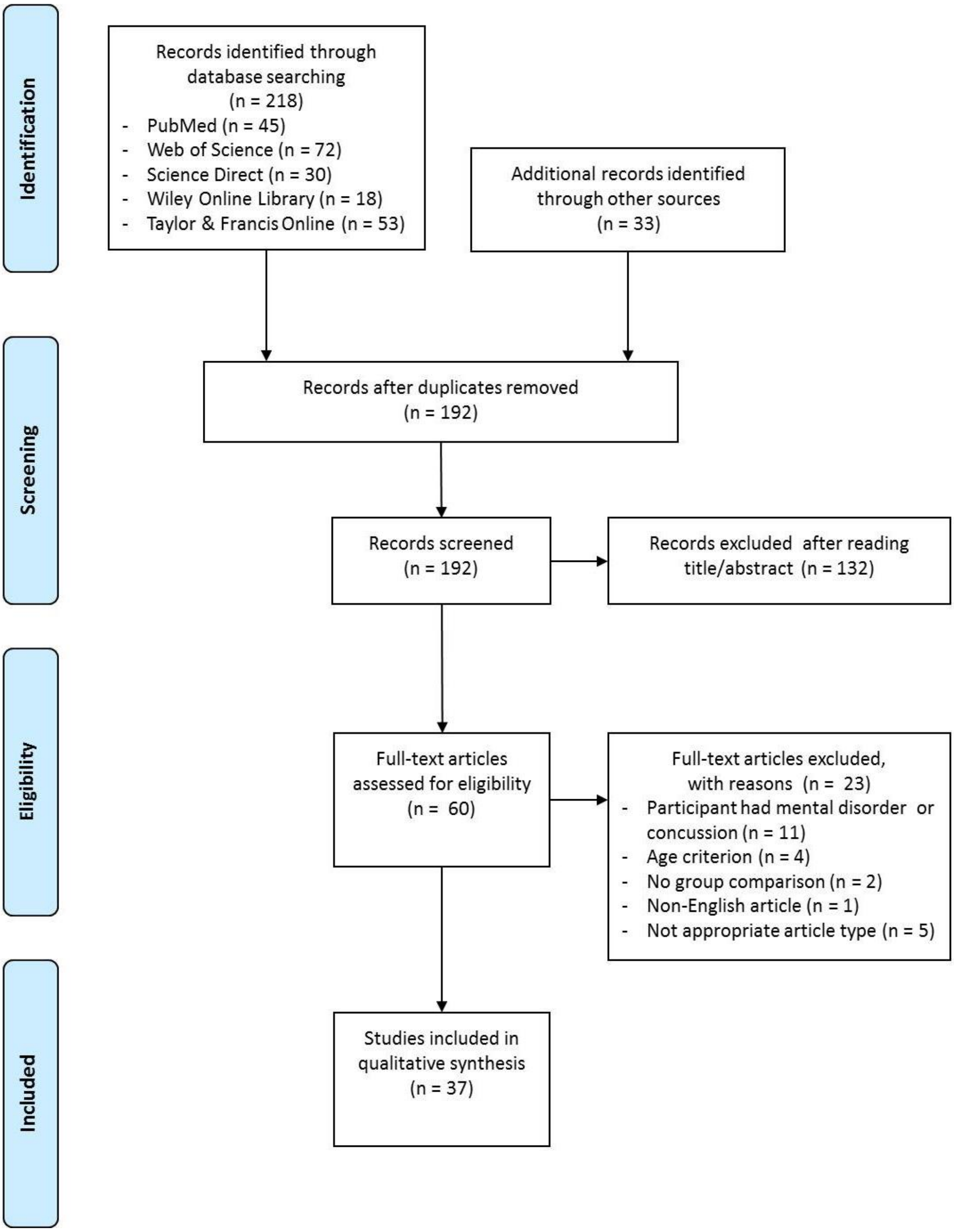

Figure 4. PRISMA flow diagram of study selection.

Participants in total were 2,504 which consisting athletes 74.3%, non-athletes 25.7%, and male 72.3%, female 27.7%. Participants' average age ranged from 8.78 to 29.4 years old. With regard to gender, the combination of male and female participants was examined in 20 studies, 15 studies included only male participants, and the remaining two studies assessed female only. Experience in sports of athletes ranged from 1 - 21 years. This review article has included 17 studies employing single cognitive performance, whereas multiple cognitive tasks were conducted in the rest of studies. Most of studies examined executive functions (inhibitory control, working memory, and twitching).

3. Assessment of cognitive function

Twenty-seven different cognitive tools were employed to evaluate five major cognitive domains including attention, memory, executive function, information processing, and spatial ability. Executive controls consisting of five sub-domains such as action inhibition, working memory, mental flexibility, planning, and problem solving were the most of cognitive outcome measurement utilizing in 24 studies, as presented in Table 2.

Table 2. *Summary of cognitive domain, sub-domains, measurements, and related studies.*

Domain	Sub-domain	Measurement	Study no.
Attention		The Functional field of view test	2
		Multiple object tracking test	2
		Inattentional blindness test	2
		Visuo-spatial attention test	19
		Attention network test	17, 25, 26, 27
	Selective attention	Visual discrimination test	12, 20, 33
	Sustained attention	d2-R test	21
Memory		Digit span forward test	20, 25
		Iconic memory test	27
Executive function	Inhibition	Stop signal test	10, 14, 17, 18, 25, 27, 32, 37
		Stroop test	9, 16, 23, 29, 34
		Flanker test	10, 30, 35
		Go/Nogo test	1, 5, 28
	Working memory	Visuo-spatial working memory test	17, 19
		Digit span backward test	18, 20, 25
		Demanding working memory test	34
		Corsi Block-tapping test	3, 20
		Change detection test	10, 27
	Cognitive flexibility	Design fluency test	9, 18, 22, 34
		Trail making test	9, 18, 22, 34
		Task switching	10, 27, 36
		Wisconsin card sorting test	29
	Planning & Problem solving	Tower test	16, 20, 29
Information processing	Reaction time	Simple reaction time test	1, 4, 5, 6, 15, 33, 36
		Choice reaction time test	6, 13, 15, 33
	Processing speed	Digit symbol substitution test	16
Spatial ability	Mental rotation	Mental rotation test	7, 8, 11, 21, 24, 31

4. Cognitive function and athletic status

4.1 Attention

As illustrated in Table 2, ten studies investigating variety aspects of attention corresponding to athletic level applied seven different instruments. The general attention abilities were evaluated in 2 studies using 4 cognitive measurements such as functional field of view, multiple object tracking task and computerized inattentional blindness, and visuo-spatial attention task. A study of Wang et al. (2015) observed that collegiate badminton players responded shorter on visuo-spatial attention task (non-delayed condition) compared to non-athletes. Whereas, no significant differences were observed between expert athletes (handball and track sports) and amateur athletes were observed on multiple attention tasks including functional field of view, multiple object tracking task and computerized inattentional blindness (Memmert et al. 2009).

With regard attention network capacity. Four studies employing attention network task (ANT) to examine alerting, orienting, and executive of attention abilities in relation to athletic skill (Verburgh et al., 2014, 2016; Wang et al., 2016; Yao, 2016). A study of Verburgh et al. (2014) indicated that young talented soccer player were better on only alerting attention relative to non-talented soccer players. Similar to the result of Yao (2016), groups of expert athletes consist of swimmers, fencers, and basketball players, were found to be superior on alerting task of ANT as compared to non-athlete controls. While, executive network performance of badminton players had higher than age-matched non-athletes (Wang et al., 2016). However, significant differences on attentional network were not found between elite youth, non-elite youth soccer players, and non–athlete youths (Verburgh et al., 2016).

Selective attention, an overlap sub-component of attention and executive function, is the ability to focus on a relevant stimulus while ignoring irrelevant stimulus. Three studies measured selective attention skill in sport employing visual discrimination task (Alesi, Bianco, Luppina, Palma, & Pepi, 2016; Lesiakowski, Krzepota, & Zwierko, 2017; Lesiakowski, Zwierko, & Krzepota, 2013). One of these was interventional studies conducting 6-month soccer training program in young athletes. The finding showed that young soccer players had better on accuracy and speeding performances of visual discrimination task relative to sedentary children. Moreover, the significant improvements of on attention and executive abilities in soccer group were observed after completed exercise program (Alesi et al., 2016). Another two studies used Special Ability Signal Test, discrimination of visual stimuli task, of Vienna Test System to investigate long-term selective attention (Lesiakowsi et al., 2013, 2017). Results from correct response and stimulus reaction time of Special Ability Signal Test indicated significantly better in high-skilled athlete group of volleyball, soccer, and rowing, as compared to non-athlete (Lesiakowsi et al., 2017). However, there was no significant different between elite boxers and non-athlete controls (Lesiakowsi et al., 2013).

Sustained attention is the ability to concentrate on an actively particular stimulus object in the environment over a long period of time without distraction. The finding of Heppe, Kohler, Fleddermann, & Zentgraf (2016) showed that elite volleyball and soccer players outperformed novices on sustained attention ability which was tested by the d2-R test.

4.2 Memory

Memory was measured in 3 studies using 2 instruments including digit span forwards task and iconic memory test (Alesi et al., 2016; Verburgh et al., 2016; Yao, 2016). On the measure of short-term memory using digit span forwards task, Verburgh et al. (2016) indicated that elite young soccer players who were involved in regular sport training and talent development program at youth academy of professional soccer club exhibited better on short-term memory task than a group of young sedentary. While, no significant difference was found after completed 6 months sport specific training in young soccer player compared to non-athletes (Alesi et al., 2016).

In the study employing Iconic memory test to assess visual sensory memory, elite athletes from swimming, fencing and basketball were found to perform superior to non-athletes (Yao, 2016).

4.3 Executive function

A variety of cognitive tools were employed to examine a various sub-aspects of executive functions (e.g., inhibitory control, working memory, cognitive flexibility, and making decision and problem solving etc.).

4.3.1 Inhibition

Of the sixteen studies examining motor inhibition, seven of these employed stop signal task or stopping task (Alves et al., 2013; Brevers et al., 2018; Huijgen et al., 2015; Liao et al., 2017; Verburgh et al., 2014, 2016; Yao, 2016). The analyses of Alves et al. (2013) indicated that professional volleyball players were significantly faster on stopping task than non-athletes, and young athletes also responded faster than junior controls. There were three studies investigating inhibition control regarding sport performance in soccer. Talented young soccer players were better than aged-matched amateur soccer players (Verburgh et al., 2014), elite youth soccer players have better inhibition skill compared to sub-elite athletes (Huijgen et al., 2015), and high-skilled young soccer players had better inhibition ability than lower skill young soccer players and non-athletes (Verburgh et al., 2016). In other sport athletes, elite basketball players (Yao, 2016), elite badminton players (Liao et al., 2017), and professional cyclists (Brevers et al., 2018) were superior to non-athlete controls.

Five studies examined inhibition using stroop or color-word interference task (Chang et al., 2017; Jacobson & Matthaeus, 2014; Martin et al., 2016; Vestberg et al., 2012, 2017). Two studies of Jacobson and Matthaeus (2014) and Martin et al. (2016) revealed that athlete groups, regardless self-paced and externally paced sports, performed better than control group and elite cyclists were superior to recreational cyclists, respectively. Whereas, the finding of Chang et al. (2017) found no statistically significant difference between the expert athletes (marathon and wushu) and non-athletes. Another two studies of Vestberg et al. (2012, 2017), the stroop test was used as additional measurement to confirm the primary test results.

Two studies regarding sporting expertise assessed selective inhibition using flanker task (Alves et al., 2013; Chiu, Chen, & Muggleton, 2017). Female volleyball players responded shorter on speeding task of flanker test than female sedentary (Alves et al., 2013), and volleyball players performed better on accuracy task of flaker test relative to exercise group and controls (Chiu et al., 2017).

There were three studies employing Go/no-go task to investigate response inhibition ability in sports. Two finding found that athletes outperformed controls (Bianco et al. 2017; Nakamoto & Mori, 2008), but the significant difference was not presented between fencers and non-fencers in the literature of Chan, Wong, Liu, Yu, & Yan (2011).

4.3.2 Working memory

Nine articles utilized 5 different measurements to assess working memory performance such as visuo-spatial working memory task (Verburgh et al., 2014; Wang et al., 2015), backward visual memory span test (Alesi et al., 2016; Huijgen et al., 2015; Verburgh et al., 2016), demanding working memory of CogStateSport (Vestberg et al., 2017), corsi block-tapping task (Alesi et al., 2016; Furley & Memmert, 2010), and Change detection task (Alves et al.,2013; Yao, 2016).

Five studies concerning sport expertise reported that there were significant differences between a variety sports athletes and non-athletes including elite volleyball players and non-athletes (Alves et al., 2013), high skilled badminton players and non-athletes (Wang et al., 2015), young soccer players and young non-athletes (corsi block tapping test: Alesi et al., 2016), elite, non-elite soccer players and non-athletes (Verburgh et al., 2016), and elite youth soccer players and normal population (Vestberg et al., 2017).

The remaining articles showed that the performance on working memory did not differ between collegiate basketball players and non-athletes (Furley & Memmert, 2010), young talented and young amateur soccer players (Verburgh et al., 2014), elite youth and sub-elite youth soccer players (Huijgen et al., 2015), top-level cyclists and novice athletes of soccer and sedentary (Backward Visual Memory Span: Alesi et al., 2016), and between three athlete groups of basketball, fencing and sedentary (Yao, 2016).

4.3.3 Cognitive flexibility

Eight researches investigated ability of cognitive flexibility employing 4 different tools including design fluency test, trail making test, task switching, and Wisconsin card sorting test (Alves et al., 2013; Chang et al.,2017; Huijgen et al., 2015; Lundgren et al., 2016; Vestberg et al., 2012, 2017; Yao, 2016; Yu et al., 2017).

Of four studies utilized both Design Fluency task (DF) and Trail making test to assess general executive function, three studies employed DF and modified TMT from D-KEFS test battery (Delis et al., 2001) which DF was a primary examination and TMT were used additional measurements (Lundgren et al., 2016; Vestberg et al., 2012, 2017), while one study used DF from D-KEFS test battery and original TMT which both of them were primary tests (Huijgen et al., 2015). The results of four studies demonstrated that the mental flexibility performances were significantly better in higher league soccer players (Vestberg et al., 2012), elite adolescent soccer players (Huijgen et al., 2015; Vestberg et al., 2012), and professional hockey players (Lundgren et al., 2016), as compared to comparison groups or standardized sample score.

From the three sports expertise-related studies utilizing task switching tests, the results of two studies reported that top level of volleyball players (Alves et al., 2013), and elite badminton players and track and field athletes (Yu et al., 2017), were better than sedentary controls. However, the significant difference was not seen between three athlete groups (basketball, fencing and swimming) and controls (Yao, 2016).

The computer-based Wisconsin card sorting test was employed to assess shifting aspect of execution in the study of Chang et al. (2017), indicating no significant differences between groups of expert athletes (marathon and wushu) and non-athlete controls.

4.3.4 Planning and problem solving

Planning and problem solving abilities are crucial skills of executive functioning which related to sports performance. Typically, it has been evaluated by tower tests. As seen in this review literature, three articles used two different version of tower tasks, the D-KEFS Tower test (Jacobson & Matthaeus, 2014), Tower of London (Alesi et al., 2016; Chang et al., 2017). The results of two studies found non-athletes exhibited significantly worse than athletes (Jacobson & Matthaeus, 2014) and young soccer players (Alesi et al., 2016). However, no significant differences were reported across marathoner, wushu athletes, and sedentary (Chang et al., 2017).

4.4 Information processing

4.4.1 Reaction time

Reaction time tasks have been widely administered in the experiments of sport science to evaluate reaction and decision speed of motor performances. According to the table, two types of reaction time were employed included simple (SRT) and choice reaction time (CRT) task. With regard to three literatures using both SRT and CRT, analyses of Cojocariu (2011) showed that Romanian national athletes of Qwan Ki Do sport responded statistically significant shorter on CRT relative to amateur athletes in same sport and non-athletes, but the differences between three groups on SRT were not statistically significant. In another combat sport, the results of both SRT and CRT did not differ between elite judo athletes and sedentary controls (Cojocariu & Abalasei, 2014). Recently, the finding of Lesiakowsi et al. (2017) indicated that the reaction time ability of professional team sport athletes (volleyball and soccer) were significantly shorter than those of non-athletes on SRT and CRT. The results of another four studies utilized only simple RT, the collegiate athletes who involved in baseball, basketball, cross-country running, gymnastics, soccer, swimming, track and field, tennis, and wrestling, performed significantly shorter than non-athletes (Chaddock, Neider, Voss, Gaspar, & Kramer, 2011; Nakamoto & Mori, 2008). However, the differences were not seen between experienced fencer and non-fencers (Chan et al., 2011), and between both athlete groups (badminton and track and field) and non-athlete controls (Yu et al., 2017).

4.4.2 Processing speed

A data from Digit Symbol Substitution Test did not show a significant difference between recreational athletes and non-athletes (Jacobson & Matthaeus, 2014).

4.5 Spatial ability

Five papers employed a diverse range of two and three-dimension stimulus types of mental rotation task to investigate spatial skills.

A study of Jansen et al. (2012) utilizing computerized mental rotation task with three types of three-dimensional stimuli, one abstract pictures (cubes) and two embodied pictures (human and body postures), found that university soccer players and non-athletes did not differ in spatial ability.

In a series experiment of Heppe et al. (2016) using human figures of mental rotation test observed no significant difference on both mental process and response action of mental rotation performance between female elite athletes (handball and soccer) and recreational athletes. Similarly, following experiment revealed that the differences between elite athlete (volleyball and handball) and recreational athletes were not seen, but the speed of mental rotation ability in athletes were significantly faster than controls. According to the finding of Feng, Zhang, Ji, Jia, & Li (2017), the adolescent excellent divers responded statistically significant shorter, as compared to controls.

The remaining two studies employed different paper-pencil mental rotation tests MRT. In the article of Jansen and Lehmann (2013), the modified MRT with human postures and cube figures (Alexander & Evardone, 2008) was administered to examine the skill of mental rotation among two groups of athlete (gymnastics and soccer) and one comparison group. They found that only gymnasts had significantly better performance in MRT compared to non-athletes. While, Schmidt et al. (2016) used original MRT-A (Peters et al., 1995; Vandenberg & Kuse, 1978) in their experiment. They found that athletes who participated in gymnastics and orienteering sport exhibited greater than sedentary on spatial skills.

5. Cognitive function and type of sport

A growing body of literature incorporating various cognitive domains has investigated in athletes involving in different types of sports.

5.1 Attention

A study of Lesiakowsi et al. (2017) aimed at investigating selective attention by using visual discrimination task in four elite athlete groups (boxing, rowing, soccer, and volleyball) and non-athlete controls. The higher accuracy responses were found in a group of volleyball, as compared to boxers and sedentary as well as soccer and volleyball players exhibited significantly quicker on detection time task of visual stimulus discrimination than boxers.

5.2 Memory

Yao (2016) examined visual sensory memory using Iconic memory test between three types of sports, interceptive, static, and strategic sport athletes, and non-athletes. The result indicated that basketball players (strategic sport) outperformed fencers (interceptive sport), swimmers (static sport), and non-athletes.

5.3 Executive function

5.3.1 Inhibition

There were two articles measuring inhibitory control via stop signal task in relation to sport typology. Results from a research defining types of sports as open-skill and closed-skill sports, found that collegiate tennis players (open-skill) performed more effective relative to swimmers (closed-skill), and non-athletes (Wang et al., 2013). Another study determining different definitions of sports type, interceptive, static, and strategic sport, revealed that there were statistically significant better on inhibition skills in basketball players (interceptive sport), relative to fencers (interceptive sport), swimmers (static sport), and non-athletes (Yao, 2016).

Based on review literature regarding stroop task, there were two study investigating response inhibitions across various types of sport terms such self-paced and externally paced sport (Jacobson & Matthaeus, 2014) and endurance sport and motorically-complex sport (Chang et al., 2017). Previous study conducted by Jacobson and Matthaeus (2014) indicated that self-paced sport athletes performed more accurately on a paper-based modified stroop test (D-KEFS Color-Word Interference Test) than externally-paced sport athletes and controls. While, the recent finding of Chang et al. (2017) showed no statistically significant differences on response time of paper-pencil stroop task between marathon runners (Endurance sport), wushu athletes (motorically complex sport), and non-athlete.

With regard to the study utilizing flanker task in sport-related executive function domains. Previous literature indicated that volleyball players exhibited better selective inhibition performances than exercise group of running and swimming, and non-athletes (Chiu et al., 2017). In addition, the finding of Wang et al. (2017) observed that there were significantly better in open skill sport (badminton players), as relative to closed-skill sport (track and field and dragon boat athletes).

As another measure of inhibition, Go/Nogo reaction time task. It has been recently shown that elite fencers perform executive tasks requiring response inhibition with higher accuracy than elite boxers (Bianco et al., 2017), while there was no significant difference between baseball and basketball athletes (Nakamoto & Mori, 2008).

5.3.2 Working memory

There were no significant differences on ability of working memory using change detection test between interceptive sport (fencing), static sport (swimming), strategic sport (basketball) athletes, and non-athletes (Yao, 2016).

5.3.3 Cognitive flexibility

Yao (2016) revealed a significant difference on global cost performance of task-switching task between fencers (interceptive sport) and swimmers (static sport), which swimmers were better on cognitive flexibility. Another significant difference between sport types was seen in a paper of Yu et al. (2017), open-skilled sport athletes (badminton) were found greater than athletes from closed-skill sport and non-athletes on proactive control of task-switching task. However, no significant difference was observed in a research using Wisconsin card sorting test across three groups of endurance sport athletes (marathon), motor complex sport athletes (wushu), and non-athletes (Chang et al., 2017).

5.3.4 Planning and problem-solving

The research employing D-KEFS Tower Test to examine performances of planning and problem-solving according to sport modality indicated that of externally-paced sport athletes were superior to self-paced sport athletes and non-athletes (Jacobson & Matthaeus, 2014). A recent finding using Tower of London task^{DX} found no significant difference among three groups of endurance sport (marathon) athletes, motor complex sport (wushu) athletes, and non-athletes (Chang et al., 2017).

5.4 Information processing

5.4.1 Reaction time

There were three researches investigating the relationship between motor performance and sports typology. Previous finding of Nuri et al. (2013) indicated that sprinters (closed-skill sport) responded faster to auditory CRT task than volleyball players (open skill sport). The recent results of Lesiakowsi et al. (2017) using data from both SRT and CRT showed that volleyball and soccer were significantly faster on reaction time performances of SRT and CRT compared to boxers, rowers and non-athletes. In contrast, there were no significant differences on SRT between baseball and basketball players (Nakamoto & Mori, 2008), and open-skill sport (badminton), closed-skill sport (track and field) athletes, and sedentary (Yu et al., 2017).

5.4.2 Processing speed

There were no significant differences between externally-paced sport and self-paced sport athletes on speed of information processing by measuring digit symbol substitution test (Jacobson & Matthaeus, 2014).

5.5 Spatial ability

Amateur wrestlers were observed superior to amateur runners on mental rotation performance after 10 months of sport training intervention program (Moreau et al., 2012). The finding of Jansen and Lehmann (2013) observed that mental rotation skills of gymnasts differed from non-athletes, whereas soccer players did not. According to Schmidt et al. (2016), gymnasts and orienteers were significantly greater than non-athletes, but endurance runners were not. In contrast, a series experimental study of Heppe et al. (2016) found no significant difference between elite athletes (handball, soccer, and volleyball) and recreational athletes which participated in various sports.

6. The theoretical model of cognitive functions related to sport performance

According to preliminary systematic review results of neurocognitive study, the crucial cognitive functions related to sport expertise were considered to be included in a series of cognitive performance assessment batteries for further study. In order to specify cognitive functioning tools, the criteria for test selection are outlined in the following; 1) There were evidencs showing cognitive function related to sport performance; 2) The cognitive measurement has been applied in context of sports; 3) The result of previous study using cognitive tool which could distinguish between athlete and non-athlete, or elite and amteur athlete, or talented and non-talented athlete. Furthermore, it is necessary to understand various conceptual cognition, aspects and sub-aspecst of cognitive performance, and relevant evaluating tools. Finally, based on extracted information from 37 studies, the critical cognitive domains, sub-domains, and measurments were determined and lead to construct the theoretical cognitive model corresponding to sport performances (Figure 5).

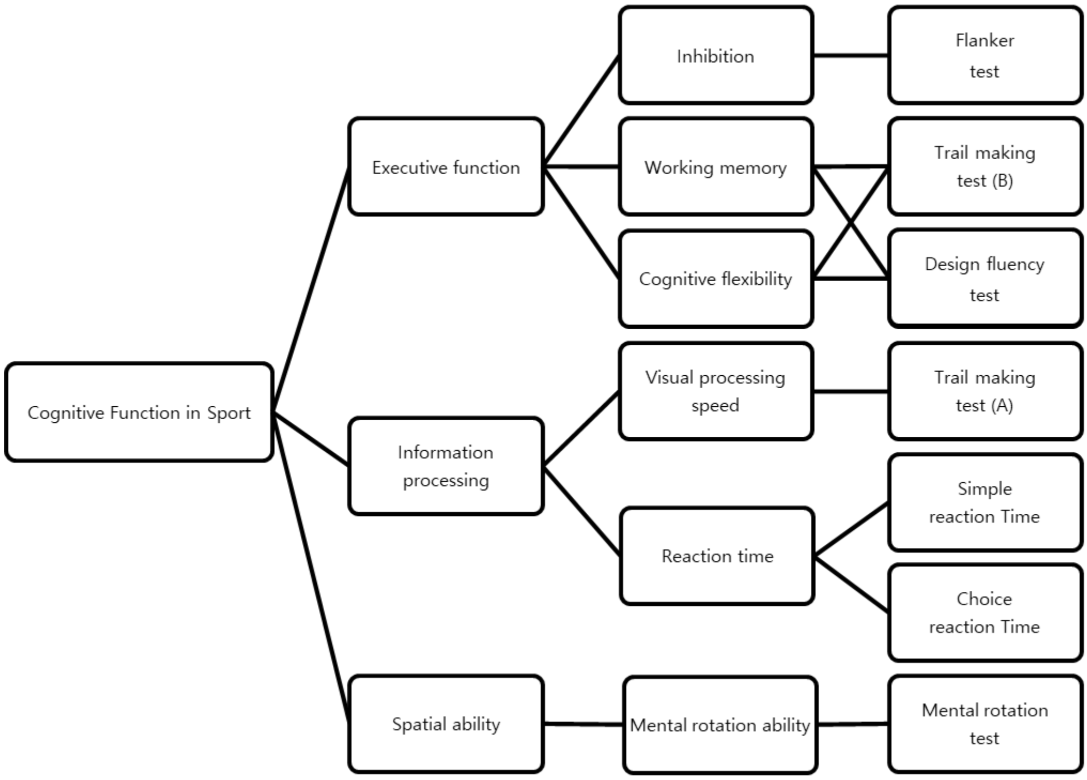

Figure 5. Theoretical model of sport-related cognitive function.

Discussion

The present study systematically synthesizes 37 relevant literatures examining the relationship between cognitive performances athletic status, sports expertise and type of sport. Key findings of this literature review yield the presence of substantial links between 1) cognitive function and athletic status or level of expertise; 2) cognitive function and type of sport. Based on the majority of evidence reviewed, it is important to shed light on the vital components of sport-related cognitive function including executive function, information processing and spatial ability.

There is growing evidence indicating cognitive skill variables have been positively related to sport expertise. Most of the primitive papers showed that the superiority on multiple aspects of cognition had been observed in high-performance athletes in comparison to amateur and non-athletes. The present findings are consistent to the latest meta-analytic study that athletes had significantly better than non-athletes on processing speed and attention, supporting the positive effect of exercise and sport training on development of cognition (Voss et al. 2010). The advantage for expertise in sports on cognitive components can be demonstrated by the notion of broad cognitive skill transfer that long-term involvement in systematic sports training contributes to the enhancement of both fundamental cognitive skills according to skill-differences and unrelated-expert cognitive domain (Furley & Memmert, 2011; Voss et al., 2010). This is supported by previous interventional study that suggested the 6-month sports training program are beneficial on the improvement of attention, memory and executive function, in young soccer players (Alesi et al., 2016). Furthermore, as a group of literature found higher memory skill, alerting attention, response inhibition, working memory and mental flexibility in young talented athletes (Huijgen et al., 2015; Verburgh et al., 2014, 2016; Vestberg et al., 2017), cognitive skills could be considered to be equipment for identifying and discriminating young players to be chosen into the talent athlete development program of elite sports system.

Our study also has investigated the existence of the relationship between cognitive performances across different types of sports. Several studies revealed the effects of sport type on cognitive abilities, suggesting that regular participation in certain competitive sport training could specifically modify inhibition, cognitive flexibility, and spatial ability. Accordingly, Moreau et al. (2012) demonstrated that athletes who practiced in 10-month training of wrestling could improve more mental rotation ability than who athletes who trained in same-duration of running. However, there were some controversial studies indicating closed-skill (self-paced) athlete from multiple sports exhibited more effective than open-skill sports (externally-paced) athletes on the inhibition task using color-word interference test or stroop task (Jacobson & Matthaeus, 2014), while a study of Wang et al. (2013) utilizing stop-signal task found that open-skill sport (tennis players) were better than closed-skill sport (swimmers). Importantly, it has to be noted that even same aspect of cognitive functions was examined in two studies, the varied results might be affected by differences in gender of participants, number of sport included, experience in sport, measurement used. Thus, results proved to be divergent when comparing by those different variables.

The reviewed literature provides an overview of the effects of athletic status, sports excellence, and types of sports on cognitive performance. Whereas study has focused on the cognitive abilities in young adult athletes, there is increasing evidence that cognition is crucial in young players for developing their potential performances. Furthermore, our review also reveals the gaps in the literature and further study is needed for clarifying the association between sport expertise, type of sport and cognitive function.

IV. Study 2: The difference of cognitive performance according to athletic status and type of sport

Method

Participants

There were 120 male participants in total which consist of 90 athletes including 30 interceptive (boxing), 30 static (shooting), 30 strategic (soccer) athletes, and 30 age-matched non-athletes. The participants were classified by athletic status (Figure 6) and type of sport (Figure 7). Participants whose age range between 20 to 30 were eligible for inclusion. Exclusion criteria included: 1) mental disease and 2) head injury at the date of measurement. Written informed consents were obtained from all participants, and the study protocol was conducted after approval of an institutional review board (IRB).

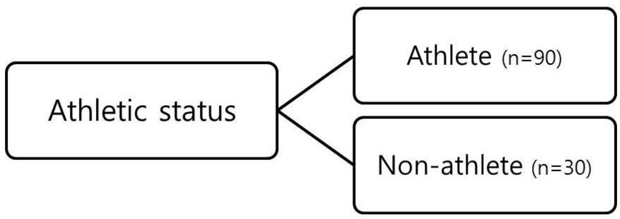

Figure 6. Classification of athletic status.

Table 3. *Demographic information of participants according to athletic status.*

Group	*n*	Age (year) *M ±SD*	Athletic experience (year) *M ±SD*
Athlete	90	23.58 ±2.83	10.49 ±3.50
Non-athlete	30	24.80 ±2.67	-

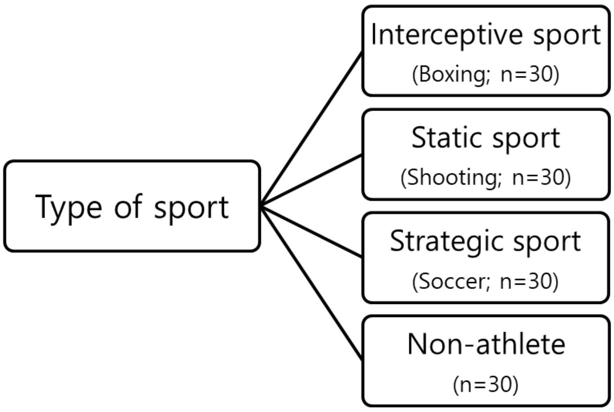

Figure 7. Classification of type of sport.

Table 4. *Demographic information of participants according to type of sport.*

Group	*n*	Age (year) *M ±SD*	Athletic experience (year) *M ±SD*
Interceptive sport : Boxing	30	24.40 ±2.41	10.37 ±2.73
Static sport : Shooting	30	21.43 ±2.06	7.83 ±2.52
Strategic sport : Soccer	30	24.90 ±2.68	13.27 ±2.91
Non-athlete	30	24.80 ±2.67	-

The development of computer-based cognitive function program

Based on findings of the study 1, five sport-related cognitive tests were initially developed to be computer-based programs including simple reaction time test, choice reaction time test, flanker test, trail making test, mental rotation test, and a paper-pencil design fluency test.

The computerized cognitive function measurement was developed in the following processes (Table 5).

Table 5. *The process to develop the computer-based cognitive function program.*

Component	Content
Operating system	Microsoft Windows 10
Programming language	C#
Content development	Microsoft Visual Studio and Microsoft Power point
Application Environment	Microsoft Windows 10

1. Based on the operating system of Microsoft Windows 10, the source code was implemented using the C# language. User interface (UI) was also implemented using C #. The program test environments, experimental environment, were made into Microsoft Windows 10.

2. For the design of the program, the basic UI will be configured using Microsoft Power Point and implement the UI and function using C#. All actions were performed based on user-initiated events

3. Prior to the examination, the user's personal information was entered. For understanding of measurement, the user was provided the opportunity to practice. In each cognitive test, the user was assessed reaction time and accuracy rate. After complete the test, the result was automatically calculated and recorded.

4. The paradigm of cognitive task development were shown in the Tables 5-11

5. All development procedures were done through collaborative research with computer software developers.

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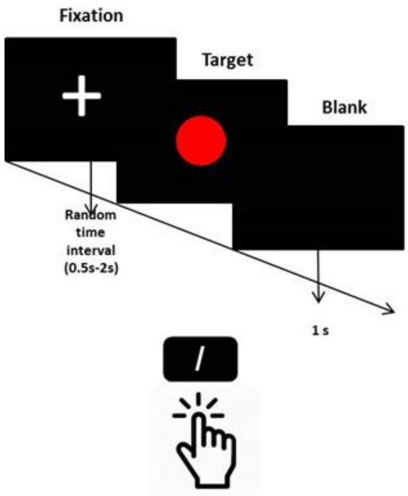
Table 6. *The paradigm of simple reaction time test development.*

Simple reaction time test			
Measurement function	- Reaction time - Information processing	Outcome measures	1. Mean reaction time 2. Accuracy rate

Test paradigm



Test description

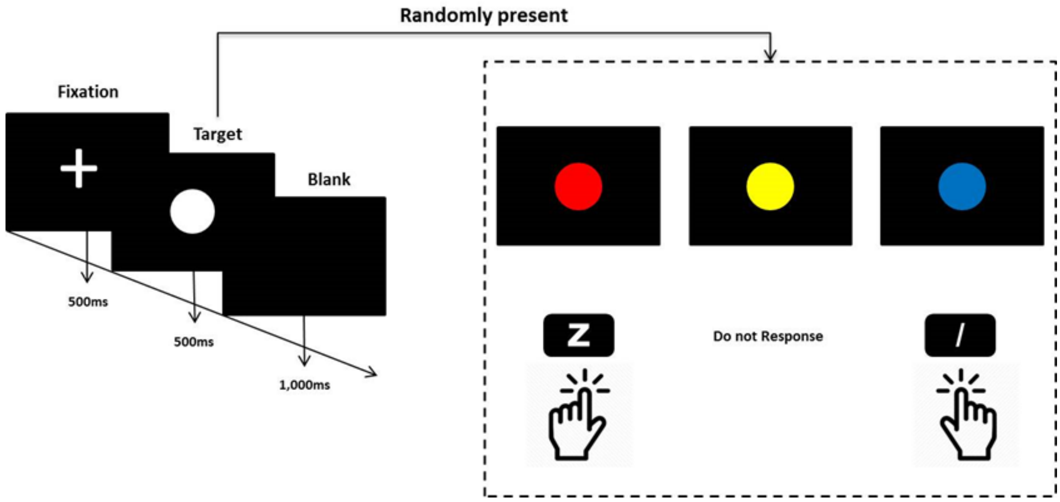
Task responding to a stimulus

- At fixation stage, the white cross signal will appear on the center of computer screen.
- Then, the stimuli will appear on the center of screen with random time interval (0.5-2 s).
- After response, black blank screen will automatically appear.
- The stimuli are 20 red circles.
- Participant is required to response by pressing the "/" button when the stimuli appear as quickly as possible.
- Practice session is provided to confirm the task understanding of participant.
- Measure the reaction time from the stimuli appearing until response to stimuli.

Table 7. *The paradigm of choice reaction time test development.*

Choice reaction time test			
Measurement function	- Reaction time - Information processing	Outcome measures	1. Mean reaction time 2. Accuracy rate

Test paradigm



Test description

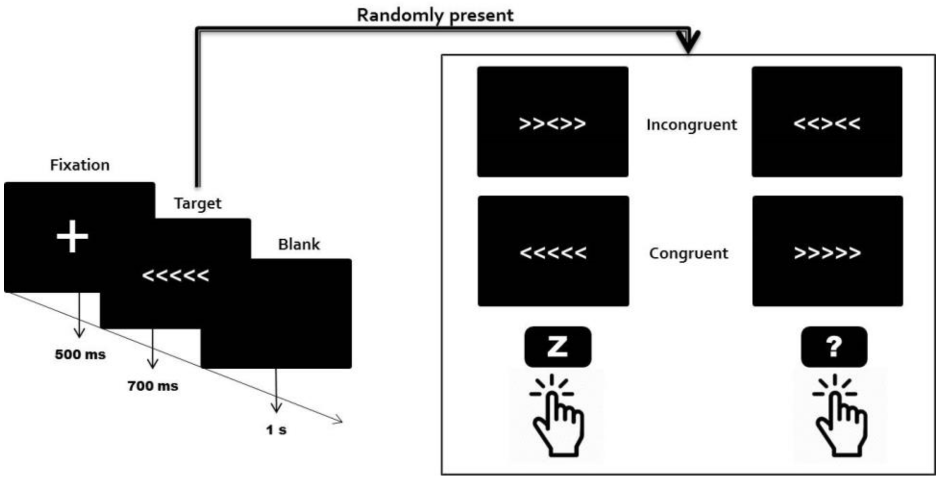
Task responding three different stimuli.

- At fixation stage, the white cross signal will appear on the center of computer screen.
- Then, the stimuli will randomly appear on the computer screen with time limit 500 ms.
- After response, black blank screen will automatically appear.
- Three stimuli are red, blue, and yellow circle.
- Total stimuli are 60 which consist of 20 of each condition.
- Participant is required to response by pressing the corresponding button as quickly as possible.
    - Press the "Z" button when the **red** circle appears.
    - Press the "/" button when the **blue** circle appears.
    - Do not response when the **yellow** circle appears.
- Practice session is provided to confirm the task understanding of participant.
- Measure the reaction time from the stimuli appearing until response to stimuli.

Table 8. *The paradigm of flanker test development.*

Flanker test			
Measurement function	- Executive function (Inhibitory control, selective inhibition)	Outcome measures	1. Reaction time of congruent and incongruent tasks 2. Accuracy rate of congruent and incongruent tasks

Test paradigm



Test description

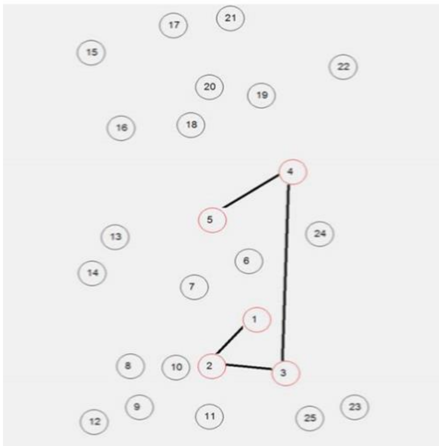
- At fixation stage, the white cross signal will appear on the computer screen.
- Then, the stimuli will randomly appear on the computer screen with time limit 700 ms.
- After response, black blank screen will automatically appear.
- The stimuli are five arrows of each stimulus condition which will randomly appear
- The stimuli of congruent task are < < < < < and > > > > >
- The stimuli of incongruent task are < < > < < and > > < > >
- Total stimuli are 40 which consist of 20 of each condition.
- Participant is instructed to focus on **only a central arrow** and response by pressing the corresponding button as quickly and accurately as possible.
- Press "Z" button when the central arrow point to the **left** (< < < < <) or (> > < > >)
- Press "/" button when the central arrow point to the **right** (> > > > >) or (< < > < <)
- Practice session is provided to confirm the task understanding of participant.
- Measure the reaction time from the stimuli appearing until response to stimuli.

Table 9. *The paradigm of trail making test development.*

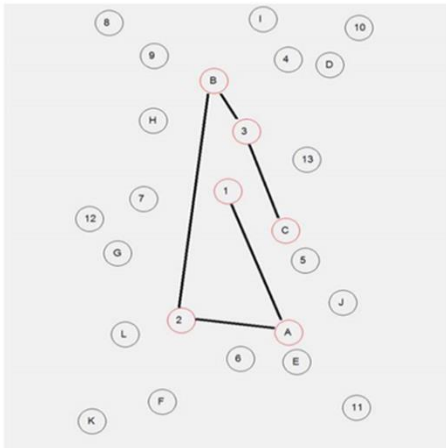
Trail making test			
Measurement function	- Processing speed (TMT-A) - Mental flexibility and working memory (TMT-B)	Outcome measures	1. Time to completion 2. Total number of incorrect answer

Test paradigm

TMT-A



TMT-B



Test description

Task responding relevant numerical and alphabetical circle stimuli.

Part A

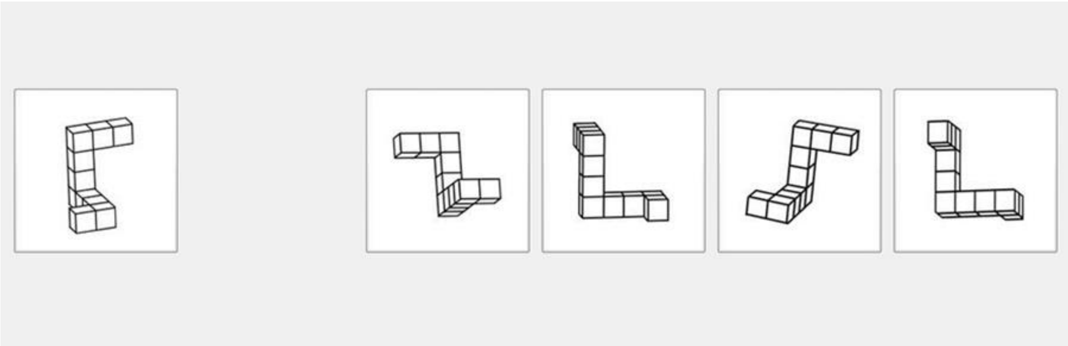
- There are circles containing number from 1 to 25.
- Participant is instructed to find and connect consecutive numbers from 1 to 25 by mouse-clicking as quickly and accurately as possible.

Part B

- Two different groups of circles containing numbers (1-13) and alphabetical letters (A-L).
- Participant is instructed to find and connect alternately between numbers and alphabet letters in order as fast and correctly as possible (e.g. 1 > A > 2 > B > 3 > … > L > 13).
- Practice session is provided to confirm the task understanding of participant.
- Measure the time to completion from beginning to finishing the test.

Table 10. *The paradigm of mental rotation test development.*

Mental rotation test			
Measurement function	Mental rotation ability (Spatial ability)	Outcome measures	Total score of correct answer
Test paradigm			



Test description

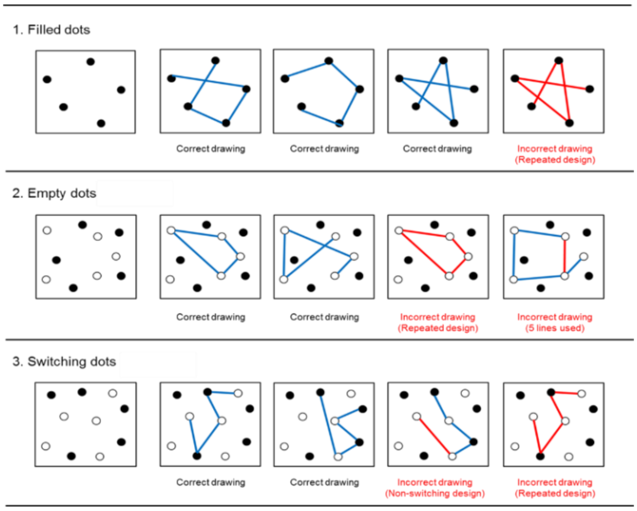
Task responding the two relevant three-dimension cubes figure as target figure.

- There are two sub-tasks MRT consist of 12 items each, 24 items in total.
- One item is separately shown on the computer screen.
- Each item includes one target stimulus on the left side and four alternative stimuli on the right side.
- Participant is instructed to identify and response by mouse clicking to 2 target-matched figures among 4 alternative stimuli as accurately as possible.
- Three minutes are given to solve the 12 items of each sub-task and break time between two sub-tasks is 2 minutes.
- Three practice items are provided to confirm the task understanding of participant.
- Scoring: one point is given if both figures were correctly identified (range 0-24).

Table 11. *The paradigm of design fluency test development.*

Design fluency test			
Measurement function	- Cognitive flexibility - Working memory	Outcome measures	1. Number of unique figure of each task 2. Total number of unique figure of all task

Test paradigm



Test description

Task generating unique picture using four straight lines

- Paper-pencil design fluency task (DFT) of Delis-Kaplan Executive Function System.
- There are three conditions of DFT including filled dots, empty dots, and switching task.
- Participant is given 3 paper test forms consisting 35 boxes which contain different dots pattern according to each task condition.
- Participant is instructed to create a variety picture using 4 straight lines following the rule of each task as many as possible in 1 minute.
    1) Filled dots task: draw unique picture by connecting only **black dots**.
    2) Empty dot task: draw unique picture by connecting only **white dots.**
    3) Switching dot task: draw unique picture by **alternating connections between black and white dots**.
  - Practice session is provided to confirm the task understanding of participant.
  - Scoring: number of unique figure of each condition and total score of 3 sub-tasks.

Procedure

The experiment of this study was conducted in a computer laboratory of the University of Ulsan and in a quiet room at sport training venues of each sport. The neurocognitive abilities were measured using five computerized-tasks (simple and choice reaction time tests, flanker test, trail making test, and mental rotation test), and one paper-based task (design fluency test). The entire tests would approximately take 45 minutes and the measurements were administered in the following order for all participants: 1) simple reaction time test; 2) choice reaction time test; 3) trail making test; 4) flanker test; 5) mental rotation test; and 6) design fluency test. Prior the examination, participants were described to understand the purposes of the research and an entire process of experiment. After the completing the informed consent, participants were seated in front of the computer screen and before beginning of each test, a testing protocol were explained to them. The participants were provided the opportunity to ask and practice trials for confirming the understanding of measurements

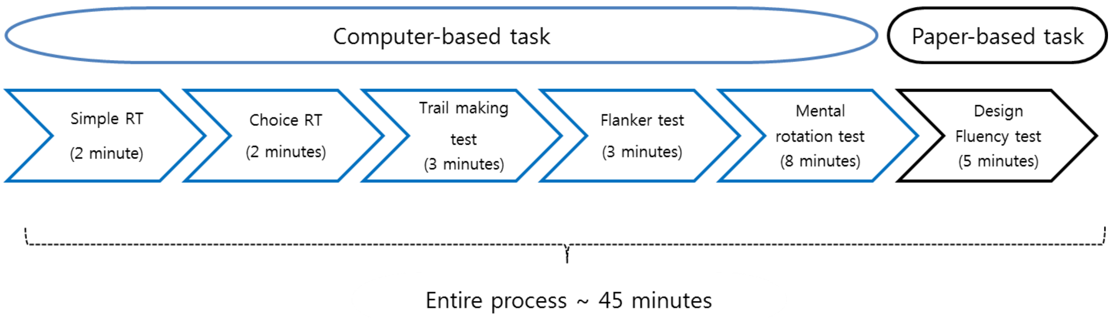


Figure 8. Schematic illustration of the entire process of procedural examination.

Measurement

1. Simple reaction time test (SRT)

Simple reaction time task was applied to evaluate the human's reaction speed ability (Cojocariu, 2011; Cojocariu & Abalasei, 2014). The participants were instructed to press "/" button on keyboard as quickly as they can when a red color circles appeared on the center of computer monitor. The stimuli of SRT are totally 20 red circles which are presented with an inter-stimulus time interval varied between 0.5 - 2 s. The output data was recorded consisting of the percentage of accuracy and average reaction time in millisecond (ms).

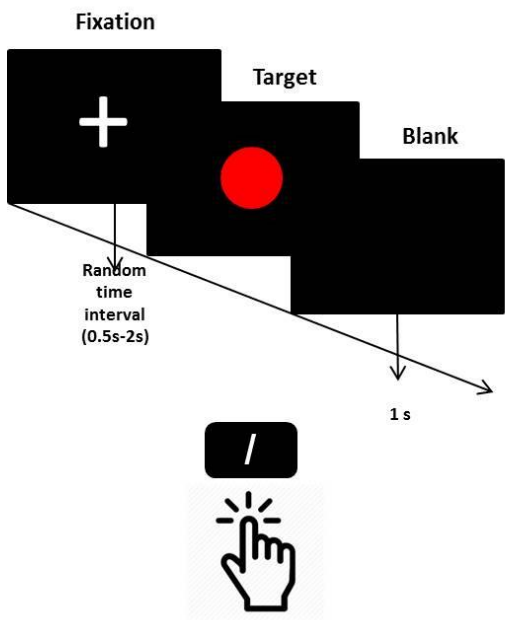


Figure 9. Schematic illustration of the simple reaction time test paradigm.

2. Choice reaction time test (CRT)

The visual choice reaction time test (김선진, 2010) was employed to assess the information processing. The participants have to respond as fast and precisely as possible to a random stimulus appearing on the middle of screen with 500 ms time limit, by pressing the relevant keyboard button in accordance with the three different conditions of stimuli; 1) press the “Z” button to a red circle; 2) press “/” button to a blue circle; and 3) do not press any button when a yellow one is showed. There were 60 trials, which consist of 20 stimuli of each condition. The percentage of response accuracy and mean reaction time (RT) were collected.

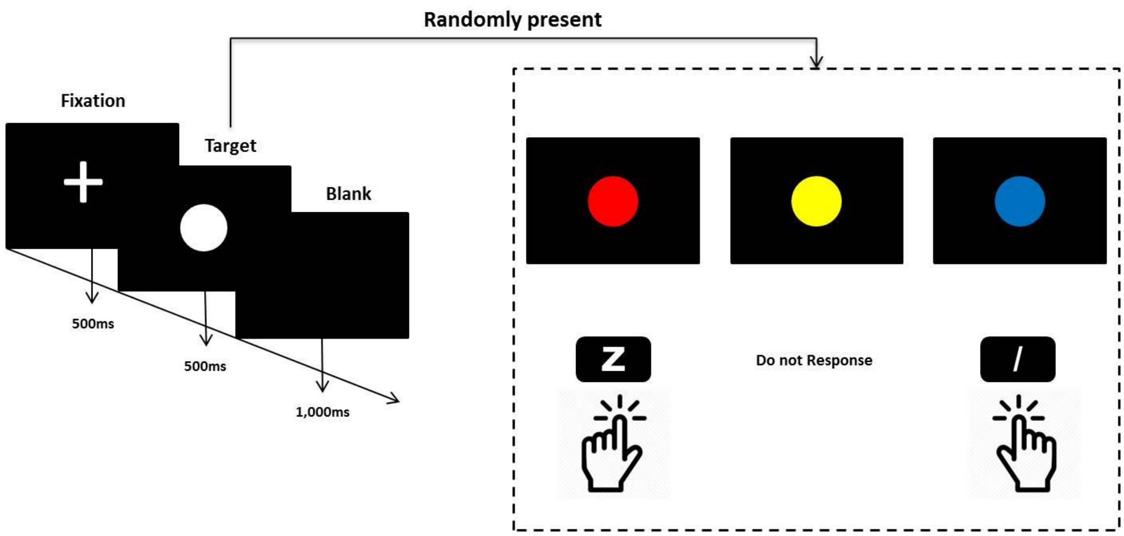


Figure 10. Schematic illustration of the choice reaction time test paradigm.

3. Flanker test (FKT)

A flanker task (Colcombe et al., 2004; Pontifex & Hillman, 2007) was used in order to examine the ability to pay attention to specific relevant objects while ignoring irrelevant information (selective attention and action inhibition). The tests consist of congruent and incongruent trials. The test-retest reliability for accuracy and reaction time of the congruent stimuli were high (r = 0.78) and moderate (r = 0.58), and for accuracy and reaction time of the incongruent stimuli were high (r = 0.86) and moderate (r = 0.64), respectively (Wöstmann et al., 2013). In Congruent task, there are five arrows in same direction (< < < < < or > > > > >), while incongruent trials presenting central arrow in opposite direction (< < > < < or > > < > >). Participants were suggested to response by pressing on computer keyboard corresponding to task condition, press "Z" button if the central arrow point to the left, whereas, press the "/" button in case the central arrow point to the right. Forty stimuli of both conditions were randomly appeared with 700 ms time limitation of each stimuli. The average reaction time (ms) and accuracy (%) of congruent and incongruent were separately recorded.

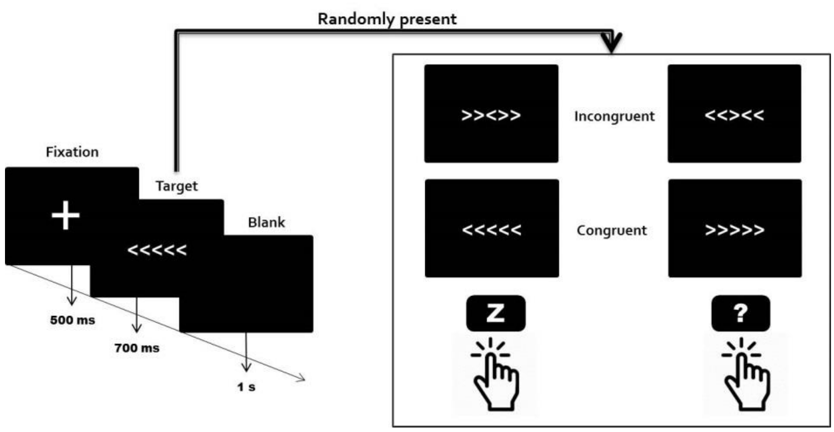


Figure 11. Schematic illustration of the flanker test paradigm.

4. Trail making test (TMT)

Trail making test (Delis et al., 2001; Swanson, 2005) in this study is computerized test consisting two parts, A and B. The test-retest reliability, by analyzing the Pearson correlation coefficients, of TMT-A was high (r = 0.74) and TMT-B was moderate (r = 0.61) (Piper et al., 2015). The objectives of TMT-A is to examine the abilities of quick visual searching, processing speed and attention. The participants were instructed to perform connecting circles containing consecutive numbers from 1 to 25, by mouse-clicking on corresponding numbers as a quickly and accurately as they can. TMT-B has been designed to investigate the ability of cognitive flexibility, and working memory that require the participants to connect alternating numbers (1-13) and alphabet letters (A-L) in the circles (i.e., 1-A-2-B-3-C, etc.) as fast and correctly as possible using mouse of computer. The results regarding time to completion (second) of each task were collected.

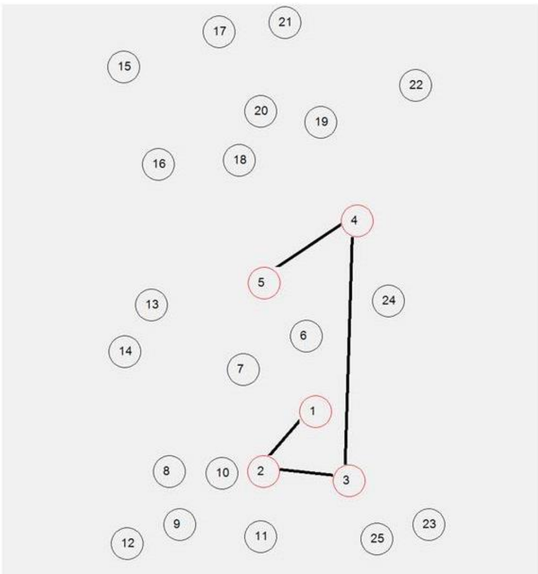


Figure 12. Schematic illustration of the trail making test - part A paradigm.

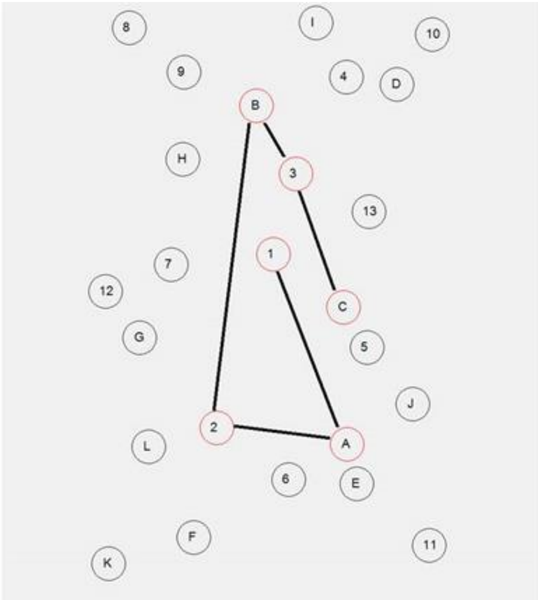


Figure 13. Schematic illustration of the trail making test - part B paradigm.

5. Mental rotation test (MRT)

The computerized mental rotation test of a redrawn version by Peters et al. (1995), which was originally created by Vandenberg and Kuse (1978) with three-dimensional cube figures developed by Shepard and Metzler (1971), was employed to determine spatial ability. The test–retest reliability coefficient of original paper-pencil MRT was high (r = 0.83) (Vandenberg & Kuse, 1978). The MRT involved two sets of 12 items each, each item consists of a three-dimension cubes target figure on the left side of computer monitor followed by four alternatives on the right side consisting two target-matched figures and two distracter figures. All participants were instructed to properly identify two correct figures from four alternatives corresponding to the questioned-stimulus figure by vertical or horizontal stimuli rotating. Each task is given 3 minutes to complete 12 items and 2 minutes breaking time between first and second task. According to the scoring procedure of Peters et al. (1995), a point is provided for only two selected-correct answers. Therefore, the range of total score could be 0-24, which was used for data analysis.

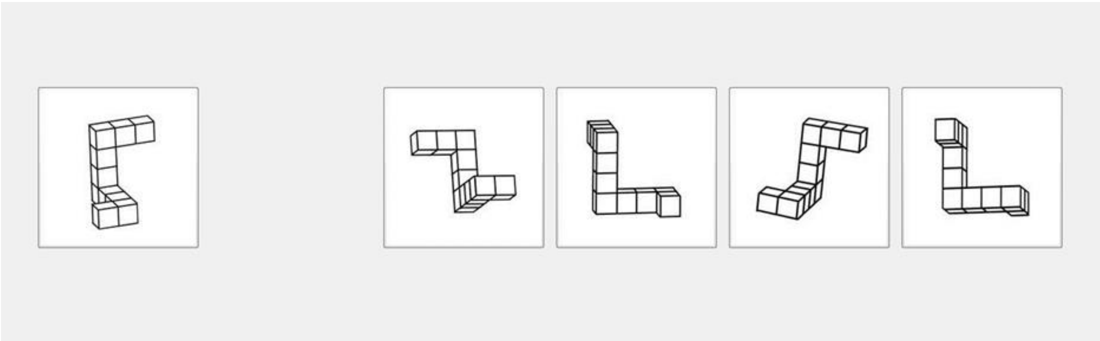


Figure 14. Schematic illustration of the mental rotation test paradigm.

6. Design fluency test (DFT)

A paper-based design fluency test (Delis et al., 2001; Swanson, 2005) was utilized examining a combination aspect of executive function including mental flexibility, inhibitory control, working memory and creativity. The test-retest reliability were low (0.32) to moderate (0.58) (Delis et al., 2001). There are three sub-tasks of DFT; filled dots, empty dots, and switching task. The participants were instructed to create the diverse figures as many and correctly as they could within 1 minute of time limitation for each task by connecting each dot using only 4 straight lines in accordance with the rule of each DFT sub- task as following. In DFT task 1- filled dots, drawing the picture by writing the line between only filled dots. In DFT task 2-empty dots, to link only between empty dots was suggested. In DFT task 3, the participants were asked to generate the alternating connections between black and white dots. The numbers of correct figures of each task was noted.

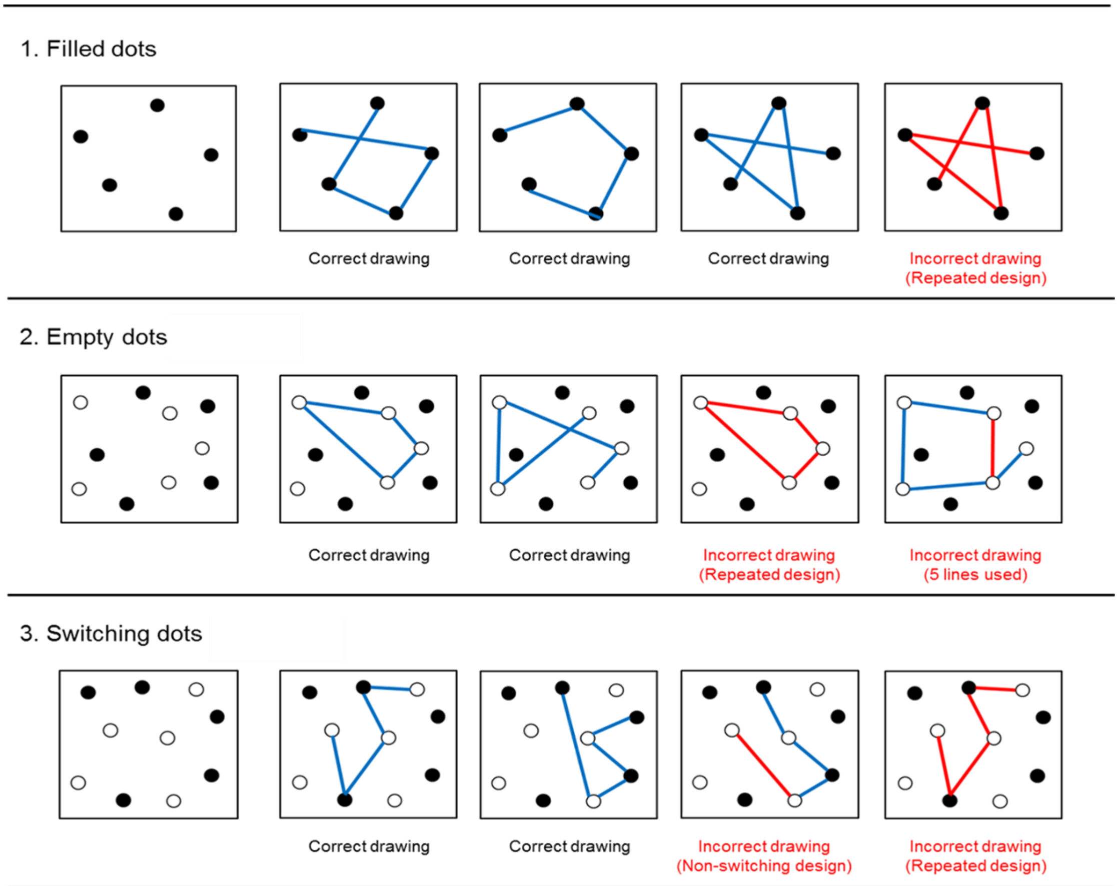


Figure 15. Schematic illustration of the design fluency test paradigm.

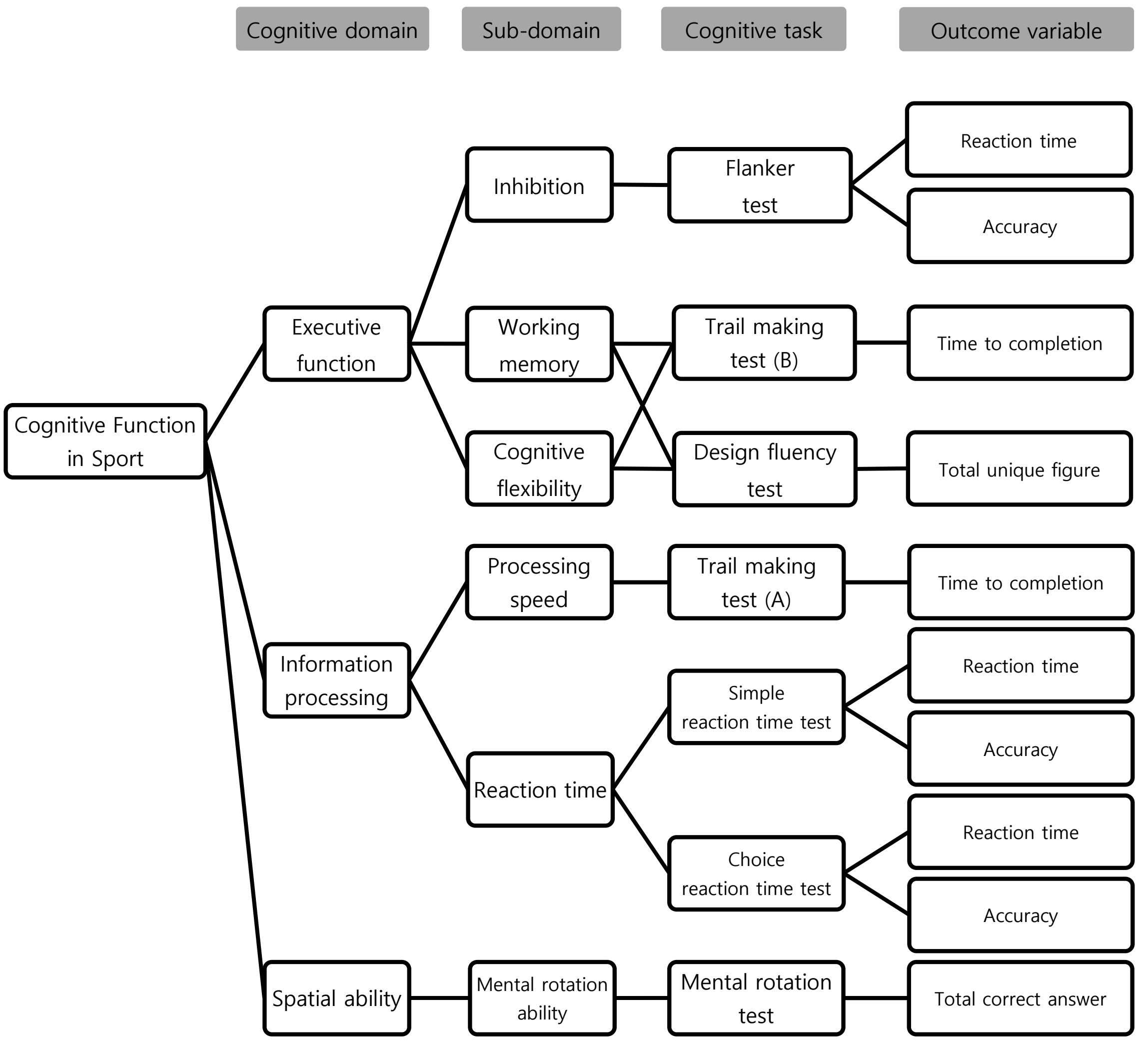


Figure 16. Schematic illustration of cognitive domain, sub-domain, measurements, and outcome variables.

Statistical analysis

All statistical analyses were performed using SPSS and statistical significance was $\alpha = .05$. Participants' demographic were calculated by performing mean and standard deviation. A Kolmogorov-Smirnov test was employed to examine the normal distribution of all variables. All cognitive function outcomes consisting reaction time and accuracy rate of FKT, SRT and CRT, time to completion of TMT, total unique figure of DFT and score of MRT, were used to determine the difference between groups of athletes and non-athletes, and among three sport types (interceptive, static, strategic sport athlete and non-athletes) by conducting independent t-test and one-way multivariate analysis of variance (MANOVA), respectively. Follow-up univariate analysis of variance (One-way ANOVA) were executed in the instance of a significant effect from MANOVA result. Post-hoc comparison using Bonferroni was further employed according to only significant result of ANOVA.

Result

1. The cognitive function according to athletic status

1.1 Simple reaction time test

Significant difference according to athletic status was observed on reaction time ability of simple reaction time test ($t(118) = 2.957$, $p = .004$), which athletes ($M = 299.43$, $SD = 46.83$) responded shorter in comparison to non-athletes. ($M = 332.04$, $SD = 66.32$). With regard to accuracy rate of simple reaction time test, no significant difference between groups of athlete and non-athlete was found (Table 12).

Table 12. *Independent samples t-test analysis of simple reaction time test.*

	Group	*n*	*M* ±*SD*	*t*	*p*
Reaction time (ms)	Athlete	90	299.43 ±46.83	2.957	.004**
	Non-athlete	30	332.04 ±66.32		
Accuracy (%)	Athlete	90	97.61 ±3.98	0.708	.480
	Non-athlete	30	98.17 ±2.78		

*p < .05, **p < .01, ***p < .001

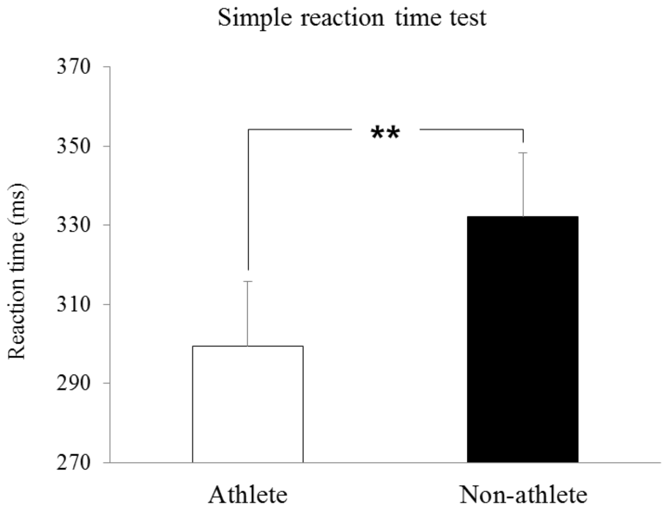


Figure 17. Reaction time of simple reaction time test according to athletic status.

1.2 Choice reaction time test

There was a significant effect for reaction time of choice reaction time test ($t(118) = 4.492$, $p < .001$), athletes ($M = 427.45$, $SD = 17.15$) performing faster than non-athletes ($M = 446.85$, $SD = 28.37$). Athlete group also significantly exhibited more accurate than non-athlete participants ($t(118) = -2.968$, $p = .004$) (Table 13).

Table 13. *Independent samples t-test analysis of choice reaction time test.*

	Group	*n*	*M* ±*SD*	*t*	*p*
Reaction time (ms)	Athlete	90	427.45 ±17.15	4.492	.000***
	Non-athlete	30	446.85 ±28.37		
Accuracy (%)	Athlete	90	86.94 ±11.55	-2.968	.004**
	Non-athlete	30	78.83 ±16.57		

$^*p < .05$, $^{**}p < .01$, $^{***}p < .001$

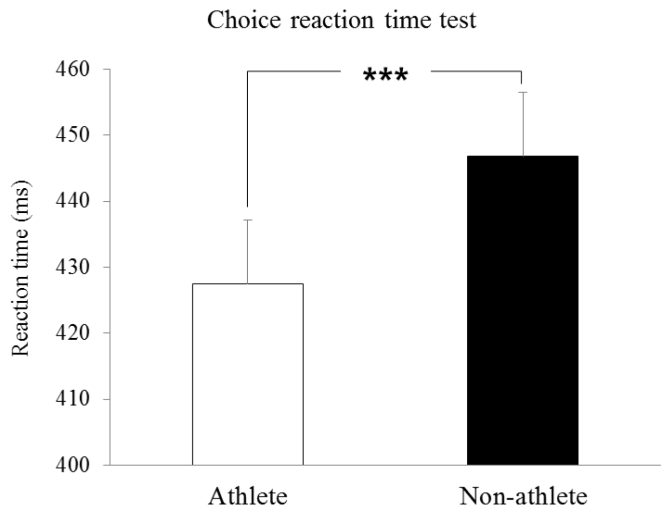


Figure 18. Reaction time of choice reaction time test according to athletic status.

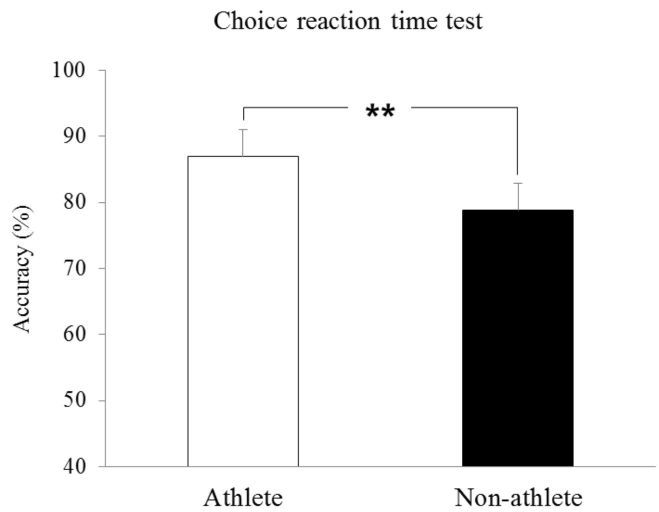


Figure 19. Accuracy of choice reaction time test according to athletic status.

1.3 Flanker test

The results of independent t-test analysis revealed no significant difference between athletes and non-athletes on both congruent and incongruent of flanker test evaluating accuracy and reaction time abilities (Table 14).

Table 14. *Independent samples t-test analysis of flanker test.*

		Group	*n*	*M* ±*SD*	*t*	*p*
Congruent	Reaction time (ms)	Athlete	90	412.53 ±37.11	1.515	.132
		Non-athlete	30	425.27 ±47.45		
	Accuracy (%)	Athlete	90	96.39 ±10.78	1.400	.164
		Non-athlete	30	99.17 ±1.90		
Incongruent	Reaction time (ms)	Athlete	90	484.83 ±39.64	0.951	.344
		Non-athlete	30	493.10 ±45.88		
	Accuracy (%)	Athlete	90	83.16 ±13.60	-0.700	.485
		Non-athlete	30	81.17 ±13.37		

$^*p < .05$, $^{**}p < .01$, $^{***}p < .001$

1.4 Trail making test

There was statistically significant on completion time of part A ($t(118) = 2.985$, $p = .003$) that athletes ($M = 21.02$, $SD = 3.79$) exhibited faster than non-athletes ($M = 24.44$, $SD = 8.74$). However, no significant difference was reported for part B of trail making test (Table 15).

Table 15. *Independent samples t-test analysis of trail making test.*

	Group	*n*	*M* ±*SD*	*t*	*p*
Part A (s)	Athlete	90	21.02 ±3.79	2.985	.003**
	Non-athlete	30	24.44 ±8.74		
Part B (s)	Athlete	90	48.78±13.61	-1.427	.156
	Non-athlete	30	44.78 ±12.24		

*p < .05, **p < .01, ***p < .001

Figure 20. Time to completion of trail making test - part A according to athletic status.

1.5 Mental rotation test

There was no significant difference between two groups on the scores of mental rotation test (Table 16).

Table 16. *Independent samples t-test analysis of mental rotation test.*

	Group	*n*	*M* ±*SD*	*t*	*p*
Score	Athlete	90	8.64 ±5.88	1.286	.201
	Non-athlete	30	10.27 ±6.29		

*p < .05, **p < .01, ***p < .001

1.6 Design fluency test

As depicted by Table 17, the results of the t-test revealed that there were significant differences in filled dots ($t(118) = -3.032$, $p = .003$), empty dots ($t(118) = -2.937$, $p = .004$), switching dots ($t(118) = -3.249$, $p = .002$), and total scores of three sub-tasks ($t(118) = -3.908$, $p < .001$),which athletes had significantly higher scores of unique figure than non-athletes for all sub-task and total score.

Table 17. *Independent samples t-test analysis of design fluency test.*

	Group	*n*	*M* ±*SD*	*t*	*p*
Filled dots	Athlete	90	12.92 ±4.09	-3.032	.003**
	Non-athlete	30	10.33 ±3.92		
Empty dots	Athlete	90	13.56 ±3.75	-2.973	.004**
	Non-athlete	30	11.23 ±3.58		
Switching dots	Athlete	90	9.37 ±4.21	-3.249	.002**
	Non-athlete	30	6.57 ±3.70		
Total score	Athlete	90	35.84 ±9.58	-3.908	.000***
	Non-athlete	30	28.13 ±8.64		

$^*p < .05$, $^{**}p < .01$, $^{***}p < .001$

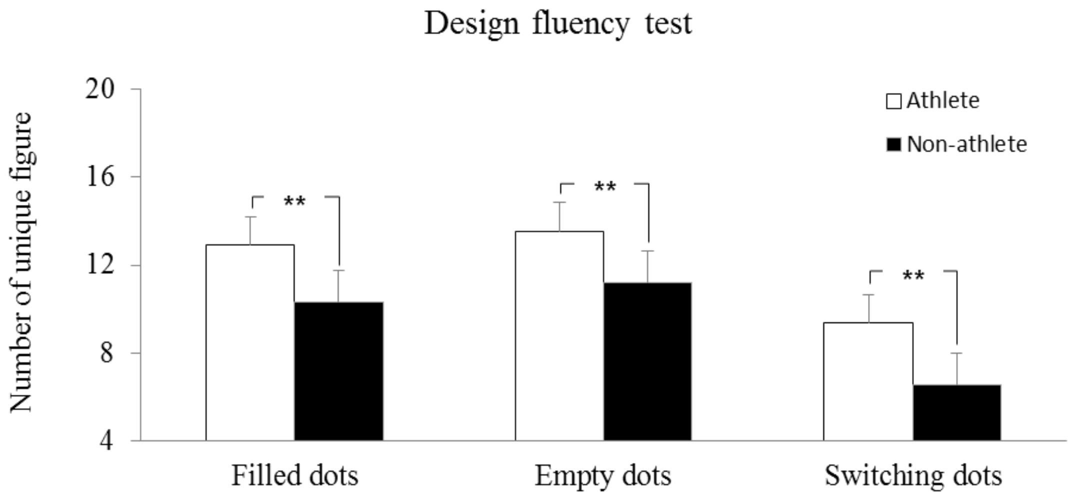


Figure 21. Number of unique figure of each sub-task of design fluency test according to athletic status.

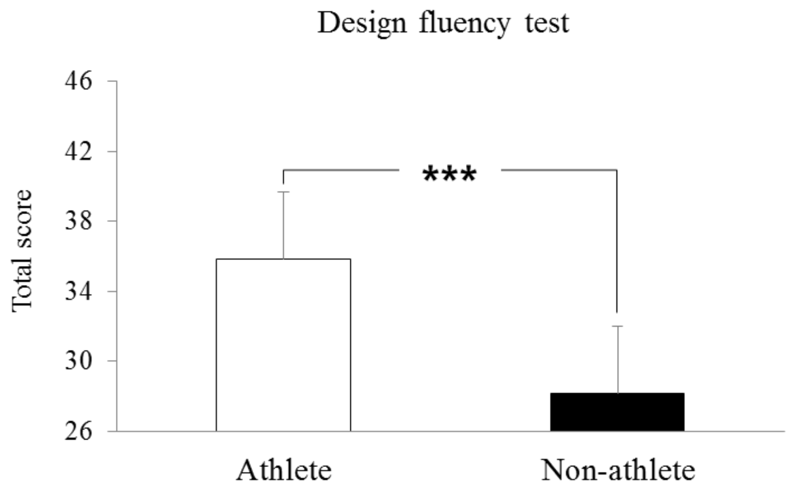


Figure 22. Total score of three sub-tasks of design fluency test according to athletic status.

2. The cognitive function according to type of sport

A one-way multivariate analysis of variance (MANOVA) was performed to investigate sports type differences in the variables examined. Fifteen dependent variables were employed including mean reaction time and accuracy rate of simple reaction time test, choice reaction time test, congruent and incongruent of flanker test, completion time of trail making test part A and B, total correct answers of mental rotation test, and unique drawings of empty dots, filled dots, switching dots tasks and total unique picture of design fluency test.

Prior to the MANOVA analysis, the normality tests were conducted and the distributions of all variables were found to be normal. There was a statistically significant difference between interceptive sport, static sport, strategic sport and non-athlete on the combined dependent variables, $F(42, 306) = 3.838$, $p < .001$; Wilks' Lambda = 0.285; partial eta squared = 0.342. After significant multiple analysis of variance (MANOVA), follow-up univariate ANOVA was applied to determine the effect of sports types on each dependent measure separately. Post-hoc analysis using Bonferroni was further applied based on significant result of ANOVA.

2.1 Simple reaction time test

The analysis of variance indicated that the effect of sports types significantly influenced reaction time of simple reaction time test (Table 19), $F(3, 116) = 7.899$, $p < .001$). Post hoc analyses using Bonferroni showed that the average reaction time was significantly faster in interceptive sport than strategic sport athletes (p = .005) and non-athletes (p = .001), and athletes from static sport responded quicker than strategic sport athletes (p = .017) and non-athletes (p = .005), but no significant differences were found between interceptive and static sport, and between strategic sport and non-athlete group. There was no significant difference on accuracy of simple reaction time test.

Table 18. *Descriptive statistics of simple reaction time test.*

	Interceptive sport n = 30	Static sport n = 30	Strategic sport n = 30	Non-athlete n = 30
	M ±*SD*	*M* ±*SD*	*M* ±*SD*	*M* ±*SD*
Reaction time (ms)	283.22 ±20.58	287.93 ±43.27	327.14 ±56.85	332.04 ±66.32
Accuracy (%)	97.50 ±4.10	97.17 ±3.87	98.17 ±4.04	98.17 ±2.78

Table 19. *Analysis of variance of simple reaction time test.*

	Source	*df*	*SS*	*MS*	*F*	*p*
Reaction time	Between groups	3	58803.320	19601.107		
	Within groups	116	287854.159	2481.501	7.899	.000***
	Total	119	346657.480			
Accuracy	Between groups	3	22.500	7.500		
	Within groups	116	1620.000	13.966	.537	.658
	Total	119	1642.500			

*p < .05, **p < .01, ***p < .001

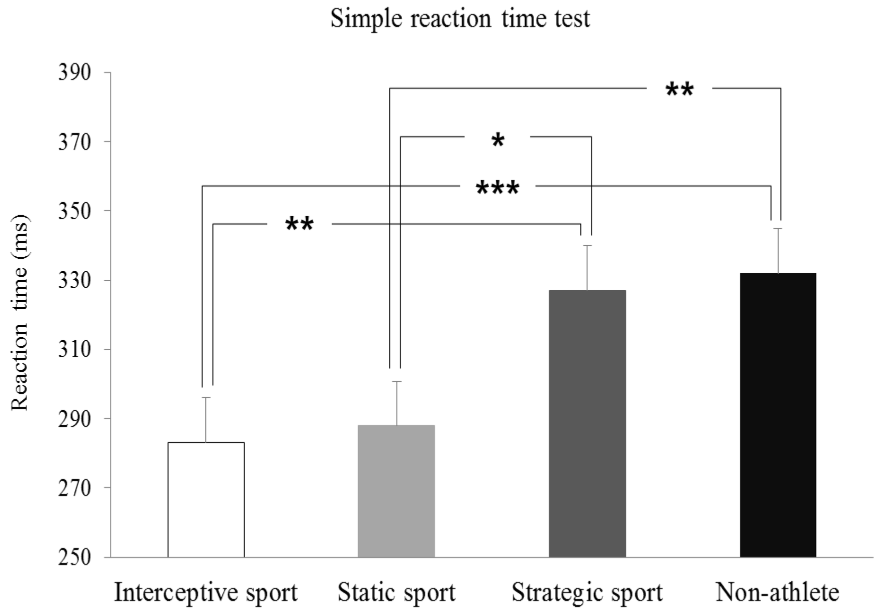


Figure 23. Reaction time of simple reaction time test according to type of sport.

2.2 Choice reaction time test

As shown in Table 21, analysis of variance showed a main effect of types of sports on mean reaction time $F(3, 116) = 7.157$, $p < .001$) and rate of accuracy $F(3, 116) = 4.487$, $p = .005$) of choice reaction time test. Post-hoc comparison using Bonferroni indicated that non-athletes had significantly slower reaction time ability than interceptive sport ($p < .001$), static sport ($p = .005$), and strategic sport athletes ($p = .01$), however, significant differences between three sport types were not observed. With regards to percentage accuracy, only interceptive sport athletes scored significantly higher than non-athletes ($p = .004$).

Table 20. *Descriptive statistics of choice reaction time test.*

	Interceptive sport $n = 30$	Static sport $n = 30$	Strategic sport $n = 30$	Non-athlete $n = 30$
	$M \pm SD$	$M \pm SD$	$M \pm SD$	$M \pm SD$
Reaction time (ms)	423.89 ±16.54	428.64 ±16.13	429.81 ±18.68	446.85 ±28.37
Accuracy (%)	90.50 ±6.92	86.83 ±11.25	83.50 ±14.47	78.83 ±16.57

Table 21. *Analysis of variance of choice reaction time test.*

	Source	*df*	*SS*	*MS*	*F*	*p*
Reaction time	Between groups	3	9057.413	3019.138		
	Within groups	116	48931.668	421.825	7.157	.000***
	Total	119	57989.080			
Accuracy	Between groups	3	2215.243	738.414		
	Within groups	116	19089.139	164.562	4.487	.005**
	Total	119	21304.382			

*$p < .05$, **$p < .01$, ***$p < .001$

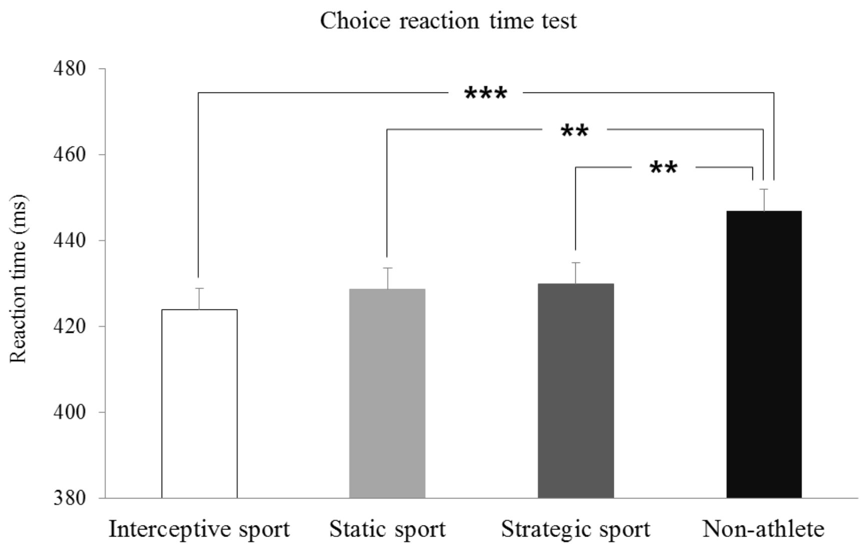


Figure 24. Reaction time of choice reaction time test according to type of sport.

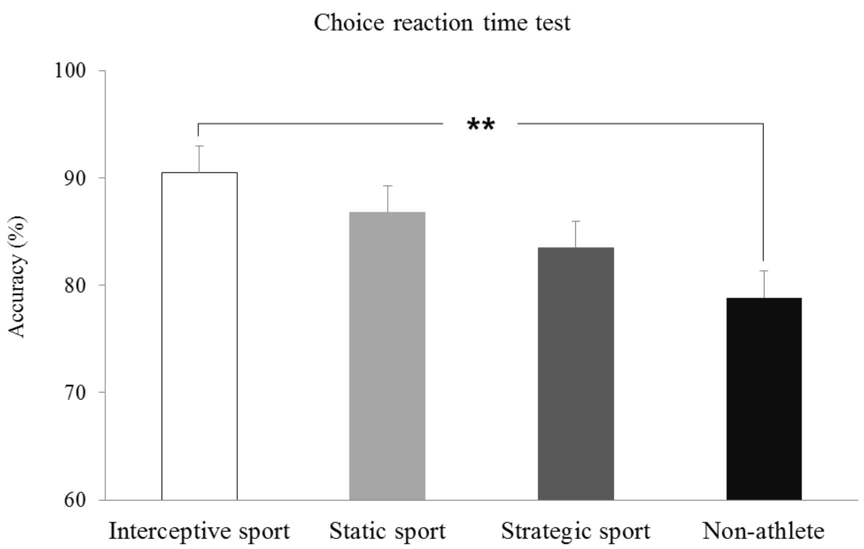


Figure 25. Accuracy of choice reaction time test according to type of sport.

2.3 Flanker test

A one-way ANOVA revealed that average reaction time ($F(3, 116) = 2.625$, $p = .054$) and percentage accuracy ($F(3, 116) = 2.303$, $p = .081$) of congruent flanker test according to athletic status did not differ significantly. As well as, athletes' reaction time ($F(3, 116) = 1.199$, $p = .313$) and accuracy abilities ($F(3, 116) = .245$, $p = .0865$) were not significantly differences to non-athletes on incongruent stimuli of flanker test (Table 23).

Table 22. *Descriptive statistics of flanker test.*

		Interceptive sport *n* = 30	Static sport *n* = 30	Strategic sport *n* = 30	Non-athlete *n* = 30
		M ±*SD*	*M* ±*SD*	*M* ±*SD*	*M* ±*SD*
Congruent	Reaction time (ms)	404.60 ±30.25	406.75 ±36.74	426.23 ±40.84	425.27 ±47.45
	Accuracy (%)	97.67 ±5.37	98.17 ±3.59	93.33 ±17.34	99.17 ±1.90
Incongruent	Reaction time (ms)	478.52 ±42.98	481.21 ±40.23	494.77 ±34.63	493.10 ±45.88
	Accuracy (%)	82.50 ±12.02	84.17 ±10.83	82.83 ±17.45	81.17 ±13.37

Table 23. *Analysis of variance of flanker test.*

		Source	*df*	*SS*	*MS*	*F*	*p*
Congruent	Reaction time	Between groups	3	12173.853	4057.951	2.625	.054
		Within groups	116	179345.723	1546.084		
		Total	119	191519.576			
	Accuracy	Between groups	3	597.500	199.167	2.303	.081
		Within groups	116	10031.667	86.480		
		Total	119	10629.167			
Incongruent	Reaction time	Between groups	3	6090.247	2030.082	1.199	.313
		Within groups	116	196326.952	1692.474		
		Total	119	202417.199			
	Accuracy	Between groups	3	136.667	45.556	.245	.865
		Within groups	116	21610.000	186.293		
		Total	119	21746.667			

$^*p < .05$, $^{**}p < .01$, $^{***}p < .001$

2.4 Trail making test

There were significant effect of sports types on time completion of TMT- part A ($F(3, 116) = 3.382$, $p = .021$), but no significant difference was observed on TMT- part B ($F(3, 116) = 2.488$, $p = .064$) (Table 25). Post hoc analyses using Bonferroni revealed that static sport athletes did faster on part A of trail making test than non-athletes ($p = .02$), but significant differences were not reported as compared to interceptive sport and strategic sport groups.

Table 24. *Descriptive statistics of trail making test.*

	Interceptive sport $n = 30$	Static sport $n = 30$	Strategic sport $n = 30$	Non-athlete $n = 30$
	M ±*SD*	*M* ±*SD*	*M* ±*SD*	*M* ±*SD*
Part A (s)	21.82 ±4.65	20.22 ±3.22	21.02 ±3.29	24.44 ±8.74
Part B (s)	47.25 ±12.07	45.86 ±11.43	53.24 ±16.14	44.78 ±12.24

Table 25. *Analysis of variance of trail making test.*

	Source	*df*	*SS*	*MS*	*F*	*p*
Part A	Between groups	3	302.253	100.751		
	Within groups	116	3456.060	29.794	3.382	.021*
	Total	119	3758.313			
Part B	Between groups	3	1281.076	427.025		
	Within groups	116	19913.270	171.666	2.488	.064
	Total	119	21194.346			

$^*p < .05$, $^{**}p < .01$, $^{***}p < .001$

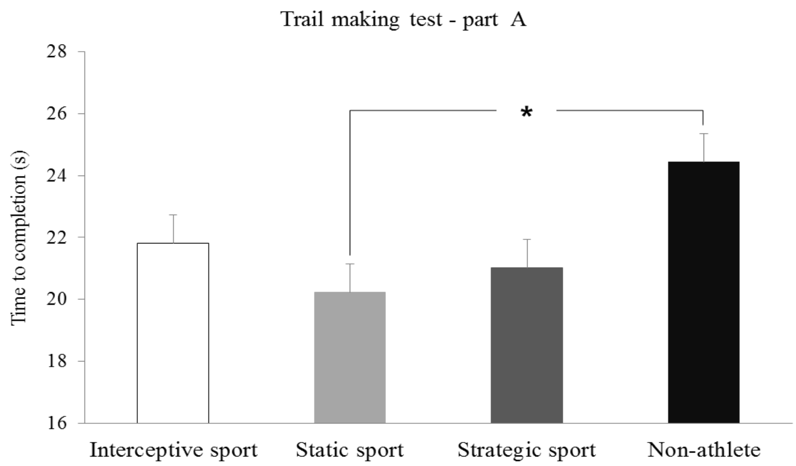


Figure 26. Time to completion of trail making test -part A according to type of sport.

2.5 Mental rotation task

ANOVA yielded a significant effect of sport type on performance of mental rotation ($F(3, 116) = 12.416$, $p < .001$) (Table 27). The results of post-hoc comparisons demonstrated the significance level for differences between the interceptive sport athletes and strategic sport athletes ($p < .001$), between interceptive sport athletes and static sport athletes ($p = .006$), and between non-athletes and strategic sport athletes ($p = .001$).

Table 26. *Descriptive statistics of mental rotation test.*

	Interceptive sport $n = 30$	Static sport $n = 30$	Strategic sport $n = 30$	Non-athlete $n = 30$
	$M \pm SD$	$M \pm SD$	$M \pm SD$	$M \pm SD$
Score	12.87 ±6.39	8.27 ±4.83	4.80 ±2.86	10.27 ±6.29

Table 27. *Analysis of variance of mental rotation test.*

	Source	*df*	*SS*	*MS*	*F*	*p*
	Between groups	3	1041.700	347.233		
Score	Within groups	116	3244.000	27.966	12.416	.000***
	Total	119	4285.700			

*$p < .05$, **$p < .01$, ***$p < .001$

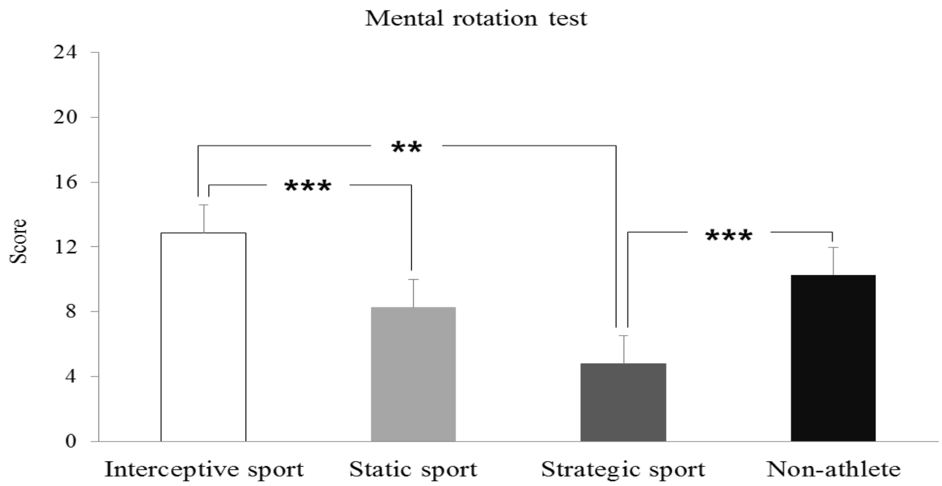


Figure 27. Score of mental rotation test according to type of sport.

2.6 Design fluency test

The analysis of variance revealed significant effect of sport type on design fluency test including filled dots task ($F(3, 116) = 6.326$, $p = .001$), empty dots task ($F(3, 116) = 9.721$, $p < .001$), switching dots task ($F(3, 116) = 4.595$, $p = .004$) and total figures of three sub-tasks ($F(3, 116) = 8.838$, $p < .001$) (Table 29). The follow-up post-hoc analyses of filled dots task reported that non-athletes did worse scores than interceptive sport ($p = .044$) and strategic sport athletes ($p = .001$), and static sport athletes had lower score in comparison to strategic sport athletes ($p = .019$). For empty dots task, strategic sport group had better skill than interceptive sport ($p < .001$), static sport ($p = .015$) and non-athlete ($p < .001$) groups. Significant differences of switching dots task were found between interceptive sport athletes and non-athletes ($p = .009$), and between strategic sport athletes and non-athletes ($p = .016$). Total scores of three sub-tasks was observed to be statistically different as strategic sport had better than static sport ($p = .013$) and non-athletes ($p < .001$), and interceptive sport had higher scores than non-athletes ($p = .022$).

Table 28. *Descriptive statistics of design fluency test.*

	Interceptive sport $n = 30$	Static sport $n = 30$	Strategic sport $n = 30$	Non-athlete $n = 30$
	$M \pm SD$	$M \pm SD$	$M \pm SD$	$M \pm SD$
Filled dots	13.10 ±3.95	11.30 ±3.99	14.37 ±3.86	10.33 ±3.92
Empty dots	11.97 ±3.52	12.97 ±3.26	15.73 ±3.48	11.23 ±3.58
Switching dots	10.00 ±3.82	8.30 ±4.74	9.80 ±3.93	6.57 ±3.70
Total score	35.07 ±9.21	32.57 ±9.00	39.90 ±9.33	28.13 ±8.64

Table 29. *Analysis of variance of design fluency test.*

	Source	*df*	*SS*	*MS*	*F*	*p*
Filled dots	Between groups	3	293.292	97.764	6.326	.001***
	Within groups	116	1792.633	15.454		
	Total	119	2085.925			
Empty dots	Between groups	3	349.758	116.586	9.721	.000***
	Within groups	116	1391.167	11.993		
	Total	119	1740.925			
Switching dots	Between groups	3	228.200	76.067	4.595	.004**
	Within groups	116	1920.467	16.556		
	Total	119	2148.667			
Total score	Between groups	3	2171.767	723.922	8.838	.000***
	Within groups	116	9501.400	81.909		
	Total	119	11673.167			

$*p < .05$, $**p < .01$, $***p < .001$

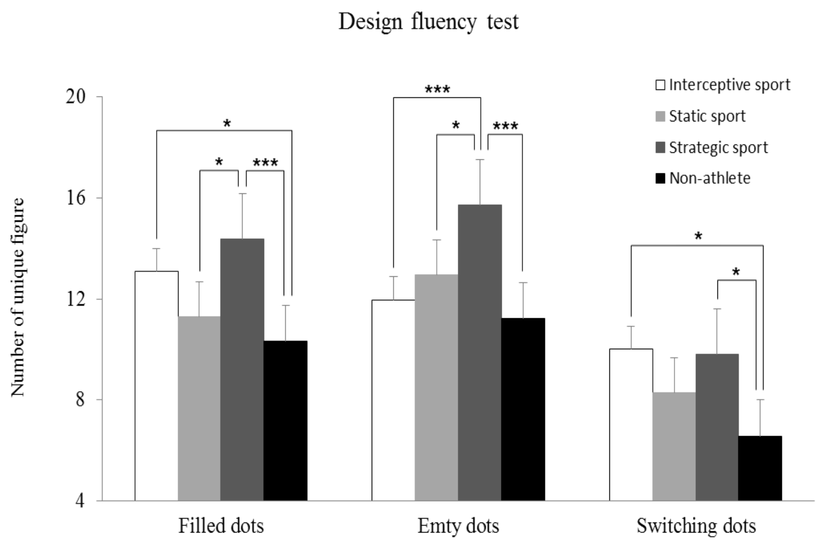


Figure 28. Number of unique figure of each sub-task of design fluency test according to type of sport.

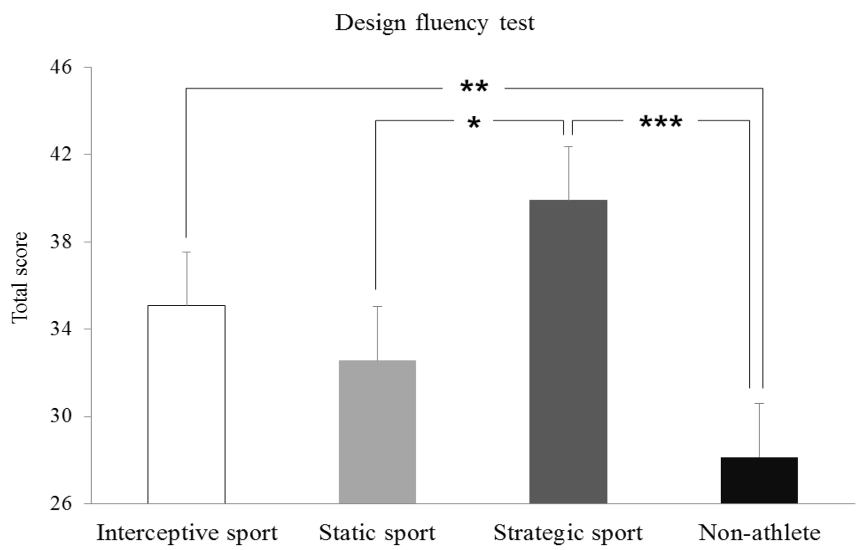


Figure 29. Total score of three sub-tasks of design fluency test according to type of sport.

Discussion

The main purposes of the current research were to empirically investigate the influences of athletic status and different types of sports on sport-related cognitive function according to the findings of study 1.

Cognitive function according to athletic status

The primary results of this study regarding athletic status (athlete and non-athlete) found several critical findings on simple (SRT) and choice reaction time test (CRT), trail making test (TMT) and design fluency task (DFT). However, athletes did not differ from the non-athletes on flanker and mental rotation test, suggesting that the athletes were no better in selective attention and response inhibition and spatial skills.

As expect from reviewed literature, we found that athletes outperformed non-athletes in multiple cognitive performances including average reaction time of SRT and CRT, response accuracy of CRT, time to completion of TMT - part A and total scores of DFT, which indicate the better mental processing skills and executive function. Consistent with previous literature, meta-analytic review study of Voss et al. (2010) summarized that high-level athletes had greater than non-athletes on paradigms of processing speed and varied attention. As well as, elite karate athletes who had sport experience 4-6 years were faster than novices in both CRT utilizing video-stimulus and dot-stimulus conditions (Mori et al., 2002). This result supported the evidence of faster reaction time in athletes due to superior anticipation ability depending on accumulated sports experience from either training or competition e.g., early motion of the opponents or object (Chamberlain & Coelho, 1993; Mori et al., 2002; Williams & Elliott, 1999). The athletes in this study were from three different sports training for professional sporting competitions such as boxing, shooting, and soccer. This suggests the positive relationship between athletic status and speed of information processing capacity.

Another one cognitive aspect affecting athletic performance, executive function was examined using design fluency task (DFT). The present study revealed that players from boxing, shooting and soccer were able to create higher unique pictures relative to non-athletes. This study is in agreement with several relevant study suggesting Swedish soccer players who played in high and low national league had better executive controls (creativity, response inhibition and cognitive flexibility) in comparison to normal population for both men and women (Vestberg et al., 2012). In youth, it has been shown that superior cognitive flexibility was observed in young elite soccer players, as compared to standardized norm group (Vestberg et al., 2017). In another team sport, Lundgren et al. (2016) have accordingly found that elite and sub-elite ice hockey athletes outperformed general population on executive skills. Possibly the differences may be explained by the benefit of sport training experience as athletes in this study were classified as high-level of competitive sport performance ranging from 7.83 - 13.27 years of sport experience. Given the literatures reported the effects of fitness exercise and athletic training on the enhancements of cognitive traits and brain structure, plasticity, neural network and cortical thickness (Colcombe & Kramer, 2003; Erickson et al., 2007; Kramer & Erickson, 2007; Wei, Zhang, Jiang, & Luo, 2011). Therefore, it can conclude that participation in competitive sport training regardless the sport-specific domain is linked with the enhancement of fundamental cognitive function such as information processing and executive function (cognitive flexibility and working memory).

Cognitive function according to type of sport

The present study was designed to obtain a better understanding of sport-related cognitive skills in relation to sport typology. The results of this study revealed that some of cognitive performances were correlated to particular type of sport.

With respect to processing speed skills, our hypothesis that interceptive sport (boxer) and strategic sport (soccer player) differed from static sport (shooter) was partially supported. The present results indicate that the shortening reaction time ability of simplistic stimulus task was significantly found in skilled athletes from interceptive and static sports as compared to strategic sport players and non-athletes. Furthermore, athletes of all sports types in this study had significant better results in responding of CRT and only interceptive sport athletes also exhibited more accurate relative to non-athletes. However, there was no sport type difference on information processing using visual choice reaction test. Contrary to present study, the meta-analysis study of Voss et al. (2010) observed the sports-related difference on speeding task of information processing that interceptive and strategic sports athletes were superior to static sports athletes. In addition, recent findings also found that the adolescent athletes of interceptive sports displayed faster on multiple color stimulus of choice RT corresponding to more accumulate of sports experience, but age- matched youth athletes in static sports did not (Yongtawee & Woo, 2017). It seems that, as athletes in this study were at high skill level, the amount of particular sport training may not differently affect to the improvement of reactive speeding skills on complex stimulus condition, but was not on simple stimuli reaction task.

We also assessed information processing and mental flexibility by examining performances in double tasks of computerize trail making test, TMT-A and TMT-B, respectively. The TMT-A was employed to evaluate the visually searching speed and TMT-B was used to test the mental flexibility. The TMT results showed a significant difference between shooters (static sport) and non-athletes in TMT-A, whereas no significant difference on TMT- B. Our findings suggest that shooters were more efficient in speeded visual search relative to sedentary. As shooting has been characterized as static or close-skilled sport that exhibit performance under self-paced situation and aiming at a target, it is worth noting that the cognitive characteristics such as information processing and visual search are vital to sport performance in shooting (Causer, Bennett, Holmes, Janelle, & Williams, 2010). For example, shooters in trap and skeet events are required to such as fast and accurately detect the target location (Abernethy & Neal, 1999). Therefore, regular training in professional shooting may improve cognitive function regarding mental processing.

Another significant difference between sport types was found in mental rotation test (MRT). Interceptive sport athletes (boxing) did statistically higher scores than both groups strategic sport (soccer) and static sport (shooting) athletes. It is consistent with the findings of Moreau et al. (2012), as compared to high-skilled runners (static sport), the experts in combat sport (interceptive sport) showed higher scores of mental rotation test. However, in contrast with previous work, no difference was reported between soccer players (strategic sport) and gymnasts (static sport) (Jansen & Lehmann, 2013). In support the notion that physical training or music training may enhance mental rotation skill (Pietsch & Jansen, 2012), the superior of mental rotation abilities in boxer in this study might be demonstrated by the face that combats sports athletes have regularly faced with huge information of mental rotation processes which could be transferred to be greater spatial abilities (Moreau, 2015). Further evidence reported that participants who was intervened by 10-months of wrestling training outperformed participants who participated in equal duration of running training. This benefit could be explained by specific brain adaptations due to the sport training. In static sport, professional golfers were reported to be increasing in gray matter in the intraparietal sulcus, a brain area which is related to spatial performance (Jäncke, Koeneke, Hoppe, Rominger, & Hänggi 2009). However, non-athletes in this study exhibited better than strategic sport athletes (soccer) on MRT. This result was contradictory to previous study showing soccer players have superior mental rotation speed than non-athletes on only embodied stimulus (human figures and body postures), but not on the cube stimulus which is similar to this study (Jansen et al., 2012). One plausible reason for this might be the influence of stimulus type used, which soccer players are likely favoring on embodied stimuli due to they were often trained recognizing the manipulation of human structures (e.g., their bodies, teammate bodies, opponent team bodies, and object (ball) in the pitch (Jansen et al., 2012). Since mental rotation ability depending on different stimuli, the particular mental rotation tasks should be applied for the further study according to type of sport. Furthermore, the difference of mental rotation performance between strategic sport athletes and non-athletes in present study might be associated with academic accomplishment, as the mathematical knowledge (Hegarty & Kozhevnikov, 1999) and academic thinking (Peter et al., 1999) were related to mental rotation performance. Therefore, academic success or educational level variables may need to be accounted as covariate variable for the future research.

Regarding the cognitive flexibility, there was significant effect of sport type on overall points of design fluency task, indicating strategic sport players (soccer) had statistically higher scores in comparison to static sport players (shooting) and non-athletes, and Interceptive sport athletes (boxing) were found to be better than non-athlete group. Several previous articles utilized the design fluency test (DFT), one of a neurocognitive test battery of the Delis-Kaplan Executive Function System (D-KEFS; Delis et al., 2001) to assess the ability of creating the unique drawing as many as possible in 1 minute depending on each sub-task rule (fill dots, empty dots and switching dots tasks). Recently, most of previous studies investigate EFs (creativity, response inhibition and cognitive flexibility) using DFT in soccer player in relation to athletic characteristics (athlete and non-athlete), skill level (elite, sub-elite and novice, or higher and lower competitive division), giftedness in sport (talented, sub-talented and non-talented) (Huijgen et al., 2015; Sakamoto, Takeuchi, Ihara, Ligao, & Suzukawa, 2018; Vestberg et al., 2012, 2017).

Base on this present results indicating strategic sport (soccer) had higher scores on DFT, one relevant explanation for the group differences in executive functions might be that soccer players are cognitively trained to make the new decisions as quickly and accurately (cognitive flexibility, creativity and problem solving), recognize the opponent or object location or recall team strategic formation (working memory) and stop or cancel inappropriate plan or action (inhibitory control) on simultaneously changing situations and unpredictable environments (Huijgen et al., 2015). These cognitive skills seem not to be associate with static sports which mostly are individual sport that perform under no time pressure with self-paced action.

Interestingly, this result also suggests that the multiple aspects of executive functions were comparable between interceptive sport athletes (boxers) and non-athletes. Due to the evidence that cognitive skill can be developed by sport training (Voss et al., 2010), it is likely participating in competitive training of interceptive action sports could improve executive function as boxing has been defined as the sport that athletes learn to gather information during competition or training and select appropriate reactions to dynamic circumstance or surrounding environments such as opponent's attacking or moving of sports equipment.

There were a number of limitations that can be addressed by future experimentation. Based on the present result that strategic sport athletes had lower mental rotation skill than non-athletes, future investigations is required applying different mental rotation test and identifying the educational status as controlling variable due to the academic knowledge influenced the intelligence and spatial ability. Furthermore, to understand clearly in another sport area, the future study regarding cognitive function is extensively needed in various populations such as female athlete, retired athlete, disabled athlete and sport referee etc.

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Appendix

	울산대학교 생명윤리위원회 University of Ulsan Institutional Review Board	심의서식 10호 (VER.1.1, 2014.03.28)

연구대상자 동의서

연구과제명 : 스포츠 유형에 따른 인지 기능 및 손가락 길이 비율에 관한 연구

IRB 승인번호 : 1040968-A-2017-016

- 본인은 본인과 연구자 및 울산대학교 사이에 본인의 연구 참여 결정에 영향을 줄 수 있는 어떠한 관계도 없습니다.

☐ 확인 시 체크하세요.

- 본인은 연구 관련자로부터 이 연구에 대해 충분한 설명을 들은 후, 본인이 직접 설명문을 읽고 이해하였으며, 궁금한 사항에 대해 적절한 답변을 들었습니다.

☐ 확인 시 체크하세요.

- 아무런 강압 없이 자발적으로 본 동의서를 작성하며 이에 본 연구에 참여한다는 것을 서명으로 확인합니다.

☐ 확인 시 체크하세요.

(날짜 및 서명은 반드시 자필로 작성)

연구대상자	(성명)__________	(자필서명)__________	(서명일)__________
법정대리인(해당 시)	(성명)__________	(자필서명)__________	(서명일)__________
	(연구대상자와의 관계) __________		
입회인(해당 시)	(성명)__________	(자필서명)__________	(서명일)__________
연구책임자	(성명)__________	(자필서명)__________	(서명일)__________

본 연구는 울산대학교 생명윤리위원회(UOU IRB)에서 심의하여 승인한 동의서만을 이용합니다.

VALID DURATION

2017. 10. 0 1 - 2018 09. 3 0

울 산 대 학 교 IRB

- 9 -

국문초록

선수여부와 스포츠 유형에 따른 스포츠 관련 인지기능의 차이

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체육학전공
용타위 앗차랏

엘리트 선수들의 운동수행력은 크게 체력, 기술, 심리 3 가지 요인에 의해 결정된다. 이러한 요인들이 완벽한 조화를 이루었을 때 선수들은 자기의 기량을 100% 발휘하는 최고수행(peak performance)을 하게 된다. 최근 특정한 인지기능이 스포츠 경기력에 중요한 역할을 할 수 있다는 주장이 제기되고 있다. 실제로 인지기능이 우수한 선수들의 경기력이 뛰어나고, 스포츠 종목에 따라 선수들 인지기능에 차이가 있다는 연구결과가 보고되고 있다. 이에 스포츠와 관련된 인지기능을 탐색하고, 스포츠 종목별 중요한 인지기능이 있는 지를 조사할 필요가 있다. 따라서 본 연구의 목적은 1) 스포츠 수행과 인지기능에 대한 체계적 문헌연구를 통해 스포츠 관련 인지기능을 조사하고, 2) 선수가 비선수보다 스포츠 인지기능이 높은 지, 스포츠 종목별로 스포츠 인지기능에 차이가 있는 지를 규명하는 것이다.

연구 1: 스포츠 인지기능 요인 탐색을 위한 문헌고찰

연구 1 의 목적은 인지기능과 스포츠 경기력 혹은 수행(performance)이라는 주제로 출판된 논문들에 대한 체계적인 문헌고찰을 통해 스포츠 인지기능 요인을 탐색하는 것이다. 문헌고찰은 체계적 문헌고찰과 메타분석 지침인 PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) 에 준하여 수행되었다. PubMed, Web of Science,

Science Direct, Wiley Online Library, and Taylor & Francis Online databases 검색엔진과 Google scholar 를 활용해 관련 논문을 검색하였다. 문헌연구에 포함되는 문헌의 기준은 정신적, 신체적으로 건강한 8-35 세를 대상으로 운동 경기력, 선수 경력, 스포츠 종목에 따라 최소 하나 이상의 인지기능의 차이나 관계를 조사한 연구이다. 키워드를 통해 검색된 총 192 개의 논문들 중 위의 기준을 충족하는 37 편의 논문이 분석에 포함되었다. 해당 선행연구들은 스포츠 숙련성, 기술수준, 스포츠 영재성과 관련된 스포츠 인지기능들을 보고하였다. 경기력과 인지기능에 관한 문헌고찰 결과, 경기력이 뛰어난 선수들은 경기력이 떨어지는 선수, 아마추어 운동선수, 일반인들보다 인지기능이 우수한 것으로 나타났다. 또한 스포츠 주니어 영재들은 영재성이 떨어지거나 영재성이 없는 주니어 선수들보다 집행기능(executive function)이 높았다. 스포츠 유형별 인지기능 관련 연구들의 문헌고찰 결과, 전략(strategic) 종목 선수들은 interceptive 나 정적(static) 종목보다 더 뛰어난 집행기능을 보이며, 개방기술(open skill) 종목 선수들은 폐쇄기술(closed skill) 선수들보다 반응금지(inhibition), 시공간 기술, 인지 유연성이 더 높았다. 또한 외적 조절(externally-paced) 종목 선수들은 자기조절(self-paced) 종목 선수들이나 비선수들보다 계획과 문제해결능력이 높게 나타난 반면, 자기조절 종목 선수들은 외적조절 종목 선수들과 비선수들보다 더 높은 반응금지 능력을 보였다. 문헌고찰을 통해 스포츠 경기력이나 스포츠 종목 특성과 유의한 관련성을 가진 인지능력은 집행기능(금지반응, 활동기억, 인지유연성), 정보처리(시각적 처리 속도, 반응시간), 공간능력(정신회전능력)으로 축약되며, 이러한 스포츠관련 인지기능을 측정하기 위해 사용된 인지검사는 플랭커검사(Flanker: 금지반응), 숫자잇기검사(trail making A: 시각정보처리속도), 숫자-기호잇기검사(trail making B: 활동기억, 인지유연성), 설계유연성검사(design fluency: 활동기억, 인지유연성), 단순, 선택반응검사(simple and choice reaction time: 반응시간), 정신회전검사(mental rotation: 정신회전 공간 능력) 등이었다. 이와 같이 스포츠 경기력과 관련된 인지기능이 존재한다면,

스포츠 경기력을 예측하기 위한 하나의 요인으로 스포츠 인지기능의 가능성을 고려해 볼 필요가 있다. 비록 스포츠 유형과 선수들의 기술수준에 따른 인지기능에 대한 선행연구가 수행되었지만, 체계적 문헌고찰을 통해 스포츠 관련 인지기능을 규명하고 종목별, 기술수준별 스포츠관련 인지기능의 차이를 체계적으로 조사한 연구는 드물다. 따라서 연구 1 의 문헌고찰에 의해 밝혀진 스포츠 관련 인지기능을 토대로, 선수와 비선수 간, 스포츠 종목별 스포츠 인지기능에 차이가 있는 지를 연구 2 에서 조사하였다.

연구 2: 선수여부, 스포츠유형에 따른 스포츠 인지기능 차이

연구 2 에서는 선수여부(선수, 비선수), 스포츠 유형(interceptive, static, strategic 종목)에 따른 스포츠 인지기능 차이를 조사하는 횡단연구를 수행하였다. 연구대상자는 총 120 명으로 30 명 복싱선수(interceptive), 30 명 사격선수(static), 30 명 축구선수(strategic)와 30 명 비선수로 구성되었다. 연구 1 의 문헌고찰에 근거해 단순, 선택반응검사, 플랭커 검사, 기호-숫자잇기 검사, 정신회전검사, 디자인 유창성 검사를 실시하였다. 검사의 정확한 반응시간과 검사시간 측정을 위해 단순, 선택반응검사, 플랭커 검사, 기호-숫자잇기 검사, 정신회전검사는 컴퓨터 버전으로 개발하였고, 직접 창의성을 갖고 패턴을 그려나가는 검사인 디자인유창성 검사는 지필검사 형태를 유지하였다. 따라서 연구대상자는 컴퓨터 기반 인지기능 검사를 완료한 뒤, 디자인 유창성 검사를 수행하였다. 선수와 비선수 인지기능을 비교하기 위해서, 선수 90 명과 비선수 30 명의 각 인지기능에 대해 독립표본 t 검증을 실시하였다. 그 결과, 선수들은 비선수들보다 단순, 선택반응시간이 빠르고, 선택반응검사의 정확률이 높게 나타나고, 숫자잇기와 설계유연성 점수가 높게 나타났는데, 이는 선수들이 시각정보처리 속도가 빠르고 활동기억, 인지유연성이 비선수보다 뛰어나다는 것을 의미한다. 스포츠 종목별(interceptive, static, strategic, 비선수) 인지기능 차이를 조사하기 위한 일원변량분석 결과, 모든 종목의 선수들은 비선수들보다 선택반응시간이 짧아 정보처리속도가 빨랐다. 특히 interceptive 종목 선수들은 빠른 정보처리속도를

유지하면서, 비선수보다 정확성이 높은 것으로 밝혀졌다. 또한 Interceptive 종목 선수들은 static 과 strategic 선수들보다 공간능력을 검사하는 정신회전검사에서 더 높은 점수를 받았다. 경쟁선수의 끊임없는 공격에 대응하면서 환경의 자극에 대해 신속한 반응이 요구되는 interceptive 종목의 특성 때문에, 장기간 해당 종목의 훈련을 통해 정보처리가 빠르면서 정확성이 높고, 공간정보처리 능력이 향상되었을 것으로 예측된다. 공과 같은 도구를 사용하면서 팀원, 상대팀의 움직임 등 무수한 정보의 동시적 처리가 요구되는 strategic 종목 선수들은 인지적 유연성과 활동기억을 측정하는 디자인 유창성 검사에서, static 선수나 비선수들보다 더 높은 디자인 유창성 점수를 보였다. 이는 strategic 종목 선수들이 변화하는 상황에 대해 정신적으로 유연성 있게 적응할 수 있는 능력과 이러한 작업 수행을 위해 정보를 유지하는 능력이 비선수나 static 선수보다 뛰어나다는 것을 의미한다.

본 연구의 결과를 종합해 보면, 운동선수들이 비선수들보다 우수한 인지기능은 인지적 유연성이며, 정보처리속도가 빠르다. 스포츠 종목별 우수한 인지기능이 존재하는 것으로 보이며, interceptive 종목은 인지 정보처리속도가 빠르고, 시공간 기술 능력이 뛰어나고, strategic 종목의 경우 활동기억과 인지 유연성을 포함하는 집행기능이 우수한 것으로 밝혀졌다. 사격과 같은 static 종목의 경우 시각정보처리 속도가 다른 종목 선수들보다 뛰어났다. 본 연구는 스포츠와 관련된 인지기능의 존재와 종목별 우수한 인지기능의 특성을 이해하는데 도움이 되었다. 제한된 연구대상자의 수와 특정 종목에 한정된 결과이므로 추후 다양한 종목과 기술수준별로 연구를 확대할 필요가 있다. 추후연구를 통해 스포츠 인지기능과 경기력의 뚜렷한 관계가 검증된다면, 스포츠 인지기능을 종목별 체육영재나 선수 선발 요인이나, 경기력 예측요인의 하나로 활용할 수 있을 것이다.

주요어: 선수, 스포츠 유형, 인지기능, 집행기능, 정보처리, 공간능력