RUNNING HEAD: VISUO-SPATIAL WORKING MEMORY IN CHESS EXPERTS

Are the Advantages of Chess Expertise on Visuo-Spatial Working Memory Capacity Domain Specific or Domain General?

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Abstract

Chess Experts have repeatedly demonstrated exceptional recall of chessboards, which is weakened by disruption of the chessboard. However, chess experts still perform better than novices when recalling such disrupted chessboards suggesting a somewhat generalized expertise effect. In the current study, we examined the extent of this generalized expertise effect on early processing of visuo-spatial working memory (VSWM), by comparing 14 chess experts (Elo rating >2000) and 15 novices on a change-detection paradigm using disrupted chessboards, where attention had to be selectively deployed to either visual or spatial features, or divided across both features. The paradigm differed in the stimuli used (domain-specific chess pieces vs novel visual shapes) to evaluate domain-general effects of chess expertise. Both experts and novices had greater memory discriminability for chess stimuli than for the unfamiliar stimuli, suggesting a salience advantage for familiar stimuli. Experts however demonstrated better memory discriminability than novices not only for chess stimuli presented on these disrupted chessboards, but also for novel, domain-general, stimuli, particularly when detecting spatial changes. This expertise advantage was greater for chessboards with supra-capacity set sizes. For set sizes within the working memory capacity, the expertise advantage was driven by enhanced selective attention to spatial features by chess experts when compared to visual features. However, any expertise-related VSWM advantage disappeared in the absence of the 8x8 chessboard display, which implicates the chessboard display as an essential perceptual aspect facilitating the "expert memory effect" in chess, albeit one that might generalize beyond strictly domain-relevant stimuli.

Keywords: Chess Expertise, Visual Working Memory, Spatial Working Memory, Selective Attention, Attentional Control

Are the Advantages of Chess Expertise on Visuo-Spatial Working Memory Capacity Domain Specific or Domain General?

The cognitive capabilities of experts, particularly chess experts, have long been studied as an avenue for examining the malleability and limits of general human cognition (de Groot, 1965; Gobet & Simon, 2000). Chess experts have been extensively studied because of a widely-adopted quantitative system for operationalizing their expertise, namely the Elo rating system (Elo, 1978). Chess experts have an exceptional recall of rapidly-presented chessboard stimuli (Chase & Simon, 1973), which has been argued to be driven by a well-developed knowledge framework of game-legal spatial-piece configurations (Gobet & Simon, 1996a, 1996b; Chase & Simon, 1973; Simon & Gilmartin, 1973). This well-developed knowledge framework is argued to be sufficiently automatized, such that when processing rapidly-presented chessboard stimuli, experts activate game-legal chessboard configurations from their extensive long-term memory. This, in turn, enhances processing of chessboard stimuli in their working memory which manifests as higher working memory capacity for domain-relevant stimuli in chess experts (Ericsson & Kintsch, 1995, Gobet & Simon 1996b, Gobet & Waters 2003).

As robust and reliable as this effect is, the "expert memory advantage" in chess has also been demonstrated to be extremely specific, such that even slight changes in opening strategy result in reduced performance (Bilalić, McLeod, & Gobet, 2009). Additionally, experts show reduced recall for randomized or unstructured chess boards, compared to game-legal chess boards (Chase & Simon, 1973). Chess experts nonetheless still outperform novice players on such tasks, which feature unstructured, game illegal configurations that have no long-term memory representations (Bilalić, Langner, Erb, & Grodd, 2010; Gobet, de Voogt, & Retschitzki, 2004; Gobet & Simon, 1996a; Schultetus & Charness, 1999). These findings indicate that some aspect of the advantage seen in these experts survives the disruptive effects of randomization. A prominent theory explaining this result states that this enhanced memory performance results from the preservation of some chess information, i.e. identifiably legal “chunks”, in the randomized stimuli, thereby rendering such stimuli more salient to chess experts compared to novices even at short presentation times (Gobet & Simon, 1996b). This is a plausible explanation of this effect, particularly in older paradigms which relied on analogue manipulation of game-legal board configurations (i.e. rearranging/mirroring of quadrants, Chase & Simon, 1973; Gobet & Simon, 1996b), but is less plausible for paradigms that utilize fully randomized boards which more thoroughly disrupt this spatial information (i.e. Bilalić, Langner, Erb, & Grodd, 2010), which is more likely to disrupt the spatial-relational information (Gobet & Waters, 2003). Indeed, Gobet & Waters (2003) found that the expert memory advantage tended to decrease under greater degrees of randomization, which they attribute to probabilistically less spatial information preserved in more randomized boards.

Extensive deliberate practice has long been argued as the prime determinant of the development of expertise in any domain (Ericsson, Krampe, & Tesch-Römer, 1993; Ericsson, Nandagopal, & Roring, 2009), and the elaborated chess knowledge structure exhibited by chess experts is hypothesized to be but one specific example of the cognitive impact of such extensive training in a domain (Ericsson & Kintsch, 1995). However, recent research has implicated fundamental cognitive processes such as intelligence and reasoning ability as potentially a major determinant of expert ability. A meta-analysis by Macnamara, Hambrick, & Oswald (2014) indicated that only 26% of variance in performance on board games (including chess) was explained by time spent in deliberate practice, and the authors implicate general intelligence/reasoning and working memory ability as cognitive factors which likely account for much of this unexplained variance. Later research has supported this hypothesis: general intelligence/reasoning has been found to predict chess ability (Bilalić, McLeod, & Gobet, 2007a; Sala et al. 2017), and working memory capacity has been found to predict ability in a different domain of visual expertise, namely musical sight reading (Meinz & Hambrick, 2010). Considering that variation in reasoning/intelligence measures has been demonstrated to be strongly predicted by individual differences in working memory (Kyllonen & Christal, 1990; Swanson & Jerman, 2006), these above findings might not reflect the contribution of two different cognitive factors to the "expert memory advantage" in visual processing domains, but one – the working memory ability. Supporting this in relation to the domain of chess, chess experts' recall for chessboard stimuli has been demonstrated to be hindered by disruption of visuo-spatial working memory (VSWM) via a concurrent divided-attention task, implicating VSWM to be integral aspect of expert memory of chessboard stimuli (Robbins et al., 1996).

The embedded-process model of working memory (Cowan, 2001) argues that working memory capacity is limited by the capacity of the focus of attention (FoA), where items are readily available and quickly accessible (Cowan, 2001; Verhaeghen & Basak, 2005; Basak & Verhaeghen, 2011a; 2011b). The focus of attention is typically limited to about 1 item when stimuli are presented sequentially and require continuous updating (McElree, 2001; McElree, 1998; Suß, Oberauer, Wittman., Wilhelm, & Schulze, 2002; Basak & Verhaeghen, 2011a; 2011b; Vaughan, Basak, Hartman & Verhaeghen, 2008; Verhaeghen & Basak, 2005), whereas a broader focus of attention of about 3 to 4 items (Cowan, 2001) is found when stimuli are presented simultaneously (e.g., subitizing spans; Basak & Verhaeghen, 2003; change detection paradigms; Luck & Vogel, 1997, 2013; Vogel & Machizawa, 2004; Vogel, Mccollough, & Machizawa, 2005; Zhang & Luck, 2011; Zhang & Luck, 2008). In the context of chess expertise, it has been observed that individual differences in expertise is related to chunks of chess-related differences, such that higher skilled chess experts outperform lower skill chess experts in both structure and content of chunks (Gong, Ericsson & Moxley, 2015). These chunk sizes are argued to be limited by short term capacity or working memory span (Chase & Ericsson, 1982; Gong & Ericsson 2015). As the fundamental item in a chunk of chess information is a single piece on a particular square, and the relational information that that piece connotes (Chase & Simon, 1973), we can similarly conclude that a single "item" of chess in the embedded processing model is composed of these same features (piece, location, relational information).

Long-term memory must necessarily be invoked to process stimuli beyond the capacity of the focus of attention, where the detailed and automatized knowledge framework in long-term memory described by Ericsson & Kintsch (1995) and Gobet & Simon (1996b) comes into play in enabling expert processing of domain-relevant stimuli. This is not to say that an expertise advantage is expected only for supra-capacity items - considering the essential contribution of the working memory system to the binding of information in long-term memory (Chekaf, Cowan, & Mathy, 2016; Portrat, Guida, Phénix, & Lemaire, 2015), it is conceivable that attaining expertise in chess via the development of a sufficiently elaborate LTM structure expands broader overall working memory capacity. In fact, Verhaeghen, Cerella, & Basak (2004) have found that 10 hours of extensive practice on an n-back task, which typically yields a FoA of 1, was sufficient to expand participant's FoA from one to four items. Considering the amount of practice time necessary to attain expertise at chess (Ericsson, Krampe, & Tesch-Römer, 1993; Ericsson, Nandagopal, & Roring, 2009), and the visuospatial demands of the task, it is conceivable that the attainment of expertise in chess entails not only the development of elaborated retrieval structures as proposed by Ericsson & Kintsch (1995) and Gobet & Simon

(1996b), but also an expansion of VSWM capacity over time as observed by Verhaeghen, Cerella, & Basak (2004). Chess experts have indeed demonstrated an advantage in learning chess-legal, randomized, and non-chess-piece board configurations in a repeated short-term recall task when compared to novices (Schneider, Gruber, Gold, & Opwis, 1993). Interestingly, that advantage was not demonstrated for immediate recall of non-chess-piece board configurations in that same study, despite expert's more rapid learning of piece configurations during that condition, suggesting that at least some aspects of the "expertise advantage" as it pertains to VSWM ability is domain-specific. Chess experts have also demonstrated greater performance in change detection paradigms compared to chess novices (Ferrari, Didierjean, Marmèche, 2006), though, as far as we are aware, such an effect has not been demonstrated in change detection paradigms using unrelated stimuli.

Although expanded VSWM capacity is predicted to directly affect learning and retaining of chess expertise, there is some evidence that this effect may be mediated via attentional control mechanisms, not just by capacity. Individual differences in working memory capacity have been shown to be correlated with performance in both selective attention (Conway, Cowan, & Bunting, 2001) and divided attention (Colflesh & Conway, 2007), two types of attentional control mechanisms. These relationships extend beyond chess expertise. Working memory capacity and divided attention have been found to be correlated in expert musicians, with expert conductors significantly outperforming students of music in both types of cognition (Wöllner & Halpern, 2016). Within the domain of chess expertise, there is evidence that experts' processing of chess stimuli engages similar cognitive processes to the layperson's processing of face stimuli (Boggan, Bartlett, & Krawczyk, 2012) – a type of automatized holistic processing that depends heavily on deploying simultaneous attention to multiple features of an object (Young, Hellawell,

& Hay, 1987). Considering this evidence, we hypothesize that expanded VSWM capacity may contribute to chess expertise via the bolstering of divided attention capability. Therefore, chess experts are expected to demonstrate a greater ability to simultaneously attend to multiple features of an object. An alternate explanation to this could be that chess experts' enhanced VSWM capacity is due to their superior inhibitory control during selective attention; this may allow them to focus their attention more selectively on a set of target features of a complex stimuli by ignoring irrelevant features and distractors. No study till date has tested the role of selective attention vs divided attention in VSWM advantage in chess experts, particularly for different types of stimuli that extend beyond legal chess configurations.

The main aim of this study was to fill the above mentioned gap in the field by investigating whether the VSWM advantage extends to domain-general, novel visual objects, ones that do not involve verbal memory or any prior semantic knowledge. In the current study, chess experts were compared with novices on a change-detection paradigm of VSWM, where unstructured, randomized piece configurations were used. These configurations were comprised of either chess stimuli or non-chess, visual stimuli. Based on past research (e.g. Bilalić, Langner, Erb, & Grodd, 2010; Chase & Simon, 1973; Gobet & Simon, 1996b), we hypothesized that chess experts will show enhanced working memory capacity relative to novices when processing randomized chess piece configurations, even though these configurations are not game-legal. However, it is unknown whether this enhanced VSWM capacity is limited to domain-specific, extensively practiced objects (i.e., chess pieces) or is it also extended to novel visual objects implicating domain-general effects of enhanced VSWM capacity in chess experts.

Another aim of this study was to investigate whether enhanced VSWM capacity, if any, is mediated by attentional control processes of selective attention or divided attention. In the current paradigm, participants either monitored location changes or identity changes or changes in both identity and location; the latter condition relies more on divided attention, whereas the former conditions rely more on selectively deploying attention to one feature of an integrated whole while ignoring the other feature. It is possible that any enhanced VSWM capacity of chess experts could be due to their enhanced divided attention capability to an integrated whole, or to their ability to selectively focus attention on one specific feature and inhibit the other feature.

Method

Participants.

Fifteen chess experts and 16 chess novices, who were undergraduate students at The University of Texas at Dallas, were recruited for this study. The 15 experts in this study were recruited from the UT Dallas' Chess Team, who met the inclusion criteria of minimum FIDE Elo rating of 2000. An Elo rating of 2000 or higher corresponds to the rank of *Candidate Master* within the FIDE ranking system (Elo, 1978), and the rank of *Expert* in the USCF rating system (Just & Burg, 2003). The Elo rating curve is standardized to have a mean of 1500 and a standard deviation of 200, meaning that chess players ranked at 2000 or better are at a minimum of 2.5 standard deviations above mean chess skill as measured by that system (Elo, 1978).

Novices, who had no Elo ratings, were recruited from the UT Dallas' School of Behavioral and Brain Sciences, and received course credits for participating. We continuously recruited novices until we had a) matched their number to that of the Expert participants, and b) found no significant age or gender difference between the two groups, which was accomplished after recruitment of 16 novice participants.

One expert was dropped from the analysis due to incomplete data, resulting in a final sample of 14 chess experts (average age in years= 22, *SD* = 2.91; 28.57% female; average years of reported chess experience = 16.21, *SD* = 4.15; average Elo rating = 2433.79, *SD* = 177.27). One novice participant was unable to complete the entire testing session due to hardware issues of the testing machine, resulting in 15 novices (average age in years = 22.63, SD_{Age} = 2.36; 38% female; average years of reported chess experience = 4.08, *SD* = 4.23; none possessed an Elo rating). The two groups did not differ in average age, $t(28) = .65$, $p = .52$, or gender, $\chi^2(1) = .27$, $p = .71$, but differed significantly in years of chess experience, $t(28) = -7.51$, $p < .01$.

Materials and procedure. Before testing, all participants were administered a questionnaire (see Appendix A) to assess their experience and practice habits with the game of chess. This study utilized a change-detection paradigm designed to measure VSWM capacity (Delvenne, 2005; Luck & Vogel, 1997; Luck & Vogel, 2013), implemented in the MATLAB software environment. In this experiment, visual stimuli were displayed on the 17-inch screen of a 733 MHz PC. Responses were collected from the computer keyboard, and the participants were seated approximately 60 cm from the computer. At this distance, the stimuli array subtended a 13.88° visual angle.

In a trial, N stimuli (N varied from 1 to 8) were presented in the stimulus array for 300 ms on an 8x8 chessboard grid, subtending 13.88° visual angle. This was followed by an empty board (1 s), after which a target array of the same number of stimuli was presented on the same 8x8 board until the participant responded (Figure 1A). Participants were instructed to press either "p" key (for "change") with right forefinger or "q" key (for "identical") with left forefinger as rapidly as possible. Both response times (RT) and accuracies were recorded. Inter-trial interval was 100 ms.

There were 2 sets of three blocks; one set with randomized chess piece configurations and another set with abstract visual stimuli; see Figure 1B. Participants were given up to a 15 minute break between these sets upon request. For randomized chess piece configurations, random combinations with replacement of only 10 pieces were used; there were 5 chess pieces (pawn, knight, bishop, rook, and queen) in black and in white. Kings were excluded in each configuration to avoid the possibility of accidentally displaying a game-legal configuration. For abstract visual stimuli, 10 novel shapes of equivalent size and complexity as the chess stimuli were used; 5 shapes each in black and in white. The presentation order of these two sets (chess, shapes) was randomly counter-balanced across the participants. Furthermore, each set had 3 blocks: two Single Attention blocks followed by one Dual Attention block. In the first block, participants had to determine if any piece had changed in its identity in the target array compared to the stimulus array (*Identity-change*). In the second block, participants were instructed to attend to the locations of the displayed stimuli, and report if location of any object in the target array had changed compared to the stimulus array (*Location-change*). In the third block, participants were instructed to attend to both the identity and location of all objects, and to report if the identity and/or location of any of the objects had changed. In this block, change trials comprised of either *Identity-change*, *Location-change*, or where both location and identity of a single stimulus changed (*Both-change*) (Figure 1A). The first two blocks are collectively called *Single Attention* blocks, because in these blocks, attention had to be selectively deployed to one of the two features of the object in order to successfully perform the task. The third block is called a *Dual Attention* block, because, to successfully perform the task, attention during change trials could be selectively deployed to either one of the two features of the object (Identity-change vs. Location-change trials) or to the integrated whole (Both-change).

Each *Single Attention* block included 240 trials, with 30 trials for each N (N varying from 1 to 8); half were change trials. The *Dual Attention* block also had 240 trials, with 30 trials for each N (N varying from 1 to 8); 50% were change trials, with 40 trials (16.7%) each for either Identity-change, Location-change, or Both-change. In sum, there were a total of 1440 trials, with 720 trials for randomized chess piece configurations and 720 trials for abstract shapes.

Finally, after the two sets outlined above were completed, a shorter *Board-Absent* set consisting of three 30-trial blocks was administered to all participants. This block consisted of only trials of set size 4, using only non-chess stimuli. Critically, stimuli in this condition were displayed on a neutral gray background rather than a chessboard. As with both sets described above, this *Grid Absent Condition* set included two *Single Attention* blocks (one *Location-Change* and one *Identity Change)*, as well as a *Dual Attention* block. Aside from the restricted set size and lack of a chessboard display, these blocks were constructed identically to the *Single Attention* and *Dual Attention* blocks described earlier. The design of the *Grid Absent Condition* set was designed to closely replicate the change detection paradigms traditionally used to assess VSWM (Delvenne, 2005; Luck & Vogel, 1997; Luck & Vogel, 2013; Woodman, Vogel, & Luck, 2001; Woodman, Vogel, & Luck, 2012), thus allowing us to test the extent of generalizability of any chess expertise advantage that we may observe in the first two sets.

Stimuli placement details. Object placement in the 8x8 chessboard was randomized such that objects were equally likely to occur on all the four quadrants of the board (each quadrant was made of a 4x4 grid). Stimuli did not appear in the center four squares of the chess board to minimize any center effects, which could influence performance. The difference in visual angle between two stimuli was between 1.82^{o} (for stimuli displayed in adjacent cells) and 13.88^{o} (for two stimuli on opposite corners of eligible area). The center square area in which no stimuli were displayed occupied a visual angle of 3.64°. No more than a single stimulus appeared in any given quadrant on trials with N (i.e., set-size) of 1 to 4, and no more than two stimuli appeared in any given quadrant on any trial. Stimulus color was balanced to produce an approximately equal ratio of black to white stimuli across all trials. In *Identity-change* trials, a stimulus was replaced with a randomly selected object of the same color that was not used in the stimulus array. In *Location-change* trials, a stimulus was offset from its original location by one board square in a random direction, within the constraints that it was not placed outside the bounds of the eligible area of the chessboard, overlapping with another stimulus, or placed outside the bounds of its original quadrant.

Calculation of Outcome Measure: Memory sensitivity (*d'*), the primary dependent variable for this analysis, was calculated using the difference in standardized hit rates for change trials and standardized false-alarm rates for *No-change* trials ($Z_{FA} - Z_{hit}$). The 1/2*N* correction was applied to account for floor and ceiling effects (Macmillan, & Creelman, 2005).

For the *Dual Attention* block, *d'* was calculated separately for *Identity-change*, *Location-change*, and *Both-change* trial types, using the hit rates for that specific trial type and the false alarm rate for all *No-change* trials from this block. While using the same FA rate across all three trial types presents a potential confound in terms of deviation from the strict definition of the measure, we believe this modification still preserves the purity of the *d'* measure for the purpose of our intended comparisons, and such a method has been used in similar VSWM analyses in the past (Forrin, Groot, & MacLeod, 2016; Qin, Ray, Ramakrishnan, Nashiro, O'Connell & Basak, 2016).

Trial Binning: Trials were binned into three Setsize ranges for analyses: Setsize 1, Setsize 2-3, Setsize 4, and Setsize 5-8. Setsize 1 and Setsize 2-3 together reflect working memory capacity (Shipstead & Engle, 2012), with former reflecting automatic information processing within a highly accessible FoA and the latter reflecting a broader, outer store of near-automatic processing in working memory (Basak & Zelinski, 2013; Basak & Verhaeghen, 2011; Oberauer, 2002; Oberauer & Hein, 2012; O'Connell and Basak, 2016; Suß, Oberauer, Wittman, Wilhelm, & Schulze, 2002; Verhaeghen et al., 2004). Setsizes 5 to 8 are considered to be outside the working memory capacity that require controlled processing, indicated by a steep RT slope of >200 ms/N (Basak & Verhaeghen, 2003), and have been argued to be processed in activated long-term memory (Cowan, 2005). Even extensive practice of 10 hours in an n-back task, where participants reached their asymptotic performance within 6 hours, failed to include Set-size 5 within the FoA, suggesting a limitation on the expanded FoA in a sequential working memory task. Setsize 4 was however separately binned, as the capacity of VSWM has been demonstrated to vary greatly between individuals, with an average capacity limit of 3 to 4 items (Basak & Verhaeghen, 2003; Todd & Marois, 2005); therefore Setsize 4 cannot be assumed to be reliably within the VSWM capacity for all participants. Considering this, trials of Setsize 4 were only included in those analyses for which the distinction between automatized working memory processing and controlled long-term memory processing was not relevant.

Results

Influence of chess expertise on visual vs spatial aspects of working memory

To investigate the influence of chess expertise on visual and spatial aspects of working memory, a 2x2x2 (Skill [Expert, Novice] x Stimuli [Chess, Non-chess] x Feature-change [Identity, Location]) mixed-model analysis of variance (ANOVA) was conducted[1]. We found

[1] Type-III Sum-of-Squares was utilized in all analyses of variance reported in this manuscript.

significant main effects of Skill, $F(1,27) = 28.17$, $p < .01$, Stimuli, $F(1,27) = 7.14$, $p = .01$, Feature-change, $F(1,27) = 68.39$, $p < .01$. This suggests that the chess experts outperformed the novices overall in this VSWM task. Moreover, chess stimuli facilitated easier change detection than novel shapes in both experts and novices, and that across both groups of participants, *Location-change* was easier to detect than *Identity-change*. Skill was found to interact marginally with Stimuli, $F(1,27) = 3.11$, $p = .09$, with the expertise advantage exaggerated with chess stimuli. However, Skill did not interact with Feature-change, $F(1,27) = 0.63$, $p = .43$, suggesting that although the experts outperformed the novices at the *Identity-change* condition, the degree to which the *Location-change* condition was advantageous over *Identity-change* condition was same in chess experts and in novices. The three-way interaction between Skill, Stimuli and Feature-change was also significant, $F(1,27) = 14.9$, $p < .01$. A visual inspection of these data revealed that chess experts exhibited a strong advantage over novices not only in all trials with the chess stimuli, but also in the *Location-change* trials with non-chess stimuli, but not in the *Identity-change* trials with non-chess stimuli (see Figure 2). Outside of the aforementioned interactions with Skill, the two-way interaction between the Stimuli x Feature-change interaction was also found to be significant in this analysis, $F(1,27) = 16.18$, $p < .01$, suggesting that *Location-change* detection was equally good for both chess and non-chess stimuli, whereas the *Identity-change* detection was easier for chess stimuli.

Influence of chess expertise on visual vs spatial aspects of working memory: automatic processing vs controlled processing

In order to investigate whether these expertise advantage in VSWM varies with near-automatic processing inside the FoA vs controlled processing entailed for items outside the FoA, we conducted three separate 2x2x2 ANOVAs (Skill [Expert, Novice] x Stimuli [Chess, Non-chess] x Feature-change [Identity, Location]); one each for Setsize 1, Setsize 2-3, and Setsize 5-8. As discussed above, SetSize 4 was not considered for these individual analyses as it could not be assumed to be reliably within the working memory capacity or outside the working memory capacity (Basak & Verhaeghen, 2003; Todd & Marois, 2005). Full reports of each of these analyses can be found in Table 1.

For the Setsize 1, the main effects of Skill, $F(1,27) = 10.24$, $p < .01$, and Feature-change, $F(1,27) = 6.77$, $p = .01$, were significant, suggesting that the chess experts outperformed the novices and that *Location-change* was easier to detect than *Identity-change*. The main effect of Stimuli was not significant (see Table 1). Interestingly, no significant interactions between Skill and other variable were observed, indicating that the chess experts outperformed novices on all four conditions for items in FoA (see Figure 3a). These results contradict the overall findings, where chess experts did no show an advantage over novices in *Identity-change* of novel shapes.

For the Setsize 2-3, all main effects were significant: Skill, $F(1,27) = 35.63$, $p < .01$; Stimuli, $F(1,27) = 6.65$, $p = .02$; Feature-change, $F(1,27) = 41.39$, $p < .01$. Although Skill x Feature-change interaction was not significant, $F(1,27) = .02$, $p = .88$, Skill significantly interacted with Stimuli, $F(1,27) = 5.61$, $p = .03$, reflecting the selective expertise advantage with chess-like stimuli within working memory capacity. The three-way Skill x Stimuli x Feature-change interaction was also significant, $F(1,27) = 3.68$, $p = .01$, showing similar patterns to that of the overall dataset (compare Figure 3b with Figure 2).

For Setsize 5-8, ANOVAs again revealed the significant main effects of Skill, $F(1,27) = 23.09$, $p < .01$, Stimuli, $F(1,27) = 48.61$, $p < .01$, and Feature-change, $F(1,27) = 107.61$, $p < .01$. The Skill x Stimuli interaction was not significant, $F(1,27) = 3.2$, $p = .09$. Importantly, unlike other set-sizes, the two-way Skill x Feature-change interaction was significant, $F(1,27) = 12.07$,

$p < .01$. Inspection of the data (Figure 3c) revealed that experts demonstrated a selective advantage of discriminability in *Location-change* trials, but only for processing outside the WM capacity. Additionally, the Skill x Stimuli x Feature-change interaction was found to be significant, $F(1,27) = 18.51$, $p < .01$. This result is similar to that of Setsize 2-3, suggesting that when encoding Setsize supersedes FoA capacity of 1 item, experts failed to exhibit the domain-general benefits to early processing of visual identity of novel stimuli in VSWM, although domain-general benefits to spatial processing were still observed.

Is the enhanced visuo-spatial capacity of chess experts disrupted by dual feature monitoring?

To assess the potential interaction between the attentional control processes (Selective Attention and Divided Attention) and chess expert's advantage in processing of visuo-spatial stimuli, we next conducted a Skill [Expert, Novice] by Attention [Single, Dual] ANOVA. The main effect of Skill was significant, $F(1,27) = 28.17$, $p < .01$, but the main effect of Attention was not, $F(1,27) = 2.68$, $p = .11$. However, Skill x Attention interaction was significant, $F(1,27) = 4.1$, $p = .05$, with experts demonstrating a greater advantage over novices for *Single Attention* compared to *Dual Attention* trials (see Figure 4).

As in the previous analyses, we conducted three Skill by Expertise ANOVAs, one each for Setsize 1, Setsize 2-3, and Setsize 5-8, in order to determine how the observed Skill by Attention interaction manifests at different levels of controlled processing. At Setsize 1, a significant main effect of skill was observed, $F(1,27) = 10.24$, $p < .01$, but neither the main effect of Attention, $F(1,27) = 3.93$, $p = .06$, nor the Skill by Attention interaction, $F(1,27) <.01$, $p = .97$, reached significance. At Setsize 2-3, both main effects [Skill $F(1,27) = 35.63$, $p < .01$; Attention $F(1,27) = 14.16$, $p < .01$] and the Skill by Attention interaction, $F(1,27) = 7.24$, $p = .01$, were significant. For Setsize 5-8, both main effects demonstrated significance [Skill $F(1,27) = 23.09$, $p < .01$; Attention $F(1,27) = 14.16$, $p < .01$], but there was no interaction between Skill and Attention, $F(1,27) = 0.2$, $p = .66$. These results demonstrate a selective advantage in chess experts for single-attention processing outside of the focus of attention but within semi-automatized processing i.e. within working memory capacity.

Is the enhanced visuo-spatial capacity of chess experts affected by detection of simultaneous feature changes under dual monitoring conditions?

Our earlier analysis demonstrated that experts possess a distinct advantage in processing *Location-change* over novices, even though both groups performed better when asked to process location changes compared to changes in identity. However, that analysis did not address the question of whether participants may be processing individual stimuli as whole objects or are selectively processing each aspect of the stimuli separately – it is plausible that differences between experts and novices in *Location-change* trials is no due to enhanced spatial processing in experts, but due to a fundamental difference in how experts process a visuo-spatial stimuli compared to the novices. In order to examine this in detail, we conducted a 2x2x3 (Skill [Expert, Novice] x Stimuli [Chess, Non-chess] x Change_type [Identity-change, Location-change, Both-change]) mixed-model ANOVA for the *Dual Attention* blocks only. Crucially, *Both-change* trials were included as a third level in the previously described Feature-change variable (here called "Change_type") that had only included *Identity-change* and *Location-change* trials. Analysis of all three types of changes that is only possible in the *Dual Attention* condition will allow us to determine experts and novices differed in how they processed simultaneous changes in both features vs processing changes to either feature individually. All main effects were significant; Skill, $F(1,27) = 15.22$, $p < .01$; Stimuli, $F(1,27) = 5.5$, $p = .03$; and Change_type, $F(2,54) = 54.93$, $p < .01$. In terms of two-way interactions, neither interaction with Skill demonstrated significance [Skill x Stimuli, $F(1,27) = 3.96$, $p = .06$.; Skill x Change_type, $F(2,54) = .04$, $p = .96$], while the Stimuli x Change_type interaction did, $F(2,54) = .04$, $p = .96$. Finally, the three-way Skill x Stimuli x Change_type demonstrated significance, $F(2,54) = 4.22$, $p = .02$.

Post-hoc comparisons, using Bonferroni corrections, for Change_type variable demonstrated that *d'* for *Identity-change* was significantly lower than for *Location-change* trials (Mean Difference = -.72; $p < .01$) and *Both-change* trials (Mean Difference = -.81; $p < .01$), whereas performance for *Location-change* and *Both-change* trials did not significantly differ, (Mean Difference = -.1; $p = .63$, see Figure 6). These results demonstrate that, across both skill groups, trials in which the identity of the stimuli changed were easier than location-change only trials. Additionally, as performance for *Location-change* and *Both-change* was nearly identical, we can conclude that performance in the *Both-change* trials was driven by participant attention to the location feature of the stimuli.

Chess expertise advantages in a standard visual change detection task

To test the generalizability of chess expertise advantage to a standard VSWM task, a 2x2x2 (Skill [Expert, Novice], Attention [Single Attention, Dual Attention], and Feature-change [Identity, Location]) mixed-model ANOVA was conducted on data from the *Board-Absent* set. We observed just a main effect of Feature-change, $F(1,36) = 8.43$, $p = .01$. Neither main effect of Skill, $F(1,37) = .94$, $p = .34$, nor its interaction with other variables [Skill x Attention, $F(1,36) = .18$, $p = .67$; Skill x Feature-change, $F(1,36) = .21$ $p = .65$] were significant.

These results from this baseline board-absent task are contrary to the results from our previous analyses, where experts demonstrated enhanced discriminability for all conditions, with the exception of identity-change trials with novel stimuli. This observed difference could be due to the lack of the 8x8 chess-board structure in this experiment. Fluency in binding chess stimuli to this chessboard structure could explain the relatively higher performance of chess experts on tasks that have involved randomized piece configurations, as well as performance with novel, stimuli presented on such a structure. To investigate this possibility, we compared the data from the *Board-Absent* set with comparable trials collected from grid-present blocks using abstract stimuli, specifically those of Setsize 4. This allowed us to directly compare performance in trials in which the chessboard was present, and those for which it was absent.

Effect of presence of chess board on expertise advantage for abstract, non-chess stimuli

To investigate the effect of the chessboard display on expert visual processing, we conducted a Skill [Expert, Novice] x Board [Board-present, Board-absent] x Attention [Single Attention, Dual Attention] x Feature-change [Identity, Location] mixed-model ANOVA. This analysis revealed significant main effects of Skill, $F(1,32) = 7.55$, $p = 0.01$, Board, $F(1,32) = 7.96$, $p = .01$, and Feature-change, $F(1,32) = 59.9$, $p < .01$, as well as a significant Skill by Board interaction, $F(1,32) = 4.98$, $p = .03$, with experts demonstrating a selective advantage when the board was present (Figure 5A). Additionally, a significant Skill by Feature-change interaction was also observed, $F(1,32) = 7.17$, $p = .01$, with experts demonstrating a selective advantage for *Location-change* trials, as seen in previous analyses. This advantage was limited to the presence of the 8x8 chess board (Figure 5B). Finally, a significant four-way interaction between all factors was significant, $F(1,32) = 4.66$, $p = .04$. A visual inspection of the data (see Figure 7) reveals that experts exhibited a specific advantage in terms of *d'* on *Single Attention Location-change* trials when a board was present, highlighting the specificity of the expertise effect in this circumstance.

Discussion

The current study was designed to examine potential advantages in visuo-spatial working memory from extensive chess experience and identify attentional control mechanisms that explain such expertise advantages in working memory. An important feature of the study design was to determine whether the expertise advantages observed in prior research extend beyond chess-specific information. We compared chess experts (defined by their Elo ratings) to a group of novices with similar age and gender distribution to our expert group on a rapid change-detection paradigm of VSWM.

We found that chess experts showed significantly higher memory discriminability for chess stimuli, irrespective of type of features (visual vs spatial) they attended to in this rapid VSWM task. Although both experts and novices showed enhanced processing of chess stimuli compared to unfamiliar novel stimuli, experts outperformed novices in these stimuli, implicating that familiar stimuli are more salient. While chess experts demonstrating an advantage in processing chess-like stimuli is not surprising, it is important to note that even the most chess-like conditions of the paradigm used in the present study utilized extremely disrupted stimuli which differed greatly from a game-legal board state, via fully random piece placement as well as the absence of kings. Similar disruptions of chess information have been demonstrated to greatly reduce or negate the "expert memory advantage" in numerous other studies of chess expertise (Bilalić, Langner, Erb, & Grodd, 2010; Chase & Simon, 1973; Gobet & Simon, 1996a; Schultetus & Charness, 1999). It can be argued, then, that the expertise effect demonstrated in the present study represents a certain degree of transfer from advanced chess ability to a visual memory task that only tangentially relies on chess information. However, chess stimuli would certainly involve encoding a certain amount of spatial configuration (i.e. possible moves), even if the board configuration as a whole was nonsensical, and the enhanced performance of chess experts in this paradigm may be driven by that preserved chess information (Gobet, de Voogt, & Retschitzki, 2004).

The non-chess conditions of the present study were designed specifically to avoid the issue described above – the non-chess stimuli used in these conditions do not carry any inherent spatial-relational information, and on this basis would not allow chess experts to utilize that additional information to facilitate performance on this memory task. Experts outperformed novices with these novel, non-chess shapes as well, exhibiting a similar advantage as with chess stimuli, but importantly this advantage was only demonstrated when detecting changes in spatial location. When processing changes in object identity with non-chess objects, experts performed no better than novices. This finding supports the explanation that chess experts are utilizing spatial-relational information to enhance performance on the task used in this paradigm: chess piece stimuli carry inherent spatial-relational information in the form of possible moves, and a change in piece identity confers a change in the spatial relations of the entire board stimuli – even a randomized, nonsensical one – which chess experts are able to process automatically due to deep, automatized knowledge structures in long-term memory (Ericsson & Kintsch, 1995; Gobet & Simon, 1996b). Similarly, a change in the location of any stimuli on the board – even if those stimuli are not chess pieces and therefor do not carry any inherent information in the form of possible moves – results in a change in the spatial relations of the board, which again chess experts are able to easily detect. This latter point is particularly interesting as it suggests that chess experts are not relying solely on information relevant to the game of chess to process these stimuli. Rather, chess experts, compared to novices, may be able to better process the evident spatial-relational information of the stimulus arrays used in this study, and therefore more readily detect rapid changes in briefly presented information in the complex arrays if that spatial configuration changed. This is supported by past research that has linked the mechanism of chess experts automatic processing of chessboards to the general population's ability to holistically process facial stimuli (Boggan, Bartlett, & Krawczyk, 2012; Bartlett, Boggan, & Krawczyk, 2013), a process which is known to rely heavily on the automatic processing of spatial-relational information (Haig, 1984; Bartlett, Searcy, & Abdi, 2003; Rothshtein, Geng, Driver, & Dolan, 2007; Richter, Mack, Gauthier, & Palmeri, 2009).

We further examined this effect by separately investigating set size bins indicative of different levels of automatic and controlled processing. In set-sizes 2-3, where items are within the limits of working memory capacity, the pattern of results closely resembled the pattern from the overall dataset. That is, experts outperformed novices on all trials save for identity-change trials using non-chess stimuli, as demonstrated by a significant Skill by Stimuli by Feature-change interaction for this span. However, the expertise advantage in spatial processing was further exaggerated in set sizes of five or greater, with a significant Skill by Feature-change interaction demonstrating greater expert performance in location-monitoring regardless of other consideration. As these set-sizes are outside of the limits of working memory capacity, they are argued to evoke controlled processing and involve activated long-term memory (Basak & Verhaeghen, 2003, Cowan 2005). Therefore, we can view the expertise advantage within this range as derivative of processes operating within long-term memory. This provides further evidence that the automatized LTM structures of chess experts may facilitate processing of spatial-relational information generally, and is not strictly limited to information related to the game of chess.

Critically, experts demonstrated no advantage in discriminability when stimuli were not presented on the 8x8 chessboard pattern. These results strongly implicate the board structure as a necessary perceptual component of expert memory performance with chess and chess-like stimuli. However, as demonstrated in the board-present conditions the presence of the chessboard facilitates improved discriminability in expert chess players, even when processing non-chess stimuli. While piece and board information both are fundamental to this knowledge framework (Chase & Simon, 1973; K. Ericsson & Kintsch, 1995), the board itself may serve as an automatized retrieval structure that is generalizable beyond chess information – perhaps serving as a template on which to bind the spatial-relational information of stimuli presented upon it. As the present study only manipulated the presence/absence of board structure, we cannot determine the specificity of the expertise advantage with grid-based processing. It is unclear whether the chessboard structure in necessary to facilitate expert-level performance in chess expertise, or whether other variations of board structure could also facilitate the expertise advantage. If we assume that the latter is the case, this mechanism may explain the correlation between chess expertise and general intelligence that has been observed in some cases (i.e. Bilalić, McLeod, & Gobet, 2007b; Frydman & Lynn, 1992, see Burgoyne et al., 2016 for a meta-analytic review) but not in others (i.e. Bilalić et al., 2007a; Horgan & Morgan, 1990), as many commonly-used intelligence measures, including Raven's Progressive Matrices and WISC utilized gridded information in whole or in part, (Cormier, Kennedy, & Aquilina, 2016; Raven 1962) which may benefit from this expertise effect. Alternatively, an automatized grid-based retrieval structure could facilitate the use of certain conscious mnemonic strategies, i.e. memory palace, though such a strategy would not be feasible in rapid-presentation paradigms such as the one used in the present study. Importantly, previous research into chess cognition has vastly favored paradigms which utilized board-present stimuli, including in those cases where the chess framework was otherwise disrupted, such as randomized piece configurations (e.g. Bilalić, Langner, Erb, & Grodd, 2010; Chase & Simon, 1973; Gobet & Simon, 1996b). If chess experts do in fact have a general ability to bind neutral stimuli to the 8*8 chessboard display, that would serve as a domain-general alternate hypothesis to chess-specific retrieval structures facilitating this advantage. Further examination of potential transfer of chess expertise effects to grid-like structures beyond those seen in chess is warranted.

An additional area of investigation in this study was the interaction of attentional control ability and VTSM capacity, and how this may be relatively changed in chess expertise. To investigate this, we included both single-attention blocks in which only a cued feature of the stimulus array (stimuli identity, stimuli position) changed, as well as dual attention blocks in which either or both of these features may change, the latter necessitating dual deployment of attentional resources to both the identity and positions of all stimuli in the array. As before, experts of chess demonstrated selective advantage in a certain condition of this manipulation, specifically in single-attention trials with set sizes of 2 or 3. As this span reflects processing of information within working memory but beyond the narrow focus of attention (Basak & Zelinski, 2013; Basak & Verhaeghen, 2011; Oberauer, 2002; Oberauer & Hein, 2012; O'Connell and Basak, 2016; Suß et al., 2002; Verhaeghen et al., 2004), these findings may reflect an enhancement of controlled inhibitory processes operating within working memory in experts. As noted by earlier research, parallel processing of information is possible within working memory, and controlled inhibitory processing can be invoked to facilitate processing of information within that zone (Basak & O’Connell, 2016; Oberauer & Hein, 2012). An enhanced capability to consciously inhibit information present within working memory would allow experts to devote more attentional resources to their change detection efforts, resulting in the pattern of behavior observed. By this conceptualization, novices were unable to effectively inhibit extraneous information in the single-attention conditions, resulting in identical behavior to the dual-attention condition in that participant group. Alternatively, enhanced performance of experts on these trials could be driven by an increased ability to rapidly bind (i.e. chunk) displays of 2-3 items into a single unit.

As described, both of the selective advantages demonstrated on this task by chess experts were expressed in set sizes of greater than one. In other words, these advantages were demonstrated within the domains of near-automatic working memory processes (set sizes 2-3; Basak & Zelinski, 2013; Basak & Verhaeghen, 2011; Oberauer, 2002; Oberauer & Hein, 2012; O'Connell and Basak, 2016; Suß et al., 2002; Verhaeghen et al., 2004) and the realm of effortful supra-capacity cognitive process (set sizes 5-8; Basak & Verhaeghen, 2003), but not within the narrow Focus of Attention (set size 1, McElree, 2001; McElree, 1998; Suß, Oberauer, Wittman., Wilhelm, & Schulze, 2002; Verhaeghen, Cerella, & Basak, 2004). Within the focus of attention, experts still outperformed novices overall, but no interaction with any other observed factor was identified. This lack of interaction makes it difficult to theorize as the possible mechanisms that underlie this advantage. That being said, considering processing within the Focus of Attention is by-in-large automatic and relatively effortless (Basak and Verhaeghen, 2011a, 2011b; McElree, 2001; McElree, 1998; Suß et al., 2002; Verhaeghen, Cerella, & Basak, 2004), the various knowledge structures and attentional control mechanisms we have invoked thus far to explain the “expert memory advantage” would not apply to processing in this domain. Indeed, it is difficult to imagine how any domain-specific processing could occur within the narrow Focus of Attention of 1 item, suggesting that the advantage exhibited here is of a more fundamental and universal in nature. Discerning whether this advantage is the result of the development of chess expertise, the result of self-selection among that group, or due to another factor will require targeted investigations of this finding.

Conclusions

The present study has demonstrated an "expertise effect" in chess experts in a variety of working memory tasks, some of which build on the past findings from chess research and some of which are novel. In line with past findings, chess experts demonstrated enhanced memory discriminability when compared to novices in any condition where chess stimuli were used, as well as in conditions in which novel, non-chess stimuli were used as long as changes were limited to spatial configuration only. We interpret these results to indicate that chess experts are relying on automatic encoding of spatial-relational information to process these rapidly presented stimuli, and therefore demonstrate enhanced ability whenever the overall spatial configuration of the stimuli is changed (either by replacing one chess piece with another or by changing the location of an object on the board). Crucially, this advantage was not replicated in conditions without a chessboard display, indicating that this board structure may be necessary for chess experts to successfully invoke their chess-related automatized memory processes.

Furthermore, we found evidence for qualitatively different processes operating inside and outside the focus of attention on this task. When the memory load was low (i.e. the number of items presented did not exceed the capacity of the focus of attention), expertise advantage was observed only when the attention needed to be focused to a single feature of the target stimuli (i.e. identity or location) while ignoring the other feature, potentially reflecting enhanced inhibitory control operating within the focus of attention. When the memory load was high (i.e. the number of items presented exceeded the focus of attention and thus engendered controlled processing), experts demonstrated further enhanced discriminability for detecting changes in the location. Collectively, these results indicate that a) chess expertise appears to interact with cognitive processes operating within and outside the focus of attention in qualitatively different ways, b) these advantages extend beyond chess stimuli in certain circumstances, particularly to the processing of spatial relations in supra-capacity FoA conditions, and c) the 8x8 chessboard structure appears to be necessary for experts to properly leverage these advantages.

While examining the nature of visual-spatial working memory in chess experts was the primary goal of this study, our results also potentially describe an interesting effect in non-expert memory. Specifically, for set sizes greater than one, performance with chess stimuli was better in all conditions than performance in non-chess stimuli for both experts and non-experts alike. Our non-expert group reported minimal prior chess experience and were universally unranked by any formal chess body, so we can reasonably assume that an advantage with chess stimuli in this group is not due to any explicit skill. Rather, we must attribute this advantage to other known differences between the chess and non-chess stimuli sets, namely that chess stimuli are familiar whereas the non-chess stimuli used are not. This has interesting implications for the role of prior knowledge in producing salience in these stimuli, especially considering that the initial stimulus display is only 300 ms, far too quick to facilitate any intentional encoding strategies, such as covert rehearsal, for complex stimuli that require binding of two features in non-experts (Cowan, Blume, and Saults, 2013; Qin, Ray, Ramakrishnan, Nashiro, O'Connell & Basak, 2016; van Lamsweerde, Beck & Elliot, 2015). This result suggests that minimal semantic knowledge – familiarity – is sufficient to produce a detectable salience effect in this paradigm.

Limitations & Future Directions

While the authors remain confident in the conclusions stated above, there are a number of limitations in the present study which should be considered when interpreting the results and designing future investigations. First is the lack of counter-balancing between the board-present and board-absent conditions used in our final analyses. We had not initially intended to compare these two conditions, and thus did not ensure proper counter-balancing between these two conditions. As a result, we must consider the finding that removal of the board display similarly removed any expertise advantage – one of the more striking findings of this study – in light of potential fatigue effects, as the board-absent condition was administered after the board-present condition for all participants. While the lack of an expertise effect in this condition follows from previous research and theorizing regarding the "expert memory effect" in chess, we cannot definitively disentangle the effect of the lack of a board and simple fatigue on performance in the board-absent condition for experts and novices. As a counter-argument to this, reduced performance was not observed across all conditions when chessboard was absent as one would expect from a fatigue effect; rather performance of all participants was reduced for location-change trials but no for shape-change trials (see Figure 6, panel B). Again, this is not definitive evidence that the effect observed is not the result of fatigue, and replication of this effect via a paradigm specifically designed to test it is warranted.

Second, the use of set size four in the board-absent condition limits our ability to draw conclusions about processes that may be working within or outside working memory span, for reasons already discussed above. This is especially important considering the evidence that the present study has produced suggesting qualitatively different mechanisms operating on sub and supra-capacity information. Replication of this manipulation using exclusively stimuli of set size 2-3, or set size 5 or greater, would allow us to compare results of the board manipulation to the results obtained from the other manipulations conducted at those set sizes.

Third, the present study does not examine the possible effect of participant strategy on performance on this task. It is possible that chess experts used a strategy such as intentionally encoding the non-chess stimuli as chess pieces which could drive the increased performance we observed with non-chess stimuli in some specific conditions of this study. However, if such a strategy was used, it did not benefit identity-change condition for these novel, non-chess stimuli, suggesting the limitations of chess expertise on visuo-spatial working memory.

In light of the current study's limitations, as well as its significant findings, there are numerous ways this work could be extended in future studies. First and foremost, the board effect we observed in the final analysis of this study requires replication. Assuming the effect can be replicated while controlling for fatigue effects, such studies also provide an opportunity to examine limits of the board effect. Do chess experts still exhibit an advantage in processing spatial change on hexagonal or rhombic board, or on a board larger or smaller than 8*8? Does this effect apply to egocentric tasks such as navigation if a grid-based encoding mechanism can be utilized? Such investigations would allow us to determine exactly how far this "expertise effect" generalizes beyond strict chess-related information. The notion of strategy use by participants is also a potentially fertile field of investigation, as aside from representing a potential confound in the "non-chess" conditions of this study, such investigations also have the potential to elucidate the interplay between intentional and automatic processes in chess cognition. Beyond implications for chess expertise specifically, the apparent salience effect observed for chess stimuli in non-expert populations raises interesting implications of the interaction between retrieval of semantic knowledge and autonomous or near-autonomous memory processing.

Open Practices Statement

All pertinent data related to this project are detailed in this manuscript. However, summarized data for this study can be made available upon reasonable request to the corresponding author. The experiments are not clinical trials and thus were not preregistered.

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Table 1

Results of Separate Skill by Stimuli by Feature-change ANOVAs Conducted within each Setsize range.

	SS 1				**SS 2-3**				**SS 5-8**			
Source	**df**	***F***	***p***	**Partial η^2**	**df**	***F***	***p***	**Partial η^2**	**df**	***F***	***p***	**Partial η^2**
Skill	1/27	10.24	**<.01**	0.28	1/27	35.63	**<.01**	0.57	1/27	23.09	**<.01**	0.33
Stimuli	1/27	0.01	0.91	<.01	1/27	6.65	**0.02**	0.20	1/27	48.61	**<.01**	0.64
Feature_Change	1/27	6.77	**0.01**	0.20	1/27	41.39	**<.01**	0.61	1/27	107.61	**<.01**	0.80
Skill * Stimuli	1/27	0.74	0.40	0.03	1/27	5.61	**0.03**	0.17	1/27	3.18	*0.09*	0.11
Skill * Feature_Change	1/27	0.61	0.44	0.02	1/27	0.02	0.88	<.01	1/27	12.07	**<.01**	0.31
Stimuli * Feature_Change	1/27	0.12	0.73	<.01	1/27	14.82	**<.01**	0.35	1/27	16.48	**<.01**	0.38
Skill * Stimuli * Feature_Change	1/27	0.42	0.52	0.02	1/27	9.15	**0.01**	0.25	1/27	18.50	**<.01**	0.41

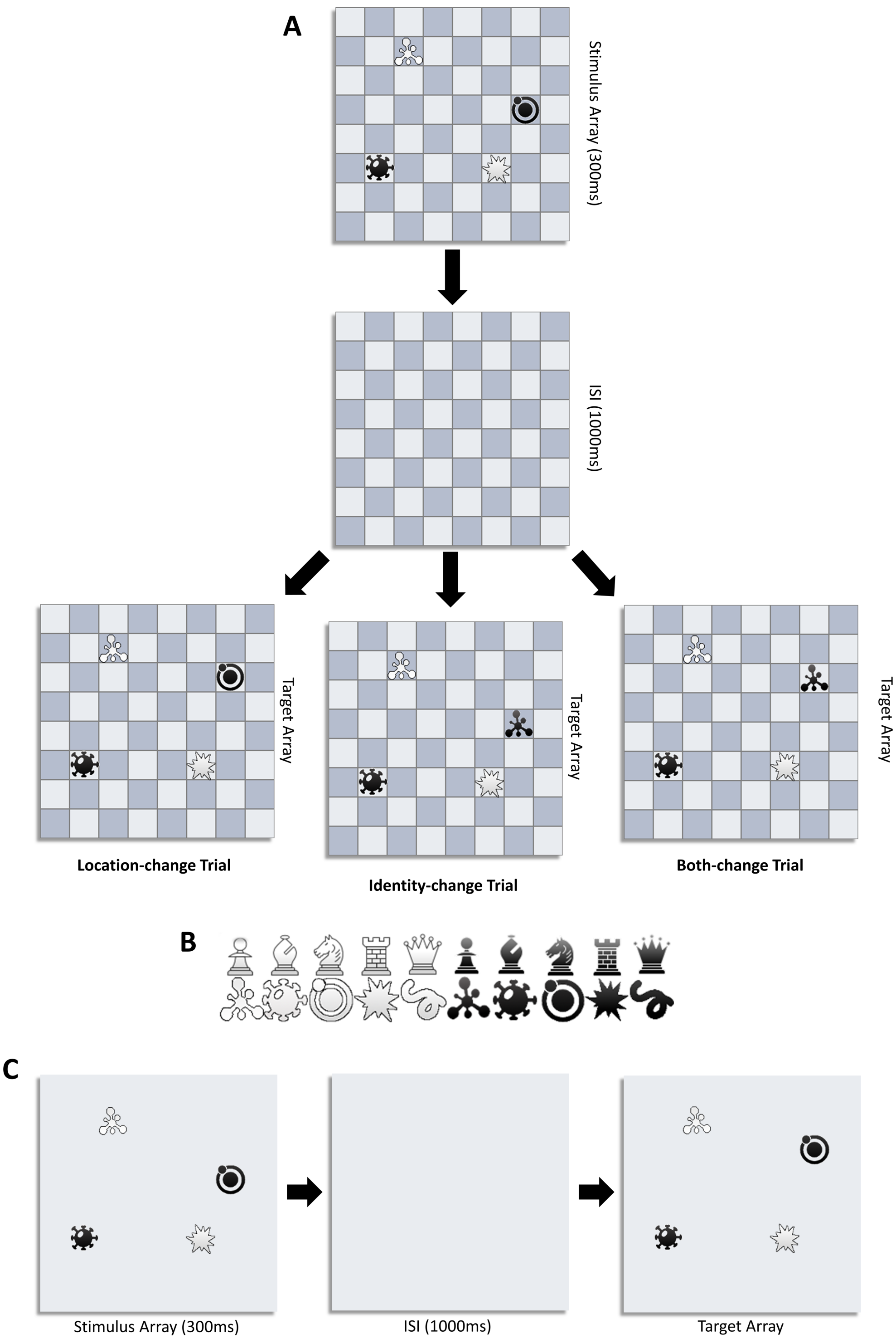

Figure 1. A) Demonstration of a single trial of Setsize 4 using non-chess stimuli. The three possible target arrays for the three different types of change trials (Identity-change, Location-change, Both-change) are also shown. B) Two sets of stimuli used: Chess (top row) and Non-Chess (bottom row). C) Demonstration of a location-change trial at set-size 4 in the board-absent condition.

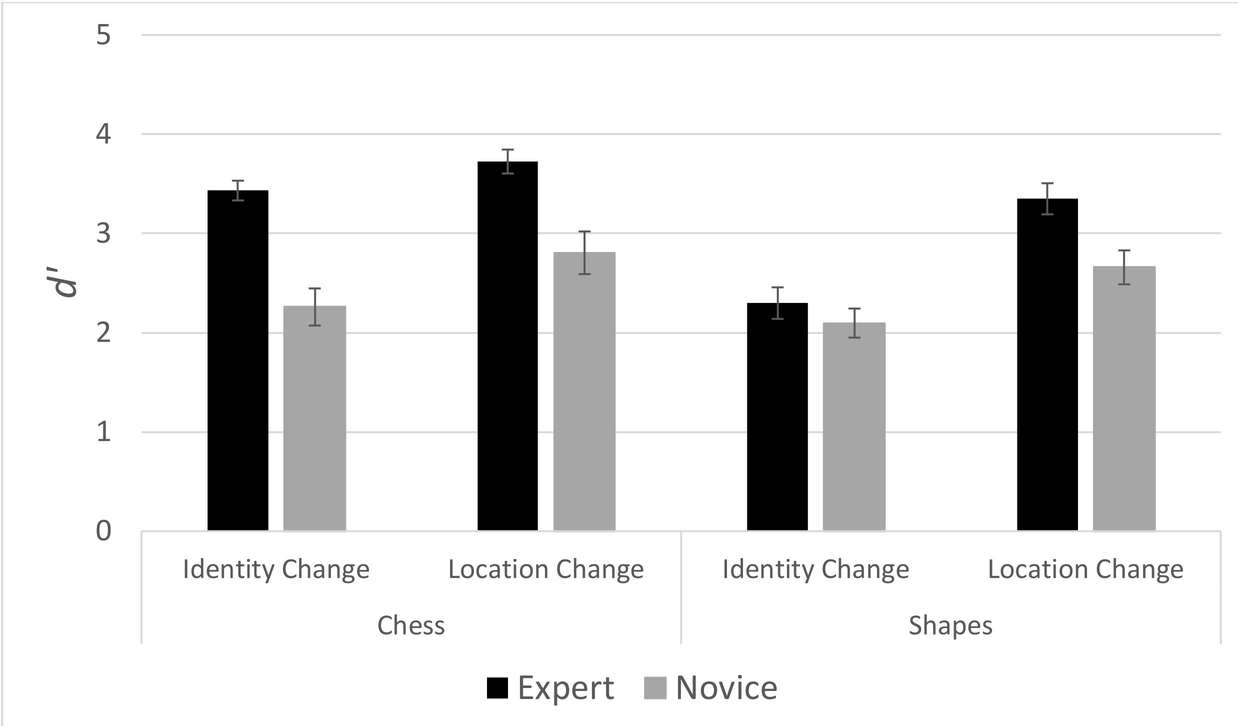

Figure 2. Memory discriminability (*d'*) for both experts and novices, plotted by Stimuli and Change_type. Error bars represent standard error of the mean.

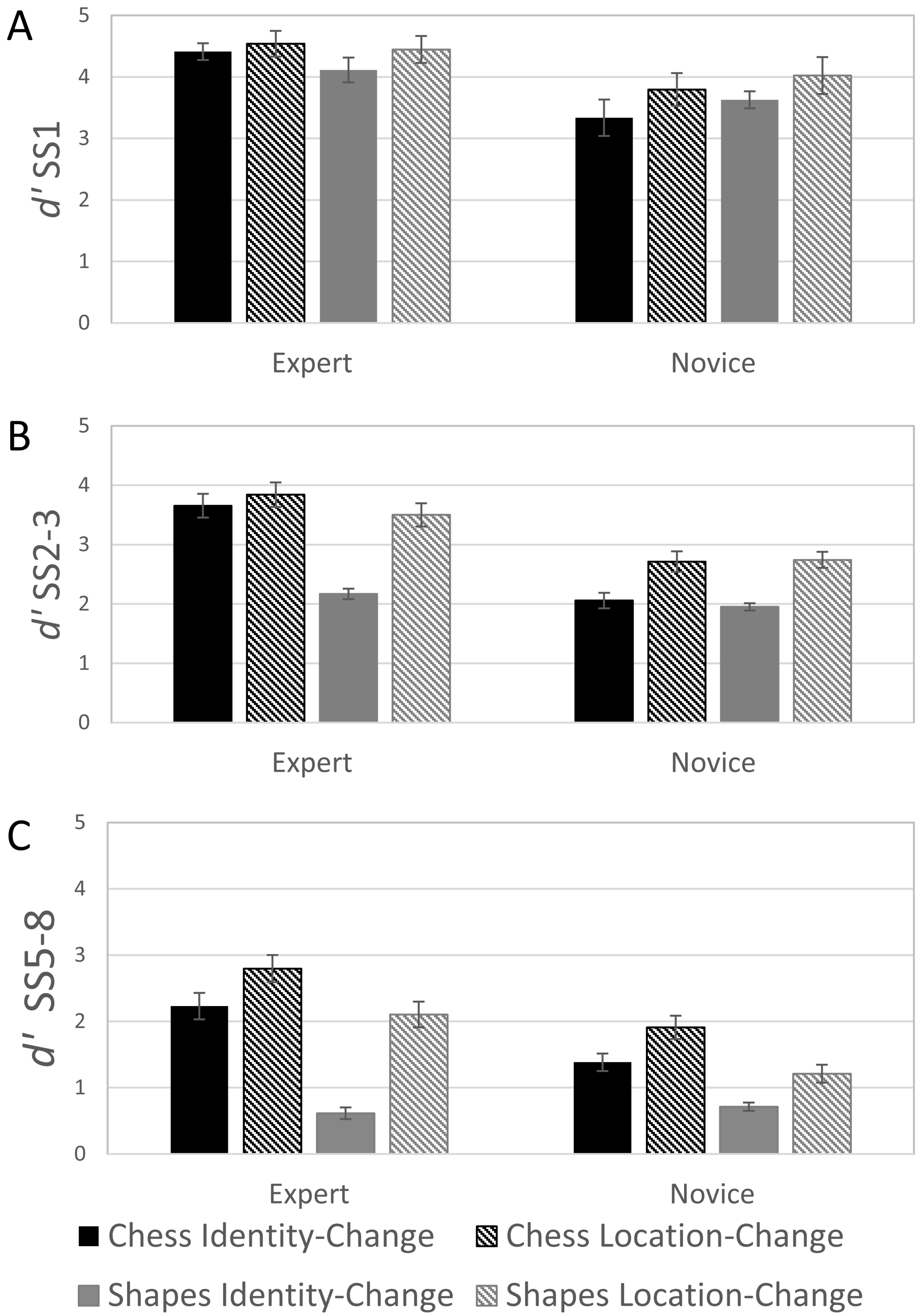

Figure 3. Memory discriminability (*d'*) of Experts and novices, plotted by Stimuli and Change_type. Panel A includes results for Setsize 1 (SS1), panel B for Setsize 2-3 (SS2-3) and panel C for Setsize 5+ (SS5-8). Error bars represent standard error of the mean.

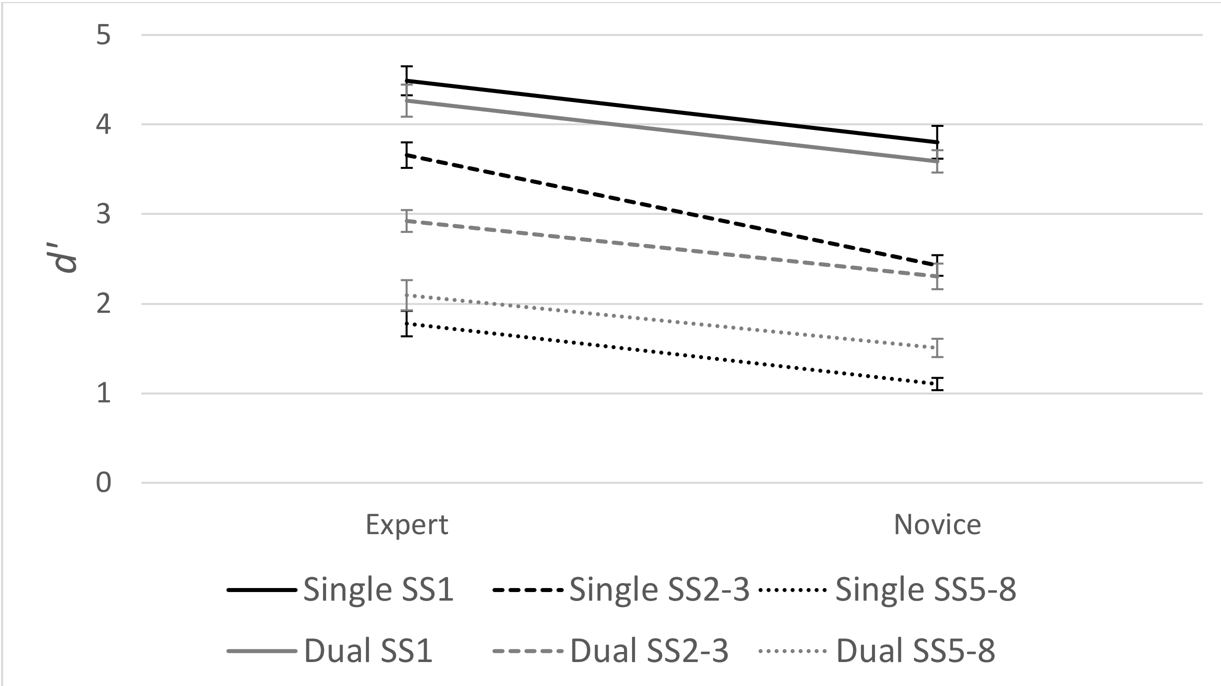

Figure 4. Memory discriminability (*d'*) for Single and Dual Attention blocks as a function of Skill, plotted separately for Setsize 1 (SS1), Setsize 2-3 (SS2-3) and Setsize 5+(SS5-8). Error bars represent standard error of the mean.

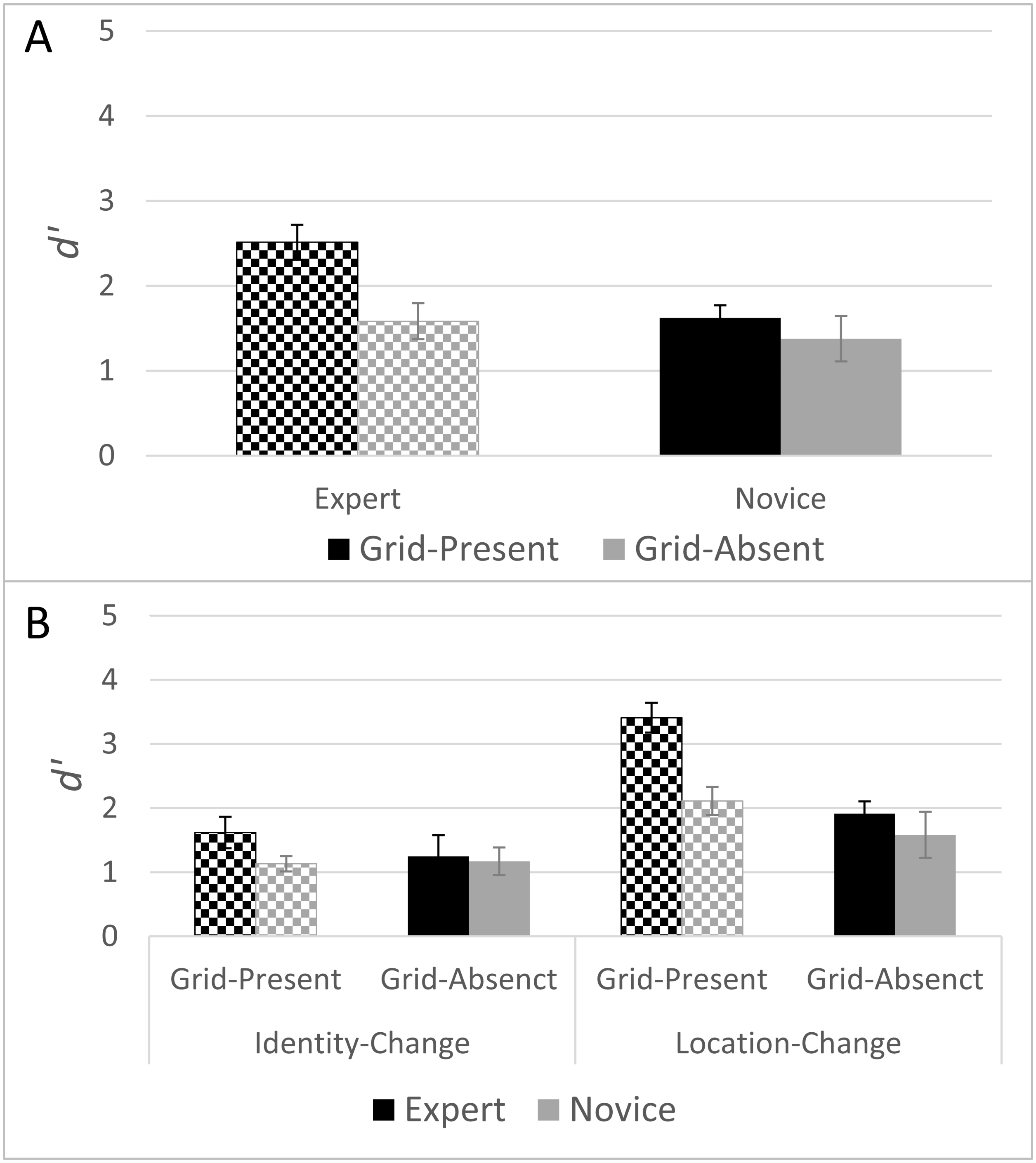

Figure 5. **A)** Memory discriminability (*d'*) in board-present and board-absent trials as a function of Skill. **B)** Memory discriminability (*d'*) expert and novice participants for novel shape stimuli, plotted by presence of grid and type of change. Error bars represent standard error of the mean.

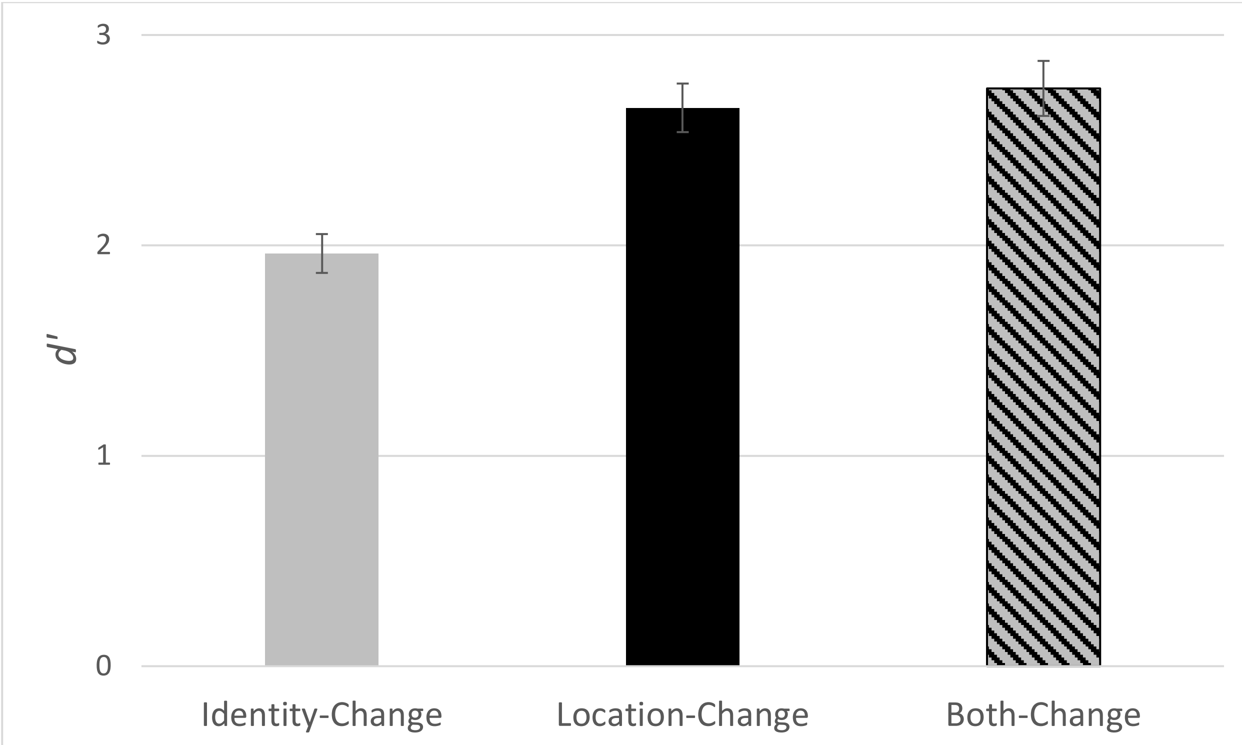

Figure 6: Memory discriminability (*d'*) across all participants in the *Dual Attention* block, separated by change type. Error bars represent standard error of the mean.

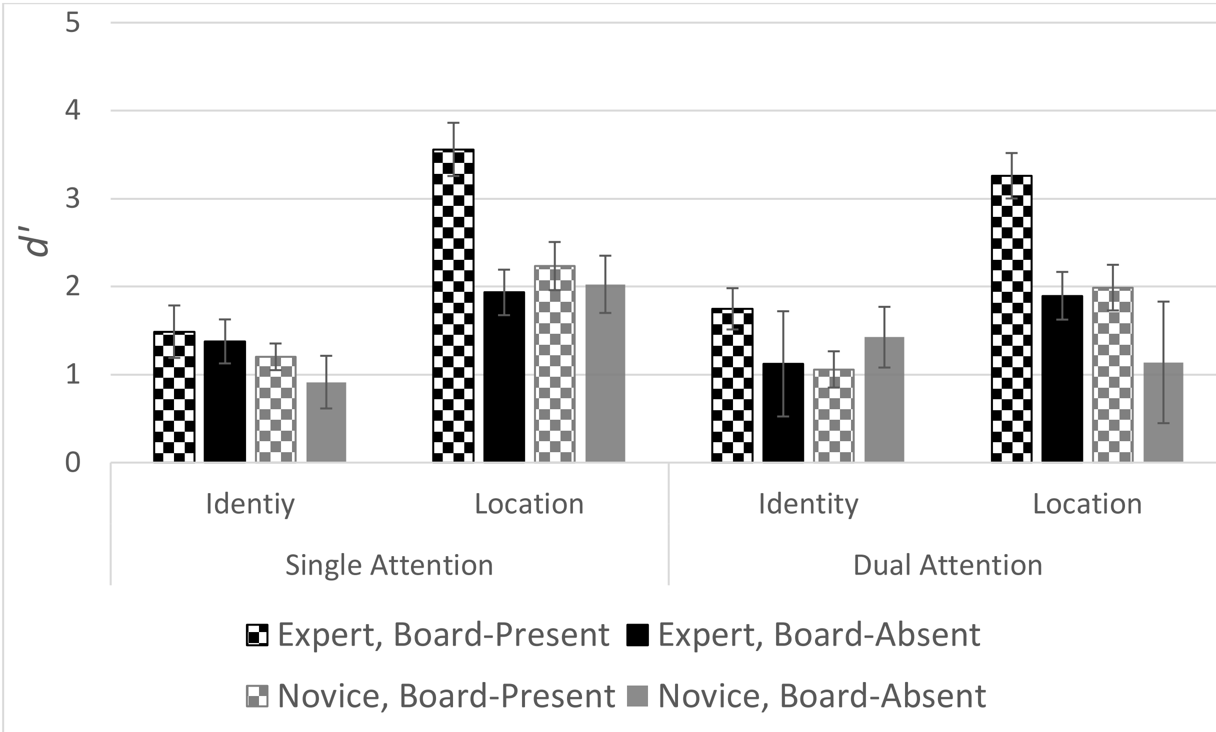

Figure 7. Memory discriminability (*d'*) across all participants and trial types in our comparison of board-present and board-absent non-chess trials. Error bars represent standard error of the mean.

Appendix A

Chess Questionnaire **Subject #________**

Current Date: ____________

Birthdate: _____________

Gender: M F

I have played chess for: ____________________________

Can you set up a chessboard to start a game? YES NO

Do you know how all of the pieces move? YES NO

Approximately how many games of chess have you played?
a. none b. less than ten c. over fifty d. over one hundred

I learned to play chess from: ____________________________

Number of family members who play chess:_____________________________

Have you ever played chess on the internet: YES NO

If so, how much internet chess do you play in an average month? _________________

Do you regularly practice chess? YES NO

If YES, please rank how often you utilize the following types of practice in, order from (1) most often to (7) least often:

____ Practicing alone with written material such as chess books.

____ Practicing alone with computer program.

____ Practicing together with other players.

____ Playing chess just for fun (without deliberate practice).

____ Giving private lessons in chess.

____ Getting private lessons in chess.

____ Watching current tournaments in the media.

I am a member of the U.S. Chess Federation YES NO

I have participated in (circle all that apply):

no tournaments / non-rated tournaments / rated tournaments

Number of tournaments in the last 12 months: _____________

What is your current Elo Rating? _______________

The strongest part of my game is:

a. opening b. middlegame c. endgame d. unsure