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The Influence of Open-skilled Sports on Individual's Interference Inhibition Abilities

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Abstract: *Sports activities can be divided into open-skilled and close-skilled according to their contexts and predictabilities. Compared with closed-skilled sports, open-skilled sports are more complex and involve more cognitive demands and challenges, and individuals can have more opportunities to practice interference inhibition for such sports' attributes. Long-term interference inhibition training can optimize attention resource allocation, promote the efficient organization of neural networks, improve the neural processing efficiency of individuals in cognitive tasks, and strengthen top-down cognitive control, resulting in improved interference inhibition. Future studies can further explore the impact of open-ended skill sports on individual's abilities to interference inhibition from the aspects of individual differences, dose effects, and special group interventions.*

Keywords: *sports activities; open-skilled sports; closed-skilled sports; interference inhibition*

1. Introduction

Sports activities have significant benefits for individual cognitive function [1-4]. Most studies believe that sports activities have a greater impact on executive function [5-9]. Executive function, also known as cognitive control, refers to a high-level, self-regulating cognitive process that helps monitor thinking and action. It mainly includes three core subcomponents: inhibition control, working memory, and cognitive flexibility [10]. Compared to the other two subcomponents of executive function, sports activities have the most significant impact on inhibition control [11-13]. Inhibition control involves the ability to inhibit a dominant response to support a different response and the ability to resist interference, distraction, or habit to maintain focus [14], including interference inhibition/interference control and response inhibition/behavioral inhibition [15]. Interference inhibition, also known as conflict resolution or executive attention, refers to the ability of individuals to eliminate or inhibit interference information unrelated to the current goal through willpower efforts in goal-oriented activities, thereby better focusing their attention on the current goal [16,17]. At present, research paradigms for interference inhibition mainly include Flanker-task [18], Stroop-task [19], and Simon-task [20].

Recently, researchers have proposed that there are differences existed in the impact of different types of sports activities on individual's interference inhibition ability [21-22]. According to the consistency and predictability of the execution environment, sports activities can be divided into open-skilled sports (such as ball games and martial arts) and closed-skilled sports (such as running, walking, and cycling) [23]. Studies have found that open-skilled training is more conducive to improving individual's interference inhibition ability compared to closed-skilled training [21-22, 24-26]. Open-skill sports, also known as perceptual or strategic sports, are conducted in a constantly changing and dynamic environment [27], with characteristics such as unpredictability and continuous adaptability [28-29]. Individuals engaged in open-skilled sports must constantly change their response to randomly occurring external stimuli [30], and thus open-skilled sports is also considered to be an externally rhythmic sport [24]. In open-skilled sports, individuals often face the situation of inhibiting interference information unrelated to their current goals (i.e., interference inhibition), which is extremely important for sports success and selecting the correct behavior in daily life [30]. Currently, it is not clear how open- skilled sports affect individual's interference inhibition ability. Therefore, this paper attempts to explore the effective mechanism of open-skilled sports affecting individual's interference inhibition by systematically reviewing relevant literatures on the relationship between open-skilled sports and interference inhibition, hoping to provide a new perspective and direction for future research in this field.

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2. On the Performance of the Influence of Open-skilled Sports on Individual's interference inhibition Ability

Individuals who engage in open-skill sports such as tennis, football, basketball, badminton, and table tennis for a long time have better interference inhibition abilities, mainly manifested in shorter reaction times and higher accuracy in Flanker-task or Stroop-task [21]. Ball games are closely related to object control skills and rely on internal models for hand-eye coordination and cognitive (predictive and control) functions. Individuals must adapt to an environment that requires high predictive ability, rapid decision-making and effective tactics. Compared to a more closed and stable environment, individuals are more likely to benefit from this unpredictable environment, thereby performing faster cognitive processing in interference inhibition tasks.

For example, tennis, as a relatively common form of exercise in open-skilled sports research, requires individual's excellent response, prediction, and control abilities to coordinate complex body movements, adapt to changing task requirements, and quickly perceive movement and hand-eye coordination [30]. In tennis competitions, tennis players must focus on the information prompts of their opponents' actions, quickly determine their opponents' operations and tactics, and resist the noise, wrong actions, and unrelated thoughts of external crowds. An intervention study found that both 50 minutes of tennis training and 50 minutes of tennis competition can improve the individual's interference inhibition ability. When individuals acquire new tennis skills, selecting and activating specific cognitive processes related to inhibition can play a role in the emergence of new coordination. Individual cognitive participation and sensorimotor learning in tennis are considered as key mechanisms for connecting training and cognitive enhancement. Tennis competition involves more uncertainty and greater time pressure. Tennis players must constantly move, adjust, and react when hitting and positioning the ball. These actions are based on the actions of their opponents, following the ext"rnal'rhythm. This constantly changing environment may be related to greater retention of sport skills and increased activation of the cortical system involved in executive function. Therefore, there may be a positive correlation between more frequent tennis activities and an individual's better interference inhibition ability.

A high-intensity football game can also improve the individual's interference inhibition ability. Football is a popular open-skilled sport. Due to the constantly changing sports environment, individuals are required to quickly identify and select relevant stimuli, inhibit pre-planned responses, predict actions, and coordinate physical actions based on complex and dynamic sensory information. Specifically, a football player should cancel his intention to pass the ball to a teammate when the teammate is suddenly defended. If it is no longer possible to perform effective dribbling or shooting due to changes in field conditions, the action should be suspended and a new plan shall be formulated. If a player's football performance level is evaluated by the number of goals and secondary attacks, the higher the player's interference inhibition ability, the better his football performance is. In football competitions, players are required to have the ability to quickly inhibit their athletic reactions and make new decisions. The ability to inhibit inappropriate tactical decisions and athletic reactions is extremely important for players to succeed in the game. Therefore, the high-level performance of football players requires better interference inhibition ability, which can also be obtained through regular football practice [21]. In daily life, specific research on ball games such as basketball, badminton, and table tennis has also proven the positive effect of open-skilled sports on individual's interference inhibition ability.

In addition to ball games, the individual's interference inhibition ability of regularly practicing martial arts has also been significantly improved. Martial arts, regarded as an open-skilled sports, includes many forms of Chinese traditional martial arts, karate, and taekwondo. Martial arts is closely related to the individual's self-control ability, which can be understood as the ability to inhibit, suppress and control automatic reactions, as well as the ability to maintain focus through the use of attention. Martial arts involve constantly changing movement situations, and individuals focus their attention on their opponents or goals when practicing martial arts, stimulating goal-oriented behavior. Complex sports skills require higher levels of cerebral cortex. Some cognitive factors, such as attention or interference inhibition, may not be fully developed after simple closed-skilled sports, but can be significantly enhanced after martial arts exercises. For example, Johnstone (2018) et al. conducted an attention network test on 48 subjects, with one group having more than two years of martial arts experience, while the other group did not. The results showed that all individuals practicing martial arts showed higher attention and inhibition abilities. Successful karate performance requires a high level of cognitive involvement, switching attention resources from one task to another, and inhibiting automatic thinking and action. Therefore, cognitive function of individuals who regularly practice karate will be significantly improved. Similarly, after 16 weeks of taekwondo training, individual's interference inhibition ability will also be significantly improved. The above studies shows that open-skilled sports involve relatively

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complex sports skills, providing individuals with a large number of external environmental stimuli, and their predictability is relatively low. Individuals need more cognitive involvement in sports, which gives them more opportunities to practice interference inhibition [22].

3. The Neural Basis of the Effect of Open-skilled Sports on Individual's Interference Inhibition Ability

Open-skilled sports, as a complex sport, can effectively improve the individual's interference inhibition ability [21-22, 24-26]. What is the neural basis for the effect of open-skilled sports on individual's interference inhibition? Based on existing research, we speculate that open -skilled sports can lead to changes in the activation mode, structure, and function of the brain, as well as neurons, thereby improving the individual's interference inhibition ability.

First of all, the complex sport mode inherent in open-skilled sports have higher requirements on the cerebral cortex. As the complexity of sport mode increases, the cerebral blood flow in the cognitive area will increase. The increase in cerebral blood flow can provide additional glucose, oxygen, and energy substances to supply the prefrontal cortex and pre-assisted motor cortex, thereby improving individual cognitive function. The cognitive stimulation hypothesis believes that complex sport that has high coordination requirement and non-automation can activate the same brain regions used to control high-level cognitive processes. Based on the theoretical hypothesis of shared information processing processes in sport and cognitive control, the intervention effect of open skill sports can also be explained from the specific activation of brain regions related to sport and cognitive control. Recent studies have found that the association between complex sport skills and cognitive function may be due to the co-activation of the cerebellum and prefrontal cortex. The cerebellum is heavily involved in motor control and plays an important role in complex and coordinated movements, while the prefrontal cortex is associated with inhibitory control and plays an important role in resisting interference and maintaining goals. Therefore, the joint activation of the two supports the relationship between open skill movement and interference inhibition.

Secondly, open-skilled sports can lead to changes in brain structure and function, thereby improving cognitive function. Changes in the brain structure of individuals after exercise are not widely distributed, but are limited to specific brain regions related to exercise. For example, individuals who frequently participate in open-skilled sports exhibit greater white matter integrity in the primary motor cortex, cerebellum, and basal ganglia. The primary motor cortex, as a part of the frontal lobe, is primarily responsible for planning, controlling, and executing motion. The basal ganglia plays an important role in motor behavior and skill training, mainly responsible for motor selection, motor preparation, and acquisition of motor skills. However, neural plasticity induced by motor occurs not only in motor related brain regions, but also extends to brain regions related to cognitive function. For example, the development of the cerebellum is closely related to the development of the prefrontal cortex, and many cognitive tasks require a combination of both. Therefore, it can be speculated that open-skilled sports may improve individual cognitive abilities related to sports by changing the brain structure. In addition, changes in brain function after sports training also frequently occur in brain regions related to neural processing of specific motor skills. Engaging in more complex sports can help promote connections between brain regions involved in cognitive and motor skills. For example, complex Taekwondo movements can enhance functional connections from the cerebellum to the parietal and frontal cortices. Compared to non-athletes, professional karate athletes have stronger functional connections between the cerebellum and left thalamus to the inferior frontal cortex, upper parietal cortex, and upper temporal cortex. The increase in brain functional connectivity after open-skilled training will enable individuals to exhibit higher neural efficiency in cognitive processing, thereby improving their performance in inhibition tasks. Therefore, it can be found that changes in brain structure and function also support the causal relationship between open-skilled sports and interference inhibition.

Finally, it has been proved that sports activities in complex environment can increase cortical thickness, neurogenesis, and improve neurotransmission, thereby having a greater positive impact on the individual's interference inhibition ability. Compared to moderate intensity running, complex sports tilting and exercise seem to have more long-term benefits for the cerebellar neurotrophic system (i.e., the production of Brain-derived Neurotrophic Factors (also known as BDNF) and their receptor's functions). BDNF can promote the growth and survival of various neurons, and plays a key role in neural plasticity. Therefore, BDNF is considered as a biomarker of cognitive benefits induced by sports. In addition, Vascular Endothelial Growth Factor (also known as VEGF) and Insulin-like Growth Factor 1 (also known as IGF-1) also increased significantly after open-skilled sports. IGF-1 is an upstream factor that

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regulates BDNF expression signaling pathways. VEGF is a vascular growth factor that contributes to the production of neurons in the hippocampus. These neurotrophic factors play an important role in nerve growth and neuronal survival, and the changes in neurons are associated with better cognitive function, such as increasing synaptic neurotransmission and plasticity, promoting dendritic growth, and improving arousal level and attention. Therefore, changes in brain neurons may also be a potential neural basis for the development of individual's interference inhibition ability through open-skill sports.

4. The Influence Mechanism of Open-skilled Sports on Individual's interference inhibition Ability

Open-skilled sports represent a complex sport that involves more cognitive requirements and challenges. Previous studies have shown that the intensity and complexity of sports activities are related to interference inhibition, but when the intensity of sports activities is similar, open-skilled sports have a greater positive impact on individual's interference inhibition ability than closed-skilled sports. The reason behind this may be that there is a low demand for exercise intensity for individuals who participate in multiple open-skilled sports, and the overall complexity of exercise is sufficient to improve the individual's interference inhibition ability.

The higher the complexity of sports activities, the more cognitive resources individuals invest. Therefore, some researchers have proposed that there are at least two ways for open-skilled sports to improve individual cognitive function, namely, the cognitive requirements inherent in sports activities and the cognitive effort required to perform complex sports. Although all sports activities impose certain cognitive requirements on individuals, the cognitive requirements encountered during open-skilled sports are externally driven and vary with changes in circumstances. The typical characteristic of open-skilled sports is that cognitive ability is more involved in the exercise process, requiring individuals to process information in rapidly changing and unpredictable environments, inhibiting planned motor responses and some distracting competitive stimuli before selecting and executing tactical decisions, placing higher demands on their interference inhibition ability and more practice opportunities. By comparison, closed-skilled sports are conducted in a predictable and stable environment, and individuals are less likely to be exposed to multisensory stimuli. Therefore, when completing a challenging goal or coordinating the body to perform complex actions, the cognitive resources mobilized are relatively small [29]. Compared to sports activities with less cognitive demands, investing more cognitive resources in sports activities has greater benefits for interference inhibition. According to the generalized transfer hypothesis, the more cognitive and executive requirements involved in a specific sports project, the more training individuals receive in their cognitive skills, and the more likely these skills will be transferred to cognitive tasks unrelated to sports. Taking football as an example, the cognitive requirements inherent in football itself can lead players to conduct interference inhibition training more frequently, and thus players will be better at performing interference inhibition related tasks on computers. Therefore, the sports attributes of open-skilled sports itself determine that individuals can have more opportunities to practice interference inhibition abilities, thereby improving their performance in interference inhibition tasks.

Compared to closed-skilled sports, individuals engaged in open-skilled sports need to continuously adapt to unpredictable environments and stimuli, and also need to invest more cognitive resources to improve their efficiency in visual attention, decision-making, inhibition control, and action execution [30]. For example, individuals who frequently engage in open-skill sports exhibit faster reaction and higher accuracy in interference inhibition tasks [21], and this behavioral efficiency may be consistent with better neural efficiency. Evidence from Event-related Potential (also known as ERP) shows that compared to the control group, the open-skilled sports group exhibits greater P200, P300, and N450amplitudes, as well as smaller N200 amplitudes when performing interference inhibition tasks. P200 component is related to perceptual processing processes that require attention resource allocation . P300 component reflects the effective allocation of attention or neural resources related to tasks. N450 component is associated with the selection of competitive responses and conflict monitoring processes. N200 component reflects the cognitive control process and is related to the monitoring and resolution of reaction conflicts. This indicates that long-term open-skilled sports can improve the individual's attention resource allocation function during cognitive processing. In addition, the neuro-efficiency hypothesis believes that due to extensive practice over a long period of time, expert athletes will form a centralized and efficient organization of task related neural networks, resulting in a decrease in the activation level of their neural networks. For example, compared to non-athletes, when performing cognitive tasks, professional table tennis players have lower levels of brain activation in the following brains parts: the bilateral middle frontal gyrus, the right inferior frontal gyrus, the right supplementary motor area, the right paracentral lobule, the right pre-cuneiform region, the left superior lateral gyrus, the right angular gyrus, the left inferior temporal gyrus, the left middle temporal gyrus, the bilateral lingual gyrus and the

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left cerebellar gyrus. This indicates that long-term open-skilled training can enable individuals to centralize and effectively organize neural networks related to cognitive tasks.

To sum up, since open-skilled sports is a complex sport that involves more cognitive requirements and challenges, individuals can have more opportunities to practice interference inhibition for such sports' attributes. Long-term interference inhibition training can optimize the attention resource allocation function and can promote centralized and efficient organization of neural networks, thereby improving the neural processing efficiency of individuals in processing cognitive tasks and strengthening top-down cognitive control, resulting in improved interference inhibition abilities.

5. Conclusions

Previous studies have largely demonstrated the positive effects of open-skilled sports on individual's interference inhibition ability, but there are still some issues that need further exploration in the future：

Firstly, open-skilled sports can help improve the interference inhibition ability of various age groups [26], but its effect and mechanism of action may be affected by factors such as family socio-economic status, gender and age. Taking age as an example, compared to adults, open-skilled sports may have a greater positive impact on children and the elderly's ability to inhibit interference. Children's brain and cognitive function are developing, while older people's cognitive function is declining, and their cognitive function is at a stage of ongoing change. Relatively speaking, adult's cognitive function is relatively mature and stable. However, it is currently unclear whether there are differences in brain structure and function changes among different age groups after open-skilled sports. Therefore, Functional Magnetic Resonance Imaging (also known as fMRI) should be used more in the future to explore whether the impact of open-skilled sports on brain structure and function will vary depending on individual differences, thereby providing more neuroimaging evidence for the effective mechanism of open-skilled training on the interference inhibition ability of different individuals.

Secondly, current research has proven that there is a significant dose effect between closed-skilled sports and individual's interference inhibition abilities, such as exercise time [15], exercise intensity, exercise frequency and aerobic fitness. So, does this dose effect also exist for open-skilled sports? Although a few studies have demonstrated that exercise frequency and aerobic fitness can affect the relationship between open-skilled sports and interference inhibition, explanations for exercise time and exercise intensity are still vague. Therefore, future researches are required to deeply explore the dose effect of open-skilled sports, and further clarify what dose of open-skilled sports is more conducive to the improvement of individual's interference inhibition ability.

Thirdly, in clinical applications, sports activity is considered to be an effective means to improve mild cognitive impairment and dementia. Previous studies have shown that closed-skilled training can not only effectively improve the inhibition and control abilities of children with Attention Deficit and Hyperactivity Disorder (ADHD) and Autistic Disorder (ASD), but also delay cognitive decline in patients with Alzheimer's disease. However, research on the relationship between open-skilled sports and cognitive function in special groups is still very limited. For normal individuals, in specific areas of executive function, open-skilled training has a better improvement effect than closed -skilled training [21-22, 24-26]. It is speculated that the unique advantages of open-skilled sports in improving cognitive function may also be applicable to special groups. Therefore, future researches should further explore the impact of open-skilled sports on special groups, so as to provide a basis for selecting more effective sports therapy options.

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