Characteristics and Mechanisms of Perceptual and Memory Processing in Mind Sports Experts

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Abstract

Intellectual sports are competitive activities aimed at developing intelligence and involving substantial cognitive processes. Research indicates that long-term experience in intellectual sports influences experts' behavioral performance in perception and memory, as well as their brain activity, during domain-specific tasks. Such experience not only increases experts' perceptual span but also promotes holistic perceptual processing of piece relationships, a process associated with regions including the temporoparietal junction, supramarginal gyrus, retrosplenial cortex, collateral sulcus, and fusiform gyrus; the specific (spatial location) and abstract information (knowledge, strategies, piece relationships, etc.) stored in long-term memory forms the basis of experts' memory advantages, a process related to the medial temporal lobe, frontal lobe, and parietal lobe. Future research may investigate the neural mechanisms underlying the holistic perceptual and memory advantages of intellectual sports experts by examining different types of intellectual sports, innovating experimental paradigms, and integrating measurement equipment with cognitive characteristics, thereby providing theoretical foundations for artificial intelligence and skill training.

Full Text

Processing Characteristics and Mechanisms of Perception and Memory in Mind Sports Experts

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Abstract: Mind sports are competitive activities aimed at developing intelligence that involve extensive cognitive processing. Research indicates that long-term experience in mind sports influences experts' behavioral performance and brain activity in perception and memory during domain-specific tasks. Mind sports experience not only increases experts' perceptual span but also promotes holistic processing of piece relations, a process associated with brain regions including the temporo-parietal junction, supramarginal gyrus, retrosplenial cortex, collateral sulcus, and fusiform gyrus. The memory advantage of experts is based on both concrete information (spatial locations) and abstract information (knowledge, strategies, piece relations) stored in long-term memory, a process linked to the medial temporal lobe, frontal lobe, and parietal lobe. Future research can explore the neural mechanisms underlying holistic perceptual and memory advantages in mind sports experts by examining different types of mind sports, developing innovative experimental paradigms, and combining measurement devices with cognitive characteristics, thereby providing theoretical foundations for artificial intelligence and skill training.

Key words: mind sports, holistic perceptual advantage, memory advantage, abstract information, brain plasticity

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The term "mind sports" was proposed by the International Mind Sports Association (IMSA) in 2005 to describe activities aimed at developing intelligence (Gentile et al., 2018; Kobiela, 2018). Currently recognized mind sports include bridge, chess, Go (baduk), draughts, Chinese chess (xiangqi), and mahjong.

Unlike traditional physical sports that involve muscles and bones and focus on motor skill acquisition, mind sports primarily involve mental skills—the ability to apply learned rules or procedures to successfully complete intellectual tasks (Kobiela, 2018). Through prolonged, systematic training, mind sports experts achieve performance significantly superior to novices in their specific domains. Research demonstrates that mind sports training enhances cognitive performance, improving not only basic cognitive abilities such as attention, perception, and memory (Bilalić, Langner, et al., 2011; Burgoyne et al., 2016; Chu-Man et al., 2015; Fattahi et al., 2015; Iizuka et al., 2018; Sala & Gobet, 2017a), but also higher-order cognitive functions including reasoning, planning, problem-solving, and metacognition (Aciego et al., 2012; Bilalić et al., 2019; Cheng et al., 2014; Joseph et al., 2016; Kazemi et al., 2012; Subia et al., 2019; Unterrainer et al., 2006). These enhanced cognitive performances in experts are referred to as "expertise effects" (Ferrari et al., 2008; Whitaker et al., 2020).

During mind sports activities, experts must maintain focused attention, integrate current perceptual information with rules stored in long-term memory, formulate and evaluate plans mentally, and select optimal solutions (Bart, 2014). Consequently, experts exhibit advantages in both basic and higher-order cognitive processes. Basic cognitive processes form the foundation for higher-order processes, and the essence of mind sports lies in learning rules about abstract information regarding artificial objects–specifically, the ability to discover abstract relationships among limited stimulus prototypes through observation and generalize them to novel stimuli (Schonberg et al., 2018). This process reflects adaptive perceptual changes to mind sports-related stimuli (e.g., chess positions, card distributions) and the accumulation of knowledge and experience, driving plasticity in perception and memory capabilities. Researchers contend that rapid perceptual processing forms the basis of expertise in mind sports (Chase & Simon, 1973; Reingold & Charness, 2005; Reingold, Charness, Pomplun, & Stampe, 2001; Reingold, Charness, Schultetus, & Stampe, 2001), while memory constrains rule learning processes (Frank & Gibson, 2011). Therefore, experts' exceptional performance builds upon their perceptual and memory advantages, with higher-order cognitive processes such as reasoning and problem-solving further grounded in these basic cognitive mechanisms. Perception and memory thus constitute the core of expertise in mind sports.

However, current research has yet to reach consensus on the specific processing mechanisms underlying experts' perception and memory. While studies confirm stable domain-specific perceptual advantages in mind sports experts, debate persists regarding the underlying mechanisms. Some researchers attribute experts' advantages to holistic information processing (Kundel et al., 2007; Sheridan & Reingold, 2017), whereas others argue that experts primarily process important local information (Brams et al., 2019). Regarding memory advantages, some studies emphasize the importance of concrete information (Chase & Simon, 1973; Gobet & Simon, 1998), others highlight the greater relevance of abstract information acquisition (indirectly cited from Gobet, 1998; original source: Holding, 1985), and some suggest both types contribute (Linhares & Brum, 2007; Linhares & Chada, 2013). In light of these controversies, this review synthesizes research progress in mind sports studies using the expert-novice paradigm, revealing the internal processing patterns and mechanisms of experts based on perception and memory, while outlining future research directions to better understand the neural mechanisms of expertise effects.

1.1 Behavioral Evidence

The ability to perceive important pieces or cards is crucial in mind sports, as recognizing key pieces facilitates retrieval of corresponding rules from long-term memory to determine move selection. Early studies demonstrated that chess experts exhibited shorter reaction times than novices during visual search tasks in both real and random chess positions (with some studies requiring search for knights, others for combined knights and bishops), yet no significant differences emerged when identifying single pieces in isolation (Bilalić, 2016; Bilalić, Kiesel, et al., 2011; Bilalić et al., 2010; Bilalić, Langner, et al., 2011; Saariluoma, 1985).

The perceptual advantage exhibited by chess experts in domain-specific tasks likely stems from their ability to holistically encode chess positions. Using the composite paradigm, researchers required participants to judge consistency between current and previous positions based solely on the lower half of the board, finding that changes in the upper half also influenced consistency judgments. This indicates that experts automatically process the entire board configuration (Boggan et al., 2012).

Two factors contribute to experts' holistic perceptual advantage. First, extensive training increases experts' perceptual span. Eye-tracking studies reveal that experts possess a larger perceptual span for real chessboards, enabling rapid target localization and task completion with fewer fixations (Bilalić, Kiesel, et al., 2011; Bilalić et al., 2010; Reingold & Charness, 2005; Reingold, Charness, Pomplun, & Stampe, 2001).

Second, experts automatically process abstract piece relations (attack and defense relationships between pieces) in parallel. Check-detection tasks demonstrate significantly shorter reaction times for experts when processing piece relations compared to novices (Bilalić, 2016; Bilalić, Kiesel, et al., 2011; Bilalić, Langner, et al., 2011; Wright et al., 2013). Even under unconscious conditions, experts can process piece relations in chess positions (Kiesel et al., 2009). Unlike novices who process piece relations sequentially, experts automatically process multiple relations simultaneously (Reingold, Charness, Schultetus, & Stampe, 2001). Even when instructed to evaluate only whether a piece at a cued location can deliver check, experts automatically process pieces at other positions (Postal, 2012). Eye-tracking data further indicate that experts distribute more fixations between pieces rather than on individual pieces (Bilalić, Kiesel, et al., 2011; Reingold & Charness, 2005; Reingold, Charness, Pomplun, & Stampe, 2001). Due to their expanded perceptual span and extensive prior knowledge, chess experts can parallel-process abstract piece relations, manifesting holistic perceptual advantages in domain-specific tasks. These findings align with the holistic model of image perception, which posits that larger perceptual spans enable experts to utilize parafoveal vision for rapid information extraction, thereby achieving holistic-local processing of images (Brams et al., 2019; Kundel et al., 2007; Sheridan & Reingold, 2017). Similar results have been observed in Chinese chess experts, who demonstrate larger perceptual spans, utilize parafoveal information extraction, and exhibit strong holistic perceptual processing abilities (Wang et al., 2016).

1.2 Neuroimaging Evidence

Research indicates that the temporo-parietal junction (TPJ), supramarginal gyrus (SMG), retrosplenial cortex (RSC), collateral sulcus (CoS), and fusiform gyrus (FFA) constitute the neural basis for holistic perceptual advantages in mind sports experts during domain-specific tasks.

Previous studies have linked TPJ activation to holistic perceptual processing (Bloechle et al., 2018; Huberle & Karnath, 2012; Rennig et al., 2015). Rennig et al. (2013) reanalyzed previously collected fMRI data with TPJ as a region of interest, finding that chess experts showed higher TPJ activation than novices during real chess positions, with no differences observed for random positions.

This suggests that long-term training expands experts' perceptual span, enabling them to holistically process real chess positions based on extensive stored prior knowledge, thereby eliciting TPJ activation.

SMG participates in the awareness of abstract piece relations. For instance, Bilalić et al. (2012) employed a threat detection task requiring processing of abstract piece relations (judging whether black pieces attacked exactly four white pieces) and found greater SMG activation in chess experts compared to novices. However, no differences emerged between experts and novices in this region during visual search tasks that did not require abstract piece relation processing (Bilalić et al., 2010). Thus, SMG may represent the neural substrate for parallel processing of abstract piece relations underlying holistic perceptual processing. Since piece relation processing often builds upon piece identification, some researchers have found that chess experts exhibit specific activation in the occipito-temporal junction (OTJ) during piece identification (Bilalić et al., 2010), though no significant differences from novices appear in shape recognition tasks (Bilalić, Kiesel, et al., 2011).

Furthermore, comparative studies of brain activation patterns between real and random positions in chess experts provide empirical support for the neural mechanisms of holistic perception based on abstract piece relations. Real positions contain meaningful abstract piece relations, and learned position experience facilitates experts' parallel processing of multiple piece relations—that is, holistic perceptual processing. Research demonstrates that chess experts show stronger activation in RSC and CoS for real versus random positions, while exhibiting stronger FFA activation for random versus real positions; novices show no differential activation patterns between real and random positions (Bilalić et al., 2010; Bilalić et al., 2012; Bilalić, Langner, et al., 2011). RSC activation relates to piece relation processing, CoS to rapid orientation processes (Bilalić et al., 2012), and FFA activation to holistic perceptual processing (Bilalić et al., 2016; Ross et al., 2018). Although FFA is traditionally considered a specialized region for face processing (Kanwisher & Yovel, 2006), various types of experts show FFA activation when processing domain-specific stimuli (Bilalić et al., 2016; Gauthier et al., 2000; Ross et al., 2018). Moreover, inversion effects occur in both face and other stimulus processing, leading to the view of FFA as an experience-modulated visual processing region primarily responsible for holistic processing (Bilalić et al., 2016; Ross et al., 2018). Through chess experience, experts holistically process stimuli (real positions). High familiarity with real positions reduces visual complexity, enabling rapid target localization and capture of abstract piece relations. This process likely reflects the neural mechanisms underlying experts' holistic perceptual advantages in domain-specific tasks.

Wan et al. (2011) investigated the neural basis of specific perceptual processing in Japanese chess (shogi) experts. Results showed that experts exhibited significant precuneus activation for real positions (e.g., opening, endgame) compared to random positions or other stimuli (e.g., chess, scenes, faces), whereas lowlevel amateur groups showed no differences between real and random positions (or other stimuli). This suggests that the precuneus may also participate in holistic perceptual processing within experts' domains.

1.3 Issues for Further Investigation

Analysis of previous research reveals that holistic perceptual advantages in mind sports experts primarily benefit from increased perceptual span and parallel processing of abstract piece relations. Under the influence of mind sports experience, experts more readily demonstrate holistic perceptual advantages for real positions, though controversy remains regarding advantages in random positions. Some researchers have observed expert advantages in random positions (Bilalić et al., 2010; Bilalić, Langner, et al., 2011), possibly because increased perceptual span facilitates perception of pieces and their relations in random positions, or because random positions may still contain some meaningful piece relations, making it impossible to ensure all relations are meaningless. However, other studies have not observed such perceptual advantages (Bartlett et al., 2013; Krawczyk et al., 2011; Reingold, Charness, Pomplun, & Stampe, 2001). Future research should further investigate the role of parallel processing of piece relations and increased perceptual span in experts' perception of random positions.

Neural mechanisms underlying holistic perceptual advantages in chess experts remain controversial. Researchers have found that right TPJ activation is higher for real versus random positions in check detection tasks, yet lower for real versus random positions in piece identification tasks (Rennig et al., 2013). Both tasks involve piece identification, but check detection additionally requires processing of piece relations (Bilalić et al., 2010, 2012; Bilalić, Langner, et al., 2011). This raises the question of whether holistic processing is modulated by processing depth. Furthermore, behavioral research indicates that experts' perceptual advantages are domain-specific—that is, experts show perceptual advantages in domain-specific tasks but perform similarly to novices in domain-general tasks (Bilalić, Kiesel, et al., 2011; Bilalić et al., 2010; Bilalić, Langner, et al., 2011). However, this phenomenon is not reflected in brain activation patterns, as some neuroimaging studies show that experts exhibit significantly higher activation in relevant brain regions than novices even during domain-general tasks. For example, experts show greater FFA activation than novices in dot judgment tasks (Bilalić, Langner, et al., 2011), with similar results observed in TPJ (Rennig et al., 2013).

Moreover, current research on domain-specific perceptual advantages in mind sports experts has concentrated heavily on chess experts. While studies on other types of mind sports have also observed holistic perceptual advantages, the underlying neural processes differ. For instance, chess experts show higher precuneus activation for random versus real positions (Bartlett et al., 2013), whereas shogi experts show the opposite activation pattern. These discrepancies may also stem from differences in experimental paradigms and analytical methods. Systematic investigation is needed to resolve these issues.

2.1 Behavioral Evidence

Memory is fundamental to acquiring knowledge and skills, and this basic cognitive process is particularly critical in mind sports. Previous research demonstrates that mind sports experts exhibit more accurate and flexible memory for positions, showing stable domain-specific memory advantages.

In recall tasks where positions were briefly presented and participants were asked to reconstruct them, memory performance positively correlated with skill level (Gobet & Simon, 1996a). Experts recalled real positions with significantly higher accuracy than novices (Chase & Simon, 1973; Gobet & Clarkson, 2004; Gong, 2015). Memory advantages also emerged for random positions (Gobet & Simon, 1996b; Sala & Gobet, 2017b). Studies indicate that spatial location information (concrete) of pieces constitutes one component of experts' long-term memory. Compared to novices, chess experts' memory is more stable and less susceptible to interference tasks (Frey & Adesman, 1976; Gobet & Simon, 1996c; Robbins et al., 1996). Additionally, experts' memory is more flexible, with changes in position presentation format having minimal impact on memory performance. For example, when positions were presented using letters to represent pieces, experts' memory performance did not differ from that with real pieces (Campitelli et al., 2005). This suggests that experts' long-term memory contains not only concrete information about piece spatial locations but also abstract information for processing piece relations. These factors likely contribute to the emergence of memory advantages in mind sports experts.

Existing theories have explained the origins of chess experts' domain-specific memory advantages: (1) **Chunking theory** (Chase & Simon, 1973) proposes that through extensive training, spatially proximal and frequently co-occurring piece clusters become stored as chunks in chess experts' memory. Chunks thus refer to specific pieces distributed on particular squares. During real positions, experts match the current position with chunks stored in long-term memory, automatically activating and retrieving chunk information into short-term memory to complete memory tasks. Consequently, memory performance for real positions significantly exceeds that of novices. However, chunking theory struggles to explain certain findings. For example, since pieces in random positions are randomly arranged without relevant prior chunk information, researchers nevertheless observed expert memory advantages in random positions (Gobet & Simon, 1996b; Sala & Gobet, 2017b). Moreover, interference tasks do not affect chess experts' memory performance (Frey & Adesman, 1976; Gobet & Simon, 1996c). Chunking theory suggests that experts store retrieved chunk information in short-term memory, and interference tasks should disrupt short-term memory and consequently affect experts' memory performance, yet actual results contradict this prediction. Clearly, chunking theory has limitations in explaining chess experts' memory advantages.

(2) **Template theory** (Gobet & Simon, 1996c) extends chunking theory, proposing that long-term memory stores templates and retrieval structures. Templates are large chunks with information slots acquired implicitly through competition or study, with cores formed by a dozen frequently occurring pieces and slots storing variable features or related moves, plans, openings, and relations with other templates. Thus, expert memory advantages may also emerge in random positions. Retrieval structures refer to structures that allow individuals to extract useful information from long-term memory after sufficient practice and training (Chase & Ericsson, 1982), providing an explanation for why experts' memory performance is less affected by interference tasks (Robbins et al., 1996).

Both chunking and template theories posit that experts' long-term memory stores discrimination networks established through visual familiarity and differentiation processes, acquired implicitly. Experts complete memory tasks through familiarity-based recognition judgments of presented positions using chunk/template-based discrimination networks. Since visual familiarity with pieces/positions is typically constructed through concrete spatial locations (Chase & Simon, 1973; Gobet & Simon, 1998), the core of these theories—chunk formation—relies on memory for pieces' concrete spatial locations. However, researchers have found that changing position presentation formats does not affect experts' memory performance (Campitelli et al., 2005), while semantic instructions do impact memory scores (Cooke et al., 1993). Lane and Chang (2018) analyzed declarative chess knowledge and memory abilities in 79 chess experts, finding that highly generalized chess knowledge could explain 67% of variance in memory performance. This demonstrates that abstract information also influences experts' memory performance.

(3) **SEEK theory** (Search, Evaluation, and Knowledge theory; indirectly cited from Gobet, 1998; original source: Holding, 1985) proposes that experts store more abstract and generalized knowledge in long-term memory rather than concrete visuospatial information. Research shows that higher-level players possess more highly conceptualized knowledge (Chassy & Gobet, 2011). Chess experts tend to classify positions based on abstract relations rather than simple visual similarity (Linhares & Brum, 2007). Experts show no significant memory performance differences between original positions and those with horizontal mirror processing (left-right unchanged, up-down inverted) (Gobet & Simon, 1996a). These results demonstrate the role of abstract position information in expert memory. While SEEK theory emphasizes the impact of abstract information, it neglects the role of concrete information such as piece spatial locations. Linhares and Brum (2007) suggest that chunks contain different levels of encoding, including superficial location information and deep abstract structures (semantics, concepts). Schultetus and Charness (1999) found that processing piece relations significantly improved chess experts' recall performance. Expert-novice differences in memory primarily manifested for pieces with attack-defense relations (Gong et al., 2015). Vaci

et al. (2019) conducted a longitudinal tracking study finding that figural intelligence had limited predictive power for chess skill, whereas verbal intelligence had greater influence, with piece relations being more important in recognition judgments (McGregor & Howes, 2002). Thus, compared to concrete position information, highly generalized knowledge, strategies, and piece relations—abstract information—appear more important in expert memory.

Researchers have also identified expert memory advantages in recall tasks for Chinese chess, bridge, and Go. Experts in these domains all demonstrate superior reconstruction abilities for real positions compared to novices (Engle & Bukstel, 1978; Wang et al., 2016). Liu (2019) strictly controlled and matched perceptual and working memory abilities between Go experts and novices, yet still found memory advantages in Go experts.

2.2 Neuroimaging Evidence

The medial temporal lobe region, including the hippocampus and parahippocampal gyrus, represents a critical brain area for memory (Eichenbaum, 2004; Zhang et al., 2021). Studies of brain-damaged patients demonstrate that medial temporal lobe damage affects both long-term and visual short-term memory (Koen et al., 2017; Scoville & Milner, 1957). Chess experts show specific activation in the left parahippocampal gyrus when processing real positions (Campitelli et al., 2007), suggesting that extensive stored information about real positions (e.g., concrete spatial location information and abstract piece relation and strategy information) facilitates expert memory advantages.

Researchers have also identified neural substrates for experts' random position memory advantages. Compared to novices, chess experts show strong activation in the inferior parietal sulcus (IPS) when processing random positions, with IPS activation significantly correlating with recognition performance (Bartlett et al., 2013). Studies indicate that this region, besides attentional functions, is involved in strategic encoding during memory tasks (Bor & Owen, 2007; Sestieri et al., 2017). Since visual familiarity with pieces/positions is disrupted in random positions, experts' memory advantages in random positions may more strongly reflect the facilitative effect of abstract information stored in long-term memory. Therefore, IPS activation may reflect experts' use of stored abstract information for strategic encoding of random positions.

Investigations into the neural mechanisms of domain-specific memory advantages in other mind sports have revealed coordinated activity among brain regions. Nakatani and Yamaguchi (2014) used EEG to examine brain activity during reconstruction tasks in shogi experts and novices. Real positions elicited not only specific activation in experts' frontal regions at 200ms and temporal, frontal, and parietal regions at 700ms, but also functional connectivity between frontotemporal and frontoparietal areas. Similar results were obtained in Go experts (Jung et al., 2018). The frontal lobe is central to working memory, with rapid frontal activation for real positions likely reflecting initial coarse processing of position information; the temporal lobe participates in storing and retrieving prior position knowledge, while the parietal lobe processes piece spatial relations (Berlucchi & Vallar, 2018; Cabeza & Nyberg, 2000; Ptak, 2012; Vaz et al., 2019). Coordinated activity between frontal and temporal/parietal regions corresponds to the internal process of working memory processing current position information while retrieving relevant mind sports experience. This indicates that frontal and parietal lobes also participate in memory processing in mind sports experts, with their involvement varying across different types of mind sports.

2.3 Issues for Further Investigation

Regarding theories of experts' domain-specific memory advantages, some emphasize the importance of concrete information (chunking and template theories), while others stress the significance of highly conceptualized abstract knowledge (SEEK theory). However, all these theories have limitations and require modification, and their applicability to other mind sports needs further exploration. Mind sports experts may have developed a specialized "memory hierarchy tower" for domain-specific information, with the bottom level storing concrete information encoded by spatial location and the top level containing the most general abstract information such as principles, concepts, and knowledge. The hierarchy increases gradually in abstractness and generality, with interactions between levels. Consequently, mind sports experts perform well in memory tasks involving concrete information such as recalling real and random positions (Chase & Simon, 1973; Gobet & Clarkson, 2004; Gobet & Simon, 1996b; Sala & Gobet, 2017b; Gong, 2015), and also show superior performance in memory tasks involving abstract information such as changing piece presentation formats and instructions (Campitelli et al., 2005; Cooke et al., 1993). However, the specific parameters, influencing factors, and physiological basis of this conceptual model require further empirical examination.

Review of neuroimaging studies on mind sports experts' domain-specific memory advantages reveals consistent findings: the medial temporal lobe participates in forming and retrieving long-term memory, and both concrete and abstract information related to expert memory advantages may be stored in this region. However, the roles of frontal and parietal lobes in experts' memory processing remain unclear. For instance, does the frontal lobe only participate in memory advantages of shogi and Go experts? Does the parietal lobe only process piece spatial relations? What are the neural bases of relevant memory theories? Although researchers suggest IPS activation may reflect experts' effective strategic encoding of random positions using stored abstract memory information, differential activation has not been observed in other brain regions also responsible for memory strategic encoding (Bor & Owen, 2007). Whether this region truly reflects strategic encoding requires verification. Therefore, subsequent studies should employ more effective paradigms and observational methods to thoroughly investigate the neural mechanisms of mind sports experts' memory advantages and their similarities and differences across various mind sports.

3.1 Summary

In summary, the processing characteristics and mechanisms of mind sports experts' perception and memory in domain-specific tasks are as follows: (1) The holistic perceptual advantage in mind sports experts likely arises from increased perceptual span and parallel processing of abstract piece relations. The neural mechanisms may manifest as: extensive stored experience in RSC and CoS enables specific activation of TPJ and FFA for rapid holistic processing of positions, with piece identification via OTJ and parallel processing of abstract piece relations in SMG, collectively producing holistic perceptual advantages. (2) The memory advantage stems from concrete spatial location information and highly generalized knowledge, strategies, and piece relations—abstract information—stored in experts' long-term memory, partially supporting template theory and SEEK theory. Additionally, researchers have found that experts' memory advantages involve not only frontal and parietal lobes responsible for working memory and spatial relation processing, but also specific activation of temporal regions responsible for long-term memory.

Thus, mind sports experts complete holistic perception of positions through expanded perceptual span and automatic parallel processing of abstract piece relations, and evaluate both sides' positions to make optimal choices based on concrete and abstract information stored in long-term memory. Since mind sports involve acquiring abstract rules about artificial objects through learning, experts' stable advantage responses in domain-specific tasks represent an acquired special ability related to mind sports. This special ability, as part of intelligence, can be shaped through learning or training. However, the existence of expertise advantages in domain-general tasks remains controversial (Bartlett et al., 2013; Bilalić, 2016; Bilalić, Kiesel, et al., 2011; Bilalić, Langner, et al., 2011; Burgoyne et al., 2016; Fattahi et al., 2015; Joseph et al., 2016; Sala et al., 2017; Sala & Gobet, 2017a; Smith et al., 2021; Unterrainer et al., 2006), indicating that whether special abilities acquired through deliberate practice can transfer to domain-general tasks remains unclear.

Previous research demonstrates the important role of genetic factors and their interaction with deliberate practice in expert performance (Mosing et al., 2016; Ullén et al., 2016; Vaci et al., 2019). Consistent with these findings, this review indicates that deliberate practice relates to expert-novice performance differences, supporting the facilitative effect of deliberate practice on expert performance (Ericsson, 2007; Hambrick et al., 2014). However, since researchers primarily employ cross-sectional comparisons, the influence of innate genetic factors on special abilities cannot be excluded (Ullén et al., 2016). Moreover, research shows that innate genetic factors also affect general intelligence (Polderman et al., 2015; Sauce & Matzel, 2018; Savage et al., 2018), which is central to performance across different tasks (Mackintosh, 2011). Therefore, performance in domain-general tasks is primarily influenced by general intelligence. This suggests that innate genetic factors may lead to the controversial findings regarding mind sports experts' stable advantages in domain-specific tasks versus their debated performance in domain-general tasks. Future research could further investigate the role of genetic factors in the generalizability of special abilities.

3.2 Outlook

This review summarizes the effects of mind sports on experts' perception and memory—two fundamental cognitive processes—in domain-specific tasks, yet several issues require further exploration: (1) Compared to behavioral experiments, neuroimaging investigations of the neural basis of experts' holistic perceptual advantages need supplementation. Current studies infer mechanisms based solely on differences between real and random positions or activation in brain regions responsible for holistic processing, which cannot fully characterize the neural basis of experts' perceptual advantages. Moreover, inconsistencies between brain imaging and behavioral results require further investigation. Subsequent research should employ unified paradigms with large samples under strictly controlled random position conditions to examine the roles of TPJ and FFA in holistic perception and SMG and RSC in complex piece relation processing in mind sports experts. High-resolution fMRI should be used to investigate specific brain network patterns in these regions when experts process domain-specific stimuli. Additionally, investigations of the neural mechanisms underlying experts' memory advantages lack specificity, making it difficult to resolve theoretical debates about memory. Whether temporal lobe activation represents concrete information emphasized by template theory or abstract information highlighted by SEEK theory remains unclear. Current research suggests that anterior temporal and sensory-related brain regions participate more in concrete information processing (Bucur & Papagno, 2021; Loiselle et al., 2012; Straube et al., 2013), whereas medial temporal lobe, middle temporal gyrus, and inferior frontal gyrus participate more in abstract information processing (Binder et al., 2009; Bowman & Zeithamova, 2018; Reber et al., 2019; Wang et al., 2010). However, the neural distribution patterns for storage of abstract versus concrete information in mind sports experts remain unclear, as do the connections among these brain regions. Since concrete information is processed earlier than abstract information, future studies could employ MEG to investigate the temporal and spatial neural basis of experts' memory advantages. Subsequent research should also use graph theory, functional connectivity, or dynamic causal analysis to reveal cooperative relationships among temporal, frontal, and parietal lobes, explore whether influences of different brain regions on expertise advantages are specific or regulated by common mechanisms, and examine interactions among brain regions.

(2) The vast majority of research has focused on chess and Chinese chess, with

limited investigation of other mind sports. Compared to chess, all pieces have identical functions in Go and draughts, with opponents differing only in piece color, making concrete information such as color more influential in experts' perceptual processing. Bridge, conversely, relies more on abstract thinking processes like mathematical calculation. Additionally, based on the number of players, mind sports can be categorized as individual or team competitions: Go, chess, Chinese chess, and draughts are individual competitions (one-on-one or one-on-many), while bridge is a team competition (two-on-two) requiring not only individual ability but also close team member cooperation. Whether differences in cognitive demands across mind sports lead to differences in behavioral manifestations and neural substrates remains unclear.

(3) More effective measurement tools should be selected. Existing research has primarily used fMRI to investigate perceptual processing neural mechanisms, yet EEG and MEG with higher temporal resolution are more suitable for examining rapid cognitive processes like perception. Conversely, since memory involves subcortical structures, fMRI with higher spatial resolution is more appropriate for investigating this process. Additionally, for team mind sports like bridge, hyperscanning techniques based on fNIRS can reduce restrictions on individual activity while examining neural mechanisms of team member cooperation.

(4) Develop practical, standardized research paradigms. Stimulus presentation durations in perceptual tasks have not been standardized, and sufficient time may reduce group differentiation and introduce confounding cognitive components. Due to motion tolerance limitations, memory advantages' neural bases have primarily been investigated through recognition tasks, yet recognition and recall tasks differ not only in difficulty but also potentially in strategy. Previous research shows significant expert-novice differences in random position recognition but not in recall tasks (McGregor & Howes, 2002). Therefore, researchers need to develop new paradigms that combine measurement devices with cognitive characteristics to thoroughly investigate perceptual and memory processes.

(5) Conduct brain-inspired research based on intelligent activities of mind sports experts. Increasingly, mind sports data are being used for artificial intelligence development (Risi & Preuss, 2020; Schrittwieser et al., 2020), with AlphaGo defeating human Go masters. Its deep learning principle is built analogously to human neural networks. Human intelligence features developmental, flexible, and creative characteristics. Therefore, combining computer simulations with processing characteristics and neural mechanisms of human intellectual activities facilitates exploration and development of brain-inspired products.

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