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Three experiments examined the relation between working memory capacity (WMC) and two different forms of cognitive conflict: stimulus-stimulus (S-S) and stimulus-response (S-R) interference. My goal was to test whether WMC's relation to conflict-task performance is mediated by stimulus-identification processes (captured by S-S conflict), response-selection processes (captured by S-R conflict), both, or neither. In Experiment 1, subjects completed a single task presenting both S-S and S-R conflict trials, plus trials that combined the two conflict types. I limited ostensible goal-maintenance contributions to performance by requiring the same goal for all trial types and by presenting frequent conflict trials that reinforced the goal. WMC predicted resolution of S-S conflict as expected: Higher-WMC subjects showed reduced response time interference. Although WMC also predicted S-R interference, here, higher-WMC subjects showed increased error interference. Experiment 2A replicated these results in a version of the conflict task without combined S-S/S-R trials. Experiment 2B increased the proportion of congruent (i.e., non-conflict) trials to promote reliance on goal-maintenance processes. Here, higher-WMC subjects resolved both S-S and S-R conflict more successfully than did lower-WMC subjects. Experiment 3 tested for the generalizability and robustness of the effect found in Experiments 1 and 2A. This pattern of results did not generalize to other task configurations and latent variable analyses revealed that S-S and S-R conflicts were task-specific and did not represent stable across-task individual differences. Theoretical implications for the relationship between WMC and executive control are discussed.

USING DIMENSIONAL OVERLAP THEORY AS A FRAMEWORK TO EXPLAIN THE RELATIONSHIP BETWEEN WORKING MEMORY CAPACITY AND COGNITIVE CONTROL

by

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To my significant other, Jody Servon, thank you for your support and patience through this process.

APPROVAL PAGE

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CHAPTER I

INTRODUCTION

> It is probably true to say that our initial specification of the central executive was so vague as to serve as little more than a ragbag into which could be stuffed all the complex strategy selection, planning, and retrieval checking that clearly goes on when subjects perform even the apparently simple digit span task. This still seems a sensible way of starting to explore working memory, as it accepts the complexities and the ultimate need to explain them, while concentrating on analysing the simpler and presumably more tractable slave systems. (Baddeley, 1996, p. 6)

Working memory's "executive" processes are typically characterized as general-purpose mechanisms that control and coordinate the activities of subordinate brain networks in the service of complex, goal-directed behavior (e.g., Baddeley, 1986; Norman & Shallice, 1986). As Baddeley (1996) recognized, however, such broad characterizations may offer little more than an ill-specified homunculus that masks the extent of our ignorance about the self-regulation of cognition and behavior (see also Burgess, 1997; Towse & Houston-Price, 2001). The present work takes a combined psychometric-experimental approach toward incrementally specifying the nature of executive control and its contribution to working memory capacity (WMC). The logic follows Cronbach (1957) and Underwood (1975) in suggesting that psychological theories can be developed and tested by considering individual differences in the constructs of interest, especially in the ways that they interact with experimental treatments and elicit patterns of convergent and discriminant validity in their selective associations with other constructs (see also, Campbell & Fiske, 1959; Cronbach & Meehl, 1955; Kosslyn et al., 2002; Vogel & Awh, 2008). In an attempt to add specificity to the central executive's nomological network, then, its correlational boundary conditions were sought. That is, I explored whether individual differences in WMC are differentially associated with the control processes elicited by two distinct forms of cognitive conflict.

Fractionating the Central Executive

The approach here has some parallels to the fruitful research program initiated by Miyake et al. (2000) into the "unity and diversity" of executive functions thought to be linked to the brain's frontal lobes (for a review, see Miyake & Friedman, 2012). Their correlational studies have used latent-variable, factor-analytic techniques to indicate the individual-differences variance that is shared versus not shared among theoretically derived cognitive and neuropsychological tasks (i.e., to demonstrate both convergent and discriminant validity). Three broad domains, or factors, of executive functions have thus been identified: inhibiting, switching, and memory updating. These factors are partially dissociable in their correlations with one another and in their differential predictions of cognitive and behavioral outcomes (e.g., Friedman et al., 2006; 2007), indicating that the executive control construct is not monolithic. At the same time, all three factors also share considerable common variance, and this common executive factor is highly heritable and strongly predicts intelligence and externalizing behavior problems, indicating some domain general mechanisms of cognitive control (Friedman et al., 2008; Miyake & Friedman, 2012; Young et al., 2009). Of most importance here, this line of “unity and diversity” work began from relatively informal, descriptive conceptions of executive functions and, through individual-differences findings alone, has progressed to facilitate the preliminary development of formal theoretical models to instantiate different control processes (e.g., Chatham et al., 2011).

While similarly relying on individual-differences analyses, the present study more narrowly examines how normal variation in WMC, as assessed by complex memory span tasks, responds to different experimental manipulations of conflict within a single response-time (RT) task. Complex span tasks require subjects to immediately recall short lists of items that are interleaved with an unrelated processing task. These tasks are of theoretical interest because their performance predicts a variety of important cognitive capabilities, such as reading comprehension (e.g., Daneman & Carpenter, 1980; McVay & Kane, 2012), learning (Kyllonen & Stephens, 1990; Shute, 1991), multitasking (e.g., Bühner, König, Pick, & Krumm, 2006; Hambrick, Oswald, Darowski, Rench, & Brou, 2010), and reasoning through novel intellectual problems (e.g., Kane, Hambrick, & Conway, 2005; Oberauer, Schulze, Wilhelm, & Süß, 2005). As well, normal variation in WMC predicts how well people perform seemingly simple attention-control tasks, such as dichotic listening and antisaccade (e.g., Colflesh & Conway, 2007; Conway, Cowan, & Bunting, 2001; Kane, Bleckley, Conway, & Engle, 2001; Unsworth, Schrock, & Engle, 2004). The apparent generality of WMC’s predictive power, and its association with lower-level attention capabilities, has led some theorists to propose that a small number of domain-free attention or executive functions largely drive WMC variation and its covariation with other abilities (e.g., Barrouillet & Camos, 2012; Engle & Kane, 2004; Hasher, Lustig, & Zacks, 2007).

Consistent with the Miyake-Friedman “unity and diversity” findings described above (e.g., Miyake et al., 2000; Miyake & Friedman, 2012), recent individual-differences research indicates that WMC variation and covariation may fundamentally reflect a number of core abilities beyond attention control (e.g., Unsworth & Engle, 2007a, 2007b; Unsworth & Spillers, 2010), and that WMC correlates selectively with only some attentional-control processes. Many studies have yielded associations between WMC measures and attention tasks that elicit some form of conflict between target versus distractor stimuli, or between habitual versus required responses (e.g., Ahmed & de Fockert, 2012; Bleckely, Durso, Crutchfield, Engle, & Khanna, 2003; Colzato, Spapé, Pannebakker, & Hommel, 2007; Conway et al., 2001; Heitz & Engle, 2007; Hutchinson, 2011; Kane & Engle, 2003; Long & Prat, 2002; McVay & Kane, 2009; Meier & Kane, 2013; Morey et al., 2012; Redick & Engle, 2006; Unsworth et al., 2004; but see Keye, Wilhelm, Oberauer, & van Ravenzwaaij, 2009; Redick, Calvo, Gay, & Engle, 2011). In sharp contrast, WMC does not appear to correlate with performance of prototypical visual search tasks – even those thought to involve top-down influences (Kane, Poole, Tuholski, & Engle, 2006; Poole & Kane, 2009; Sobel, Gerrie, Poole, & Kane, 2007) – unless those tasks are modified to require subjects to restrict search to only particular locations or subtle stimulus dimensions (Poole & Kane, 2009; Sobel et al., 2007). Similarly, in the auditory domain, a meta-analysis conducted by Sorqvist et al. (2013) provides evidence for a dissociation between WMC variation and two types of auditory distraction. WMC appears to be uniquely related to oddball auditory distractions (with higher-WMC subjects showing less of a cost to the oddball distraction), but it does not correlate with susceptibility to more continuous forms of auditory distraction.

So, WMC does not predict performance in all varieties of attention-control tasks. Findings like these, which point to the discriminant validity of WMC, are especially important for specifying the executive-control construct. Through an inductive process of identifying boundary conditions to the association between WMC and attention control, we may eventually reverse-engineer the central executive to gain traction regarding the specific control processes it encompasses and how these processes relate to broader cognitive abilities.

Specifying the Executive Attention Account of WMC

In addition to the attentional control tasks mentioned above that are sensitive to WMC variation (i.e., dichotic listening, antisaccade, visual search, and auditory distraction), research into the executive attention account of WMC has focused on the relation between WMC measures and executive-control tasks that elicit cognitive conflict, such as Stroop (1935) and flanker (Eriksen & Eriksen, 1974) tasks. These tasks demand control, in part, by requiring the flexible regulation of behavior in the pursuit of endogenous goals (Egner, 2008), typically by presenting subjects with multiple sources of information, some task-relevant and some irrelevant. When relevant and irrelevant task information suggest competing responses, cognitive conflict is generated. The general pattern of results from investigations of the relation between WMC and cognitive control is that the higher the subject's WMC, the better he or she performs on cognitive control measures. According to the executive attention account, WMC counters interference in two ways (Engle & Kane, 2004; Kane & Engle, 2003; Kane et al., 2007; Unsworth, Spillers, Brewer, & McMillan, 2011). It has been hypothesized that higher WMC is associated with both a superior ability to proactively keep task goals accessible (i.e., resist lapses of attention) and to reactively resolve cognitive conflict (i.e., resolve interference online). In some popular models of cognitive control, goal maintenance and conflict resolution processes are intimately connected with bi-directional communication between the anterior cingulate cortex (ACC; primarily associated with conflict resolution) and lateral prefrontal cortex (PFC) regions thought to be the seat of goal maintenance (Botvinick et al., 2001; Braver, Gray, & Burgess, 2007). In these models, effective goal maintenance can eliminate the need for conflict resolution because if the goal of the task if optimally maintained and the person performing the task only attends to information dictated by task instructions, conflict will be precluded. Additionally, if a lot of conflict is experienced the ACC can signal the PFC to increase the activation of the goal. The proposal of how WMC interfaces with cognitive conflict put forth with the executive attention account differs from this integrated account and suggests that goal maintenance and conflict resolution are separable somewhat independent processes through which WMC impacts performance. Here, the focus is primarily on the latter factor of in-the-moment conflict resolution.

Executive control (or “cognitive control”) is a broad, arguably ambiguous construct (Braver et al., 2007; Funes, Lupianez, & Humphrey, 2010a) that refers to mental processes ostensibly operating from perception to action. Therefore, linking

WMC to cognitive control allows WMC many possible entry points into information processing. To move WMC theory forward, we must further specify how WMC works to resolve cognitive conflict. To understand how WMC impacts performance (and to better understand cognitive control, itself), it should be helpful to decompose cognitive-control tasks into yet smaller components that more clearly map onto aspects (or stages) of information processing, analogous to Baddeley's (1996) call and effort to "fractionate" the central executive component of the working memory system.

The Dimensional Overlap Taxonomy

Kornblum's dimensional overlap taxonomy (Kornblum, 1992; Kornblum, Hasbroucq, & Osman, 1990) provides a potential blueprint for decomposing cognitive-control tasks into separable processing elements. Tasks that provide conflicting information about what stimulus or response is the target on a given trial are often called cognitive-control tasks because control is presumably needed to counter the interference they elicit. According to Kornblum, the strength of the conflict experienced by a subject is the result of the degree to which opposing task dimensions *overlap*. Here, overlap refers to how perceptually, conceptually, or structurally similar the sets (i.e., the entire stimulus and response sets) and the elements (i.e., individual items within the stimulus and response sets) are to one another (Kornblum & Lee, 1995). That is, the more overlap there is among conflicting task sets and elements, the more the irrelevant task element (i.e., the feature that provides information that will lead to an incorrect response) will disrupt performance.

Kornblum’s dimensional overlap taxonomy distinguishes choice-RT tasks based not on conflict strength, but rather on the task dimensions that provide the conflicting information. Conflict may arise between relevant and irrelevant stimulus dimensions (*S-S conflict*), between irrelevant stimulus and relevant response dimensions (*S-R conflict*), or between irrelevant stimulus dimensions and both relevant stimulus and response dimensions (*S-S plus S-R conflict*). Information processing is often characterized by at least three broad (and further decomposable) stages: stimulus identification, response selection, and motor execution (e.g., Proctor & Vu, 2003). Accordingly, different types and combinations of dimensional overlap create different processing problems: S-S conflict impedes stimulus selection and/or identification, whereas S-R conflict interferes with response selection and/or motor execution.

To test whether S-S and S-R conflicts are independent of each other, Kornblum (1994) had subjects respond to stimuli that varied on relevant stimulus, irrelevant stimulus, and response dimensions. Color words or neutral words appeared in the center of a rectangle, which was divided into colored (red or green) and dark halves. The color of the rectangle was the relevant stimulus dimension, whereas words and the side of rectangle that was colored (left, right, top, and bottom) were irrelevant. Subjects responded to color by pressing left or right keys (e.g., left key for a red patch), and completed four conflict-type blocks: pure S-S (color word was congruent or incongruent with the color patch; the color patch was presented on the top or bottom of the rectangle, making these neutral trials on the S-R dimension), pure S-R (color patch location was congruent or incongruent with the left-right response; the words were color-neutral), mixed S-S and S-R (presenting both S-S-only and S-R-only trials), and a combined-type S-S/S-R block where the irrelevant stimulus dimension overlapped with both the relevant stimulus dimension and the response. Kornblum found that S-S and S-R effects were additive on trials that contained both, and interpreted this as support for independence of S-S and S-R conflict (but see Hommel, 1997).

Additional behavioral evidence for the utility of the dimensional overlap taxonomy comes from investigations of congruency-sequence effects, in which the prior trial's congruency modifies the magnitude of the present trial's congruency effect (for a review see Egner, 2007). Funes, Lupianez, and Humphrey (2010a, 2010b) had subjects perform a series of mixed S-S and S-R trials (with some trials being congruent and others incongruent). Carry-over effects of control were conflict-specific: S-S interference was reduced after incongruent S-S trials but not after incongruent S-R trials (and vice versa), suggesting that the control processes initiated by the preceding incongruent trial were specialized for responding to that particular type of conflict (see also Verbruggen, Liefooghe, Notebaert, & Vandierendonck, 2005, Experiment 2). Time-course data also suggest distinct origins for S-S and S-R conflict, as S-R interference tends to decrease, whereas S-S interference tends to increase, as response times get longer (Pratte, Rouder, Morey, & Feng, 2010). Finally, neuroimaging data further suggest S-S versus S-R dissociations, with hemodynamic responses in parietal cortex areas particularly associated with S-S conflict, and activity in the motor cortex more strongly associated with S-R conflict (Egner, Delano, & Hirsch, 2007; Liston, Matalon, Hare, Davidson, & Casey, 2006; Liu, Banich, Jacobsen, & Tanabe, 2004). Here, then, I propose that (and subsequently test whether) the dimensional overlap taxonomy may help specify the executive-control processes that are related to WMC.

Dimensional Overlap and WMC

Higher-WMC subjects resolve interference from Stroop color-words more quickly than do lower-WMC subjects in tasks that present a high proportion of incongruent trials (Kane & Engle, 2003; Long & Prat, 2002; Meier & Kane, 2013). These findings suggest that WMC affects performance, in part, through conflict-resolution processes (the accuracy advantage that higher-WMC subjects show in low-incongruency Stroop tasks is argued to reflect, in part, goal-maintenance abilities; e.g., Hutchison, 2011; Kane & Engle, 2003). According to the Dimensional Overlap taxonomy, the color-word Stroop task presents both S-S and S-R conflict: The irrelevant stimulus dimension (word identity) overlaps with both the relevant stimulus dimension (word color; providing S-S conflict) and the response dimension (naming the color aloud; providing S-R conflict). Given the Stroop task's complex structure involving both S-S and S-R conflict, prior WMC-related findings have an ambiguous locus. That is, it is unclear if stimulus-selection and identification processes, or response-selection processes, or both, enable higher-WMC subjects to achieve superior performance to lower-WMC subjects.

Some light may be shed on the contributions of stimulus selection by examining WMC correlations with purer S-S interference tasks. In fact, higher-WMC subjects exhibit less interference from conflicting task elements in an Eriksen-type flanker task than do lower-WMC subjects (Heitz & Engle, 2007; Redick & Engle, 2006; but see Keye, Wilhelm, Oberauer, & van Ravenzwaaij, 2009). In the Kornblum taxonomy, the typical flanker task is an S-S conflict task, because conflict is generated when response-irrelevant stimulus information (i.e., flankers) provides information opposed to the information carried by the target representation. Here, then, it is argued that the conflict is generated by the overlap and conflicting nature of relevant and irrelevant stimulus features. The data thus suggest that higher-WMC subjects achieve better cognitive control, in part, because they are able to resolve conflict between stimulus dimensions better than are lower-WMC subjects. However, we cannot yet be sure that higher-WMC subjects' superior performance is the result of better S-S interference resolution. It remains possible that, at stimulus identification and selection, both lower and higher-WMC subjects allow the same information (both task relevant and conflicting) into the processing stream, but then higher-WMC subjects are better able to resolve the conflict at the subsequent response-selection stage (or some intermediate stage). Stated differently, although conflict originates in an S-S task from the overlapping stimulus dimensions between targets and distractors, performance differences can be achieved by either blocking this conflicting information from further processing (i.e., "early," at stimulus identification and selection) or by more efficiently resolving the resulting conflict from the distractor information after it has entered the system (i.e., "late," at response selection). This ambiguity is the product of the information-processing sequence where stimulus-identification processes must happen before response-selection processes. Therefore, by exclusively examining individual differences in a traditional flanker task, it still cannot be determined with great confidence what higher-WMC subjects do to achieve their superior performance. It should also be noted that recent work by Keye and colleagues (Keye et al., 2009) has reported null relations between WMC and interference in flanker tasks, and so earlier work on WMC-flanker task performance may have overestimated the relation.

In order to most effectively discriminate between the contributions of stimulus-identification and response-selection processes to the associations between WMC and conflict tasks, we should compare conflict performance on S-S-type trials to performance on trials that present only S-R interference. Then, via subtractive logic (Donders, 1869), we may judge how WMC impacts performance. More precisely, if WMC-related differences were found in an S-S conflict task, but not in a task that presents interference only at the response selection phase (S-R task), it would suggest that WMC affects performance prior to the response-selection, most likely during the stimulus identification or selection processes.

According to the Kornblum taxonomy, one way to assess S-R conflict is via the Simon effect (Simon & Small, 1969), which reflects the overlap between the irrelevant stimulus dimension and the response. The Simon effect is typically demonstrated in tasks where subjects push a right- or left-positioned key depending on the identity of the stimulus (e.g., circle or square), and the stimulus is either presented on the left or right side of the screen. S-R conflict is produced because the stimulus location is coded as left or right and so is the response: If the stimulus is on left side of the screen, the “left” response is primed, which causes interference when the relevant dimension of the stimulus actually indicates a right response. The irrelevant stimulus location and the relevant stimulus dimension (usually the shape or color of a single object) do not overlap, so there is no opportunity for conflict between these stimulus elements (i.e., there is no S-S interference). Considerable behavioral evidence indicates that the Simon effect involves response selection and not stimulus identification (Acosta & Simon, 1976; Mewaldt, Connelly, & Simon, 1980; Simon, 1982; Simon, Acosta, Mewalt, & Speidel, 1976; Van der Molen & Keuss, 1981). For example, degrading the quality of visual stimuli, which should affect stimulus identification, does not affect the magnitude of the Simon effect (Acosta & Simon, 1976), but the size of the to-be-executed response set executed does (Mewalt, Connelly, & Simon, 1980). Therefore, the Simon task seems to provide a relatively pure window into the response-selection stage of information processing.

The evidence for WMC predicting performance in Simon tasks is mixed and limited (and seemingly more limited than that described above connecting WMC to tasks involving S-S conflict). WMC is uncorrelated with Simon effects when trials are 50% congruent (Gulbinaite & Johnson, 2013; Keye et al., 2009; Weldon, Mushlin, Kim, & Sohn, 2013) and 75% congruent (Miller, Watson, & Strayer, 2012, who also found no WMC effect on Simon-task errors). In an 80% congruent task, however, Weldon et al. observed a modest correlation between WMC and the Simon effect in RTs ($r = -.22$). It is notable that Weldon et al. only observed a significant WMC association in a Simon task with a high proportion of congruent trials. High proportion-congruency conditions put a premium on the ability to maintain the goal of the task because on the frequent congruent trials, correct responding can be achieved by either attending to the goal-mandated target or irrelevant information (Kane & Engle, 2003); WMC effects in high-congruency contexts may therefore have little to do with in-the-moment conflict resolution. In any case, the lack of a relation between WMC and Simon effects under 50% congruency task conditions suggests that WMC is not (or is only weakly) related to performance in tasks that provide only response-related conflict.

I designed Experiment 1 to test whether WMC helps resolve S-S interference, S-R interference, or both. This was done within a single task to avoid the ambiguities that arise when making across-task comparisons (e.g., differences in stimuli or task approach between Flanker and Simon tasks). I controlled the influence of goal-maintenance abilities and task switching by using a task that, first, had the same goal for both S-S and S-R conflict trials and, second, presented enough conflict trials (i.e., 50%) to help reinforce the task goals and minimize goal neglect. Subjects responded to upward or downward facing arrows by pressing left- or right-positioned keys. All that distinguished S-S from S-R trials was the location of the arrows on the screen. Therefore, any relations between WMC and a conflict type should reflect differences in conflict resolution processes.

CHAPTER II

EXPERIMENT 1

Method

Here, and in the Results section that follows, I report how I determined sample size, all data exclusions, all manipulations, and all measures in the study (Simmons, Nelson, & Simonsohn, 2012).

Subjects. Two hundred and thirty six undergraduates (aged 18-30 years) from the University of North Carolina at Greensboro (UNCG) participated and received partial credit for a psychology course requirement. The goal was to test at least 200 subjects in the course of a single semester, and our stopping rule for data collection was the end of the semester in which the goal was reached.

General procedure. Subjects volunteered to complete three testing sessions in groups of 1 – 4, with an experimenter present throughout each session to read all instructions aloud and to monitor subjects' progress through the tasks. Only the relevant tasks from the first two sessions are described and analyzed here; the other tasks were all completed after the present ones, and were designed for other studies by different sets of authors (reflecting a mix of attention and long-term memory tasks, one of which included thought probes to assess mind-wandering). On average, these two sessions (for subjects who completed both) were completed 13 days apart (SD = 12). In the first session, the Operation Span task (OSPAN), the S-S/S-R task, and then the Reading Span task

(RSPAN) were administered. In the second session, the Symmetry Span task (SSPAN) was administered as the first task, followed by the tasks for other studies. Each session was scheduled for 1.5 hr. Subjects were allowed to leave when everyone in their session finished the final task (for all sessions, no task was begun until all subjects in the session had completed the preceding task). Experimenters read on-screen instructions for each task aloud while subjects read along silently. Dell desktop computers, with 17 in cathode ray tube (CRT) monitors (85 MHz refresh rate) and running E-Prime (1.2) software, presented all task stimuli and recorded all responses.

WMC tasks. I assessed WMC with three automated "complex span" tasks (OSPAN, SSPAN, and RSPAN; Redick et al. 2012; Unsworth, Heitz, Schrock, & Engle, 2005; Unsworth, Redick, Heitz, Broadway, & Engle, 2009). In these tasks, subjects attempt to maintain or recover mental access to memory items while intermittently completing an unrelated processing task. To prevent trading off between the processing and memorial portions of the task, an individualized response deadline (*M* + 2.5 SDs) was used for the processing portion, calculated during 15 processing-task-only items. For the processing portion of OSPAN, subjects verified (via mouse-clicking a "yes" or "no" onscreen) solutions to compound arithmetic equations (e.g., *(3 * 2) - 1 = 4*). In RSPAN, subjects judged (via "yes"/"no" mouse-click) whether or not sentences made sense (e.g., "*I like to run in the sky*."). In SSPAN, subjects assessed (via "yes"/"no" mouse-click) whether or not 8 × 8 black-and-white matrix patterns were vertically symmetrical.

The memory items in OSPAN and RSPAN were capital letters (randomly selected without replacement on each trial from these twelve: *F, H, J, K, L, N, P, Q, R, S, T, Y*). A letter followed 200 ms after the response to each processing item in the task and appeared for 250 ms. After 3-7 processing-letter pairs, all 12 letters appeared onscreen in a grid formation next to a check box. Subjects identified the letters presented in serial order, via mouse click in the check box. When a subject selected a letter, it appeared on the bottom of the screen in the order it was selected (arranged left to right). Subjects were instructed to click on a “blank” button on the screen for forgotten letters, to preserve item order. Pressing the blank button placed a dash in the array of letters on the bottom of the screen. OSPAN and RSPAN presented each set length (3-7) three times in random order.

In SSPAN, 200 ms after the symmetry judgment was made, one square of a 4 × 4 grid was shaded red for 650 ms. After 2-5 symmetry judgment-grid pairs, subjects recalled the locations of the shaded squares in serial order by mouse-clicking on the squares within an empty grid. When a square was clicked, it turned red with a number inside it to indicate its serial order. As with the OSPAN and RSPAN, there was an option to click on a “blank” button. The SSPAN presented each set length (2-5) three times in random order.

In all of the complex span tasks, subjects first completed four practice trials of just the recall portion (set sizes 2 and 3), then 15 processing-portion-only practice trials, and then three combined practice trials (set size 2) of both processing and recall. Task instructions warned subjects that they must achieve 85% accuracy on the processing portion for their data to be used in the study. Between sets, the programs provided subjects with accuracy feedback for the processing and memory portions of the task for the last set and also their cumulative accuracy for processing across all preceding sets.

S-S/S-R task.

***Stimuli and trial types*.** I modeled the S-S/S-R task after Liu et al. (2004; see also Verbruggen et al., 2005). The stimuli were black arrows on a grey background. At a viewing distance of 60 cm, the arrows each occupied approximately 2° × 2° degrees of visual angle (although I did not physically restrict viewing distance, I placed pieces of blue masking tape on the floor, 60 cm from the screen on each side of each subject's chair and instructed them that their eyes should stay at this distance from the screen throughout the task). The target arrows pointed either upward or downward. Subjects were instructed to press one key for an up arrow and another key for a down arrow, using the *Q* and *P* keys on a QWERTY keyboard, which were approximately 15.5 cm apart. I counterbalanced the mapping of arrows to keys between subjects (i.e., for some subjects, upward-pointing arrows required a left-handed response [*Q* key] and downward-pointing arrows required a right-handed response [*P* key], and for other subjects upward-pointing arrows required a right-handed response [*P*] and downward arrows required left-handed response [*Q*]).

Response-Mapping practice trials presented arrows at the center of the CRT screen. For S-S/S-R task trials, the arrows appeared in eight different locations around the center of the screen. The arrows appeared approximately 2° (at a 60 cm viewing distance) from the center of the screen in one of the following eight locations: left, right, above, below, left-and-below, left-and-above, right-and-below, or right-and-above (see Figure 1). Trial order was randomized in every block for every subject. Stimuli were congruent half of the time at each stimulus location (e.g., an upward-pointing arrow presented above the center of the screen; an arrow requiring a right-key response presented on the right side of the screen). When stimuli were presented in the corner positions (e.g., left-and-above, right-and-below), S-S and S-R conflict were factorially crossed.

Procedure. Each S-S/S-R task trial presented subjects with one arrow either pointing upward or downward in one of the eight locations, and the experimenter (and onscreen instructions) asked subjects to quickly and accurately press a key to indicate whether each arrow pointed upward or downward. Subjects first completed 10 trials of response-mapping practice with immediate feedback, by responding to arrows presented in the center of the screen. Following incorrect responses, the screen flashed red for 100 ms. Next, subjects completed 100 response-mapping-practice trials (again, with centered arrows) with accuracy and RT feedback provided only at the end of the block.

Following response-mapping practice, subjects completed 24 practice trials in which the arrows could appear in any of the eight positions around the center of the screen; subjects received trial-level error feedback (screen flashing red after errors). Next, for the actual task, subjects completed four blocks of 120 trials, with short breaks (< 30 seconds) permitted between blocks. The target arrow appeared directly above, below, to the left, or to the right of fixation on 80 trials per block (20 in each of those locations). On half of these trials the arrow direction was congruent with the arrow location. On the other 40 trials per block, the arrows appeared diagonally oriented to fixation (e.g., right-and-above; left-and-below) with left, right, up, and down locations being factorially crossed. Every trial began with a black fixation cross, in 90 point bold Courier New font, for 500 ms, and remained on-screen during the 100 ms arrow presentation. After the target arrow, subjects saw a blank screen for 1250 ms. I recorded responses during the first 1150 ms of this screen. After each of the four blocks, subjects received RT and error feedback for that block. Finally, subjects completed another 100 trials of response-mapping (identical to the 100 response-mapping trials completed before the S-S/S-R task trials).

Inferential Analyses

I used the lme4 package (Bates, Maechler, & Bolker, 2013) in the R system for statistical computing (R Development Core Team, 2013) to compute inferential statistics. For RTs (from accurate trials only), I used linear mixed models (LMM). I interpreted parameters — determined by restricted maximum likelihood estimation — with t-values greater than 2 as significant; with a large number of observations the t-distribution becomes indistinguishable from the standard normal distribution, where absolute values over 2 reflect an alpha < .05. I used generalized linear mixed models (GLMM) for accuracy analyses, in order to account for the binomial distribution of trial-level accuracy (Dixon, 2008). In the raw data, correct trials were scored a 0 and incorrect trials were a 1. The betas for the GLMMS are log odds ratios with higher log odds ratios indicating that an error is more likely to be committed. In all models, I entered subjects as random effects (random intercept only) to account for the non-independence of the data, and WMC (centered on the grand mean of the experiment) was treated as a continuous variable.

Results

I dropped all data from fifteen subjects (8 who did not achieve 85% accuracy on the processing portion of at least 2 complex span tasks [two of these subjects never returned for the second session], and seven subjects — identified using box plots — who were further than three times the interquartile range from the mean accuracy for either the response-mapping or the congruent trials in the S-S/S-R task). Data remained from 221 subjects.

WMC screening. The sum of items correctly recalled in serial position was the score for each complex span task (Conway et al., 2005); the theoretical maximum score was 75 for OSPAN and RSPAN and 42 for SSPAN. If a subject did not achieve 85% accuracy on the processing portion of a span task, the score from that task was not used in analyses (all data from subjects with fewer than two valid span scores were dropped from analyses). I converted span task scores (these raw *M*s and SDs are reported with the correlations below) to *Z* scores (using the *M*s and SDs from our laboratory database of more than 3,000 UNCG students; for published norms generated from this sample, see Redick et al., 2012) and averaged them into a WMC composite. The raw span scores correlated with *r*s of .68 (RSPAN [*M* = 50, SD = 15] × OSPAN [*M* = 53, SD = 14]; N = 199), .51 (OSPAN × SSPAN [*M* = 26, SD = 7]; N = 178), and .43 (SSPAN × RSPAN; N = 184). *N*s varied due to individually dropped tasks. The WMC composite was unimodal and symmetrically distributed (*M* = 0.08; SD = 0.81; skew = -0.72; kurtosis = 0.01).

Response-Mapping RTs. On the pre-task mapping trials (*M* = 448 ms, SE = 4 ms), higher-WMC subjects responded faster than did lower-WMC subjects (b = -10 ms, SE = 5 ms, *t* = -2.2). I further divided the pre-task mapping trials to examine WMC's relation to RTs for the first versus second half of mapping. Higher-WMC subjects responded significantly faster than did lower-WMC subjects on the first 50 mapping trials (b = -9 ms, SE = 5 ms, *t* = -2.0) and the second 50 mapping trials (b = -11 ms, SE = 5 ms, *t* = -2.3). When I examined only the last 25 trials of mapping, higher-WMC subjects were no longer significantly faster than lower-WMC subjects (b = -9 ms, SE = 5 ms, *t* = -1.8), but the modest WMC effect on RTs was of similar magnitude no matter how it was analyzed. In the post-task mapping trials (*M* = 464 ms, SE = 4 ms), WMC did not predict RTs (b = -5 ms, SE = 5 ms, *t* = -1.0).

Response-Mapping errors. Subjects were entered as a random effect and WMC as fixed effect in a GLMM predicting errors. Higher-WMC subjects were less likely to commit errors than were lower-WMC subjects, overall (b = -0.26, SE = 0.06, Z = -4.2), on the first 50 trials (b = -0.31, SE = 0.07, Z = -4.2), and over the last 50 trials (b = -0.26, SE = 0.06, Z = -4.2). As in mapping RTs, when I examined only the last 25 trials, I did not find significant WMC-related differences (b = -0.09, SE = 0.08, Z = -1.2).

Although WMC-related differences in mapping RTs and errors seemed to be resolving over the last 25 trials of practice, one might be concerned that overall differences in responding to arrow stimuli without conflict might affect any WMC-related differences in conflict resolution with these stimuli. I thus adopted a conservative strategy that used subjects' centered mean RTs or error rates from the last 50 trials of pre-task mapping as a covariate in all of the following analyses (I also report all theoretically important effects that changed without the covariate, to eliminate concerns about researcher degrees of freedom; Simmons, Nelson, & Simonsohn, 2011). No interaction terms with this covariate were included our models. Unless otherwise noted, I entered subjects as a random effect and WMC and trial congruency as fixed effects. I coded trial congruency as a -.5/+.5 contrast, so this parameter represents the experimental effect.

S-S RTs. Table 1 presents descriptive statistics for Experiment 1. I found significant S-S interference, such that responses to incongruent trials were slower than responses to congruent trials (b = 38 ms, SE = 1 ms, *t* = 32.8). WMC did not predict RTs, overall (b = -3 ms, SE = 4 ms, *t* = -0.7). However, higher-WMC subjects experienced less S-S interference than did lower-WMC subjects (b = -7 ms, SE = 1 ms, *t* = -5.1); that is, higher-WMC subjects showed a smaller RT difference between incongruent and congruent trials. To decompose this interaction between WMC and trial type, I analyzed congruent and incongruent trials separately: Higher-WMC subjects did not significantly differ from lower-WMC subjects on congruent-trial RTs (b = 1 ms, SE = 4 ms, *t* = 0.3) or on incongruent-trial RTs (b = -6 ms, SE = 4 ms, *t* = -1.7), but it appears that the significant reduction in S-S interference for higher-WMC subjects was due primarily to better performance on incongruent trials. (Parallel analyses without the mapping-RT covariate similarly indicated significant S-S interference [b = 38 ms, SE = 1 ms, *t* = 32.8] and a significant WMC × trial-type interaction [b = -7 ms, SE = 1 ms, *t* = -5.1], but additionally showed a main effect of WMC on RTs [b = -11 ms, SE = 5 ms, *t* = -2.2].)

S-S errors. Error rates also demonstrated significant S-S interference, with subjects making more errors on incongruent than on congruent trials (b = 0.87, SE = 0.05, Z = 19.2). WMC did not predict errors overall (b = 0.06, SE = 0.06, Z = 1.1), nor did it interact with trial congruency (b = -0.08, SE = 0.06, Z = -1.4). (Without the mapping-accuracy covariate, the only parameter to change was for the WMC main effect, which remained non-significant [b = 0.00, SE = 0.07, Z = 0.3].)

S-R RTs. Subjects exhibited significant S-R interference (b = 45 ms, SE = 1 ms, *t* = 39.8). WMC did not predict overall RT (b = -3 ms, SE = 3 ms, *t* = -0.9), nor did WMC interact with S-R interference (b = -1 ms, SE = 1 ms, *t* = -0.9); in contrast to S-S interference, then, S-R interference was insensitive to variation in WMC. (Analyses without the mapping-RT covariate showed no change to the parameters representing S-R interference or the WMC × trial-type interaction, but the main effect of WMC on RTs was significant [b = -12 ms, SE = 5 ms, *t* = -2.3].)

S-R errors. Subjects made more errors on incongruent trials then on congruent trials, indicating significant S-R interference (b = 1.39, SE = 0.05, Z = 29.6). Overall, WMC did not predict errors (b = -.04, SE = 0.05, Z = -0.8), but WMC did interact with S-R congruency in the opposite of the predicted direction (b = 0.13, SE = 0.06, Z = 2.3). Here, higher-WMC subjects were non-significantly *more* likely to commit an error on incongruent trials than were lower-WMC subjects (b = 0.02, SE = 0.05, Z = 0.4), and non-significantly less likely to commit an error on congruent trials (b = -0.11, SE = 0.07, Z = -1.6). (Without the mapping covariate, the only parameter that changed was for the main effect of WMC, which remained non-significant [b = -0.10, SE = 0.06, Z = -1.7].)

Comparison of S-S and S-R trials. For these analyses, conflict type was dummy-coded. S-R trials (arrows presented directly to the right or left of fixation) were set as the reference level and S-S trials (arrows presented directly above or below fixation) were the comparison level.

RTs. S-S trials yielded slower responses than did S-R trials (b = 11 ms, SE = 1 ms, *t* = 13.1) and subjects exhibited less S-S than S-R interference when contrasting incongruent to congruent trials (b = -7 ms, SE = 2 ms, *t* = -4.2). As evident in the significant interaction depicted in Figure 2a, WMC influenced the S-S interference difference score more than the S-R difference score (WMC × S-S × S-R interaction, b = -6 ms, SE = 2 ms, *t* = -3.0). That is, consistent with results reported above, higher-WMC showed a greater RT advantage over lower-WMC subjects in resolving S-S interference than in S-R interference. (None of these parameters changed in analyses without the mapping-RT covariate.)

***Errors*.** Error rates were statistically equivalent across S-S and S-R trials (b = -0.04, SE = 0.03, Z = -1.4), but subjects again showed less S-S than S-R interference when contrasting congruent to incongruent trials (b = -0.53, SE = 0.07, Z = -8.1). As depicted in Figure 2b, WMC negatively predicted interference in S-S trials and positively predicted interference in S-R trials, yielding a significant interaction among WMC, S-S, and S-R conflict types (b = -0.21, SE = 0.08, Z = -2.6). (None of these parameters changed in analyses without the mapping covariate.)

S-S/S-R Combination Trials

To analyze the trials that appeared in the “corners” of the display and were composed of a factorial combination of congruency and S-S and S-R conflict types, I entered S-S and S-R conflict separately as fixed effects (entered as -.5/+.5 contrasts). Data from only the combination trials were included in these analyses.

RTs. Subjects showed significant S-S interference (b = 27 ms, SE = 1 ms, *t* = 23.1) and S-R interference (b = 36 ms, SE = 1 ms, *t* = 31.6) and, consistent with prior research (e.g., Kornblum, 1994), these effects did not interact on trials that contained both conflict types (b = -1 ms, SE = 2 ms, *t* = -0.3). There was no main effect of WMC on RT, overall (b = -2 ms, SE = 4 ms, *t* = -0.6). Consistent with results from the pure trials analyzed above and, as shown in Figure 3a, higher-WMC subjects experienced less S-S interference than did lower-WMC subjects (b = -4 ms, SE = 1 ms, *t* = -2.7), but this pattern did not hold for S-R interference (b = -2 ms, SE = 1 ms, *t* = -1.1). However, the three-way interaction among WMC, S-S conflict, and S-R conflict was not significant (b = -3 ms, SE = 3 ms, *t* = -1.0). (In an analysis without the mapping-RT covariate, the only parameter that changed was the overall main effect of WMC on RT, which was now significant [b = -11 ms, SE = 5 ms, *t* = -2.1].)

Errors. Subjects' error rates showed both significant S-S (b = 0.67, SE = 0.5, Z = 13.5), and S-R interference (b = 1.14, SE = 0.05, Z = 23.0) but here, in contrast to the RT analyses, trials that presented both S-S and S-R conflict yielded an under-additive interaction approaching my significance criterion (b = -0.18, SE = 0.10, Z = -1.8). Again, there was no main effect of WMC on errors in these combination trials (b = 0.02, SE = 0.06, Z = 0.4). As in the pure conflict trials, WMC did not predict S-S interference (b = 0.07, SE = 0.6, Z = 1.2), but, as depicted in Figure 3b, higher-WMC subjects were more likely to commit errors on trials with S-R conflict than were lower-WMC subjects (b =

0.19, SE = 0.6, Z = 3.1). The three-way interaction among WMC, S-S conflict, and S-R conflict was not significant, however (b = -0.17, SE = 0.13, Z = -1.3). (Without the mapping-errors covariate in the analyses, only the main effect of WMC changed, becoming non-significantly negative [b = -0.03, SE = 0.06, Z = -0.5].)

Delta plots. Next, I examined whether WMC-related differences in resolving interference were more pronounced in particular areas of the RT distribution. That is, I tested whether higher-WMC subjects showed an advantage over lower-WMC subjects because they experienced less interference on the fastest trials, on the slowest trials, or across the whole RT distribution. To accomplish this, I binned all subjects' correct-trial RTs (from pure trials only) separately for congruent and incongruent trials into five bins each. The bins were ordered so that each subject's fastest 20% of trials represented the first bin, 2nd fastest 20% of trials the second bin, etc., until I had five bins of approximately equal size for each subject for both conflict types for congruent and incongruent trials. I then subtracted each congruent-trial bin from its corresponding incongruent-trial bin, which left with five difference scores per subject for each conflict type.

S-S trials. For illustrative purposes, I plotted these bins collapsed across the highest and lowest third of WMC scores. As shown in Figure 4, the differences between higher and lower-WMC subjects were not localized to any specific portions of the RT distribution. This observation was confirmed by a LMM with subjects as a random effect and WMC (as a continuous variable) and bin (1-5) as fixed effects. Only bin (b = -2 ms, SE = 1 ms, *t* = -2.8) was a significant predictor of the S-S conflict difference score, with interference decreasing across bins. Typically, in tasks that present only S-S conflict in isolation, more interference is observed on the slowest trials (Pratte et al., 2010). However, when in tasks presenting both S-S and S-R conflict trials mixed within blocks, we know less about the expected delta-plot pattern. Here, I did not observe a main effect of WMC possibly because of reduced power in the analysis of aggregated data. In any case, of most importance here is the null interaction between WMC and bin (b = -1 ms, SE = 1 ms, *t* = -1.6), suggesting that the significant effect of WMC observed in our initial non-aggregated analysis above was relatively constant throughout the RT distribution.

S-R trials**.** Although my prior analyses showed that WMC did not predict resolution of S-R interference in RTs, for completeness I examined delta plots of these trials, as well. On blocked S-R trials, where the irrelevant stimulus feature is location (as it is here) and the stimuli are presented horizontally, interference effects typically decrease as RTs slow (Pratte et al., 2010; Proctor, Miles, & Baroni, 2011). But again, we know less about what to expect when S-S and S-R trials are mixed. Figure 5 shows a good deal of overlap between the distributions, as well as some separation among WMC scores at the slowest RTs. The only statistically significant predictor in the LMM, however, was bin (b = 2 ms, SE = 1 ms, *t* = 2.9), with the difference scores getting larger as RTs got longer. As in the S-S trial analyses above (and consistent with the null WMC effect in S-R interference), WMC did not interact with bin (b = -1 ms, SE = 1 ms, *t* = -1.5).

Discussion

Here, in a task that presented 50% conflict trials as a means to control for WMC-related differences in goal maintenance (e.g., Kane & Engle, 2003), higher-WMC subjects showed less S-S interference in RTs than did lower-WMC subjects, but they showed equivalent S-R interference in RTs. Indeed, not only did higher-WMC subjects not experience less S-R RT interference than did lower-WMC subjects, they actually experienced *greater* S-R interference in errors than did lower-WMC subjects (a possible explanation of this effect is included in the discussion of Experiment 2A). This pattern of results was evident in both pure and combination trials. Clearly, Experiment 1 yielded a dissociation in the relation of WMC variation to performance on trials that present conflict between stimulus elements and trials that present conflict between stimulus and response elements.

Delta plots did not reveal any localized WMC-related differences in the experience of either S-S or S-R interference across the RT distribution. Differential slowing in the tail end of the RT distribution, with lower-WMC subjects experiencing greater slowing, has previously been interpreted as evidence for WMC-related differences in (lapses of) goal maintenance (Unsworth, Redick, Spillers, & Brewer, 2012). Because I saw no such localized differences here, I interpreted the dissociation of WMC with S-S versus S-R interference as being consistent with the notion that higher WMC is particularly effective in resolving conflict between relevant and irrelevant stimulus features, but is less effective (or even detrimental, with respect to errors) in resolving conflict between irrelevant stimulus dimensions and response dimensions. The dissociation revealed here provides evidence for a conflict-specific WMC-related individual difference in identifying or selecting among competing visual stimuli.

CHAPTER III

EXPERIMENTS 2A AND 2B

I sought to replicate my novel findings in Experiment 2A, which eliminated arrows that were presented in the diagonal positions to determine whether the WMC-conflict dissociation would be found in a simpler task environment that only allowed arrows to appear in four locations (e.g., above, below, left, and right). That is, I simplified the task environment as a way to rule out that WMC was somehow related only to performance on S-S trials because of the sheer number of stimulus-response pairings in the original version (16 stimulus-response pairs in Experiment 1 versus 8 stimulus-response pairs in Experiments 2a and 2b). In Experiment 2B, the proportion of congruent trials was increased from 50% to 80% to bring goal maintenance processes into play; here I tested whether WMC would thus moderate performance across both conflict types. In a goal-supportive context (like that in Experiment 1 and Experiment 2A) where the goal of the task is reinforced by frequently occurring incongruent trials (forcing subjects to try and only attend to the relevant stimulus feature), WMC-related differences in goal maintenance are minimized. However, in a context where a majority of the trials are congruent and allow subjects to respond correctly by either attending to the relevant or irrelevant stimulus features, lower-WMC subjects seem to lose the goal of the task periodically and thus show greater interference than do higher-WMC subjects when they encounter the infrequent incongruent trials (Kane & Engle, 2003). In addition, previous work using the same task as used in the current studies has shown that increasing the proportion of congruent trials affects performance across conflict types (Funes et al., 2010a) suggesting that proportion congruency manipulations impact performance at a global level. In Experiment 2B, I tested whether WMC interacts with this generalized (i.e., not conflict-type specific) form of control.

In Experiments 2A and 2B, in addition to testing whether WMC was differently related to S-S and S-R conflict resolution, I examined a potential mediator of this differential relation: the effect of prior trial congruency on the performance of the current trial. Congruency-sequence effects are often used as markers of in-the-moment cognitive control (Botvinick et al., 2001; for a review, see Egner, 2007). Using the same task as the one in this study, Funes et al. (2010a, 2010b) found a large reduction in interference following an incongruent trial only when the previous trial type was the same as the current trial type. For example, interference was reduced on incongruent S-S trials that followed incongruent S-S trials, and on incongruent S-R trials that followed incongruent S-R trials, but not on incongruent S-S trials following incongruent S-R trials and vice versa. Previously, I have found WMC to be unrelated to congruency-sequence effects in a Stroop task (Meier & Kane, 2013), and this jibes with Unsworth et al. (2012), who also found no evidence of a WMC and congruency-sequence relation in a flanker or Stroop task and Keye et al. (2013) who found no relations between WMC and congruency-sequence effects in vertical or horizontal Simon task.

Other recent work, however has reported relations between WMC and congruency-sequence effects in tasks that presented S-R interference, with lower-WMC subjects experiencing a greater change in responses to incongruent trials following incongruent trials than did higher-WMC subjects (Gulbinaite & Johnson, 2013; Keye et al., 2009; Weldon et al., 2013). My aim with this analysis was to place the work presented here in the context of the prior work examining WMC and congruency-sequence relations and to test whether congruency-sequence effects were responsible (at least in part) for any WMC-related differences in the resolution of S-S and S-R conflict.

Method

Subjects. I randomly assigned subjects to either Experiment 2A or 2B. One hundred and forty-four UNCG undergraduates participated in Experiment 2A and 151 participated in Experiment 2B (toward partial fulfillment of a psychology course requirement, as in Experiment 1). All were 18-30 years old and none had participated in Experiment 1.

General procedure. Subjects volunteered to complete two testing sessions, in groups of 1 – 4, over the course of one semester. For subjects that completed both sessions, an average of 15 days (*SD* = 15) passed between sessions for both Experiments 2A and 2B. I administered the OSPAN task at the beginning of the first session, followed by the S-S/S-R task and the SSPAN task. In the second session, the RSPAN was administered after subjects had completed two tasks for another study, not reported here (again involving a mix of memory and attention tasks, conducted by different sets of investigators). I used the same computer hardware, software, and general procedures as in Experiment 1.

I had intended to terminate data collection after one semester (with the goal of testing at least 100 subjects in each experiment), but the number of subjects that were tested in the first semester was unambiguously insufficient to conduct individual difference analyses. In the first semester of testing, 57 subjects were tested for Experiment 2A, and 47 subjects for Experiment 2B. I had to drop the data from five subjects in Experiment 2A and twenty-five subjects from 2B because of programming errors (details provided below), which left 52 usable Experiment 2A subjects 22 usable subjects in Experiment 2B. I therefore conducted data collection for a second full semester.

S-S/S-R task.

Materials and design. For both Experiments 2A and 2B, I modified the task from Experiment 1 by not presenting arrows in the corner positions. That is, arrows only appeared directly above or below, or directly to the left or right, of fixation. I manipulated the proportion of congruent trials between Experiments 2A and 2B, with 50% congruent trials in Experiment 2A (as in Experiment 1) and 80% congruent trials in Experiment 2B.

***Procedure*.** The procedure was identical to that in Experiment 1.

Experiment 2A Results

I dropped all data from twenty-four subjects: 8 who did not meet the processing-accuracy criterion for the WMC composite (i.e., ≥ 2 complex span tasks with 85% accuracy), 11 who were further than three times the interquartile range from the mean accuracy rate for either mapping-practice or congruent trials, and 5 who, because of a programming error, received erroneous accuracy feedback during the mapping practice. I analyzed data from the remaining 120 subjects.

WMC screening. I assessed WMC the same way as in Experiment 1. Complex span scores correlated with *r*s of .58 (RSPAN [M = 46, SD = 16] × OSPAN [M = 51, SD = 15]; N = 100), .40 (OSPAN × SSPAN [M = 26, SD = 8]; N = 104), and .50 (SSPAN × RSPAN; N = 98). The WMC composite mean was -0.07 (SD = 0.84), which did not differ from that in Experiment 1 (*M* = 0.08, SD = 0.81; *t*(339) = 1.6, *p* = .12). Also as in Experiment 1, the composite was unimodal and symmetrically distributed (skew = -0.44; kurtosis = -0.40).

Response-Mapping RTs. Table 2 contains descriptive statistics for Experiment 2A. I entered subjects as a random effect and WMC as a fixed effect predicting RT. In the mapping trials that preceded the S-S/S-R task, WMC did not predict RT, overall (b = 2 ms, SE = 6 ms, *t* = 0.3), nor did it predict RT on the first half of trials (b = 1 ms, SE = 6 ms, *t* = 0.1), the second half (b = 3 ms, SE = 7 ms, *t* = 0.5), or the last 25 mapping trials (b = 1 ms, SE = 7 ms, *t* = 0.1). In the mapping trials following the S-S/S-R task, WMC again did not predict RTs (b = -10 ms, SE = 6 ms, *t* = -1.6).

Response-Mapping errors. Higher-WMC subjects were less likely than lower-WMC subjects to make errors during the mapping trials that preceded the S-S/S-R task (b = -0.17, SE = 0.09, Z = -2.0). Higher-WMC subjects made significantly fewer errors on the first half of trials (b = -0.21, SE = 0.10, Z = -2.2), but not in the second half (b = -0.11, SE = 0.10, Z = -1.1), or in the last 25 trials of this block (b = -0.09, SE = 0.12, Z = -

0.7). After the S-S/S-R task, WMC did not predict errors on mapping trials (b = 0.00, SE = 0.00, Z = -0.5).

To be consistent with the Experiment 1 analyses (and to facilitate cross-experiment comparisons), I entered the centered mean RT or error rate for the last 50 mapping trials as a covariate in the following analyses (and again I additionally report all key results without the covariate).

S-S RTs. Subjects demonstrated significant S-S interference, with slower responses to incongruent than to congruent trials (b = 35 ms, SE = 1 ms, *t* = 26.5). WMC predicted RTs, overall, with higher-WMC subjects responding faster than did lower-WMC subjects (b = -12 ms, SE = 5 ms, *t* = -2.5). Most importantly, however, and replicating Experiment 1, higher-WMC subjects experienced less S-S interference than did lower-WMC subjects (b = -4 ms, SE = 2 ms, *t* = -2.4). I decomposed this interaction by examining congruent and incongruent trials separately. Here, in contrast to Experiment 1, higher-WMC subjects were significantly faster than were lower-WMC subjects on both congruent (b = -10 ms, SE = 5 ms, *t* = -2.0) and incongruent trials (b = -14 ms, SE = 5 ms, *t* = -2.9), but with a larger effect on incongruent trials. (In a model without the mapping-RT covariate, only the WMC main-effect parameter changed, remaining significant [b = -10 ms, SE = 7 ms, *t* = -1.5].)

S-S errors. Subjects committed significantly more errors on incongruent than on congruent trials (b = 0.76, SE = 0.05, Z = 15.6). Overall, higher-WMC subjects were less likely to make an error (b = -0.1, SE = 0.07, Z = -2.1), but WMC did not predict the magnitude of S-S interference (b = 0.05, SE = 0.06, Z = 1.0). (Without the mapping covariate, only the parameter value for WMC changed, remaining significant [b = -0.17, SE = 0.07, Z = -2.3].)

S-R RTs. Subjects showed S-R interference, responding significantly more slowly on incongruent trials than on congruent trials (b = 43 ms, SE = 1 ms, *t* = 33.1). Overall, higher-WMC subjects were faster than lower-WMC subjects on S-R trials (b = -11 ms, SE = 4 ms, *t* = -2.6). Again replicating Experiment 1, WMC did not predict the RT difference between incongruent and congruent trials (b = -1 ms, SE = 2 ms, *t* = -0.7). (Without the covariate, only the WMC main-effect parameter changed, and was no longer statistically significant, [b = -9 ms, SE = 6 ms, *t* = -1.5].)

S-R errors. Significant S-R interference was also evident in errors (b = 1.39, SE = 0.05, Z = 27.3). WMC did not predict errors overall (b = -0.8, SE = 0.07, Z = -1.2). As in Experiment 1, however, higher-WMC subjects experienced significantly more S-R interference in errors than did lower-WMC subjects (b = 0.19, SE = 0.06, Z = 3.3). Again, as in Experiment 1, the increase in error interference by higher-WMC subjects was the product of a negative slope on congruent trials (b = -0.19, SE = 0.09, Z = 2.0) and a non-significant positive slope on incongruent trials (b = 0.01, SE = 0.08, Z = 0.1). (Without the covariate, only the overall WMC parameter changed, remaining non-significant [b = -0.10 ms, SE = .07, Z = -1.4].)

Comparison of S-S and S-R trials. For these analyses, trial type was dummy-coded. S-R trials were set to the reference level and S-S trials the comparison level.

RTs. S-S trials were slower than S-R trials (b = 12 ms, SE = 1 ms, *t* = 13.5), and subjects experienced less interference on S-S trials than on S-R trials (b = -8 ms, SE = 2 ms, *t* = -4.2; see Figure 6a). Despite the significance of the WMC effect in S-S interference but not in S-R interference (see above) that replicated Experiment 1, here, the WMC slope for S-S interference was not significantly steeper than that for S-R interference (b = -3 ms, SE = 2 ms, *t* = -1.2),. (None of these parameters changed in a model without the mapping-RT covariate.)

Errors**.** There were no overall differences in the amount of errors made on S-S and S-R trials (b = -0.06, SE = 0.04, Z = -1.7), but subjects exhibited less interference on S-S trials than on S-R trials (b = -0.63, SE = 0.07, Z = -8.9; see Figure 6b). Also inconsistent with Experiment 1, there was no significant difference in the relation between WMC and interference on S-S and S-R trials (b = -0.15, SE = 0.08, Z = -1.8), despite the significance of the WMC effect in S-R (favoring lower-WMC subjects) but not in S-S interference (see above) that replicated Experiment 1. (None of these parameters changed in a model without the mapping covariate.)

Delta plots.

S-S trials. The delta plot for S-S trials in Experiment 2A (see Figure 7) looked strikingly like the one from Experiment 1, again showing a slight reduction in the amount of interference for longer RTs and a consistent WMC-related difference across the entire distribution of RTs. This visual assessment was confirmed by a LMM with subjects as a random effect and WMC and bin as fixed effects. Both bin (b = -2 ms, SE = 1 ms, *t* = -4.1) and WMC (b = -7 ms, SE = 3 ms, *t* = -2.1) were significant predictors of S-S interference, but of most importance, WMC and bin did not interact (b = 1 ms, SE = 1 ms, *t* = 1.3).

***S-R trials*.** Also as seen in Experiment 1, S-R interference was relatively flat over RT bins and substantial WMC-related differences did not emerge over any part of the RT distribution (see Figure 8). Again, this is expected, given the finding of no overall WMC-related RT differences in S-R conflict. This visual observation was confirmed with a LMM in which neither WMC (b = 0 ms, SE = 4 ms, *t* = 0.1), bin (b = 0 ms, SE = 1 ms, *t* = 0.4), nor their interaction (b = -1 ms, SE = 1 ms, *t* = -0.6), significantly predicted S-R interference.

Congruency-Sequence effects. First, I specified a LMM with subjects as a random effect and current trial congruency, previous trial congruency, WMC, and trial-type repetition as fixed effects (no covariates were included in this model). The trial-type repetition variable distinguished between trials where the trial type had repeated (e.g., an S-S trial preceded by an S-S trial) or alternated (e.g., an S-S trial preceded by an S-R trial). Current trial congruency and previous trial congruency were -.5/+.5 contrast coded. Trial-type repetition was dummy coded with non-repetition trials (i.e., switch trials) as the reference level. On trials where the trial type did not repeat, subjects showed slightly reduced interference on incongruent trials following incongruent trials versus incongruent trials following congruent trials (b = -6 ms, SE = 3 ms, *t* = -2.2), suggesting some generality of control processes. However, control-specific carry-over effects were considerably more impressive: subjects showed an even greater reduction in interference on trials where the trial type repeated (b = -34 ms, SE = 4 ms, *t* = -8.4; note that this parameter reflects the additional reduction of interference over and above the parameter that was given for the non-repeat trials). WMC did not relate to reductions in interference following incongruent trials, either on non-trial-type-repeat trials (b = -3 ms, SE = 3 ms, *t* = -1.0) or on repeat trials (b = -2 ms, SE = 5 ms, *t* = -0.4).

Next, to examine congruency-sequence effects that might be specific to either S-S or S-R trials, and to assess their potential relations to WMC, I specified separate models for S-S and S-R repetition trials (i.e., consecutive S-S or S-R trials), with subjects as a random effect and current trial congruency, previous trial congruency, and WMC as fixed-effect predictors. In S-S trials, congruency-sequence effects were found, with interference being reduced after an incongruent trial versus a congruent trial (b = -38 ms, SE = 4 ms, *t* = -8.8), but there was no interaction between these congruency-sequence effects and WMC (b = 5 ms, SE = 5 ms, *t* = 1.0). S-R trials produced the same pattern, with substantial congruency-sequence effects (b = -41 ms, SE = 4 ms, *t* = -9.5), but no interaction with WMC (b = -2 ms, SE = 5 ms, *t* = -0.3).

Experiment 2B Results

All data from forty-five subjects were dropped: 12 who did not meet the processing-accuracy criterion of at least two complex span tasks with 85% accuracy for the WMC composite (two of whom never returned for the second session), 8 who were further than three times the interquartile range from the mean accuracy for either pre-task mapping or congruent trials, and 25 who, because of a programming error during the first semester of data collection, only received 20% congruent S-R trials. I analyzed data from the remaining 106 subjects.

WMC screening. Complex span scores correlated with *r*s of .69 (RSPAN [M = 44, SD = 15] × OSPAN [M = 51, SD = 16]; N = 84), .41 (OSPAN × SSPAN [M = 26, SD

= 8]; N = 91), and .49 (SSPAN × RSPAN; N = 79). In Experiment 2B, the mean WMC composite was -0.11 (SD = 0.84) and was unimodal and symmetrically distributed (skew = -0.81; kurtosis = 0.15). This mean composite score was the lowest of the three experiments. However, a one-way ANOVA (with Experiment 2B as the reference level) indicated no main effect of Experiment, $F(2, 444) = 2.36$, $p = .10$. More specifically, the difference between Experiment 2B and Experiment 1 approached conventional significance ($t = -1.95$), whereas the difference between Experiment 2B and Experiment 2A did not ($t = -0.41$).

Response-Mapping RTs. Table 3 presents descriptive statistics for Experiment 2B. In the pre-task mapping block, WMC significantly predicted RTs (b = -15 ms, SE = 6 ms, $t = -2.5$). Higher-WMC subjects were faster than lower-WMC subjects in the first half of the block (b = -15 ms, SE = 6 ms, $t = -2.4$), in the second half (b = -14 ms, SE = 6 ms, $t = -2.3$), and in the last 25 trials, but non-significantly so (b = -13 ms, SE = 7 ms, $t = -1.9$). There were no WMC-related differences in the post-task mapping RTs (b = -7 ms, SE = 7 ms, $t = -1.0$).

Response-Mapping errors. WMC did not predict errors in the pre-task mapping trials (b = -0.12, SE = 0.08, Z = -1.5). There were no WMC-related differences in the first half (b = -0.09, SE = 0.10, Z = -0.9), second half (b = -0.15, SE = 0.10, Z = -1.5), or last 25 trials of pre-task mapping (b = -0.01, SE = 0.14, Z = -0.1). In the post-task mapping, WMC also did not predict errors (b = 0.04, SE = 0.09, Z = 0.4).

As in Experiments 1 and 2A, I entered the centered mean RT or error rate for the last 50 mapping trials as a covariate in the following analyses (and I additionally report key results without the covariate included).

S-S RTs. Subjects showed significant S-S interference, responding more slowly on incongruent trials than on congruent trials (b = 66 ms, SE = 2 ms, *t* = 38.3). Although WMC did not predict RTs, overall (b = - 5 ms, SE = 5 ms, *t* = -1.0), higher-WMC subjects experienced less S-S interference than did lower-WMC subjects (b = - 6 ms, SE = 2 ms, *t* = -3.1), just as in Experiments 1 and 2A; in decomposing this interaction, however, higher WMC subjects were not significantly faster than lower-WMC subjects on either congruent (b = - 2 ms, SE = 5 ms, *t* = -0.4) or incongruent trials (b = - 8 ms, SE = 5 ms, *t* = -1.5), though as before, the WMC effect was numerically larger on incongruent than congruent trials. (In a model that did not include the mapping-RT covariate, only the overall WMC parameter changed, becoming significant [b = -18 ms, SE = 7 ms, *t* = -2.5].)

S-S errors. Subjects made significantly more errors on incongruent trials than congruent trials (b = 1.61, SE = 0.05, Z = 30.3). WMC did not predict errors, overall (b = 0.04, SE = 0.07, Z = 0.5), and WMC did not interact with S-S error interference (b = 0.02, SE = 0.07, Z = 0.3). (Again, without the covariate, only the WMC parameter changed, remaining non-significant [b = - 0.03, SE = 0.08, Z = -0.4].)

S-R RTs. Subjects again showed significant S-R interference, with slower responding to incongruent than congruent trials (b = 82 ms, SE = 2 ms, *t* = 48.7). Overall, WMC did not predict RTs (b = -4 ms, SE = 4 ms, *t* = 1.0). In contrast to Experiments 1 and 2A, however, higher-WMC subjects experienced less S-R interference than did lower-WMC subjects (b = -5 ms, SE = 2 ms, *t* = -2.7). As for the S-S trials in this experiment, higher-WMC subjects were not reliably faster than lower-WMC subjects on either congruent (b = - 2 ms, SE = 4 ms, *t* = -0.5) or incongruent trials (b = - 6 ms, SE = 6 ms, *t* = -1.0). (Without the covariate, only the WMC main-effect parameter changed, becoming significant [b = -16 ms, SE = 6 ms, *t* = -2.5].)

S-R errors. As expected, subjects committed more errors on incongruent trials than on congruent trials (b = 2.69, SE = 0.06, Z = 47.4). WMC did not predict errors overall (b = 0.06, SE = 0.07, Z = 0.8). In contrast to Experiments 1 and 2A, here I did not detect a relation between error interference and WMC (b = 0.06, SE = 0.07, Z = 0.8). (Again, without the covariate, only the WMC parameter changed, remaining non-significant [b = - 0.00, SE = 0.08, Z = -0.0].)

Comparison of S-S and S-R trials. For these analyses, trial type was dummy-coded. S-R trials were the reference level and S-S trials the comparison level.

RTs. S-S trials yielded longer RTs than did S-R trials (b = 12 ms, SE = 1 ms, *t* = 9.9) and, as can be seen in Figure 9a, subjects experienced more interference on S-R than on S-S trials (b = - 16 ms, SE = 2 ms, *t* = -6.7). The slope for WMC in S-S interference was not significantly steeper than in S-R interference (b = -1 ms, SE = 3 ms, *t* = -0.4).

Errors. There were no overall differences in the amount of errors made on S-S and S-R trials (b = -0.06, SE = 0.04, Z = -1.5) and, as can be seen in Figure 9b, subjects exhibited less interference on S-S trials than on S-R trials (b = -1.07, SE = 0.08, Z = -

13.9). WMC did not predict interference on either S-S or S-R trials (b = -0.04, SE = 0.10, Z = -0.4).

Delta plots.

***S-S trials*.** I again plotted the difference in RTs between binned incongruent and congruent trials. Figure 10 shows that, in this high-congruency context, the difference grew between higher- and lower-WMC subjects as RTs got longer. This observation was confirmed by a LMM, in which neither the main effect of WMC (b = 0 ms, SE = 4 ms, *t* = -0.1), nor bin (b = 1 ms, SE = 1 ms, *t* = 1.2) was significant, but for the first time in this set of experiments, the interaction between WMC and bin was significant (b = - 2 ms, SE = 1 ms, *t* = -2.5). This interaction is also consistent with that found by Unsworth et al. (2012), who interpreted the pattern of lower-WMC subjects experiencing greater interference than higher-WMC subjects at slower RTs as evidence of WMC-related differences in goal maintenance abilities. The idea being that lower-WMC subjects lose the goal of the task more frequently than higher-WMC subjects resulting in long RTs and giving irrelevant stimulus features more weight than dictated by the goal of the task thereby causing more interference.

***S-R trials*.** Figure 11 shows an ascending pattern of S-R interference, with higher-WMC subjects experiencing less interference than did lower-WMC subjects across all RT bins. In the LMM, only bin significantly predicted S-R interference (b = 7 ms, SE = 1 ms, *t* = 8.1). WMC did not (b = -6 ms, SE = 5 ms, *t* = -1.2), nor did the WMC-by-bin interaction (b = 0 ms, SE = 1 ms, *t* = -0.2). It is notable in the LMM performed above on the non-aggregated RTs found that higher-WMC subjects experienced less interference than lower-WMC subjects, but here in the delta plot analysis WMC was not a statistically significant predictor. This discrepancy is most likely due to reduced power in the aggregated data used in the analysis of delta plots.

Congruency-Sequence effects. Here I used the same models as those in Experiment 2A. In contrast to Experiment 2A, subjects did not show a significant reduction in interference following an incongruent trial when the conflict type switched (b = -1 ms, SE = 4 ms, t = -0.3). But, as in Experiment 2A, subjects showed a substantial reduction in interference following an incongruent trial when the conflict type repeated (b = -34 ms, SE = 6 ms, t = -5.3), again indicating relative specificity of control. WMC did not interact with congruency-sequence effects on conflict-type-switch trials (b = 8 ms, SE = 5 ms, t = 1.6) or on repetition trials (b = -4 ms, SE = 8 ms, t = 0.5).

I again examined S-S and S-R repetitions trials (i.e., analyses for S-S and S-R trials that were preceded by the same trial type), and their associations with WMC, separately. In S-S trials, I found a significant congruency-sequence effect (b = -16 ms, SE = 4 ms, t = -3.7) and a null interaction with WMC (b = 1 ms, SE = 5 ms, t = 0.1). In S-R trials, I found the same pattern, with a significant congruency-sequence effect (b = -33 ms, SE = 7 ms, t = -4.7), but no WMC interaction (b = 9 ms, SE = 8 ms, t = 1.1).

Discussion

Experiment 2A replicated the critical finding in Experiment 1: Higher-WMC subjects showed less RT interference than did lower-WMC subjects on S-S trials but not on S-R trials; moreover, higher-WMC subjects showed *greater* interference in S-R trial error rates than did lower-WMC subjects. Experiment 2A did not, however, replicate the significant three-way interaction among WMC, S-S interference, and S-R interference. I acknowledge this limitation, but argue that replicating the overall dissociative pattern here with consistent parameter estimates across experiments (Experiment 1, WMC × S-S = -7 ms and WMC × S-R = -3 ms; Experiment 2A WMC × S-S = -4 ms and WMC × S-R = -1 ms) constitutes a successful replication. In contrast, in Experiment 2B, with a greater proportion of congruent trials that put a premium on goal maintenance, higher-WMC subjects resolved interference better than did lower-WMC subjects on *both* S-S and S-R trials. These findings suggest that when cognitive conflict resolution processes can be isolated from goal maintenance abilities (i.e., in designs presenting moderate proportions of conflict trials, such as Experiment 2A), having a higher WMC is beneficial for resolving interference close to the beginning of information-processing (i.e., at stimulus identification or selection), but it is deleterious when interference occurs with the action to be performed (i.e., at response selection). However, in situations where goal maintenance abilities are especially important (i.e., in designs presenting small proportions of conflict trials, such as Experiment 2B), higher WMC subjects show generalized performance benefits across conflict types.

Two recent studies seem to provide a possible explanation on why higher-WMC subjects do not outperform lower-WMC subjects on S-R conflict trials presented in low-congruency contexts (Wuhr & Biebl, 2011; Zhao, Chen, & West, 2010). Both studies examined the effects of a memory load on S-R task performance and reported that memory load *reduced* the magnitude of S-R conflict effects, supporting a response discrimination account of S-R conflict (Ansorge & Wuhr, 2004). The response discrimination account suggests that S-R conflict is the product of interference between S-R rules (e.g., if the arrow is pointing up, press the left key) held in working memory, and the stimulus-location codes (left or right) that enter working memory during stimulus processing. (In S-S trials, there is no conflict between left and right response codes and either the location [up or down] and the arrow direction [up or down], making S-S trials fundamentally different from S-R trials). So, by the response-discrimination account, loading WMC prevents the stimulus location codes from accessing working memory and the S-R conflict effect is thereby reduced or eliminated. Perhaps here, in the 50% congruency conditions, higher-WMC subjects' performance was not superior to that of lower-WMC subjects' on incongruent S-R trials because the higher-WMC subjects have additional capacity which allows them to grant stimulus location codes access to their working memory, thereby causing greater interference. As another way of looking at this, lower-WMC subjects can be thought of working under a constant working memory load (e.g., Kane & Engle, 2000; Rosen & Engle 1997) and thus experience less conflict because they permit less access to stimulus location codes than do higher-WMC subjects. In the 80% congruency condition, however, higher-WMC subjects constricted their greater capacity to maintain the task goal thereby occupying the capacity that stimulus location codes entered in the 50% congruency conditions.

Delta plots of the data from Experiment 2A data provided evidence that WMC-related differences in S-S interference were not localized to a specific portion of RT distribution; just as in Experiment 1, higher-WMC subjects did not perform better than lower-WMC subjects because of particular control abilities engaged when they were responding especially quickly or slowly. In contrast, in Experiment 2B, the S-S delta plots showed a pattern consistent with the ones observed by Unsworth et al. (2012), where WMC-related differences in performance increased with response times.

It is less clear what to make of the S-R delta plot in Experiment 2B, which seemed to show consistent separation between the higher and lower WMC terciles, with interference becoming greater as RTs increased. The analysis of individual differences on these binned S-R difference scores confirmed that interference did increase as RTs got longer, but WMC did not predict these difference scores or their changes over bins. Therefore, on one hand, Experiment 2B showed that, in a high-congruency task, WMC predicted S-R interference in RTs. This is consistent with an interpretation of WMC-related differences in goal maintenance abilities and it is precisely what motivated the proportion-congruency manipulation in Experiment 2. On the other hand, the WMC effect on S-R interference was not confirmed by either the patterns visually observed in the tercile plot, or in the LMM conducted on the binned data. To further assess the strength of the WMC × S-R interference interaction in Experiment 2B, I compared this interaction to the non-significant WMC × S-R interactions in Experiment 1 and Experiment 2A. In a LMM on all correct S-R trials, with experiment, WMC, and congruency as predictors, the E2B significant interaction between WMC and S-R was not significantly different from the non-significant interactions observed in Experiment 1 (t = 1.7) or 2A (t = 1.6). Therefore, although the significant WMC × S-R interference interaction is consistent with my *a priori* hypothesis (and dual-factor conceptions of cognitive control; e.g., Braver et al., 2007; Engle & Kane, 2004), I will interpret it cautiously in light of the delta plots and the cross-experiment analysis. Future replications of this effect (with this task) are needed to estimate its magnitude.

My examination of congruency-sequence effects in both Experiment 2A and 2B yielded results mostly consistent with prior reports from this task (Funes et al., 2010a, 2010b), where the control processes initiated from a previous incongruent trial only affected performance on the current trial when the same conflict type repeated (although in Experiment 2A I found a small and significant general carryover effect [-6 ms] that was dwarfed by the effect when the conflict type repeated [-40 ms]). Indeed, most studies that have combined two conflict types have found that the cognitive control initiated by an incongruent trial is specific to the particular conflict elicited by that trial (Egner et al., 2007; Funes et al., 2010a, 2010b; Kiesel, Kunde, & Hoffmann, 2006; Notebaert & Verguts, 2008; Verbruggen et al., 2005; Wendt, Kluwe, & Peters, 2006).

WMC did not moderate any of the congruency-sequence effects examined in Experiments 2A or 2B, indicating that WMC variation did not predict the reactive adjustments to control that subjects made following the processing of either S-S or S-R conflict trials. These null WMC effects confirm those reported by Meier and Kane (2013), who examined Stroop task performance (reflecting combined S-S and S-R conflict), by Unsworth et al. (2012), who examined both Stroop and flanker task performance (the latter reflecting primarily S-S conflict), and by Keye et al. (2009), who did not detect a relationship in a flanker task. However, the null WMC effects are inconsistent with two S-R-conflict-related findings: Keye et al. (2009) found a significant relation between WMC and congruency-sequence effects in a vertical Simon task (i.e., S-

R trials) with higher WMC subjects showing less trial-to-trial adjustment, and Weldon et al. (2013) reported the same pattern in a horizontal Simon task. Although this collection of S-R findings varied with aspects of the design – null effects here with mixed S-R and S-S trials, and significant WMC effects in Keye et al. and Weldon et al. in pure S-R blocks, it is currently unclear how these designs would differentially affect WMC-related variation (or why design would interact with WMC in S-R but not in S-S conditions).

CHAPTER IV

EXPERIMENT 3

The results from Experiments 1 and 2 suggested that by evaluating WMC-related performance differences in conflict tasks through the lens of the Kornblum taxonomy we may be getting closer to a mechanistic account of what WMC allows us to do to resolve cognitive conflict. Experiment 3 was designed to further disambiguate the relationship between WMC and performance on conflict tasks and to test for the generalizability of the results of the first three experiments. Subjects completed single and dual tasks that provided S-S and S-R conflict differently than it was presented in the first 2 experiments (i.e., varying which axis S-S and S-R trials appear upon and using dimensions other than location as the irrelevant stimulus information), and using different ways to respond. To this end, subjects completed three tasks that presented both S-S and S-R conflict, two tasks that presented only S-S conflict, and two tasks that presented only S-R conflict. With these tasks, I tested whether the findings from the earlier studies were dependent on the specific conflict type and axis pairings used, the nature of the irrelevant stimulus dimension, the response mode, or the dual-conflict task context. In addition, to further assess the across-task generalizability of the S-S and S-R conflict constructs I used latent variable models.

In the previous two experiments, all S-S interference was generated by stimuli along the vertical axis and all S-R interference was generated by stimuli along the horizontal axis, and so it is possible that WMC is uniquely unrelated to managing responses to stimuli on the horizontal plane. Prior work has suggested that the processing of laterality may be special (Pratte et al., 2010; Vallesi, Mapelli, Schiff, Amodio, & Umilta, 2005; Wiegand & Wascher, 2005). Both Vallesi et al. and Wiegand and Wascher came to the conclusion that vertical and horizontal Simon tasks (i.e., S-R conflict tasks with irrelevant location information overlapping with response features) tap different underlying mechanisms. In part, both research teams based their conclusions on the findings that interference on a horizontal task decreases as RTs slow while interference remains stable or increases over RTs during vertical tasks. Moreover, different patterns of event-locked lateralized readiness potentials (LRPs; indicating response preparation processes; Coles, 1989; Eimer, 1998) were elicited by horizontal versus vertical Simon tasks. On horizontal-task incongruent trials, LRPs first reflected activations of a response ipsilateral to the stimuli, followed by (correct) activation contralateral to the stimuli. On vertical incongruent task trials, no initial activation ipsilateral to the response was detected, and only a delay of the contralateral response was found. From these results, both sets of authors suggested that the horizontal task taps a quick automatic visuo-motor response (perhaps produced from long-term memory) while the vertical task generated its interference from a higher-order translation of spatial stimulus codes to response codes. If the assertion that responses in the horizontal task are driven by long-term memory connections is correct, it offers a potential explanation of why higher-WMC committed more errors on the horizontal S-R trials. Recently, WMC has been linked to memory retrieval abilities, with higher-WMC subjects showing superior retrieval from long-term memory when compared to lower-WMC subjects (Unsworth & Engle, 2007a; 2007b). Because of their superior memory retrieval abilities, on horizontal trials, higher-WMC subjects may experience stronger facilitation towards responses ipsilateral to stimuli than do lower-WMC subjects. Therefore, counter to the pattern of results seen in Experiments 1 and 2A, we could see higher-WMC subjects experience less interference than do lower-WMC subjects on S-R trials that are presented on the vertical axis.

Moreover, in all of the previous experiments conducted here, stimulus location was the only task-irrelevant stimulus feature; thus, there may be something special about variation in executive control processes that pertains exclusively to location-based information. Tsal and Lavie (1993) found that subjects obligatorily direct attention to location information regardless of whether the location information was task relevant. For example, in their first of four experiments, subjects saw a letter cue and then reported as many letters as possible from a briefly presented (50 ms) circular array of letters. All subjects completed three conditions. In one, they reported letters only if the cue was presented in a certain location, in another, only if the cue was a certain color, and in the last condition, only if the letter met a shape criterion. In all three conditions, subjects reported letters that shared a similar location to the cue, even when it was not the task-stipulated relevant feature; in contrast, subjects showed no evidence of attending either to colors or shapes, even when they were the relevant cue features. Tsal and Lavie's findings in this and their three other experiments led them to propose that attending to stimulus location may be obligatory and thus "deserves a special status in theories of visual attention." Additional evidence for location-based information being special comes from work looking at the relation between aging and negative priming (Connelly & Hasher, 1993), a phenomenon where previously inhibited distractors elicit a performance cost when they become targets on subsequent trials. Connelly and Hasher found that older adults — a population that often shows working memory and inhibition deficits in comparison to younger adults (e.g., Hasher & Zacks, 1988) —were equally as able as younger adults to inhibit location information. However, older adults were not as effective as younger adults in inhibiting identity information (for a similar result with children see Tipper & McLaren, 1990). Clearly, there is some precedence for location information to be unique.

Furthermore, the previous three experiments conducted here found differing WMC-conflict relations within a dual-conflict context, where both conflicts were presented in one task. Because prior work has suggested that variation in WMC affects performance at a global level of task approach rather than in on-the-fly adjustments of cognitive control (Meier & Kane, 2013), we may see different patterns of results when subjects only see one type of conflict in a set of trials. For example, higher-WMC subjects may be better able than lower-WMC subjects to adjust their control settings to combat interference when only facing S-R trials, but not when they have to complete S-S and S-R trials that are intermixed. That is, higher-WMC subjects may configure their task approach at a global level and this setting may be optimally tuned for one conflict type but not the other. Below I will describe briefly the three dual-conflict tasks and then the single-conflict tasks that attempt to address these questions.

First, the joystick replication task was identical to the task in Experiment 2A in all regards, but left-right responses were made by moving a joystick instead of pressing keys. Second, the axis-shifted joystick task shifted the axis on which S-S and S-R conflict occurred, with S-S interference elicited along the *horizontal* axis and S-R interference along the *vertical* axis; subjects responded to arrows pointing either to the left or to the right with either an upward or a downward thrust of the joystick. Here, then, I attempted to overcome the confound of the consistent pairings of conflict and axis in the first two experiments (S-S along the vertical and S-R along the horizontal). A critical benefit of the joystick over a keyboard response is that up and down movements are as intuitive as left-right movements; with keyboard responses, the potential awkwardness in executing up and down responses could have confounded examination of S-S and S-R across axes. Third, the up-down numerosity Task tested whether the dissociation between WMC and S-S/S-R conflict would occur when the irrelevant stimulus dimension that conflicts with the response was not stimulus location. Here, the *number* of stimuli presented in a given trial was the irrelevant stimulus dimension (inspired by Miller, 2006). To test whether the same pattern of results was found when subjects completed tasks that presented only one conflict type (perhaps changing how the task was approached), subjects also completed an up-down arrows task (S-S trials), a flanker task (S-S trials), a Simon Task (S-R trials), and a task that manipulated numerosity to create S-R interference (S-R trials).

In addition to examining the above hypotheses within each of the dual-conflict tasks and across the single-conflict tasks, I used latent variable analyses to determine whether the S-S and S-R constructs were stable and distinct across tasks. Latent variable analyses allowed me to test whether the ability to resolve S-S and S-R conflict systematically covaried across tasks, that is, whether an individual's ability to resolve S-S (or S-R) interference in one task allows me to make predictions about how they will also resolve S-S (or S-R) interference in another task. Models specified separate S-S and S-R conflict factors to pool the covariances across tasks (and thereby eliminate task-specific method variance). In this way, I tested the robustness of Kornblum's taxonomy: If individual differences in response to S-S and S-R conflict uniquely covaried amongst themselves across tasks (e.g., the ability to resolve S-R conflict related to the ability to resolve S-R conflict, but not S-S conflict), this would suggest independent conflict resolution processes, thereby providing strong support for Kornblum's taxonomy as a fruitful framework for understanding individual differences in the different stages of information processing.

Method

Subjects. Two hundred and seventy-six UNCG undergraduates (aged 18-30 years) participated and received partial credit for a psychology course requirement. The goal was to test at least 150 subjects, and the stopping rule for data collection was the end of the semester in which the goal was reached. I collected data in the Spring and Fall semesters of 2013.

General procedure. Subjects volunteered to complete two testing sessions, in groups of 1 – 4, over the course of one semester. In this experiment, subjects were scheduled to complete the second testing session exactly one week after the first. On the occasions when a subject missed their second appointment, or if a second appointment occurred on a day when school was not in session, alternate arrangements were attempted for the subject to complete testing. Two hundred sixty-one subjects completed both sessions, with an average of 8 days (*SD* = 4) between sessions (232 subjects completed their second session exactly a week after their first).

The order of task administration is reported in Table 4.The same computer hardware, and general procedures were used as in Experiment 1, except all tasks besides OSPAN and SSPAN were programmed in E-prime 2.0 (Schneider, Eschmann, & Zuccolotto, 2002) rather than E-prime 1.2. In all S-S and/or S-R tasks, subjects whose error rates were greater than three times the interquartile range from the mean error rates for mapping and congruent trials were excluded from analyses of that task to eliminate concerns that any results were driven by subjects not understanding the tasks or not putting forth any effort. Any additional data exclusions will be reported for specific tasks.

All conflict tasks were counterbalanced with regards to stimuli and responses. Subjects were assigned a counterbalancing condition in the first session, which was maintained across sessions to assure consistent mappings between stimuli and responses. For example, if a subject was assigned to respond left to an upward pointing arrow in the first task, for all of the tasks that subject completed, left and up were consistently paired. This was done to control for the “task switching” conflict that might arise if subjects repeatedly had to shift S-R mapping rules from task to task. In addition to having consistent S-R pairings across sessions to control for carry-over and order effects, I made superficial alterations to the appearance of the conflict tasks to distinguish them from one another. For example, arrow shapes and colors and the background-screen colors were different across tasks.

In all conflict tasks, before beginning the testing block, subjects were alerted that sometimes relevant stimulus features and irrelevant stimulus features were going to be congruent with each other (e.g., upward facing arrows on the top portion of the screen) and sometimes relevant and irrelevant stimulus features were going to be incongruent with each other (e.g., upward facing arrows on the bottom part of the screen), and therefore for best performance they should always ignore irrelevant features (the same instructions were used for Experiments 1, 2A, and 2B). All degrees of visual angle were calculated from a distance of 60 cm.

WMC tasks. The OSPAN and SSPAN tasks used in Experiment 3 were identical to those used in Experiments 1, 2A, and 2B. In Experiment 3, I also used a RSPAN task that had words instead of digits as memoranda. This change was motivated by the desire to reduce method variance between OSPAN and RSPAN tasks, which had previously both used letters as memoranda, and thus yield a more pure measure of the WMC construct. In accord with this goal, I also used an updating task (Oberauer, Süß, Schulze, Wilhelm, & Wittmann, 2000; Salthouse, Babcock, & Shaw, 1991) to assess WMC with a non-complex-span task.

RSPAN presented set sizes of 2-6 sentence-word pairs. Like the other complex span tasks, each of these set sizes was repeated 3 times. The memory items were four-letter words (randomly selected without replacement on each trial from the following: Bald, Cuff, Dunk, Fuse, Glow, Hush, Jolt, Limb, Mole, Nest, Pail, Ramp, Soak, Tint, Wool). All other aspects of this RSPAN task are identical to the RSPAN tasks reported in Experiments 1, 2A, and 2B.

The updating task required subjects to maintain and manipulate (i.e., update) information. The updating task differed from complex span tasks because the processing task (adding or subtracting numbers) was not irrelevant to the memory items. Subjects first saw a horizontal array of 3 – 5 boxes. Each trial then had three phases: learning, updating, and recall. In the learning phase, digits (from 1-9) populated the boxes for 1250 ms serially in random order until a digit has been presented in each box (100 ms between each digit presentation). The task instructions asked the subjects to remember these starting values. Then, during the immediately succeeding updating phase, at least some of the original digits were replaced by another digit for 1333 ms with a plus or minus sign (i.e., +2). There was a 250ms break between each update presentation. The subjects were instructed to update the starting value by whatever sign and digit occupied the same box. That is, if the subject originally saw a *3* in the second box, and then a *-1* in that same box, the subjects should have subtracted 1 from the starting value of 3 and updated the current value of the box to 2. Each trial presented 2 – 6 updates; some boxes were updated multiple times while others might not have been updated at all. Finally, during the immediately succeeding recall phase, box outlines turned red in random order to prompt the subject to enter (via the number keypad) the updated value for that box. Recall proceeded until a value has been entered for every box in the trial (i.e., there was no time limit for responding). Prior to beginning the task, subjects were told that the final updated values were always between 1 and 9. Each set size (i.e., the 3-5 boxes initially presented) was crossed with the number of updates (2-6) to generate 15 trials. Subjects initiated the beginning of every trial be pressing the space bar. The dependent variable for this task was the overall correct proportion of final box values entered. The trial order for this task was randomized once. All subjects were presented with the same trial order.

This updating task has been shown to be a reliable and valid measure of WMC. In three experiments, Lewandowsky, Oberauer, Yang, and Ecker (2010) reported Cronbach's α between .85 and .91. They also found that the updating task loaded highly on a WMC latent factor along with two complex span tasks (OSPAN and SSPAN) and a spatial short-term memory task (loadings = .79 - .88 across experiments); zero-order correlations between the updating task and the complex span tasks were moderate, ranging from .30 to .68. In summary, when making a composite WMC score, this updating task and the complex span tasks pick up common variance that mapped onto the construct of WMC, but the inclusion of the updating task produced a WMC score that eliminated shared variance from the common method of the complex span tasks.

Dual-Conflict tasks. For all tasks designed to measure S-S and/or S-R conflict, subjects were instructed to be fast and accurate. Following initial task instructions, all dual-conflict tasks had 10 practice trials where error feedback was presented after every trial followed by 100 response-mapping practice trials. All tasks were composed of 3 testing blocks of 120 trials. Half of all test trials were congruent. The order of trials was randomly determined for every subject. RTs and errors were the dependent variables for all task conditions.

Joystick replication task. This task was modeled closely on Experiment 2A. The differences between the current and the previous iteration of the task were the response method and task length. In Experiments 1, 2A, and 2B, responses were made by pressing the *Q* (upper left of the keyboard) and *P* (upper right of the keyboard) keys of a QWERTY keyboard. In this version, responses were made by pushing a joystick (Logitech Attack 3) either left or right. A directional response was recorded when the joystick moved 50 X or Y coordinate points from its initial position when the target stimulus was presented.

This task presented 360 trials, making it 120 trials shorter than the tasks in Experiment 1, 2A, and 2B. Analysis of the data from those tasks indicated that the effects of interest (i.e., interference effects and WMC × interference interactions) were present if the final 120 were excluded (making the task any shorter than this results in uncomfortably large standard errors of the estimates). All other aspects of this task were identical to the Experiment 2A task.

Axis-shifted joystick task. This task was similar to the joystick replication task with a few notable exceptions, the most important of which were that: (1) the S-S conflict occurred on the horizontal axis while S-R conflict occurred on the vertical axis, and; (2) subjects responded with upward versus downward joystick thrusts to left- and right-pointing arrows (counterbalanced across subjects). Here, S-S conflict was the result of a left pointing arrow appearing on the right side of the screen (or vice versa) and S-R conflict came from having to respond to an arrow that either appeared on the top or bottom of the screen with a joystick move in the opposite direction. In this task, the arrows were green and of a more rounded shape than those used in joystick replication task. The background color for this task was black rather than the gray of joystick replication task. Like the previous dual-conflict tasks, arrow stimuli were approximately 2° of visual angle and were positioned 2° of visual angle for the screen's center. To encourage the encoding of responses as up or down in contrast to forward and back, subjects placed the joysticks on a three-inch binder with the raised end of the binder closest to the monitor. In this way the joystick responses were literally either up or down.

Up-Down numerosity task. Here, S-S conflict was created in the same way that it was created on the previously described dual-conflict tasks, by having arrow direction as the relevant stimulus dimension (upward versus downward pointing) and arrow location as the irrelevant stimulus dimension (above versus below fixation). On S-R trials, however, the irrelevant dimension was changed from stimulus location to numerosity; that is, S-R conflict was generated between the irrelevant stimulus dimension of numerosity (represented by how many arrows appeared on the display) and the response dimension (which was pressing one key or two keys for an arrow depending on its orientation). Subjects experienced conflict on incongruent trials by having to press two buttons when presented with one arrow and press one button when presented with two arrows. More specifically, on S-R trials, either one or two upward or downward arrows appeared. Subjects were instructed to press the "1" key for up arrows and the "1" and "2" keys for down arrows. To prevent overlap between the number of arrows and responses on S-S trials, all S-S trials presented 4 arrows. Stimuli were blue arrows presented on a white background.

On mapping trials, a single up or down arrow was presented and subjects responded by pressing one key for up arrows (e.g., a key with a “1” label on the keyboard) and two keys for a down arrow (e.g., keys with the labels “1” and “2” on them). For these two key responses, subjects were instructed to press these keys simultaneously. On test trials, all arrows appeared upon the vertical axis, with S-S trials appearing towards the top or the bottom of the screen, and S-R trials appearing at center. For example, S-S conflict occurred when there were four downward pointing arrows above the midline of the screen (*down* direction conflicted with *up* location) and S-R conflict occurred when two upward arrows appeared at central fixation (*one* key press conflicted with *two* stimuli presented). The RT used for the two-key responses was the average RT for the key pressed first and the key pressed second. Pilot testing revealed differences of approximately 15 ms between these key presses.

Single-Conflict S-S or S-R tasks. Following initial task instructions, all single conflict tasks had 10 practice trials which were all congruent where error feedback was presented after every trial, 50 response-mapping practice trials (either congruent or neutral regarding the irrelevant stimulus dimension) where error and RT feedback was presented at the end of the block of trials, and then 10 practice trials with congruency manipulated (50% congruent) where error feedback was given after every trial. All single-conflict tasks contained 120 trials with 50% congruent trials. The order of trials was randomly determined for every subject. The dependent variables for all S-S or S-R conflicts tasks were RTs and error rates.

Up-Down arrows task (S-S conflict). The stimuli were red arrows presented on a green background. The stimuli measured 2° × 8° of visual angle. Each stimulus in the task was a set of 4 arrows that all pointed in the same direction. On a given trial, subjects were presented with arrows that either pointed up or down. Subjects were instructed to press the *S* or the *L* key depending on the orientation of the arrow set. The arrows appeared approximately 6° of visual angle either above or below the screen center. Subjects were given a brief reminder of the instructions and then proceeded to complete 120 trials where half the trials were congruent. Every trial began with a black fixation cross, in 36 point bold Courier New font, for 500 ms. Next a blank screen was presented for 100 ms and immediately followed by the target stimulus which was on screen until response or 1200 ms. After the target arrows, subjects saw a blank screen for 250 ms before the sequence started again.

Flanker task (S-S conflict). The stimuli in this task were sets of 5 arrows. The arrows were black, thin, and had rounded ends. Each stimulus was approximately 6° × 1.5° of visual angle. These stimuli were presented on a yellow background. The arrows in the array either pointed up or down. Subjects were instructed to press a key in response to the center arrow in the array. Some subjects were instructed to press the *F* key for up arrows and the *J* key for down arrows while other subjects were given the opposite instructions. The stimulus was always displayed in the center of the screen. On congruent trials, all of the arrows pointed in the same direction. On incongruent trials the center target arrow pointed in one direction and the 4 flanking arrows (2 on each side) pointed in the opposite direction from the target. Every trial began with a fixation cross (18 point

Courier New font) for 500 ms, followed by the stimulus which was presented until response or 1000 ms whichever came first, and then finished with a blank screen for 250 ms.

Numerosity task (S-R conflict). The stimuli in this task were thin, blue arrows with rounded ends. The arrows were presented on a white background. On some trials two arrows were presented and on other trials only one arrow was presented. The arrows were always presented in the center of the screen. The single arrows measured approximately 1.5° × 2° of visual angle and double arrows measured approximately 3° × 2° of visual angle. These arrows were either pointing up or down. On trials with 2 arrows, both arrows pointed in the same direction. Subjects were instructed to push a key labeled “1” for either up arrows or down arrows and to simultaneously press both the keys labeled “1” and “2” for arrows with the other orientation. The RT for trials that required 2 keys to be pressed was the average RT of the 2 key presses. The order of trials was randomly determined. Every trial began with a black fixation cross, in 36 point bold Courier New font, for 500 ms. Next, the target stimulus was displayed for 125 ms. After target presentation, responses were collected during a blank screen that displayed for 1250 ms. The sequence began again with the fixation cross began immediately after this blank screen.

Simon task (S-R conflict). Subjects were presented with either circles or squares. The shapes were hollow with thick black outlines. Each of the stimuli measured approximately 4° × 4° of visual angle. The background screen color was cyan. Subjects were instructed to press the *X* key for a particular shape and the *M* key for the other shape. Task instructions informed subjects that the target stimulus would appear either on the left or right side of the screen (approximately 10° of visual angle from center). The order of trials was randomly determined. Every trial began with a black fixation cross, in 90 point bold Courier New font, for 500 ms. Next, the target stimulus was displayed until response or 1200 ms (whichever was shorter). A blank screen for 250 ms followed the target presentation. The sequence with the fixation cross began immediately after this blank screen.

Results

All data from thirty-four subjects who did not meet the processing-accuracy criterion for the WMC composite (i.e., ≥ 2 complex span tasks with 85% accuracy on the processing task) was dropped. Of these excluded subjects, fifteen only completed the first session which had 1 complex span task and therefore they could not meet the criterion. This left 241 subjects for analysis. For the conflict tasks, the same outlier screening procedure from Experiments 1, 2A, and 2B was used. Subjects whose mapping or congruent trial accuracy was 3 times the interquartile range from the mean were dropped from the analysis of that specific task. Because adding the response-mapping RT and error covariates did not change critical parameter values other than the main effect of WMC on the dependent variable, models without the covariates were reported [1].

WMC screening. WMC measurement task scores correlated with *r*s ranging from .25 to .44 and had reliability estimates ranging from .70 to .85 (see Table 5). In this experiment, I created Z scores for each task using the means and standard deviations from Experiment 3 subjects rather than the Kane lab subject database (as done in the previous experiments) because I did not have corresponding means and SDs for this version of RSPAN and for the updating task (see Table 6 for descriptive statistics for working memory measures from this experiment). Therefore, I did not compare the WMC composite from Experiment 3 to those from the earlier experiments.

Dual-Conflict Tasks.

Joystick replication task. The outlier screening procedure identified nine subjects whose data were dropped from this task leaving data from 232 subjects for analysis (for all dual-conflict tasks see Table 7 for descriptive statistics). Higher-WMC subjects were faster than lower WMC subjects on response-mapping trials (b = -22 ms, SE = 10 ms, *t* = -2.3). Higher-WMC subjects were faster during the first half of the response-mapping trials (b = -24 ms, SE = 10 ms, *t* = -2.5), the second half (b = -21 ms, SE = 10 ms, *t* = -2.0), and nearly statistically faster for the last 25 trials (b = -19 ms, SE = 10 ms, *t* = -1.9). WMC also predicted errors on mapping trials, with higher-WMC subjects less likely to make an error, overall (b = -0.33, SE = 0.09, Z = -3.5), during the first half of the mapping trials (b = -0.37, SE = 0.10, Z = -3.7), the second half of mapping trials (b = -0.31, SE = 0.11, Z = -2.8), and the last 25 trials (b = -0.31, SE = 0.12, Z = -2.6).

S-S RTs. Subjects were slower on incongruent trials than on congruent trials (b = 29 ms, SE = 2 ms, *t* = 14.6). The S-S interference parameter estimate was smaller than the estimates from Experiment 1 (38 ms) and 2A (35 ms). WMC did not predict RTs overall (b = -13 ms, SE = 10 ms, *t* = -1.3). Here, unlike Experiments 1, 2A, and 2B (with key-press responding), WMC missed the significance criterion for predicting S-S interference (b = -5 ms, SE = 3 ms, *t* = -1.8; see Figure 12a).

S-S errors. Subjects experienced error interference on S-S trials (b = 0.38, SE = 0.04, Z = 8.8). WMC did not predict overall errors (b = -0.12, SE = 0.08, Z = -1.4), nor error interference (b = 0.01, SE = 0.06, Z = 0.2; see Figure 12b).

*S-R RTs***.** Subjects experienced substantial interference on S-R trials (b = 57 ms, SE = 2 ms, *t* = 29.7). This parameter estimate was larger than the S-R interference parameter from Experiments 1 (45 ms) and 2A (43 ms). WMC did not predict RTs on S-R trials (b = -12 ms, SE = 9 ms, *t* = -1.3) or S-R interference (b = -1 ms, SE = 3 ms, *t* = -0.3).

*S-R errors***.** Error rates were higher on incongruent trials than on congruent trials (b = 1.8, SE = 0.05, Z = 38.5). WMC did not predict errors overall (b = -0.11, SE = 0.09, Z = -1.3), but higher-WMC subjects experienced *less* error interference than did lower-WMC subjects (b = -0.17, SE = 0.06, Z = -2.7), in contrast to the findings from Experiments 1 and 2A. Higher and lower-WMC subjects did not differ in the amount of errors committed on congruent trials (b = -0.01, SE = 0.10, Z = -0.6), but higher-WMC subjects committed fewer errors on incongruent trials (b = -0.20, SE = 0.09, Z = -2.2).

*Comparison of S-S to S-R trials in RTs***.** For these analyses, conflict type was dummy-coded. S-R trials were the reference level and S-S trials were the comparison level. S-S trials were slower than S-R trials (b = 22 ms, SE = 1 ms, *t* = 15.9). There was less interference on S-S trials than on S-R trials (b = -29 ms, SE = 3 ms, *t* = -10.5). The relation between WMC and S-S interference was not significantly different from the relation between WMC and S-R interference (b = -4 ms, SE = 4 ms, *t* = -1.1).

*Comparison of S-S to S-R trials in errors***.** Subjects were less likely to make an error on a S-S trial than on a S-R trial (b = -0.14, SE = 0.03, Z = -4.5) and S-S trials produced less interference than did S-R trials (b = -1.43, SE = 0.06, Z = -22.5). Higher-WMC subjects did not differ from lower-WMC subjects in the amount of error interference exhibited on S-S trials, but did show an advantage over lower-WMC subjects on S-R trials, resulting in a significant three-way interaction between trial type, WMC, and congruency (b = 0.19, SE = 0.09, Z = 2.2).

Delta plots. In addition to the visual evidence provided by the delta plots of the 1st and 3rd terciles of the WMC distribution, LMMs were conducted with subjects as random effects and WMC and bins as fixed effects with the difference between the aggregated incongruent trials and congruent trials as the dependent variable.

*S-S trial delta plot***.** Although the delta plot (see Figure 13) seemed to suggest that higher-WMC subjects experienced less RT interference than did lower-WMC subjects, especially for the slowest trials, this visual impression was not confirmed by the LMM. Neither WMC (b = 0 ms, SE =6 ms, t =0.0), bins (b = -2 ms, SE =1 ms, t = -1.9), nor their interaction reached the significance criterion (b = -2 ms, SE =2 ms, t = -1.1).

S-R trial delta plot. As depicted in Figure 14, the delta plot revealed mostly overlapping lines between WMC tercile groups with interference slightly ascending as RTs slowed. The LMM was consistent with this impression. The only predictor reaching statistical significance was bin (b = 4 ms, SE =1 ms, t = 3.1). Neither WMC (b = -8 ms, SE = 6 ms, t = -1.2), nor the interaction between WMC and bin reached the significance criterion (b = 2 ms, SE = 2 ms, t = 1.4).

Congruency-Sequence effects. I used a LMM with subjects as a random effect and current trial congruency, previous trial congruency, WMC, trial type, and trial-type repetition as fixed effects. Only correct trials preceded by correct trials were used in this analysis.

Congruency-Sequence effects in RTs. On trials where the conflict type did not repeat from the previous trial, previous-trial congruency did not affect the congruency effect on the current trial (b = 0 ms, SE = 4 ms, *t* = 0.1), but on trials where the conflict type repeated there was a large effect of the previous trial's congruency on the current-trial congruency effect (b = -69 ms, SE = 5 ms, *t* = -12.9). WMC did not moderate congruency-sequence effects when the conflict type switched from trial-to-trial (b = 1 ms, SE = 5 ms, *t* = 0.3) or when the conflict type repeated (b = 9 ms, SE =7 ms, *t* = 1.2). When S-S trials were selected and examined separately, congruency-sequence effects were significant (b = -59 ms, SE = 5 ms, *t* = -10.9) and not moderated by WMC (b = 6 ms, SE = 8 ms, *t* = 0.8). On S-R trials, large congruency-sequence effects were found (b = -79 ms, SE = 5 ms, *t* = 14.8), but WMC did not significantly moderate the effect on S-R trials, either (b = 13 ms, SE = 7 ms, *t* = 1.8).

Congruency-Sequence effects in errors. Congruency-sequence effects were not found on conflict-switch trials (b = 0.1, SE = 0.09, Z = 1.5), but were found on conflict-repeat trials (b = -2.0, SE = 0.14, Z = -14.8). WMC did not moderate congruency-sequence effects on conflict-switch (b = -0.3, SE = 0.13, Z = -0.2) or conflict-repeat trials (b = -0.03, SE = 0.18, Z = -0.1). The conflict-specific analyses found congruency-sequence effects for both S-S (b = -1.33, SE = 0.14, Z = -9.7) and S-R trials (b = -2.27, SE = 0.15, Z = -14.8), WMC did not moderate either of these effects (S-S trials: b = -0.2, SE = 0.2, Z = 1.0; S-R trials: b = -0.01, SE = 0.21, Z = 0.0).

***Axis-shifted joystick task*.** Data from 234 subjects were analyzed (data from seven subjects were dropped from the outlier screening). Variation in WMC did not predict mapping RT overall (b = - 9 ms, SE = 9 ms, *t* = -1.0), for the first 50 trials (b = - 11 ms, SE = 10 ms, *t* = -1.1), for the second 50 trials (b = - 8 ms, SE = 10 ms, *t* = -0.8), or the last 25 trials (b = - 10 ms, SE = 10 ms, *t* = -1.1). WMC did predict mapping errors overall (b = -0.26, SE = 0.10, Z = -2.7), for the first 50 mapping trials (b = -0.29 SE = 0.10, Z = -2.9), the second 50 trials (b = -0.23, SE = 0.11, Z = -2.1), and the last 25 trials (b = -0.24, SE = 0.12, Z = -2.0) with higher-WMC subjects less likely to commit an error than lower-WMC subjects.

*S-S RTs***.** Subjects were slower on incongruent trials than on congruent trials (b = 23 ms, SE = 3 ms, *t* = 9.4). Variation in WMC did not significantly predict overall RT (b = -18 ms, SE = 10 ms, *t* = -1.8), or RT interference (b = 3 ms, SE = 3 ms, *t* = 1.0).

*S- S errors***.** Subjects committed more errors on incongruent than on congruent trials (b = 0.15, SE = 0.03, Z = 4.9). Overall, higher-WMC subjects committed fewer errors (b = -0.24, SE = 0.09, Z = -2.8), but showed more error interference (b = 0.08, SE = 0.04, Z = 2.1). This was the result of higher-WMC subjects having a greater advantage over lower-WMC subjects on congruent trials (b = -0.29, SE = 0.09, Z = -3.2) than on incongruent trials (b = -0.19, SE = 0.09, Z = -2.2), but higher-WMC subjects were less likely to commit errors on both congruent and incongruent trials.

S-R RTs. Incongruent trials were slower than congruent trials (b = 45 ms, SE = 2 ms, *t* = 20.5). Variation in WMC did not predict overall RT (b = -12 ms, SE = 9 ms, *t* = -1.3) or RT interference (b = 2 ms, SE = 3 ms, *t* = 0.6).

S- R errors. More errors were committed on incongruent trials than on congruent trials (b = 0.49, SE = 0.03, Z = 17.3). Overall, higher-WMC subjects made fewer errors than lower-WMC subjects (b = -0.25, SE = 0.08, Z = -3.1), and again —like in the S-S trials in this task— experienced more error interference than lower-WMC subjects (b = 0.08, SE = 0.04, Z = 2.2). Also, like the results from the S-S trials, higher-WMC subjects were less likely to make errors on both congruent trials (b = -0.25, SE = 0.11, Z = -2.2) and incongruent trials (b = -0.22, SE = 0.9, Z = -2.4).

*Comparison of S-S and S-R trials in RTs***.** Subjects were slower on S-S trials than on S-R trials (b = 15 ms, SE = 2 ms, *t* = 9.1) and experienced less interference on S-S trials than on S-R trials (b = -22 ms, SE = 3 ms, *t* = -6.6). As evident in Figure 15a, WMC did not differentially relate to S-S compared to S-R RT interference (b = 2 ms, SE = 5 ms, *t* = 0.4).

Comparison of S-S and S-R trials in errors. Subjects were less likely to commit errors on S-S trials compared to S-R trials (b = -0.21, SE = 0.02, Z = -10.1) and experienced less interference on S-S trials (b = -0.35, SE = 0.04, Z = -8.4). The difference in error interference between S-S trials and S-R trials was not moderated by WMC (b = 0.00, SE = 0.05, Z = 0.0; see Figure 15b).

Delta plots.

S-S trial delta plot. As shown in Figure 16, there was an overall descending pattern of interference as RTs got longer. For most of the bins, the WMC tercile groups overlapped, but the higher-WMC subjects leveled off from the 4th bin to the 5th bin while the lower-WMC subjects continued to exhibit a descending pattern. The LMM was mostly consistent with the visual observation. Variation in WMC did not predict difference scores overall (b = -7 ms, SE = 6 ms, *t* = -1.1). Interference did decrease significantly over bins (b = -6 ms, SE = 1 ms, *t* = -4.8), but the interaction between WMC and bins was not significant (b = 3 ms, SE = 2 ms, *t* = 1.9). I conducted a t-test between the upper and lower terciles of the WMC distribution on the slowest (5th) bin. This t-test produced a non-significant result (*t* = 1.1) suggesting a lot of within- tercile variance.

*S-R trial delta plot***.** The delta plot on S-R trials (see Figure 17) revealed an upward trajectory, with interference increasing as RTs slowed, consistent with patterns observed in prior investigations of vertically-oriented S-R tasks (Proctor et al., 2011). Like the S-S delta plot from this task, the tercile groups overlapped until the slowest bin. The LMM was mostly consistent with this observation. Interference did increase with slower RTs (b = 11 ms, SE = 2 ms, *t* = 4.8). WMC did not predict interference (b = 4 ms, SE = 12 ms, *t* = 0.3), nor was there an interaction between WMC and bin in predicting interference (b = 0 ms, SE = 3 ms, *t* = 0.1).

Congruency-Sequence effects.

*Congruency-Sequence effects in RTs***.** Congruency-sequence effects were not detected on conflict-switch trials (b = -3 ms, SE = 5 ms, *t* = -0.6), but substantial and significant congruency-sequence effects were found on conflict-repeat trials (b = -59 ms, SE = 7 ms, *t* = -8.7). WMC did not interact with either conflict-switch congruency-sequence effects (b = 0 ms, SE = 7 ms, *t* = 0.6) or conflict-repeat congruency-sequence effects (b = -3 ms, SE = 5 ms, *t* = -0.6). When examining only S-S trials that were preceded by S-S trials, congruency-sequence effects were detected (b = -61 ms, SE = 8 ms, *t* = -7.8), but were not moderated by WMC (b = 0 ms, SE = 11 ms, *t* = 0.0). S-R repetition trials produced the same pattern, with significant congruency-sequence effects (b = -64 ms, SE = 6 ms, *t* = -9.9) and no interaction with WMC (b = 4 ms, SE = 9 ms, *t* = 0.5).

Congruency-Sequence effects in errors. Significant congruency-sequence effects were not found on conflict-switch trials (b = 0.07, SE = 0.1, Z = 1.0), but were found on conflict-repeat trials (b = -0.85, SE = 0.1, Z = -8.91). WMC did not moderate this effect on conflict-switch trials (b = 0.14, SE = 0.1, Z = 1.6), or on conflict-repeat trials (b = 0.07, SE = 0.1, Z = 1.0). On S-S repetition trials, significant congruency-sequence effects were found (b = -0.53, SE = 0.1, Z = -5.3), which did not interact with WMC (b = -0.22, SE = 0.13, Z = -1.7). The model on S-R repetition trials revealed the same pattern with significant congruency-sequence effects (b = -1.05, SE = 0.1, Z = -10.8) that were no different for subjects with different WMC scores (b = 0.01, SE = 0.1, Z = 0.1).

Up-Down numerosity. After exclusion criteria were applied, data from 227 subjects remained for analysis (i.e., data from fourteen subjects were dropped). Because I aggregated subjects' response times on trials which required two buttons to be pressed, I investigated if the ability to simultaneously press 2 buttons was related to WMC by including a factor in the model that indicated if it was a trial with 1 or 2 keys that needed to be pressed. I removed 8 additional subjects whose RT difference between the 1st and 2nd key presses on the mapping trials was greater than three times the interquartile range beyond the mean leaving data from 219 subjects to analyze. For these 219 subjects, key presses differed by an average of 15 ms (SD = 12 ms) on test trials where 2 key presses were required.

On response-mapping trials, overall, WMC was not related to RT (b = -3 ms, SE = 5 ms, t = -0.6). Trials that required 2 key presses were slower than trials that required one (b = 23 ms, SE = 1 ms, t = 20.0), and WMC moderated RT depending on the response type. Higher-WMC subjects slowed down more than did lower-WMC on trials that required 2 keys to be pressed (b = 3 ms, SE = 2 ms, t = 2.1). On the first 50 mapping trials, WMC did not predict RTs (b = -4 ms, SE = 5 ms, t = -0.9), trials that required 2 keys were slower than trials that required 1 (b = -24 ms, SE = 2 ms, t = 14.8), but the interaction between WMC and response type was not significant (b = 2 ms, SE = 2 ms, t = 0.9). For the second 50 mapping trials, WMC did not predict RTs (b = -1 ms, SE = 5 ms, t = -0.2), two key responses were slower than 1 key responses (b = 22 ms, SE = 2 ms, t = 13.0), and the interaction between WMC and response type was significant (b = 5ms, SE = 2ms, t = 2.5). On the last 25 trials, WMC did not predict mapping RTs (b = -2 ms, SE = 6 ms, t = -0.3), two key response were slower than 1 key responses (b = 25 ms, SE = 2 ms, t = 10.7), but the interaction between WMC and response type was not significant (b = 1 ms, SE = 3 ms, t = 0.3).

WMC did not predict errors overall (b = -0.22, SE = 0.13, Z = -1.7), for the first 50 trials (b = -0.09, SE = 0.09, Z = -1.0), the last 50 trials (b = -0.17, SE = 0.09, Z = -1.8), or the last 25 trials (b = -0.10, SE = 0.12, Z = -0.9). Subjects were not more likely to make errors on trials where 2 keys had to be pressed compared to the one key trials overall (b = -0.05, SE = 0.12, Z = -0.4), in the first 50 trials (b = -0.09, SE = 0.09, Z = -1.0), the second 50 trials (b = -0.17, SE = 0.09, Z = -1.8), or in the last 25 trials (b = -0.10, SE = 0.12, Z = -0.9).

*S-S RTs***.** On the test trials, subjects showed congruency effects on S-S trials with incongruent trials being slower than congruent trials (b = 22 ms, SE = 1 ms, *t* = 20.0). WMC did not predict overall RT (b = -9 ms, SE = 6 ms, *t* = -1.5), nor did WMC did predict the size of the congruency effect (b = -3 ms, SE = 2 ms, *t* = -1.9). In the test trials, responses that required 2 key presses were faster than trials where 1 key was pressed (b = -3 ms, SE = 1 ms, *t* = -2.4). Response type (i.e., 1 key press vs. 2 key press responses) did not interact with the congruency effect (b = 1 ms, SE = 2 ms, *t* = 0.6) or WMC (b = 2 ms, SE = 2 ms, *t* = 1.0).

*S-S errors***.** Subjects committed more errors on incongruent SS trials than on congruent trials (b = 0.35, SE = 0.04, Z = 9.1). Overall, variation in WMC did not predict errors (b = -0.13, SE = 0.07, Z = -1.7). However, higher-WMC subjects did commit significantly fewer errors than lower-WMC subjects on 1-key response trials (b = -0.24, SE = 0.10, Z = -2.5) and this relation was significantly different from the relation between WMC and errors on 2-key response trials, where there was no WMC-related difference (b = -0.02, SE = 0.10, Z = -0.2). Errors were less frequent on 2-key responses than on 1-key responses (b = -0.09, SE = 0.04, Z = -2.3). The congruency effect was larger on 1-key trials than on 2-key trials (b = -0.34, SE = 0.08, Z = -4.4). There were no WMC-related differences in the congruency effect (b = -0.01, SE = 0.05, Z = -0.1).

S-R RTs. On S-R trials, subjects experienced interference due to the congruency manipulation (b = 40 ms, SE =1 ms, *t* = 37.2). WMC did not significantly predict overall RT (-11 ms, SE =6 ms, *t* = -1.7) or the magnitude of S-R interference (-2 ms, SE =2 ms, *t* = -1.4). Responses that required 2 response keys were slower than trials that only required 1 response key (b = 43 ms, SE = 1 ms, *t* = 39.8) and higher-WMC subjects experienced less slowing than did lower-WMCs subjects going from 1 response key to 2 response keys (b = -3 ms, SE = 2 ms, *t* = -2.2). Subjects experienced more interference on trials that required 2 response keys than on trials that required 1 (b = 17 ms, SE = 2 ms, *t* = 7.6). Response type did not affect the WMC × interference relation (b = 2 ms, SE = 3 ms, *t* = 0.8).

S-R errors. Subjects made more errors on incongruent trials than on congruent trials (b = 1.16, SE = 0.05, Z = 25.5). WMC did not predict errors overall (b = -0.13, SE = 0.08, Z = -1.6), nor did WMC predict error interference (b = -0.01, SE = 0.06, Z = -0.2). Overall, response type did not predict errors (b = -0.02, SE = 0.11, Z = -0.2), but there was an interaction between response type and interference, with larger error interference on trials that required 2 buttons to be pressed (b = 0.20, SE = 0.09, Z = 2.2). WMC did not moderate the effects of response type on error rates (b = 0.06, SE = 0.16, Z = 0.4). The three-way interaction between WMC, interference, and response type was also not significant (b = 0.06, SE = 0.13, Z = -0.5).

*Comparison of S-S and S-R trials in RTs***.** S-S trials yielded slower responses than did S-R trials (b = 17 ms, SE = 1 ms, *t* = 22.1) and subjects exhibited less S-S than S-R interference (b = -19 ms, SE = 2 ms, *t* = -11.9). As depicted in Figure 18a, WMC did not differentially relate to one type of conflict over the other (b = -1 ms, SE = 2 ms, *t* = -0.8).

*Comparison of S-S and S-R trials in errors***.** Subjects were more likely to make errors on S-S trials than on S-R trials (b = 0.17, SE = 0.03, Z = 5.6). Subjects showed significantly less S-S than S-R interference (b = -0.80, SE = 0.06, Z = -13.3). WMC did not differ in how it predicted S-S or S-R interference (b = -0.03, SE = 0.08, Z = -.40; see Figure 18b).

S-S trial delta plot. Consistent with the RT analysis, the delta plot for S-S trials (see Figure 19) showed no separation between the upper and lower terciles of the WMC. S-S interference showed a similar pattern over bins as was seen in the dual-conflict tasks in Experiments 1, 2A, and 2B, with a subtle rise in interference over the first 2 bins and then a subtle drop over the last 3 bins. The LMM on this delta plot was consistent with the visual impression. WMC did not predict interference (b = 0 ms, SE = 3 ms, *t* = 0.0). Overall, interference reduced across bins (b = -3 ms, SE = 1 ms, *t* = -5.5), and the interaction between WMC and bins was non-significant (b = -1 ms, SE = 1 ms, *t* = -1.5).

*S-R trial delta plot***.** The delta plot on S-R trials revealed an ascending pattern of interference with little separation between WMC tercile groups (see Figure 20). The LMM was in accord with the visual observation. Interference increased over bins (b = 13 ms, SE = 1 ms, *t* = 26.8). WMC did not predict interference (b = 1 ms, SE = 3 ms, *t* =

0.4), and there was no interaction between WMC and bins (b = -1 ms, SE = 1 ms, *t* = -1.6).

*Congruency-Sequence effects in RTs***.** On trials where the conflict type switched from the previous trial no congruency-sequence effects were detected (b = 3 ms, SE = 2 ms, *t* = 1.5) whereas on trials where the conflict type repeated, they were (b = -48 ms, SE = 3 ms, *t* = -15.1). WMC did not relate to congruency-sequence effects on trials where the trial type repeated (b = 2 ms, SE = 4 ms, *t* = 0.5), or on trials where it did not (b = -1 ms, SE = 3 ms, *t* = 0.2). On trials where the S-S conflict type repeated significant congruency-sequence effects were found (b = -55 ms, SE = 3 ms, *t* = -17.12) such that there was a reverse congruency effect on these trials with congruent trials being slower than incongruent trials (i.e., RT interference on S-S trials was 22 ms). Here, WMC did moderate the magnitude of the congruency-sequence effects (b = 9 ms, SE = 5 ms, *t* = 2.0). On S-R conflict-repeat trials congruency-sequence effects were found (b = -33 ms, SE = 3 ms, *t* = -10.7). These were not significantly moderated by WMC (b = -7 ms, SE = 4 ms, *t* = -1.5).

Congruency-Sequence effects in errors. On trials where the conflict did not repeat from the previous trial, congruency-sequence effects were not detected (b = 0.16, SE = 0.09, Z = 1.8). When the conflict type repeated, significant and substantial congruency-sequence effects were found (b = -1.28, SE = 0.13, Z = -9.9). WMC did not predict the size of congruency-sequence effects when the trial types repeated (b = -0.19, SE = 0.18, Z = -1.1) or did not repeat (b = 0.21, SE = 0.12, Z = 1.7).

Dual-Conflict Task Discussion

The pattern of results from the joystick replication task did not replicate the results from Experiment 2A (or Experiment 1) where higher-WMC subjects exhibited a significant RT advantage on S-S trials and a significant error disadvantage on S-R trials. Here, the WMC × SS interference parameter was comparable to the parameters from Experiments 1 and 2A (-5 ms vs. Experiment 2A [-4ms], Experiment 1 [-7ms]), but did not quite meet the significance criterion. However, the relation between WMC and errors on the S-R trials flipped in the joystick replication task from Experiments 1 and 2A. In the joystick replication task, higher-WMC subjects experienced less error interference than did lower-WMC subjects. As is the case when a replication experiment is not an exact replication, it is hard to know how the replication finding relates to the tasks used in Experiment 1 and Experiment 2A. Either the mode of responding changed the relationship between WMC and interference (specifically S-R interference) or this task provides evidence that the previously found relation between WMC and S-R error interference is not robust or reliable.

The axis-shifted task removed the confound between axis and conflict type. In this task, variation in WMC did not predict RTs, but did predict errors. Here, higher-WMC subjects experienced more S-S and S-R error interference than lower-WMC subjects (again not replicating the results from the earlier experiments). If in this task, we had found that higher-WMC subjects now experienced less S-R RT interference and more S-S error interference, the dissociation between S-S and S-R interference would have been shown to be a difference in resolving conflict on horizontal versus vertical axes. Or, if the pattern of results from Experiments 1 and 2A (higher-WMC subjects with less S-S RT interference and greater S-R error interference) were repeated here, then we would have had strong evidence for the WMC-related differences in S-S and S-R conflict resolution. The results from this experiment fit neither of these scenarios. Instead, it appears that there may be an interaction between WMC, conflict type, and axis. Or, perhaps because this task occurred deep in the second session and followed multiple tasks that displayed up-down arrows that required left-right responses, this result was influenced by the carryover of task sets with higher-WMC subjects having learned the earlier stimulus-response pairings better than lower-WMC subjects and therefore had more interference to overcome. This speculation is not supported, however, by the response-mapping data, in which higher-WMC subjects were less likely to make an error across all of the practice.

To test whether the WMC dissociations between S-S and S-R interference found in Experiments 1 and 2A were dependent on stimulus location being the irrelevant interference dimension, subjects completed the Up-Down Numerosity task. S-R interference was generated by an overlap between the irrelevant stimulus dimension, of how many stimuli were presented, and the response dimension of how many response keys needed to be pressed. Unlike Experiments 1 and 2A (and like the joystick replication and axis-shifted tasks), higher-WMC subjects were not more likely than lower-WMC subjects to commit errors on the S-R trials. In addition, variation in WMC did not predict overall S-R RT, S-S RT, or S-S error interference. Because of the differences in the overall pattern of results from Experiments 1 and 2A, the results from this task do not clearly speak to the hypothesis being tested (i.e., is there something special about the relation between WMC and irrelevant location information?), but speak more broadly to the robustness of these effects. Three not necessarily mutually exclusive explanations may be responsible for the frailty of these effects: (1) WMC-conflict resolutions relations are variable and not easy to detect consistently (suggesting the possibility of Type 1 errors in the earlier experiments); (2) the WMC-related effects are dependent on the specific task context of Experiments 1 and 2A, or; (3) these effects are reactive to previously completed tasks and are not suitable for experimental protocols like the one used here.

Single-Conflict tasks.

Up-Down arrows. Twelve outlying subjects were dropped, leaving data from 229 subjects to analyze. See Table 8 for the descriptive statistics for all single-conflict tasks. Higher-WMC subjects were faster than lower-WMC subjects on the mapping trials overall (b = -16 ms, SE = 5 ms, t = -3.3), on the first 25 trials (b = -16 ms, SE = 5 ms, t = -3.1), and on the last 25 trials (b = -15 ms, SE = 5 ms, t = -2.9).WMC did not predict accuracy in the mapping trials overall (b = 0.01, SE = 0.09, Z = 0.1), on the first 25 trials (b = 0.00, SE = 0.11, Z = 0.0), or on the last 25 trials (b = 0.03, SE = 0.11, Z = 0.3).

*RTs***.** On the test trials, subjects were slower to respond when the position and the direction of the arrows were incongruent (b = 19 ms, SE = 1 ms, t = 14.8). This S-S interference was not significantly moderated by subjects' WMC (b = -3 ms, SE = 2 ms, t = -1.5), nor was WMC a significant predictor of overall RT (b = -5 ms, SE = 4 ms, t = -

1.3). Figure 21 displays the WMC × interference parameter values for all the single-conflict tasks that presented S-S conflict.

*Errors***.** Subjects committed more errors on incongruent than congruent trials (b = 0.49, SE = 0.05, Z = 9.0). Overall, WMC did not predict errors (b = -0.13, SE = 0.07, Z = -1.7). Higher-WMC subjects experienced less S-S error interference than did lower-WMC subjects (b = -0.15, SE = 0.07, Z = -2.1).This interaction was produced because higher and lower-WMC subjects did not differ on congruent trials (b = -0.03, SE = 0.09, Z = -0.4), but higher-WMC subjects were less likely to commit an error on incongruent trials (b = -0.20, SE = 0.08, Z = -2.5).

*Delta plot***.** Although the delta plot depicts separation between higher and lower-WMC subjects at all bins (see Figure 22), in the individual difference analysis there was no main effect of WMC (b = -1 ms, SE = 3 ms, t = -0.3) or interaction between WMC and bin (b = 0 ms, SE = 1 ms, t = -0.4). Only a significant effect of bin was observed with interference decreasing as RTs slowed (b = -3 ms, SE = 1 ms, t = -6.2).

Congruency-Sequence effects. Large RT congruency-sequence effects were found (b = -93 ms, SE = 2 ms, t = -37.4) indicating a crossover interaction (i.e., the interaction parameter estimate of -93 ms is larger than the effect of congruency 19 ms). This interaction was further moderated by WMC (b = 7 ms, SE = 3 ms, t = 2.0) with higher-WMC subjects experiencing less of an adjustment after incongruent trials than did lower-WMC subjects. Subjects experienced less error interference after an incongruent trial than after a congruent trial (b = -3.35, SE = 0.15, Z = -22.0). WMC did not affect the magnitude of this effect (b = -0.24, SE = 0.20, Z = -1.2).

Flanker. Data from 235 subjects were left for analysis after six outliers were excluded. In addition to applying the mapping and congruent accuracy criteria, one additional subject who had a 95% error rate on incongruent trials was also removed. On the mapping trials, higher-WMC subjects were faster than lower-WMC subjects overall (b = -12 ms, SE = 3 ms, *t* = -3.6), on the first 25 trials (b = -10 ms, SE = 4 ms, *t* = -2.7), and on the last 25 trials (b = -14 ms, SE = 4 ms, *t* = -3.9). No WMC-related differences were found on errors in the mapping trials overall (b = -0.12, SE = 0.09, Z = -1.3), on the first 25 trials (b = -0.19, SE = 0.10, Z = -1.8), or on the last 25 trials (b = -0.01, SE = 0.11, Z = -0.1).

*RTs***.** Subjects were slower on incongruent trials than on congruent trials (b = 47 ms, SE = 1 ms, *t* = 48.3). WMC did not predict overall RT (b = -5 ms, SE = 2.9 ms, *t* = -1.7), nor did variation in WMC predict the amount of S-S interference experienced (b = 1 ms, SE = 1 ms, *t* = 1.0).

*Errors***.** Subjects made more errors on incongruent trials than on congruent trials (b = 1.3, SE = 0.06, Z = 21.4). Overall, higher-WMC subjects committed fewer errors than did lower-WMC subjects (b = -0.2, SE = 0.06, Z = 21.4), but higher-WMC subjects experienced *greater* S-S interference in errors than did lower WMC subjects (b = 0.2, SE = 0.08, Z = 3.0): Higher-WMC subjects committed significantly fewer errors on congruent trials than did lower-WMC subjects (b = -0.4, SE = 0.11, Z = 3.0), but did not differ from lower-WMC subjects in the amount of errors committed on incongruent trials (b = -0.1, SE = 0.08, Z = -1.0).

*Delta plot***.** The delta plot in Figure 23 reveals a curvilinear relationship between bins and interference. Higher-WMC subjects experienced less interference on the fastest trials than lower-WMC subjects and more interference on the slowest trials than lower-WMC subjects. Higher-WMC subjects' shorter RTs were reflected in their distribution being shifted to the left to the lower-WMC subject's distribution.

In the LMM on the aggregated interference effects, higher-WMC subjects showed less interference overall (b = -9 ms, SE = 3 ms, *t* = -3.0). In general, interference increased as bins increased (b = 2 ms, SE = 0 ms, *t* = 3.7), and there was an interaction between WMC and bins (b = 3 ms, SE = 1 ms, *t* = 5.0) with higher-WMC subjects interference effects growing faster than lower-WMC subjects over progressing bins.

*Congruency-Sequence effects***.** Subjects experienced less RT interference after an incongruent than congruent trial (b = -22 ms, SE = 2 ms, *t* = -11.0). WMC did not moderate this congruency-sequence effect (b = 0 ms, SE = 3 ms, *t* = 0.1). Congruency-sequence effects were found in errors, as well (b = -0.5, SE = 0.13, Z = -3.6). WMC variation did not affect the magnitude of the error congruency-sequence effects (b = -0.1, SE = 0.18, Z = -0.4).

***Simon*.** After excluding 12 outliers, I analyzed data from 229 subjects. Higher-WMC subjects were faster than lower-WMC subjects on mapping trials overall (b = -11 ms, SE = 4 ms, *t* = -2.5), and on the first 25 trials (b = -13 ms, SE = 4 ms, *t* = -3.0), but not on the last 25 trials (b = -9 ms, SE = 5 ms, *t* = -1.7). On the mapping trials, WMC did not meet the significance criterion for predicting errors overall (b = -0.18, SE = 0.09, Z =

-1.9) or on the last 25 trials (b = -0.12, SE = 0.11, Z = -1.1), but WMC did predict errors on the first 25 trials (b = -0.26, SE = 0.12, Z = -2.1).

*RTs***.** On the test trials, subjects experienced S-R interference from the congruency manipulation (b = 24 ms, SE = 1 ms, *t* = 18.7), higher-WMC subjects were overall faster (b = -9 ms, SE = 4 ms, *t* = -2.1), but WMC did not significantly affect the magnitude of S-R interference (b = -2 ms, SE = 2 ms, *t* = -1.4). The WMC × interference parameters for all the single-conflict S-R tasks are displayed in Figure 24.

*Errors***.** On the test trials overall, subjects made more errors on incongruent trials then on congruent trials (b = 0.63, SE = 0.05, Z = 12.1). Higher-WMC subjects committed fewer errors than did lower-WMC subjects (b = -0.14, SE = 0.07, Z = -2.0). WMC did not predict the amount of S-R interference (b = -0.06, SE = 0.07, Z = -0.08).

*Delta plot***.** As depicted in Figure 25, the delta plot for the Simon task revealed its characteristic negative slope (Pratte et al., 2010). The WMC terciles seemed had some separation only at the 2nd and 3rd bin, with higher-WMC subjects showing less interference the lower-WMC subjects. In the individual-difference analyses, WMC did not predict interference (b = -3 ms, SE = 3 ms, *t* = -0.6), but confirming the appearance of a downward slope, bins did (b = -3 ms, SE = 1 ms, *t* = -4.9). The WMC × bin interaction was not significant (b = 0 ms, SE = 1 ms, *t* = -0.2).

*Congruency-Sequence effects***.** In the model with trials only preceded by correct trials and the addition of previous trial congruency as a predictor, a large RT congruency-sequence effect was found (b = -93 ms, SE = 3 ms, *t* = -36.8). This effect was not moderated by WMC (b = 2 ms, SE = 3 ms, *t* = 0.6). In errors, congruency-sequence effects were found (b = -3.4, SE = 0.15, *Z* = -23.0). Higher-WMC subjects showed greater error congruency-sequence effects than lower-WMC subjects (b = -0.4, SE = 0.19, *Z* = -2.2).

Numerosity. After excluding subjects for mapping and congruent trial error rates, 234 subjects remained. Five additional subjects were removed whose RT difference between the 1st and 2nd key presses on mapping trials was greater than three times the interquartile range beyond the mean. This left data from 229 subjects in the analysis.

On mapping trials, WMC was not related to RT, overall (b = -8 ms, SE = 6 ms, *t* = -1.2), on the first 25 trials (b = -6 ms, SE = 6 ms, *t* = -1.0), or the last 25 trials (b = -10 ms, SE = 7 ms, *t* = -1.4). Trials that required 2 key presses were slower than trials that required one, overall (b = 15 ms, SE = 2ms, *t* = 8.1), for the first 25 trials (b = 15 ms, SE = 3 ms, *t* = 5.6), and the last 25 trials (b = 15 ms, SE = 3 ms, *t* = 5.8). WMC did not interact with the difference between the response types, overall (b = -1 ms, SE = 3 ms, *t* = -0.4), on the first 25 trials (b = -1 ms, SE = 4 ms, *t* = -0.3), or on the last 25 trials (b = -0 ms, SE = 3 ms, *t* = 0.0).

Higher-WMC subjects were less likely to commit errors on mapping trials, overall (b = -0.22, SE = 0.08, Z = -2.7) and on the first 25 trials (b = -0.24, SE = 0.10, Z = -2.3), but not on the last 25 trials (b = -0.18, SE = 0.10, Z = -1.8). WMC did not interact with response type in the prediction of errors overall (b = -0.21, SE = 0.11, Z = -1.9), or on the first 25 trials (b = -0.09, SE = 0.15, Z = -0.5) of mapping. But, on the last 25 trials of mapping, WMC interacted with response type, with higher-WMC subject less likely than lower-WMC subjects to make an error on a trial requiring a two key response (b = -0.36, SE = 0.17, Z = -2.1).

RTs. On the test trials, subjects were slower on incongruent trials than on congruent trials (b = 58 ms, SE = 1 ms, *t* = 43.9). Higher-WMC subjects were faster across all trials (b = -16 ms, SE = 6 ms, *t* = -2.6) and, as can be seen in Figure 24a, experienced less S-R interference than did lower-WMC subjects (b = -6 ms, SE = 2 ms, *t* = -3.4). Trials that required 2 keys to be pressed were again slower than trials where 1 key was pressed (b = 19 ms, SE = 1 ms, *t* = 14.3), but response type did not significantly interact with the any other predictor variables.

Errors. Subjects made more errors on incongruent trials than on congruent trials (b = 1.89, SE = 0.09, Z = 20.9). Overall, higher-WMC subjects committed fewer errors than did lower-WMC subjects (b = -0.24, SE = 0.08, Z = -3.1), but WMC did not significantly predict S-R interference (b = 0.19, SE = 0.11, Z = 1.7). No other main effects or interactions were present in the model.

*Delta plot***.** Figure 26 shows overlapping lines for the WMC tercile groups until the 5th bin, where the lower-WMC subjects appeared to be slower and to exhibit more interference. In the LMM with WMC and RT bins as predictors, there was no main effect of WMC (b = 3 ms, SE = 4 ms, *t* = 0.7). Bins predicted interference with interference increasing as RTs slowed (b = 21 ms, SE = 1 ms, *t* = 32.3). Confirming the observation from the delta plot, WMC and bin interacted (-3 ms, SE = 1 ms, *t* = -3.4) with higher-WMC subjects showing less S-R interference than did lower-WMC subjects at longer RTs.

*Congruency-Sequence effects***.** In RTs, significant congruency-sequence effects were detected (b = -27 ms, SE = 3 ms, *t* = -10.0). RT congruency-sequence effects were not moderated by WMC (b = 1 ms, SE = 4 ms, *t* = 0.3). Significant congruency-sequence effects were also detected in errors (b = -0.84, SE = 0.18, Z = -4.8). WMC did not moderate the error congruency-sequence effects (b = 0.01, SE = 0.23, Z = 0.0).

Single-Conflict Task Discussion

A clear pattern of WMC and conflict-type relations did not emerge from the single-conflict tasks. Higher-WMC subjects showed their largest RT interference advantage over lower-WMC subjects in the S-R conflict numerosity task and an error interference disadvantage compared to lower-WMC subjects in the S-S conflict flanker task. In the Simon task, WMC variation did not predict error or RT interference, while in the up-down arrows task, higher-WMC subjects showed less error interference than did lower-WMC subjects (but WMC did not predict RT interference). If there is a systematic relation between WMC and conflict resolution, the evidence from the single-conflict tasks suggests that this relation is not captured through use of the Kornblum taxonomy. I used the single-conflict tasks to determine whether the results from Experiments 1 and 2A were due to having two conflict types within one task. The trials from the up-down arrows task most closely map onto to the S-S conflict trials and the Simon trials most closely map onto the S-R conflict trials from the earlier experiments. The results from the up-down arrows task were somewhat consistent with the S-S conflict results from Experiment 1 and 2A, with higher-WMC subjects showing a non-significant advantage over lower-WMC subjects. The results from the Simon task were consistent with

Experiment 1 and 2A, insofar as higher-WMC subjects showed no advantage over lower-WMC subjects, but there was no evidence for higher-WMC subjects being at a disadvantage on these trials. This latter result suggests that having to resolve two types of conflict may have helped produce the greater error interference by higher-WMC subjects in Experiments 1 and 2A. Perhaps in the dual-conflict scenario, higher-WMC subjects bias their attention away from the vertical location, but this somehow leaves them vulnerable to the response-conflicting horizontal location. The consistency between the results from the up-down arrows and Simon tasks with the patterns observed in the earlier experiments suggests that the dissociation found in Experiments 1 and 2A was not solely due to S-S and S-R conflict being delivered within the same task.

Latent Variable Analyses

In my proposal of this experiment, models using latent variables were planned to test whether the S-S and S-R interference effects being measured here were markers of generalizable cognitive processes that could be detected with subjects showing consistent advantages or disadvantages with specific conflict types across tasks. A matrix of correlations was produced by calculating a residualized conflict score for each observed measure of interest from each task (see Table 9). For example, in the joystick replication task, each subject’s incongruent RT on S-S trials was regressed on his or her congruent RT on S-S trials. The residual from this linear model was kept as the dependent variable representing S-S interference. Residualized interference scores were chosen over simple difference scores (i.e., incongruent RT – congruent RT) or ratios (i.e., incongruent RT / congruent RT) because they tended to be less skewed, leptokurtic, or platykurtic. That being said, in Experiment 3, variables produced with these various methods correlated strongly (*r*s > .90) and lead to the same conclusions.

As seen in Table 9, the correlation matrix produced from Experiment 3 indicated weak relations among measures of S-S interference and S-R interference. The correlations within conflict types (i.e., S-S and S-R) appeared to be no stronger than the weak relations across S-S and S-R conflict measures, suggesting that behavioral measures of S-S interference and S-R interference are task-dependent and do not represent stable across-task individual differences. The reliabilities of the Experiment 3 tasks (calculated by correlating residualized interference scores from even-numbered trials with those from odd-numbered trials) were low, with few exceptions (reported on the diagonal of Table 9), limiting the potential strength of any correlations between tasks.

Although the correlation matrix and reliabilities were not encouraging, in accordance with my *a priori* analysis plan, I attempted to fit the Experiment 3 data to the proposed latent variable model. In this confirmatory factor analysis (CFA) model, three latent variables were specified. One latent variable represented the construct of WMC, another latent variable represented the construct of S-S interference, and the third construct was S-R interference. If the constructs represented consistent covariances among subjects, then I would have a model that allowed estimates of the relations among WMC, S-S interference, and S-R interference at the construct level. Not surprisingly, in light of the correlations and reliabilities, this model failed to converge, yielding no interpretable results.

I constructed another model, taking a bi-factor approach, and using raw RTs rather than residuals as dependent measures (see Table 10 for the correlation matrix). In this model, all congruent and incongruent RT measures loaded onto a general RT factor, RTs from incongruent S-S trials also loaded onto an S-S interference factor, incongruent S-R trial RTs onto an S-R interference factor, and WMC task measures onto a WMC factor. Global fit statistics provide estimates of how well the covariances in the data match the model. The comparative fit index (CFI) measures the relative improvement in the conducted model against a model that assumes no covariances among the observed model (the baseline or independence model). A CFI greater than .90 indicates acceptable model fit (Kline, 1998). The bi-factor model converged, but it had a CFI of only .48, indicating an unacceptable fit of the model to the data. The standardized root mean square residual (SRMR) and the root mean square error of approximation (RMSEA) index the differences between predicted and observed covariances; values of less than .08 indicate acceptable fit (Kline, 1998). Here, the model yielded a SRMR of .16 and a RMSEA of .28. From the correlation matrix, the failure of the model of the residualized interference effects to converge, and the poor fits from the bi-factor model, all signs pointed to the fact that, when attempting to group all of the S-S- and S-R-specific variances across the tasks in Experiment 3, there was too much task-specific variance to make meaningful, coherent groupings. In addition to the CFA models presented above, I tested separate models for single and dual-conflict tasks model (using the residual scores), a model using the raw RTs that had a general RT factor where all RTs were loaded and a general interference factor that was composed of only the incongruent RTs, regardless of conflict type. None of these models provided acceptable fits to the data.

To complement the CFAs, I conducted exploratory factor analyses (EFA) on both the residualized interference scores and the raw RTs. The purpose of the EFAs was to examine, from a bottom-up perspective, whether there was an underlying structure to the RT data that was being missed in my confirmatory analyses. For each of these EFAs, parallel analysis was used to determine how many factors to select (Humphreys & Montanelli, 1975). Factor extraction with parallel analysis is preferred over methods using scree plots or eigenvalues because it uses a Monte Carlo simulation to extract values, avoiding the subjectivity and insensitivity found when using scree plots or eigenvalues to extract factors (Glorfeld, 1995; Zwick & Velicer, 1986). The parallel analysis on the residualized data set suggested 4 factors, while the parallel analysis on the raw RTs suggested 5 factors. The EFAs were performed with maximum likelihood estimation and an oblomin rotation to allow the factors to correlate.

Table 11 shows the factor loadings from the EFA on the residualized interference scores. The first extracted factor shows a high loading from the numerosity task and weak loadings from all other tasks. The second factor shows a moderate loading from the S-R portion of the joystick replication task and weak loadings from all other measures. The third factor shows a moderate loading from S-S trials from the Up-Down Numerosity Task with weak loading from all other measures. The fourth factor shows some weak to moderate loading from three of the single-conflict tasks (Up-Down Arrows, Simon, and the Flanker). In total, the EFA on the residuals did not reveal any underlying structure (other than task-specificity).

Table 12 presents the factor loadings for the EFA on the raw RTs. Here, we see a clearer picture of task-specific relations, with the first factor representing the up-down numerosity dual-conflict task, the second factor the joystick replication task, the third the axis-shifted task, the fourth the Simon task, and the fifth the flanker task. The numerosity task had a moderate loading on the first factor with the up-down numerosity task. This was not unexpected because the numerosity portion was the same on both tasks and these measures were moderately correlated. The same could be said for the up-down arrows task and the joystick replication task which share very similar S-S trials.

Latent Variable Analyses Discussion

In Experiment 3, I tested whether tasks designed with the Kornblum taxonomy in mind would produce reliable, consistent patterns of individual variation in conflict susceptibility (whether WMC-related or not). Specifically, patterns of covariation were examined to see if S-S conflict resolution measures related more strongly with one another across tasks compared to the relation between S-S and S-R conflict resolution measures (and vice versa for S-R conflict resolution measures). Here, the data were clear. S-S and S-R conflict resolution measures did not show patterns where S-S conflict measures shared more variance with each other than they did with S-R conflict measures. Conflict measures were strongly related when they were within the same task. The correlation matrix, along with failed and poorly fitting structural models, all point to this conclusion. The low reliabilities suggest that even on the intra-individual level, the processes that combat interference are not consistently deployed or effective (or the measures used here are not sensitive enough to pick them up). One factor that may be working against picking up across-task variation is the strong within-task correlations between congruent and incongruent conditions (see Table 10).

In any case, the lack of across-task covariation with conflict measures produced here does not appear to be a unique anomaly. In a neuroimaging context, Fan, Flombaum, McCandliss, Thomas, and Posner (2003) in four experiments had subjects complete variants of flanker tasks, a color-word Stroop task, and Simon tasks. Using functional magnetic resonance imaging, they detected common brain activations across tasks, but their behavioral measures were not related (except in one experiment where they modified a flanker and Stroop task to be very similar). In a behavioral context, although Keye et al. (2009) were able to get a CFA model of flanker and Simon tasks to converge (it fit the data well), the conflict factor for the flanker task correlated only weakly with the conflict factor from the Simon task (r = .14).

Discussion

The patterns of dual-conflict and single-conflict task results did not produce patterns consistent with the proposition (and in contrast to the findings from Experiment 1 and 2A) that higher-WMC subjects are superior to lower-WMC subjects at resolving S-S interference. Nor did higher-WMC subjects experience a consistent decrement in resolving S-R conflict in comparison with lower-WMC subjects. Latent variable analyses provided evidence that S-S and S-R conflict measures are either not reliably captured by my behavioral measures or that S-S and S-R conflict measures are not generalizable beyond the task they are produced in.

The delta plots from these tasks suggested some task-specificity in the time-course of interference effects and, by extension, task-specificity in the processes used to counter this interference. Trials in which conflict was created by having arrow orientation conflict with arrow location (i.e., S-S trials in joystick replication, axis-shifted task, and the single-conflict up-down arrows task) produced a pattern where interference started off close to its asymptote and then descended as RTs slowed. The flanker task, which had irrelevant flanking arrows in conflict with the target arrow, produced a pattern where interference built over the first few RT bins and then descended. To put these S-S delta plots within some context, Unsworth et al. (2012) displayed a delta plot from a flanker and Stroop task that had interference ascending as RTs got longer. Pratte et al. (2010) also reported that interference increased as RTs got longer in multiple variants of manual Stroop tasks.

In a review of Simon task (S-R conflict) delta plots, Proctor et al. (2011) found that when tasks were horizontally aligned and either required responses from both left and right hands (like the Simon task used here) or left and right movements of one hand (like the joystick replication task used here) descending patterns of interference as RTs lengthened were produced (see also Pratte et al., 2010). The single-conflict (prototypical) horizontal Simon task used here — with conflict between side of display and the key to be pressed — produced the expected descending pattern of interference as RTs got longer. The results from the S-R trials from the joystick replication task with its ascending interference effects where S-R conflict was also on the horizontal axis suggests (along with the results from Experiments 1, 2A, and 2B) that mixing S-S and S-R tasks changes how subjects approach and therefore respond to conflict. Proctor et al. report that ascending interference patterns are found when the stimulus is presented on the vertical axis (or auditorily). Here, the vertically aligned S-R trials in axis-shifted task showed an ascending pattern of interference. In addition, the numerosity task also produced an ascending pattern of interference effects as RTs lengthened.

The patterns of interference effects displayed by delta plots have been interpreted as reflecting the cognitive processes that are engaged in conflict resolution (Pratte et al., 2010). For example, patterns of descending interference effects have been interpreted as markers of inhibition, where initial erroneous response activation has to be quelled by inhibition processes that take some time engage (Ridderinkhof, van den Wildenberg, Winjen, & Burle, 2004). Regardless of the interpretations of specific patterns, if we operate under the assumption that the patterns of interference reflect specific conflict resolution processes, the heterogeneity of the patterns presented here speak to the heterogeneity of the processes involved. Of most importance for the current investigation, the heterogeneity of delta plots for forms of conflict that are the same in the terms of the Kornblum taxonomy suggest that the taxonomy may not be useful in understanding how people overcome conflict (for a similar conclusion see Pratte et al., 2010).

In the dual-conflict tasks, congruency-sequence effects (in RTs or errors) were not found on trials where the conflict type switched. Robust congruency-sequence effects emerged, however, when the conflict-type repeated from trial-to-trial. The initial intent in analyzing congruency-sequence effects was to examine them as markers of reactive control and as potential mediators of WMC-related differences in interference control. Higher-WMC subjects only experienced significantly less RT interference in the numerosity task. In the numerosity task, significant and substantial congruency-sequence effects were found with an estimate of a 27 ms reduction in interference following an incongruent trial compared to the amount of interference following a congruent trial. WMC did not moderate this effect. In the single-conflict up-down arrows task and in the up-down arrows portion of up-down numerosity task (where the WMC × RT interference parameters were both -3 ms in favor of higher-WMC subjects, but not significant [*t*s = 1.5 and 1.9, respectively]), WMC did moderate RT congruency-sequence effects, with higher-WMC subjects showing less adjustment in congruency effects following incongruent trials than lower-WMC subjects. In the Simon task, where previous research has found relations between congruency-sequence effects and working memory capacity in RTs, no such relation was detected. However, WMC did predict the Simon congruency-sequence effects in errors. Higher-WMC subjects exhibited a greater adjustment in their performance following incongruent trials than lower-WMC subjects (b = -0.42, Z = 2.2). This finding sits in contrast to WMC × congruency-sequence effects found in prior investigations where lower-WMC subjects showed greater post-conflict adjustments (Keye et al., 2009, Weldon et al, 2013).

Found in every task, congruency-sequence effects are a robust a reliable phenomenon. What causes congruency-sequence effects is currently debated, with the top-down conflict-monitoring theory (Botvinick et al., 2001) most often pitted against the bottom-up feature-integration account (Hommel, Proctor, & Vu, 2004; Mayr, Awh, & Laurey, 2003). Regardless of whether congruency-sequence effects are caused by top-down or bottom-up processes, individual differences in the magnitude of these effects could shed light on how people approach or react to cognitive conflict. When WMC-related individual differences in congruency-sequence effects are found, they do not appear to be related to overall WMC-related performance differences and therefore do not seem to hold promise in elucidating the mechanisms or processes that are responsible for WMC and its relation to higher-order cognition.

CHAPTER V

GENERAL DISCUSSION

The primary goal of this project was to add specificity to accounts of WMC-related individual differences in conflict resolution – and our understanding of the executive control construct. Depending on which forms of conflict were sensitive to WMC-related individual differences, the findings would suggest a role for WMC in either resolving interference relatively early in the information-processing stream, at stimulus identification or selection (indicated by S-S conflict), or relatively late, at response selection (indicated by S-R conflict), or perhaps at both stages. If WMC predicted *both* S-S and S-R conflict resolution, then it may have indicated that WMC affects online conflict resolution processes at a more global level (e.g., superior goal maintenance or task approach). For example, higher-WMC subjects may better resolve all conflict (both S-S and S-R) because they have the task goal in a more activated state than lower-WMC subjects allowing for more efficient (or faster) conflict resolution processes downstream. If WMC predicted neither S-S nor S-R conflict resolution, it would suggest that the two-factor theory of cognitive control where WMC relates to attentional task performance through goal maintenance and conflict resolutions processes should be reexamined.

Using a task that minimized contributions of goal-maintenance and task-switching abilities by presenting a single goal (*attend to arrow shape and ignore arrow location*) that was frequently reinforced by conflict trials (Experiments 1 and 2A), I found that higher-WMC subjects experienced less S-S interference (in RTs) and more S-R interference (in errors) than did lower-WMC subjects. That is, in a scenario where the influence of goal-maintenance abilities was experimentally controlled, I found a dissociation in WMC's prediction of S-S versus S-R conflict. In contrast, in a similar task that boosted the contribution of goal-maintenance abilities by presenting 80% congruent trials (and thereby did not externally reinforce the task goal of ignoring stimulus location; Experiment 2B), higher-WMC subjects were less vulnerable to *both* S-S and S-R interference than were lower-WMC subjects. These results appeared to support dual-factor theories of cognitive control with proactive goal maintenance and reactive conflict resolution processes (e.g., Braver et al., 2007; Engle & Kane, 2004) and to add specificity to the account of WMC–control relations by defining a boundary condition. However, in Experiment 3, I attempted to address confounds presented in the earlier experiments and to test for the robustness and generality of the dissociation among WMC, S-S interference, and S-R interference. Experiment 3 results suggested that the dissociation seen earlier was task-specific, and therefore neither robust nor generalizable to other tasks and situations.

WMC and S-S Interference

In Experiment 1, 2A, and 2B, WMC did not significantly relate to errors caused by S-S conflict but, in these three experiments (and in both pure S-S trials and combined S-S/S-R trials in Experiment 1), higher-WMC subjects exhibited significantly less S-S interference in RTs than did lower-WMC subjects. WMC appeared to affect information processing relatively early in the process, such as during stimulus identification or stimulus selection. It seemed, then, that higher-WMC subjects were better able than lower-WMC subjects to selectively attend to the response-relevant stimulus dimension (here, arrow shape/direction) while limiting processing of the irrelevant stimulus dimension (here, arrow location). This seemed to jibe well with previous work that has found performance benefits for higher-WMC subjects in other tasks that present S-S conflict (e.g., Stroop tasks [Kane & Engle, 2003; Hutchison, 2011; Long & Prat, 2002; Meier & Kane, 2013; Unsworth et al., 2012] and flanker tasks [Heitz & Engle, 2007; Redick & Engle, 2006]). In addition, this finding was appealing because it seemed to fit with recent work that has found an association between simple sensory discrimination and IQ (Melnick et al., 2013), where subjects who were better able to deploy sensory suppression mechanisms had higher IQs. These findings would seem to mesh together to offer a partial account of the strong relations between WMC and intelligence (Conway, Kane, & Engle, 2003).

In Experiment 3, however, higher-WMC subjects did not consistently demonstrate an advantage over lower-WMC subjects in resolving S-S conflict. In three tasks that presented up-down arrows that were either congruent or incongruent with screen location (joystick replication, up-down arrows task, and the up-down arrows trials on the dual-conflict up-down arrows numerosity task), higher-WMC subjects showed a non-significant advantage over lower-WMC subjects in the amount of interference experienced (it is notable, however, that in the up-down numerosity task the *t* statistic was very close to significant [1.9] and the parameter estimate was similar to the parameter estimates from Experiments 1 and 2A). When arrow direction and screen location were in conflict on the horizontal plane in the axis-shifted task, higher-WMC subjects were non-significantly slower and significantly more error prone in resolving S-S interference than lower-WMC subjects (the same pattern as seen on the S-R trials in Experiment 1 and 2A). In the flanker task, where distractor arrows presented next to the target can interfere with the target arrow, higher-WMC subjects performed worse than lower-WMC subject in terms of error interference (no difference was observed in RT interference). The lack of a WMC-related advantage in the flanker task presented here (in Experiment 3), and the left-right arrows trials presented in the axis-shifted task, provide evidence that the previously observed relationships between WMC and tasks that presented S-S conflict cannot simply be explained by higher-WMC subjects being better able to generally handle S-S interference (see Table 13 for WMC × S-S interference parameter values across tasks). Indeed, recent research by Keye et al. (2009) has produced similar results, with higher-WMC subjects showing no benefit over lower-WMC subjecs in flanker tasks. In light of these results, perhaps the earlier work that has provided evidence for higher-WMC subjects outperforming lower-WMC subjects in flanker tasks should be reconsidered.

Heitz and Engle (2007) who used the letters *H* and *S* as stimuli in a flanker task were able to produce their WMC-related differences by comparing subjects in the upper-quaritle versus lower-quartile of their WMC distribution. Using progressively decreasing response deadlines, Heitz and Engle forced subjects to respond with a wide distribution of latencies. They examined accuracy over these latencies and found that there was separation in accuracy between the higher and lower-WMC group in the middle of the RT distribution with the higher-WMC group being more accurate. Importantly, overall differences in the amount of RT interference were not found. Heitz and Engle thus provided evidence that higher-WMC subjects can restrict their attentional focus to the target faster than lower-WMC subjects, within a particular response window, but given the task-specific results presented here and elsewhere (Keye et al., 2009), it remains an open question whether that effect will generalize to other tasks that present S-S conflict. If WMC-related individual differences are only evident when examining accuracy as a function of RT, and not when viewing overall measures of interference, it suggests that WMC may indeed affect processing in tasks using S-S interference but this processing difference has little (or no detectable) impact on typical task performance.

Redick and Engle (2006) also found differences in flanker RT interference between upper and lower quartile WMC groups, but their task used horizontal arrows as stimuli. An incongruent trial not only produced S-S interference, but also S-R interference because the responses were horizontally aligned keypresses. That is, arrows (i.e, the directions that the arrows are pointed) have been shown to produce S-R interference very similar to the interference that is generated between location and responses (Baldo, Shimamura, & Prinzmetal, 1998; Lu & Proctor, 2001) and in Redick and Engle the horizontal arrow stimuli were either congruent or incongruent with the response. By presenting both types of conflict on single trial, Redick and Engle’s flanker task was a qualitatively different one than those presented here (where arrows and responses did not conflict). Moreover, Redick and Engle found their WMC-related differences in RT interference on trials within the Attention Network Task (Fan, McCandliss, Sommer, Raz, & Posner, 2002) which, in addition to providing congruent and incongruent flanker trials, contained other manipulations. Subjects were presented with different cue types and the array of flanker stimuli appeared either above or below a fixation point to assess additional facets of attention —making this a complex task context clouding the interpretation of the WMC × interference relation. In a simpler task context without cues and moving stimulus arrays, but still using arrow stimuli, Unsworth and colleagues (Unsworth, Spillers, & Brewer, 2009; Unsworth, Redick, Spillers, & Brewer,2012) have found modest (but statistically significant) relations between WMC and flanker interference with higher-WMC subjects outperforming lower-WMC subjects. In addition to using horizontal arrow stimuli, Unsworth et al.'s subjects completed 150 trials: 50 congruent, 50 incongruent, and 50 neutral trials (that just had horizontal lines with no arrow heads flanking the target). Because of this low proportion of incongruent trials, it is reasonable that this task may have measured goal maintenance as well as any conflict resolution processes. Keye et al. (2009) also used arrow flankers, but with a 50% proportion congruency (like the flanker task presented here), and did not find a significant relationship with WMC.

Although the delta plots for all the S-S tasks — except for the flanker task — presented similar patterns of ascending interference effects (which previously has been interpreted as evidence for a common process; Pratte et al., 2010), the latent variable analyses conducted in Experiment 3 revealed that patterns of covariances did not not represent anything stable across tasks. That is, either the ability to resolve S-S conflict was not a stable individual difference, or there was a stable construct but using RTs and errors in tasks like the ones used here did not provide the sensitivity necessary to measure it. Although a pattern of results indicating WMC relations with S-S conflict resolution was found in Experiment 1 and replicated in Experiment 2A, these results do not seem generalizable to S-S conflict produced in other task contexts. I wanted to learn what higher-WMC subjects are able to do that lower-WMC subjects are not. The pattern of results here does not enable me to do that to my satisfaction. It seems that higher-WMC subjects are able to deploy attention early to aid stimulus identification but only in specific situations. In situations where the interfering stimuli is more salient, like the flanker task, it appears that this advantage is negated.

WMC and S-R Interference

In Experiments 1 and 2A, higher and lower-WMC subjects showed equivalent RT interference on S-R trials (with -3 ms per WMC standard deviation being the largest parameter value), but higher-WMC subjects showed significantly greater error interference than did lower-WMC subjects. Although the irrelevant stimulus dimension was arrow location for both S-S and S-R trials in these experiments, it seemed that whatever higher-WMC subjects were able to do to combat S-S interference was not helpful in resolving S-R interference. But in Experiment 3, with trials that presented conflict in the same way (i.e., irrelevant stimulus location conflicting with the response), that pattern was not replicated. In the joystick replication task, variation in WMC did not relate to RT interference, but it did predict error interference —in the opposite direction than what was observed in Experiments 1 and 2A. That is, in the joystick replication task, higher-WMC subjects experienced *less* error interference than lower-WMC subjects. Because the response in this task was made via the joystick, it cannot be ruled out that the response type caused the results to differ from the early experiments which used two hands and keyboard responding. In the Simon task, however, which also caused conflict between the irrelevant stimulus location and the response location but used different stimuli from the arrow tasks, subjects responded with two hands by pressing the keys on the keyboard. Here, WMC did not predict RTs or errors, suggesting that there is more in play than just a distinction between joystick and button response modes (further suggesting that, perhaps, the significant WMC advantage in the joystick replication task was a fluke). When S-R conflict was shifted onto the vertical axis, WMC did not predict RT interference, but did predict error interference. Like Experiments 1 and 2A, higher-WMC subjects experienced *more* error interference than lower-WMC subjects, but unlike those earlier experiments, higher-WMC subjects were less likely than lower-WMC subjects to make errors on both congruent and incongruent S-R trials (in the earlier experiments WMC variation did not predict congruent trial performance).

With higher-WMC subjects only performing better than lower-WMC subjects on two S-R performance indices (joystick replication errors and numerosity RTs), it seems clear that higher-WMC subjects do *not* have a pronounced advantage over lower-WMC subjects in resolving interference between irrelevant stimulus locations and the location of the response. Regarding the RT interference effect in the numerosity task, the delta plot for this task (see Figure 26) showed an ascending pattern of interference, with separation between higher- and lower-WMC subjects on the trials with the slowest RTs.

Previously, a similar pattern has been interpreted as revealing WMC-related differences in goal maintenance processes (Unsworth et al., 2012; using Stroop and flanker tasks). The rationale being, in part, that lapses of goal maintenance have been shown to be related to RTs at the slow end of the distribution (McVay & Kane, 2012; Unsworth, Redick, Lakey, & Young, 2010). It is not clear why lapses of goal maintenance would show up in a 50% congruent numerosity task when there was no evidence of them in the other 50% congruency tasks. Therefore, I do not think goal maintenance abilities are a likely account for the WMC-related differences observed in the numerosity task. However, it does seem likely that lapses of goal maintenance can account for the WMC-related performance differences in Experiment 2B, with its high proportion of congruent trials (80%), higher-WMC subjects showed less RT interference than did lower-WMC subjects (-5 ms per WMC standard deviation) and equivalent error interference. The Experiment 2B results suggest that when goal-maintenance processes are made relevant to task success by the context, WMC can influence performance, with higher-WMC subjects outperforming lower-WMC subjects.

WMC and Congruency-Sequence Effects

I examined congruency-sequence effects because they measure dynamic, reactive adjustments to experienced conflict. Prior work has theorized that higher-WMC subjects rely more on proactive control, while lower-WMC subjects have to default to a reactive strategy because they are not able to implement or maintain proactive control (Braver et al., 2007; Redick, 2014; Redick & Engle, 2011). Here, I tested whether these indicators of reactive control were moderated by WMC and, more importantly, whether congruency-sequence effects mediated any WMC-performance relations. Robust congruency-sequence effects were found in every task, for both RTs and errors, when looking at trials where the conflict type repeated. In accordance with a vast majority of the literature (for an exception, see Kan et al., 2013), much weaker and mostly non-significant congruency-sequence effects were found when the conflict type switched from trial-to-trial. The control engaged by one type of conflict was, therefore, specific and not helpful at resolving conflict created another way.

In prior work that has assessed whether WMC moderates congruency-sequence effects, the results have been mixed (Gulbinaite & Johnson, 2013; Keye et al., 2009, 2013; Meier & Kane, 2013; Unsworth et al., 2012; Weldon et al., 2013). Using Stroop and flanker tasks (both involving at least some S-S conflict), Keye et al. (2009; 1 experiment), Meier and Kane (2013; 2 experiments) and Unsworth et al. (2012; 2 experiments) found no association between WMC and congruency-sequence effects. In Simon tasks (which only elicit S-R conflict), however, Gulbinaite and Johnson (2013; 1 experiment); Keye et al. (2009; 1 experiment) and Weldon et al. (2013; 2 experiments) found that lower-WMC subjects exhibited more reactivity to the congruence of the prior trial when processing the current trial; Keye et al. (2013), in contrast, found no relations between a WMC latent variable and latent variable for congruency-sequence effects produced from horizontal and vertical Simon tasks.

In my Experiment 3 when examining conflict-repeat trials, WMC significantly moderated RT congruency-sequence effects in two of the six S-S tasks and none of the six S-R tasks. In the two S-S tasks where WMC was related to RT congruency-sequence effects, the up-down arrows single-conflict task and the up-down arrows trials in the up-down numerosity dual-conflict tasks, higher-WMC subjects exhibited less of an adjustment than did lower-WMC subjects in congruency effects after an incongruent trial. Consistent with the findings from experiments that have found WMC and congruency-sequence relations, lower-WMC subjects made greater adjustments after conflict than higher-WMC subjects. Despite this consistency, these effects are not reliably found in either S-R or S-S conflict tasks. Currently, the balance of evidence seems to be against WMC-interference resolution relations (when found) being mediated by trial-to-trial adjustments of cognitive control. At this point, those few reported WMC-congruency sequence effect relations are probably best regarded as not providing critical information towards understanding how WMC impacts performance.

Theoretical Implications

The initial findings from Experiments 1, 2A, and 2B seemed to compliment recent work in visual search and auditory distraction that has established boundary conditions for the association between WMC and executive control (e.g., Poole & Kane, 2009; Sorqvist et al., 2013). That is, WMC appeared to be selectively related to the resolution of conflict that was created by the overlap of relevant and irrelevant stimulus features. However, the results from Experiment 3 suggested that the results from Experiments 1 and 2A were the product of a specific task configuration and were not representative of general processes in the resolution of S-S and S-R interference. From previous work, it also appeared that WMC was more reliably related to some interference tasks than others. For example, WMC has been repeatedly shown to predict Stroop and flanker performance, but less so to Simon task performance. I explored the possibility that the dissociating factor for when and where WMC predicts conflict task performance was dimensional overlap type. This does not seem to be the case. In fact, the findings from all three experiments considered together, along with recent work with the flanker task (Keye et al., 2009; 2013) and Simon task (Weldon et al., 2013), question the robustness of the overall relationship between WMC and performance on conflict tasks with 50% congruent trials.

The two-factor theory of cognitive control (Engle & Kane, 2004) predicts that WMC affects performance through both goal maintenance and conflict resolution mechanisms (similar to Braver et al.'s [2007] conception of proactive and reactive control). Therefore we should see WMC × conflict task relations in tasks that produce interference but that do not put a premium on goal maintenance processes because of WMC's relation to conflict resolution mechanisms. As shown in Table 13, in RTs, higher-WMC subjects did not consistently show advantages in terms of RT interference over lower-WMC subjects (3 out of 14 trial sets examined), nor did they do so in errors (2 out of 14 trial sets examined). Lower-WMC subjects did not show any advantages over higher-WMC subjects in the amount of RT interference experienced in any task, but they did show advantages in error interference over higher-WMC subjects in 5 out of 14 trial sets examined (2 S-S tasks and 3 S-R tasks; see Table 13). The two-factor theory of cognitive control was primarily based on findings from Stroop (Kane & Engle, 2003; Meier & Kane, 2013) and antisaccade tasks (Kane, Bleckley, Conway, & Engle, 2001; Unsworth, Schrock, & Engle, 2004). For example, from the Stroop task (Kane & Engle, 2003), lower-WMC subjects committed more errors than higher-WMC subjects in high-congruency contexts. This was considered evidence for lapses of goal maintenance by lower-WMC subjects. Interpreted as evidence for differences in conflict resolution, lower-WMC subjects were slower than higher-WMC subjects in low-congruency contexts.

The two-factor theory of cognitive control may well explain WMC-related performance on the antisaccade, some Stroop tasks, and Experiments 1, 2A, and 2B, but it is not clear why the patterns predicted by the theory did not emerge from Experiment 3. Perhaps what has been previously found as support for the two factors is really just one —goal maintenance. Therefore, the findings reported here seem to be more in line with models of cognitive control that presented a tight coupling between goal maintenance and conflict resolution (Botvinick et al., 2001). However, the lack of a relation between WMC and congruency-sequence found here and elsewhere (Meier & Kane, 2013; Keye et al., 2009; Unsworth et al., 2012) does not fit with models that integrate goal maintenance and response competition. Congruency-sequence effects have been interpreted as reactive adjustments in cognitive control (Botvinick et al., 2001; Egner, 2007). Therefore in tasks where higher-WMC subjects outperform lower-WMC subjects we should see WMC-related differences on congruency-sequence effects because the superior performance should either be attributable to better proactive goal maintenance or better reactive conflict resolution. On one hand, if the cause is better goal maintenance, then higher-WMC subjects should have smaller congruency-sequence effects than lower-WMC subjects. On the other hand if the cause is better conflict resolution higher-WMC subjects should show larger congruency-sequence effects than lower-WMC subjects. As stated previously, when WMC-related differences have been found, lower-WMC subjects have shown larger adjustments than higher-WMC subjects suggesting superior goal maintenance abilities by the higher-WMC subjects. But these WMC-related reactive adjustments have not been consistently found and when they are, they have not been shown to mediate task performance. Thus, the support from studies of WMC variation for models of cognitive control that propose tight integration between goal maintenance and conflict resolution processes is limited.

WMC-related differences in low-congruency Stroop tasks have been one of the primary sources of evidence for WMC and conflict-resolution relations, but it may be that low-congruency tasks measure the activation state of the goal whereas 50% congruency tasks obscure both measures of goal maintenance and goal strength. My speculation on goal maintenance abilities and their role in the pattern of results seen is tempered by the low reliabilities observed in most of the measures used here. Low reliability will limit the strength of any potential relations. However, it is notable that in the Experiments 1, 2A, and 2B which produced consistent interpretable results, the reliability of the measures is not remarkably different than those observed in the Experiment 3 tasks (see Table 14). What is clear from the work presented here is that WMC-performance relations were not consistently related to the interference classifications derived from the Kornblum taxonomy across different tasks.

Tasks (or trial sets) that were grouped together by the Kornblum taxonomy (e.g., numerosity trials, Simon trials, S-R trials with left-right arrows, and S-R trials with up-down arrows) also produced different patterns of interference effects depicted in the delta plots. In Dimensional Overlap theory, the amount of overlap between stimulus sets (and elements within those sets) affects the amount of interference produced, but there is nothing in the model that predicts why we would see an ascending pattern of interference effects in a numerosity task and the vertically-oriented S-R trials, but a descending pattern of interference in a Simon task. Although, in the Kornblum framework, these tasks are equivalent in the type of interference presented (S-R), if we work under the assumption that the time course of interference effects reflects underlying mechanisms used to counter the interference, these tasks do not seem to tap the same mechanism. This limits the utility of the Kornblum taxonomy because, although the taxonomy does describe on one dimension how interference is being caused, it seems to tell us little about how people resolve conflict.

Moreover, the latent variable analyses provided strong evidence that the conflict tasks used here were not able to detect stable individual differences in information processing across tasks. The poor reliabilities from the conflict scores could indicate inconsistent ways of handling interference within individuals or that within-task correlations between congruent and incongruent trials (see Table 10) prohibit our ability to pick up on patterns of across-task covariation. In light of the heterogeneity of the time-course of interference effects across tasks seen in the delta plots, I prefer an interpretation that combines both the within-subject and within-task explanations. That is, the low reliability scores were produced by task-related (and not WMC-related or conflict-type related) intrapersonal inconsistencies in the deployment of control processes.

We may only consistently see WMC and attention relations in tasks that tax goal maintenance abilities therefore producing larger WMC-related performance differences. Prior work with latent variables that has shown robust associations between WMC and executive attention have included conflict measures in their executive attention latent factor (Unsworth & Spillers, 2010; McVay & Kane, 2012; Shipstead, Lindsay, Marshall, & Engle, 2014). Notably, in all of these investigations the conflict tasks presented at least 66% congruent trials –stressing goal maintenance abilities. Yet, even with this high proportion of congruent trials, measures from these tasks often load weakly onto their respective latent variables. Without their emphasis on goal maintenance abilities, I suggest these tasks would load even more weakly. If WMC and attention task relations can be boiled down to just proactive, goal-maintenance abilities, some specificity in the WMC and attention relations will be achieved. Future work using latent variable analyses should test this hypothesis by probing for a latent goal maintenance factor across a diverse array of tasks with low, medium, and high proportion congruencies. If high and low proportion congruency tasks tap goal maintenance and strength factors respectively they should either load onto the same latent factor or separate latent factors that have a moderate to high correlation while the medium proportion congruency tasks should not load well on either latent factor.

Conclusions

From the evidence provided here, it appears that the relationship between attentional (or executive) control and WMC is in need of further scrutiny to determine how and under what circumstances WMC interfaces with cognitive control. A metaanalytic approach to examining WMC-attentional control relations in the literature could provide an estimate of the overall relation between the constructs. However, this task will be complicated because a majority of the earlier work demonstrating the relationship used extreme group designs (e.g., upper quartile vs. lower quartile) which result in inflated effect sizes (Preacher, Rucker, MacCallum, & Nicewander, 2005). Therefore, it will be most helpful if all future work investigating WMC and executive control relations uses designs that accurately represent the continuous nature of the WMC construct and provides more accurate effect sizes. A meta-analysis with the use of funnel-plots may also be able to provide evidence of a file-drawer effect in investigating these relations. Perhaps, the file drawer is obscuring our ability to view the full pattern of how WMC relates to tasks that require attentional control.

The work here highlights that all interference is not the same — a point understood by many but nonetheless worth repeating — and researchers should be guarded when making broad claims based on results from one or two tasks. In addition, the present studies exemplify the utility of both direct and conceptual replications. Experiment 2A was (almost) a direct replication of Experiment 1. Experiment 2A confirmed the findings of Experiment 1 that in a task which displays up-down arrows at different screen locations higher-WMC subjects are better than lower-WMC subjects at handling one type of interference but perform worse than lower-WMC subjects at handling another type. The working hypothesis after Experiment 2A was that WMC has unique relations to both S-S interference (e.g., higher-WMC produces better performance) and S-R interference (e.g., higher-WMC produces worse performance).

The failed conceptual replications in Experiment 3 provide strong evidence that factors (e.g., goal maintenance abilities) other than (or in addition to) dimensional overlap must have produced the interaction with WMC that led to performance differences

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APPENDIX A

TABLES AND FIGURES

Table 1

Experiment 1 Descriptive Statistics

Trial Category/DV	Trial Type	*M*	Std Err	Min	Max	Skew	Kurtosis
Pure/RT	S-R congruent	457	4	310	629	0.48	-0.16
	S-R incongruent	502	4	351	708	0.46	-0.16
	S-S congruent	471	4	322	633	0.41	-0.32
	S-S incongruent	509	4	376	742	0.63	0.24
Pure/ER	S-R congruent	0.04	0.00	0.00	0.16	1.64	3.59
	S-R incongruent	0.13	0.01	0.00	0.48	1.16	1.94
	S-S congruent	0.04	0.00	0.00	0.20	1.50	2.60
	S-S incongruent	0.10	0.00	0.00	0.49	1.53	4.68
Combination/RT	S-R con/ S-S con	453	4	283	646	0.36	-0.26
	S-R incon/S-S con	480	4	342	666	0.58	0.08
	S-R con/S-S incon	490	5	324	749	0.66	0.51
	S-R incon/S-S incon	516	4	373	791	0.68	0.75
Combination/ER	S-R con/S-S con	0.03	0.00	0.00	0.20	1.78	3.56
	S-R incon /S-S con	0.06	0.00	0.00	0.25	1.31	1.41
	S-R con/S-S incon	0.09	0.00	0.00	0.38	1.31	2.04
	S-R incon/S-S incon	0.14	0.01	0.00	0.50	0.96	1.40

Note: DV = dependent variable; *M* = mean of subject means; ER = error rate; RT = response time; Std Err = standard error; S-S = stimulus-stimulus; S-R = stimulus-response; Con = congruent; Incon = incongruent.

Table 2

Experiment 2A Descriptive Statistics

DV	Trial Type	*M*	Std Err	Min	Max	Skew	Kurtosis
RT	S-R congruent	477	5	351	662	0.44	0.28
	S-R incongruent	520	6	384	733	0.51	0.36
	S-S congruent	493	6	343	683	0.27	-0.14
	S-S incongruent	528	6	404	710	0.36	-0.23
ER	S-R congruent	0.04	0.00	0.00	0.14	1.18	0.78
	S-R incongruent	0.13	0.01	0.01	0.38	0.74	-0.10
	S-S congruent	0.05	0.00	0.00	0.18	1.14	0.79
	S-S incongruent	0.10	0.01	0.01	0.29	0.94	0.79

Note: DV = dependent variable; *M* = mean of subject means; RT = response time; ER = error rate; Std Err = standard error; S-S = stimulus-stimulus; S-R = stimulus-response.

Table 3

Experiment 2B Descriptive Statistics

DV	Trial Type	*M*	Std Err	Min	Max	Skew	Kurtosis
RT	S-R congruent	435	5	338	602	0.69	0.23
	S-R incongruent	518	7	376	711	0.44	-0.13
	S-S congruent	455	6	350	661	0.71	0.46
	S-S incongruent	522	7	393	782	0.69	0.75
ER	S-R congruent	0.02	0.00	0.00	0.11	1.59	2.93
	S-R incongruent	0.26	0.01	0.04	0.60	0.56	0.10
	S-S congruent	0.04	0.00	0.00	0.14	0.99	0.68
	S-S incongruent	0.16	0.01	0.02	0.50	0.90	0.47

Note: DV = dependent variable; *M* = mean of subject means; RT = response time; ER = error rate; Std Err = standard error; S-S = stimulus-stimulus; S-R = stimulus-response.

Table 4

Experiment 3 Task Order for the Two Sessions

	Session 1	Session 2
1)	Operation Span	Flanker
2)	Joystick Replication	Divergent Thinking
3)	Divergent Thinking	Symmetry Span
4)	Fluid Intelligence	Up-Down Numerosity
5)	Divergent Thinking	Divergent Thinking
6)	Numerosity	Fluid Intelligence
7)	Fluid Intelligence	Axis -shifted Joystick
8)	Up-Down Arrows	Fluid Intelligence
9)	Updating	Reading Span
10)	Simon	

Table 5

Correlation Matrix for Experiment 3 Working Memory Measures

	OSPAN	SSPAN	RSPAN	Updating
OSPAN	0.81			
SSPAN	0.44	0.70		
RSPAN	0.43	0.40	0.73	
Updating	0.39	0.25	0.28	0.85

Note: Values on the diagonal reflect Cronbach's alpha for each measure as a reliability estimate; alphas were calculated from proportion recall on every trial (Redick et al., 2012). OSPAN = Operation Span; SSPAN = Symmetry Span; RSPAN = Reading Span

Table 6

Experiment 3 Descriptive Statistics for Working Memory Measures

	M	*SD*	Min	Max	Skew	Kurtosis
OSPAN	54.2	13.0	6	74	-0.96	0.68
SSPAN	28.6	7.3	7	42	-0.54	-0.05
RSPAN	36.4	10.4	9	58	-0.24	-0.57
Updating	0.41	0.16	0.08	0.92	0.41	-0.24

Note: OSPAN = Operation Span; SSPAN = Symmetry Span; RSPAN = Reading Span

Table 7

Experiment 3 Dual-Conflict Task Descriptive Statistics

Task	DV	Trial Type	*M*	Std Err	Min	Max	Skew	Kurtosis
Joystick Rep	RT	S-R congruent	492	9	327	847	1.28	1.75
		S-R incongruent	537	10	343	904	1.35	1.72
		S-S congruent	525	9	352	1043	1.57	3.92
		S-S incongruent	556	10	372	1247	2.14	8.28
	ER	S-R congruent	0.03	0.00	0.00	0.32	3.82	22.88
		S-R incongruent	0.14	0.01	0.00	0.62	1.09	1.31
		S-S congruent	0.05	0.00	0.00	0.18	1.02	0.35
		S-S incongruent	0.07	0.01	0.00	0.30	1.18	0.99
Axis-Shifted	RT	S-R congruent	541	7	365	864	0.94	0.83
		S-R incongruent	577	8	342	1433	2.06	10.83
		S-S congruent	567	7	341	999	1.06	1.65
		S-S incongruent	586	7	292	964	1.08	1.81
		S-R congruent	0.13	0.01	0.00	0.66	1.38	1.83

		S-R incongruent	0.19	0.01	0.00	0.59	0.69	-0.33
		S-S incongruent	0.15	0.01	0.00	0.56	1.15	0.84
UDN	RT	S-R congruent	485	4	364	683	0.39	-0.25
		S-R incongruent	523	5	371	719	0.21	-0.59
		S-S congruent	512	5	365	689	0.25	-0.59
		S-S incongruent	531	5	390	750	0.29	-0.36
	ER	S-R congruent	0.04	0.00	0.00	0.26	2.39	7.76
		S-R incongruent	0.10	0.01	0.00	0.40	1.28	1.74
		S-S congruent	0.06	0.00	0.00	0.29	1.85	4.00
		S-S incongruent	0.09	0.00	0.00	0.39	1.52	3.33

Note: DV = dependent variable; *M* = mean of subject means; RT = response time; ER = error rate; Std Err = standard error; S-S = stimulus-stimulus; S-R = stimulus-response.

Table 8

Experiment 3 Single-Conflict Task Descriptive Statistics

Task	DV	Trial Congruency	M	Std Err	Min	Max	Skew	Kurtosis
Numerosity	RT	Congruent	455	4	332	640	0.64	0.20
		Incongruent	513	5	336	758	0.51	0.09
	ER	Congruent	0.02	0.00	0.00	0.15	1.82	4.02
		Incongruent	0.11	0.01	0.00	0.55	1.96	6.83
Simon	RT	Congruent	439	3	319	607	0.46	0.43
		Incongruent	463	3	348	621	0.44	0.06
	ER	Congruent	0.05	0.00	0.00	0.22	1.27	2.24
		Incongruent	0.08	0.00	0.00	0.40	1.29	2.33
Flanker	RT	Congruent	445	3	348	632	1.01	1.51
		Incongruent	492	3	390	647	0.43	0.13
	ER	Congruent	0.03	0.00	0.00	0.17	1.68	3.35
		Incongruent	0.09	0.00	0.00	0.38	1.20	1.49
UD Arrows	RT	Congruent	482	4	351	648	0.43	-0.11

	Incongruent	501	4	381	681	0.38	-0.05
ER	Congruent	0.04	0.00	0.00	0.18	1.15	1.11
	Incongruent	0.07	0.00	0.00	0.35	1.54	3.15

Note: DV = dependent variable; *M* = mean of subject means; RT = response time; ER = error rate; Std Err = standard error; S-S = stimulus-stimulus; S-R = stimulus-response; UD = Up-Down.

Table 9

Correlation Matrix for Residual Scores

	1	2	3	4	5	6	7	8	9	10
1. Flanker (S-S)	0.65									
2. Axis-Shifted S-S	-0.02	0.38								
3. Up-Down (S-S)	0.12	0.04	0.48							
4. Joystick Rep S-S	0.04	0.06	0.17	0.35						
5. UDN S-S	-0.05	-0.03	0.21	0.12	0.37					
6. Axis-Shifted S-R	0.12	0.08	0.09	0.07	0.08	0.96				
7. Numerosity (S-R)	0.06	-0.01	0.03	0.05	0.04	-0.07	0.48			
8. Simon (S-R)	0.15	0.04	0.22	0.07	0.12	0.06	0.10	0.47		
9. Joystick Rep S-R	0.12	0.19	0.10	0.14	-0.02	0.13	0.17	0.17	0.89	
10. UDN S-R	-0.05	0.05	-0.02	0.05	0.08	0.00	0.35	-0.02	0.16	0.66

Note: Values on the diagonal reflect Cronbach's alpha for each measure as a reliability estimate; alphas were calculated from residual scores on odd and even trials. Up-Down = Up-Down Arrows Task; Joystick Rep = Joystick Replication Task; UDN = Up-Down Numerosity Task; S-S = Stimulus-Stimulus Conflict; S-R = Stimulus-Response Conflict.

Table 10

Correlation Matrix for WMC Scores and Response Times

	1	2	3	4	5	6	7	8	9	10
1. OSPAN	1									
2. SSPAN	0.44	1								
3. RSPAN	0.43	0.40	1							
4. Updating	0.39	0.25	0.28	1						
5. Flanker Con	-0.17	-0.17	-0.13	-0.22	1					
6. Flanker Incon	-0.17	-0.22	-0.12	-0.19	0.89	1				
7. Axis-Shifted S-S Con	-0.02	-0.04	-0.14	-0.15	0.33	0.30	1			
8. Axis-Shifted S-S Incon	0.00	-0.03	-0.09	-0.16	0.38	0.34	0.95	1		
8. Axis-Shifted S-R Con	0.02	-0.03	-0.11	-0.15	0.37	0.31	0.89	0.91	1	

8. Axis-Shifted S-R Incon	0.00	0.00	-0.05	-0.12	0.35	0.33	0.88	0.90	0.77	1
11. Numerosity Con	-0.09	-0.11	-0.05	-0.18	0.48	0.45	0.40	0.44	0.39	0.38
12. Numerosity Incon	-0.07	-0.16	-0.08	-0.17	0.45	0.44	0.36	0.40	0.35	0.33
13. Simon Con	-0.11	-0.02	-0.02	-0.20	0.48	0.42	0.30	0.30	0.31	0.26
14. Simon Incon	-0.12	-0.06	-0.04	-0.25	0.48	0.46	0.31	0.32	0.33	0.29
15. Up-Down Con	-0.09	-0.16	-0.08	-0.20	0.63	0.56	0.41	0.43	0.43	0.36
16. Up-Down Incon	-0.12	-0.18	-0.11	-0.24	0.62	0.57	0.43	0.45	0.43	0.38
17. Joystick Rep S-S Con	0.00	0.02	-0.03	-0.17	0.40	0.32	0.48	0.51	0.52	0.35
18. Joystick Rep S-S Incon	-0.01	0.01	-0.05	-0.20	0.43	0.36	0.48	0.50	0.51	0.36
19, Joystick Rep S-R Con	0.00	0.03	-0.05	-0.17	0.43	0.33	0.50	0.51	0.53	0.38
20. Joystick Rep S-R Incon	0.02	0.01	-0.02	-0.18	0.41	0.33	0.49	0.51	0.51	0.38
21. UDN S-S Con	0.02	-0.10	-0.02	-0.13	0.57	0.53	0.54	0.58	0.52	0.56

22. UDN S-S Incon	-0.01	-0.12	-0.01	-0.17	0.58	0.53	0.53	0.57	0.50	0.55
23. UDN S-R Con	0.00	-0.11	-0.02	-0.17	0.59	0.55	0.53	0.57	0.52	0.54
24. UDN S-R Incon	0.01	-0.13	-0.02	-0.18	0.60	0.55	0.53	0.57	0.51	0.54

11	12	13	14	15	16	17	18	19	20	21	22	23	24
1													
0.91	1												
0.56	0.54	1											
0.61	0.60	0.88	1										
0.65	0.60	0.62	0.65	1									
0.64	0.60	0.59	0.66	0.93	1								

0.47	0.47	0.44	0.48	0.62	0.64	1							
0.51	0.50	0.45	0.50	0.62	0.66	0.96	1						
0.47	0.44	0.42	0.46	0.61	0.64	0.94	0.92	1					
0.51	0.49	0.45	0.50	0.62	0.65	0.95	0.94	0.95	1				
0.69	0.64	0.42	0.47	0.63	0.62	0.47	0.49	0.46	0.46	1			
0.69	0.65	0.44	0.50	0.62	0.64	0.47	0.50	0.47	0.47	0.96	1		
0.69	0.63	0.43	0.49	0.61	0.62	0.47	0.49	0.47	0.47	0.97	0.97	1	
0.70	0.68	0.46	0.51	0.63	0.63	0.49	0.51	0.47	0.48	0.95	0.96	0.96	1

Note: OSPAN = Operation Span; SSPAN = Symmetry Span; RSPAN = Reading Span; Con = Congruent; Incon = Incongruent; Rep = Replication; UDN = Up-Down Numerosity Task; S-S = Stimulus-stimulus; S-R = Stimulus-response

Table 11

Factor Loadings for Exploratory Factor Analysis on Response Time Residuals

Dependent Variable	Factor 1	Factor 2	Factor 3	Factor 4
Flanker S-S	0.07	0.06	-0.11	**0.41**
Axis-shifted S-S	-0.10	0.34	0.00	-0.08
Axis-shift S-R	-0.13	0.21	0.10	0.10
Numerosity S-R	**0.98**	-0.01	0.00	0.01
Simon S-R	0.07	0.12	0.15	0.35
Up-Down Arrows S-S	-0.01	0.07	0.34	0.32
Joystick Replication S-S	-0.02	0.19	0.22	0.05
Joystick Replication S-R	0.00	**0.67**	-0.03	0.03
UDN Arrows S-S	0.00	-0.05	**0.62**	-0.03
UDN Arrows S-R	0.28	0.22	0.12	-0.28

Note: Factor loadings over .40 are bolded to indicate a moderate to high loading; UDN = Up-Down Arrow Numerosity Task; S-S = Stimulus-Stimulus; S-R = Stimulus-Response.

Table 12

Factor Loadings for Exploratory Factor Analysis on Raw Response Times

Trial Type	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5
Flanker Congruent	-0.01	0.03	0.00	-0.02	**0.99**
Flanker Incongruent	0.02	-0.05	0.02	0.03	**0.88**
Axis-shifted S-S Congruent	-0.01	0.03	**0.96**	0.02	-0.04
Axis-shifted S-S Incongruent	0.01	0.03	**0.97**	-0.01	0.01
Axis-shifted S-R Congruent	-0.05	0.10	**0.88**	0.01	0.03
Axis-shifted S-R Incongruent	0.08	-0.14	**0.92**	0.01	0.03
Numerosity Congruent	**0.50**	0.09	0.00	0.36	-0.03
Numerosity Incongruent	**0.47**	0.11	-0.03	0.37	-0.04
Simon Congruent	-0.06	-0.02	0.04	**0.92**	0.05
Simon Incongruent	0.02	0.02	0.01	**0.93**	0.00
Up-Down Arrows Congruent	0.19	0.29	-0.02	0.33	0.25
Up-Down Arrows Incongruent	0.20	0.33	-0.01	0.31	0.22
Joystick Replication S-S Congruent	0.02	**0.99**	0.00	-0.01	-0.03
Joystick Replication S-S Incongruent	0.03	**0.94**	-0.01	0.01	0.01
Joystick Replication S-R Congruent	-0.02	**0.97**	0.03	-0.04	0.04

Joystick Replication S-R Incongruent	-0.01	**0.96**	0.03	0.03	-0.02
Up-Down Numerosity S-S Congruent	**0.98**	0.00	0.04	-0.03	0.00
Up-Down Numerosity S-S Incongruent	**0.98**	0.00	0.01	0.00	0.00
Up-Down Numerosity S-R Congruent	**0.97**	0.00	0.01	-0.03	0.03
Up-Down Numerosity S-R Incongruent	**0.94**	0.01	0.01	0.01	0.03

Note: Factor loadings over .40 are bolded to indicate a moderate to high loading. S-S = Stimulus-stimulus; S-R = Stimulus-response.

Table 13

Working Memory Capacity and Interference Interaction Model Parameters and Test Statistics

Conflict	Task	WMC × RT Int (t Value)	WMC × Err Int (Z Value)
S-S	E 1	-7 ms (5.1)	0.06 (1.1)
	E2A	-4 ms (2.4)	0.05 (1.0)
	Joystick Replication	-5 ms (1.8)	0.01 (0.2)
	Axis Shifted	3 ms (1.0)	0.08 (2.1)
	UDN	-3 ms (1.9)	-0.01 (0.9)
	Up-Down Arrows	-3 ms (1.5)	-0.15 (2.1)
	Flanker	1 ms (1.0)	0.25 (3.0)
S-R	E 1	-3 ms (0.9)	0.13 (2.3)
	E2A	-1 ms (0.7)	0.19 (3.3)
	Joystick Replication	-1 ms (0.3)	-0.17 (2.7)
	Axis Shifted	2 ms (0.6)	0.08 (2.2)
	UDN	-2 ms (1.4)	-0.01 (0.2)
	Numerosity	-6 ms (3.4)	0.18 (1.3)
	Simon	-2 ms (1.4)	-0.06 (0.8)

Note: The WMC × Error Interference parameter is reported as log odds ratio. S-S = Stimulus-Stimulus; S-R = Stimulus-Response; ms = milliseconds; Err = Errors; Int = Interference; RT = Response Time; E = Experiment; UDN = Up-Down Numerosity.

Table 14

Reliabilities and Standard Errors for Residual Scores for All Trial Types in All Experiments

Trial Type	Cronbach α	Standard Error
Experiment 1 S-S RT	0.28	0.11
Experiment 1 S-R RT	0.65	0.06
Experiment 1 S-S ER	0.54	0.07
Experiment 1 S-R ER	0.68	0.05
Experiment 2A S-S RT	0.56	0.08
Experiment 2A S-R RT	0.73	0.06
Experiment 2A S-S ER	0.47	0.09
Experiment 2A S-R ER	0.84	0.03
Experiment 2B S-S RT	0.54	0.11
Experiment 2B S-R RT	0.54	0.08
Experiment 2B S-S ER	0.47	0.13
Experiment 2B S-R ER	0.68	0.08
Joystick Replication S-S RT	0.35	0.10

Joystick Replication S-R RT	0.89	0.02
Joystick Replication S-S ER	0.49	0.08
Joystick Replication S-R ER	0.84	0.02
Axis-shifted S-S RT	0.38	0.10
Axis-shifted S-R RT	0.96	0.01
Axis-shifted S-S ER	0.20	0.12
Axis-shifted S-R ER	0.91	0.01
UDN S-S RT	0.37	0.09
UDN S-R RT	0.66	0.03
UDN S-S ER	0.00	0.00
UDN S-R ER	0.00	0.00
Flanker RT	0.65	0.05
Flanker ER	0.57	0.07
Up-down Arrows RT	0.48	0.07
Up-down Arrows ER	0.45	0.08
Simon RT	0.47	0.08

Simon ER	0.49	0.07
Numerosity RT	0.48	0.07
Numerosity ER	0.63	0.05

Note: Reliabilities calculated on residual scores from odd and even trials. S-S = Stimulus-stimulus; S-R = Stimulus-response; RT = response time; ER = Error Rate; UDN = Up-down Arrows/Numerosity

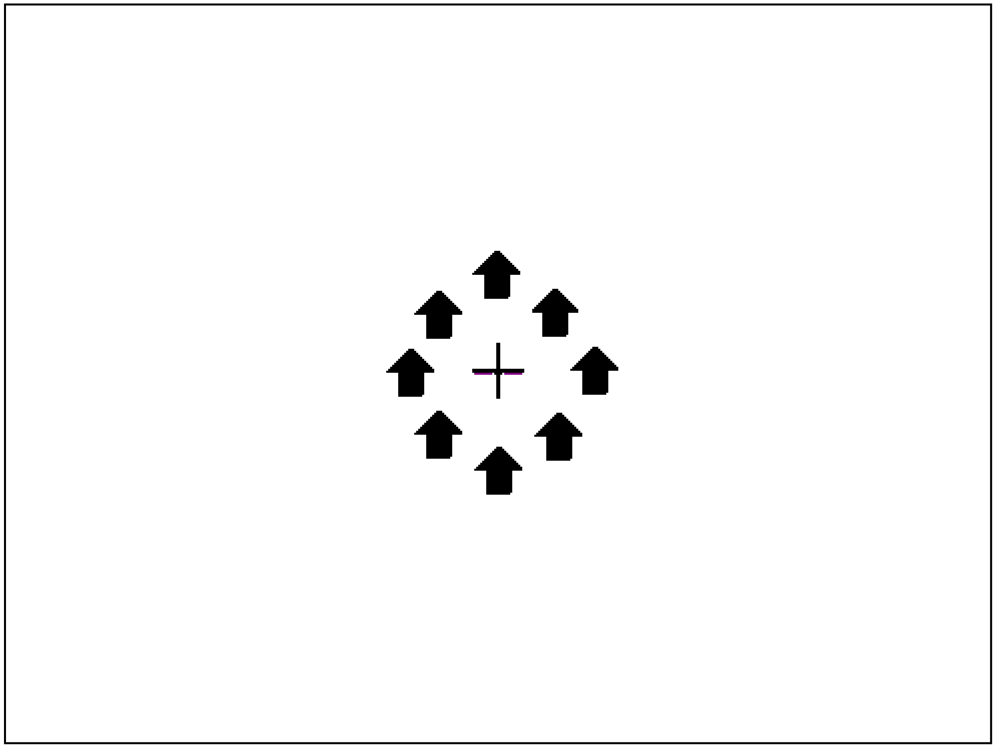
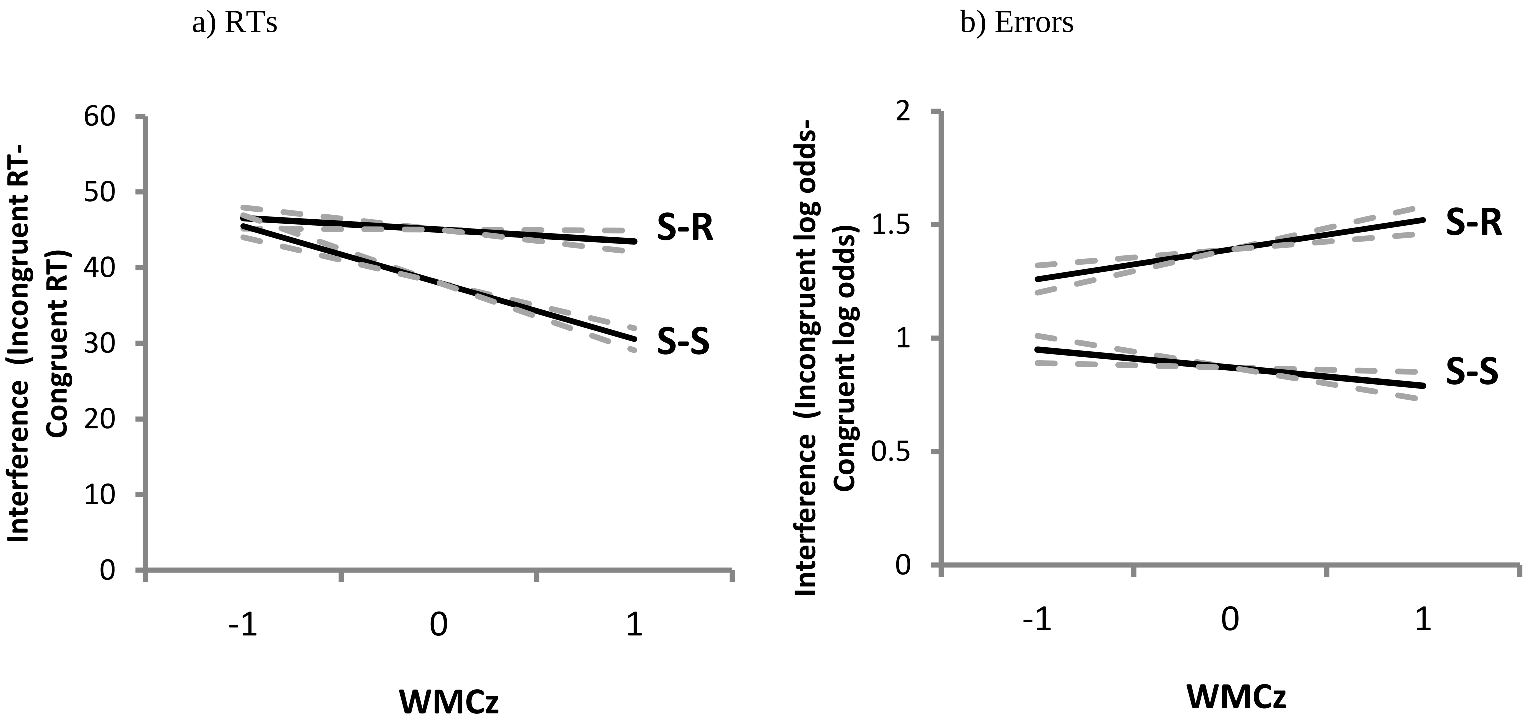


Figure 1. Eight Possible Stimulus Positions in Experiment 1. Figure not to scale.


a) RTs

b) Errors

Figure 2. Experiment 1 Model Parameters of Stimulus-Response (S-R) and Stimulus-Stimulus (S-S) Interference (Incongruent RTs/Errors – Congruent RTs/Errors) from Pure Trials as a Function of Composite Working Memory Capacity Z-score (WMCz) in Response Times (RTs; panel A) and Errors (panel B). The dotted lines represent the standard error of the estimate.

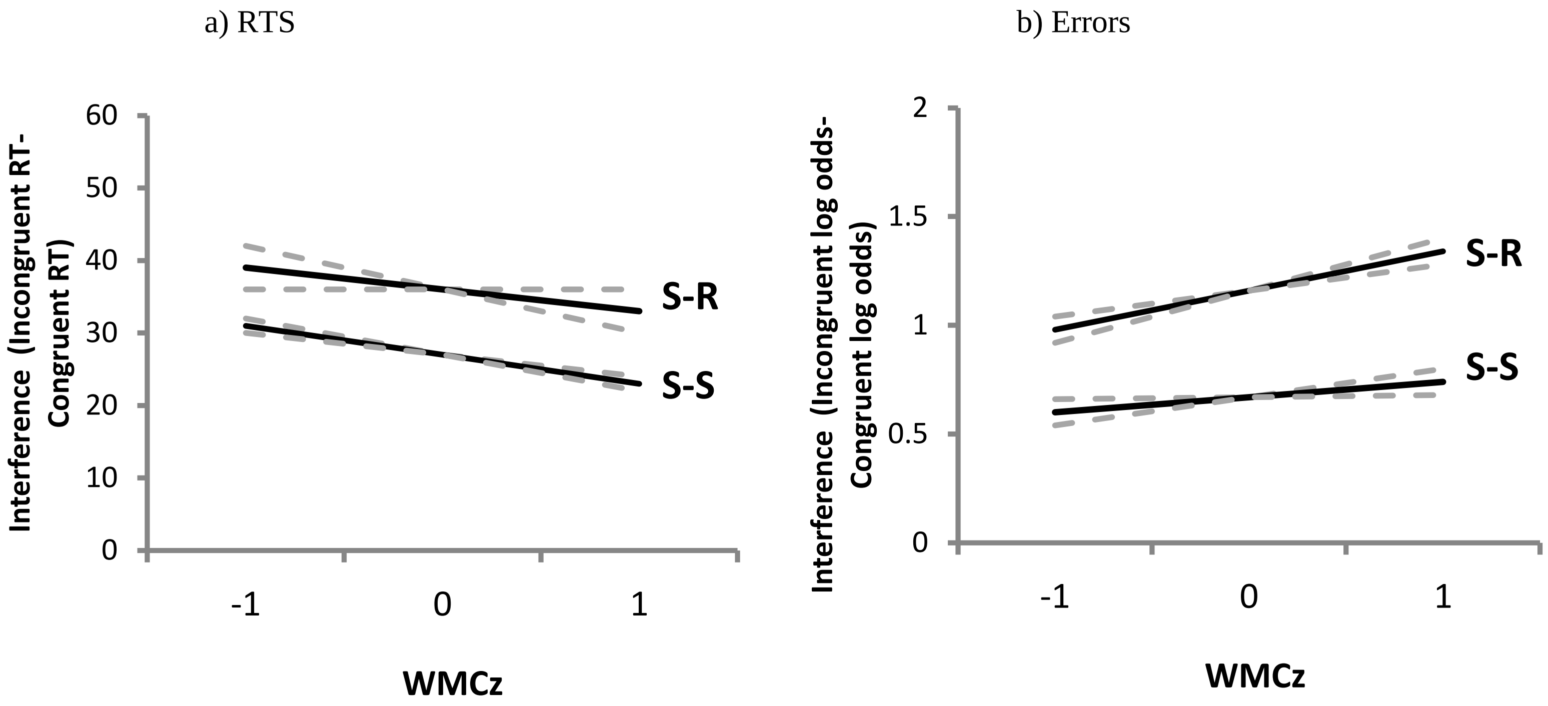


Figure 3. Experiment 1 (E1) Model Parameters of Stimulus-Response (S-R) and Stimulus-Stimulus (S-S) Interference from Combination S-S/S-R Trials as a Function of Composite Working Memory Capacity Z-score (WMCz) in Response Times (RTs; panel A) and Errors (panel B). The dotted lines represent the standard error of the estimate.

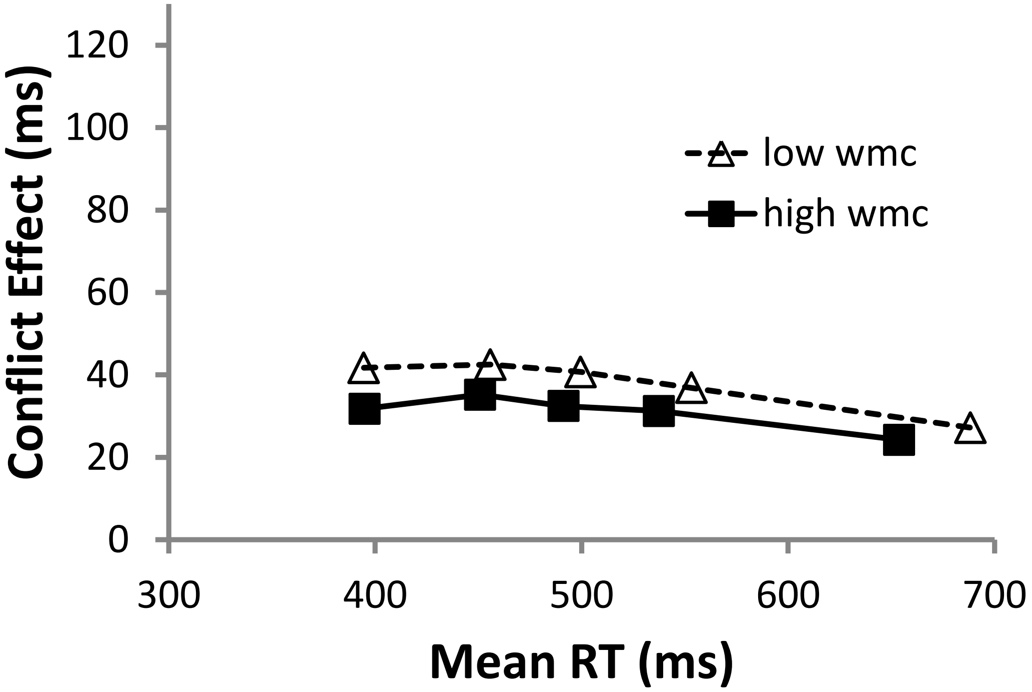


Figure 4. Delta Plot of Stimulus-Stimulus (S-S) Interference as a Function of Upper (High) and Lower (Low) Tercile of Composite Working Memory Capacity Z-score (WMC) in Experiment 1.

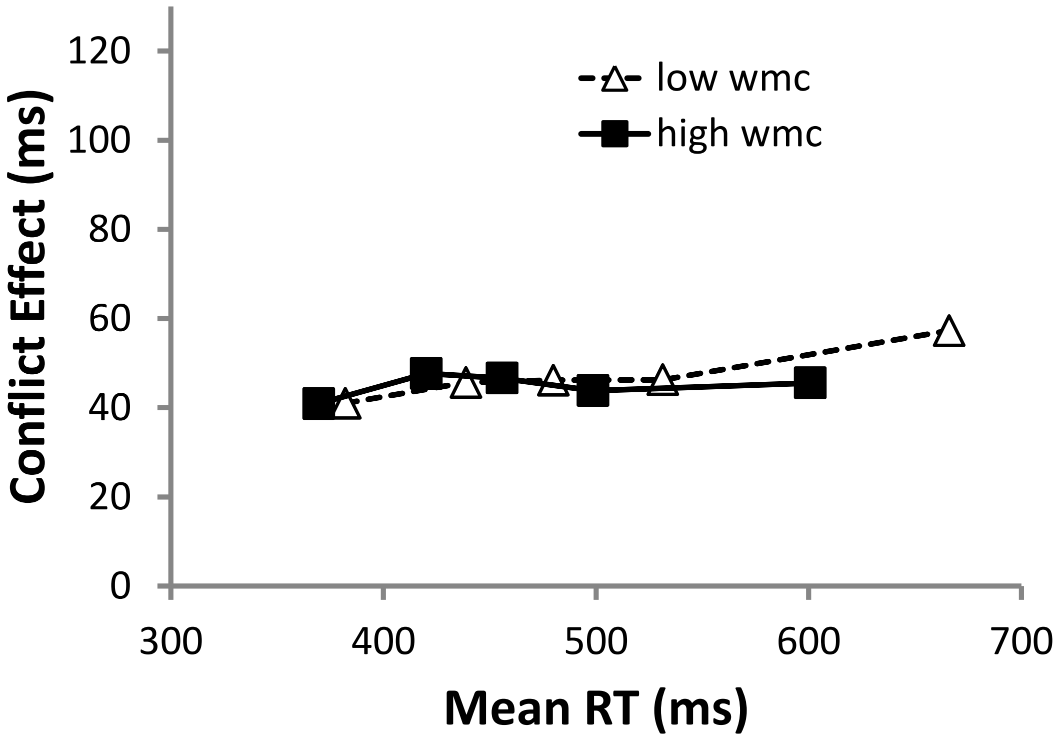
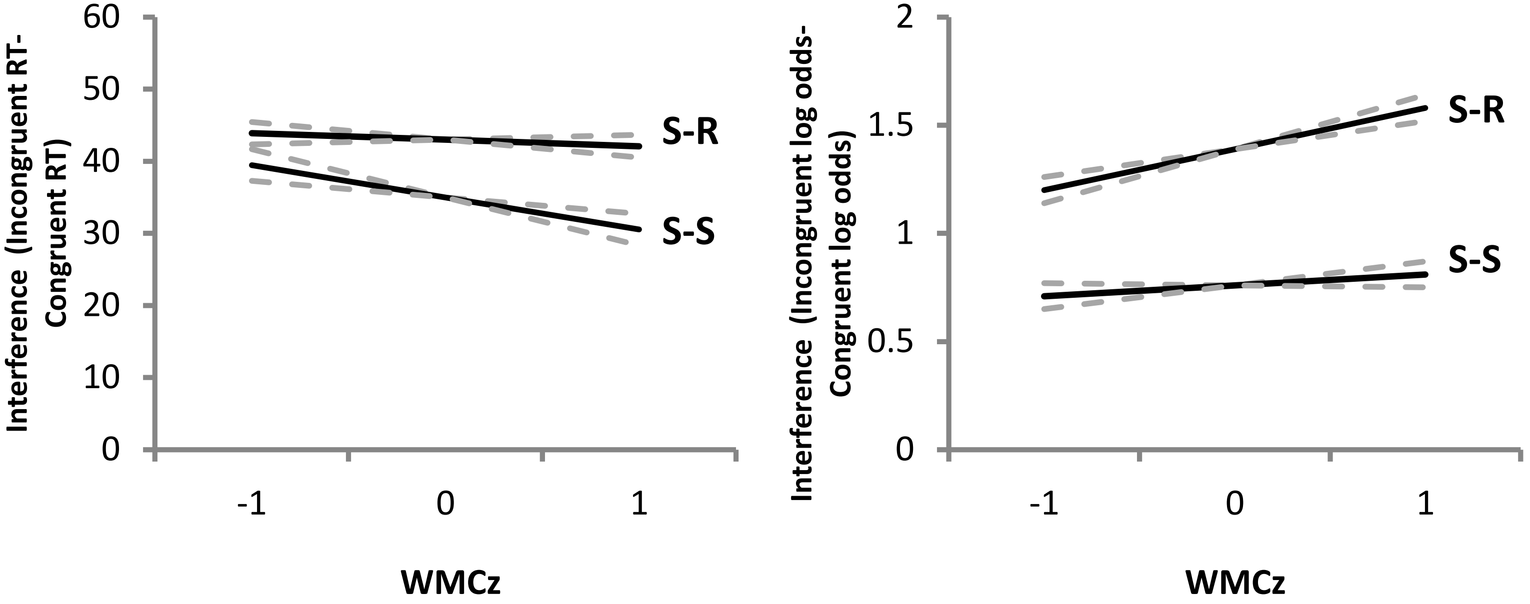


Figure 5. Delta Plot of Stimulus-Response (S-R) Interference as a Function of Upper (High) and Lower (Low) Tercile of Composite Working Memory Capacity Z-score (WMC) in Experiment 1.



a) RTs

b) Errors

Figure 6. Experiment 2A Model Parameters of Stimulus-Response(S-R) and Stimulus-Stimulus (S-S) Interference from Combination S-S/S-R Trials as a Function of Composite Working Memory Capacity Z-score (WMCz) in Response Times (RTs; panel A) and Errors (panel B). The dotted lines represent the standard error of the estimate.

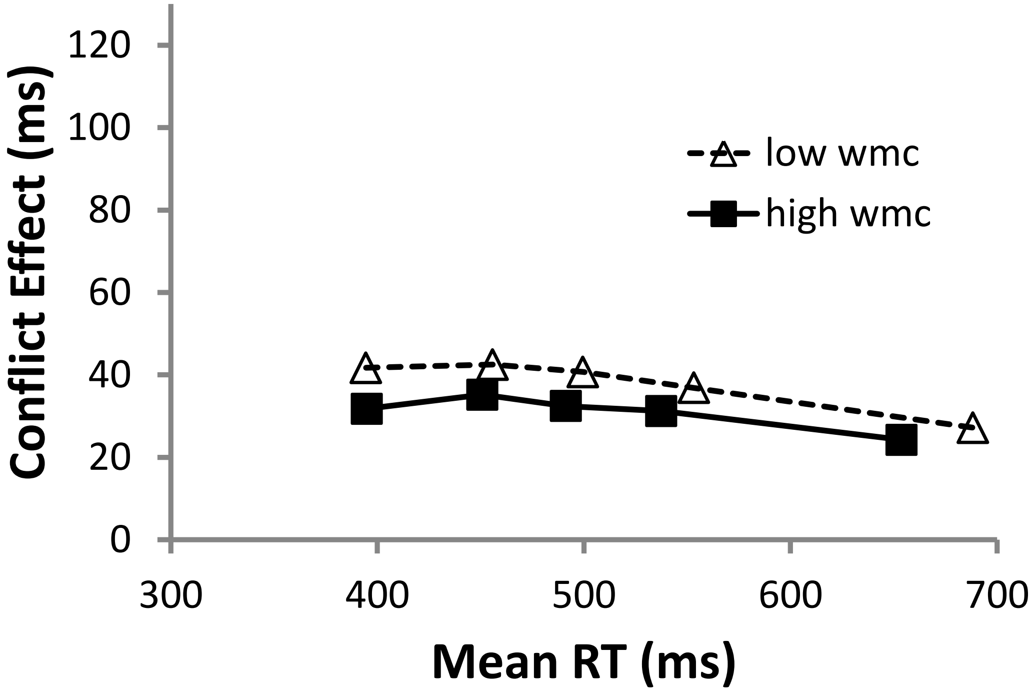


Figure 7. Delta Plot of Stimulus-Stimulus (S-S) Interference as a Function of Upper (High) and Lower (Low) Tercile of Composite Working Memory Capacity Z-score (WMC) in Experiment 2A.

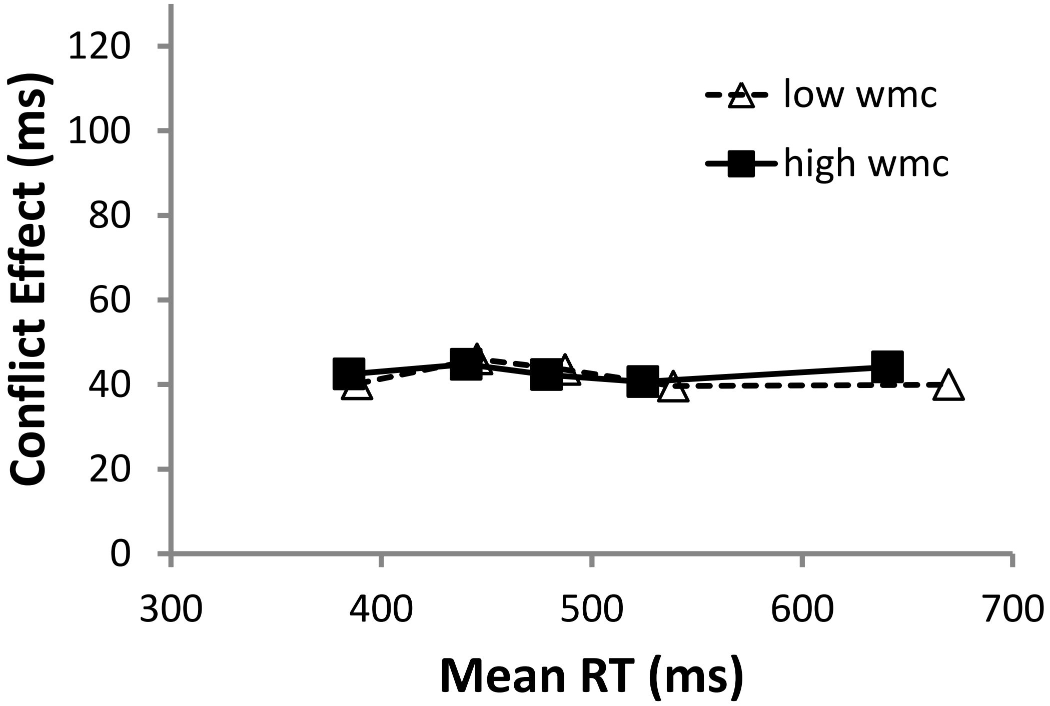
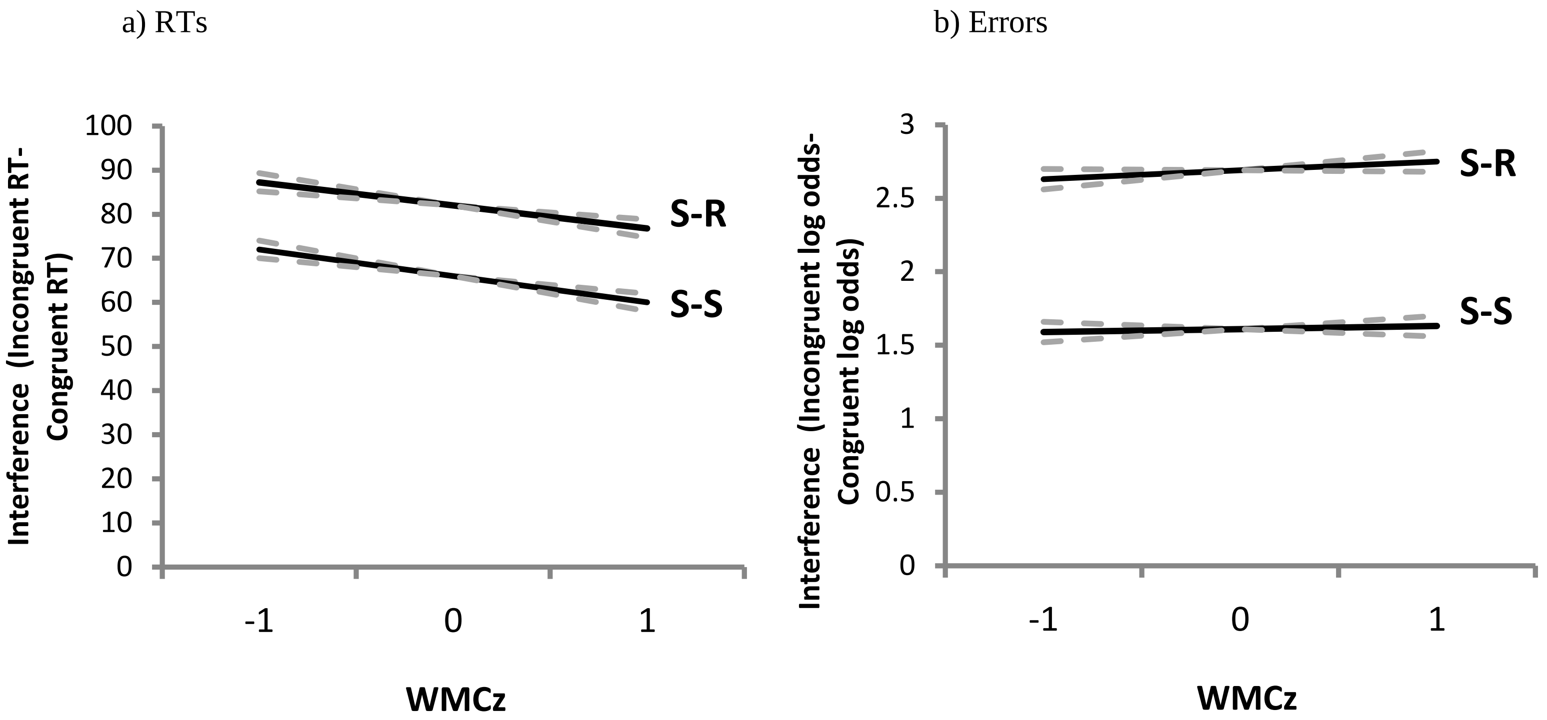


Figure 8. Delta Plot of Stimulus-Response (S-R) Interference as a Function of Upper (High) and Lower (Low) Tercile of Composite Working Memory Capacity Z-score (WMC) in Experiment 2A



a) RTs

b) Errors

Figure 9. Experiment 2A Model Parameters of Stimulus-Response (S-R) and Stimulus-Stimulus (S-S) Interference from Combination S-S/S-R Trials as a Function of Composite Working Memory Capacity Z-score (WMCz) in Response Times (RTs; panel A) and Errors (panel B). The dotted lines represent the standard error of the estimate.

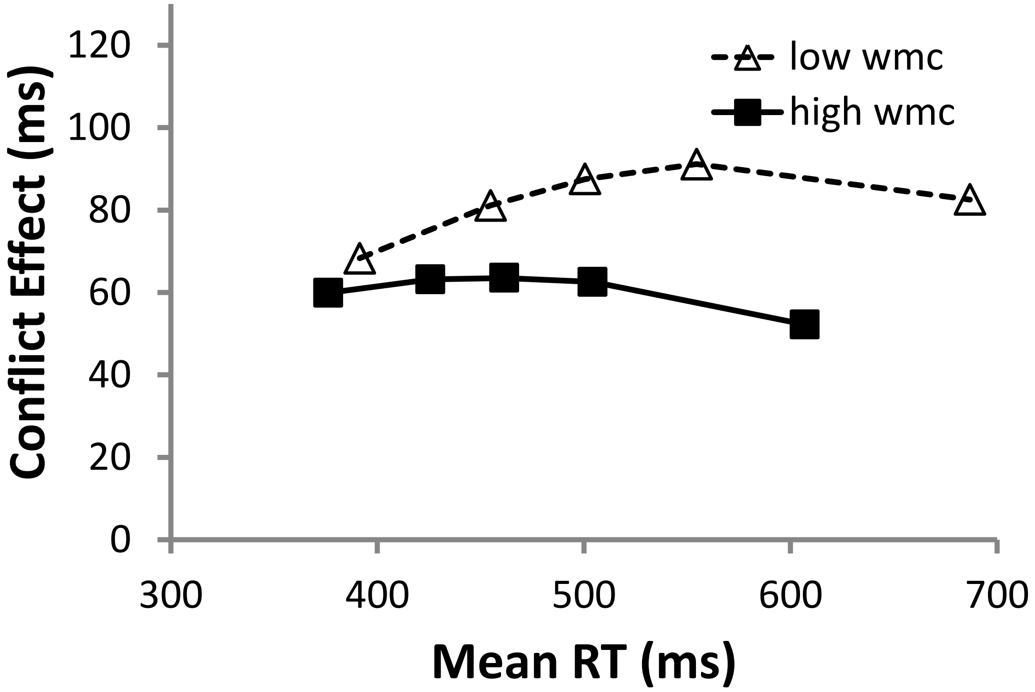


Figure 10. Delta Plot of Stimulus-Stimulus (S-S) Interference as a Function of Upper (High) and Lower (Low) Tercile of Composite Working Memory Capacity Z-score (WMC) in Experiment 2B.

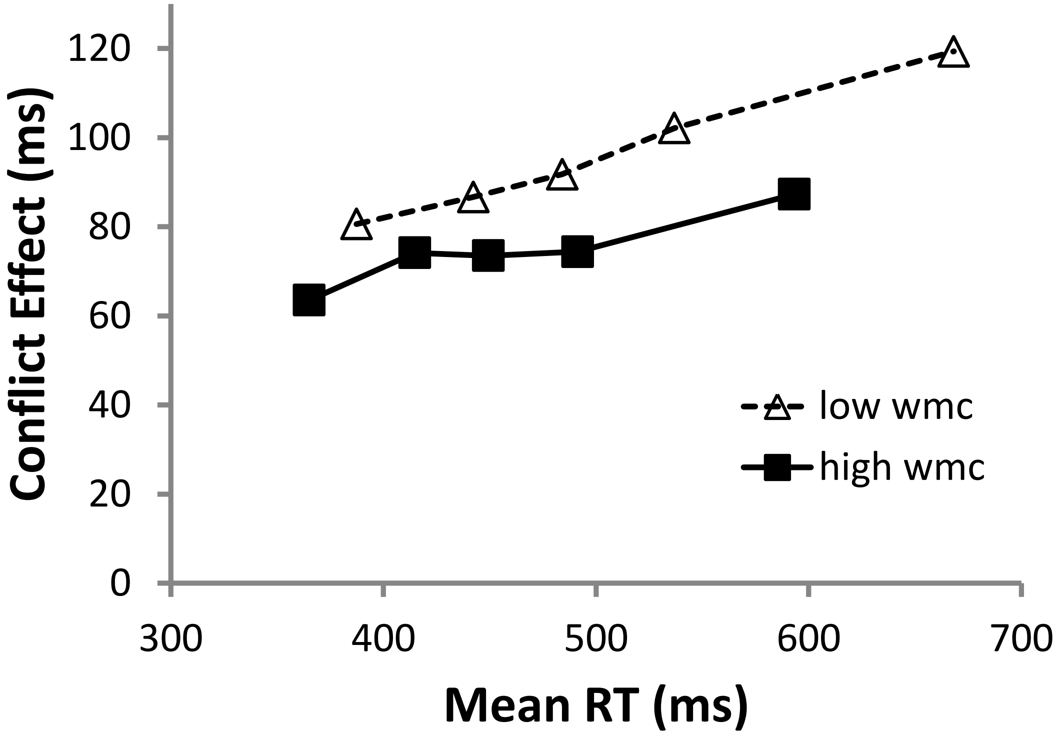
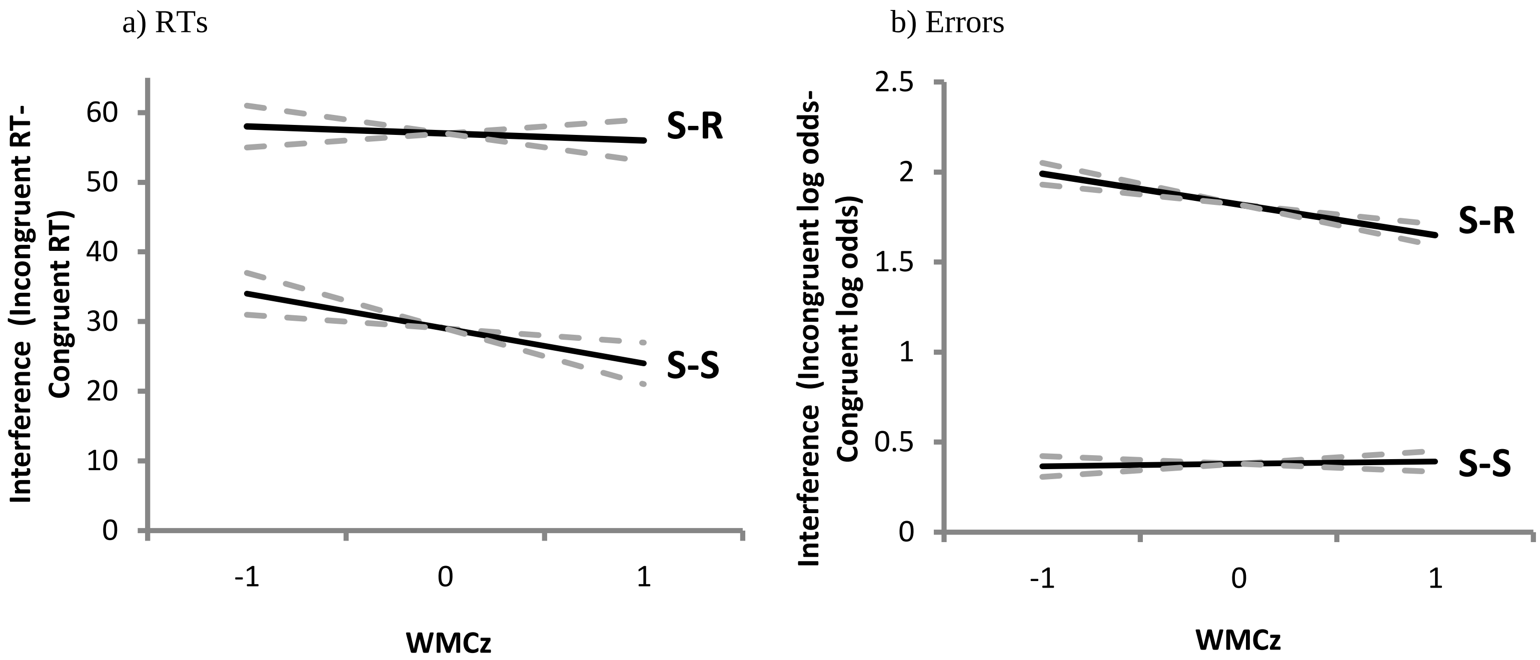


Figure 11. Delta Plot of Stimulus-Response (S-R) Interference as a Function of Upper (High) and Lower (Low) Tercile of Composite Working Memory Capacity Z-score (WMC) in Experiment 2B.


a) RTs

b) Errors

Figure 12. Experiment 3 Joystick Replication Model Parameters of Stimulus-Response (S-R) and Stimulus-Stimulus (S-S) Interference from Combination S-S/S-R Trials as a Function of Composite Working Memory Capacity Z-score (WMCz) in Response Times (RTs; panel A) and Errors (panel B). The dotted lines represent the standard error of the estimate.

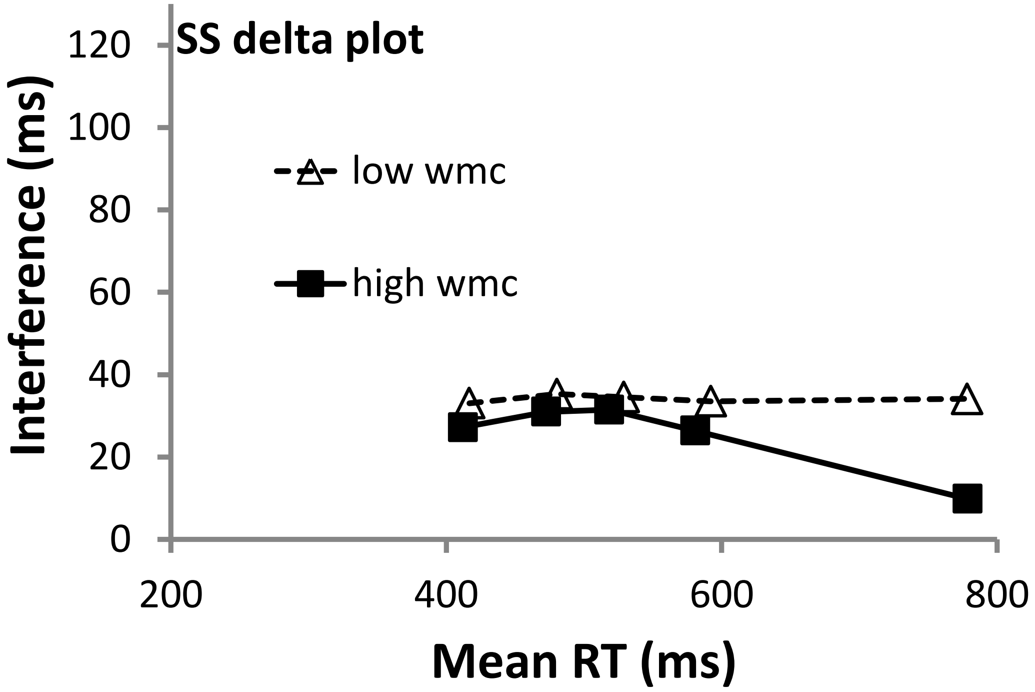


Figure 13. Delta Plot of Stimulus-Stimulus (S-S) Interference as a Function of Upper (High) and Lower (Low) Tercile of Composite Working Memory Capacity Z-score (WMC) in Experiment 3 Joystick Replication task.

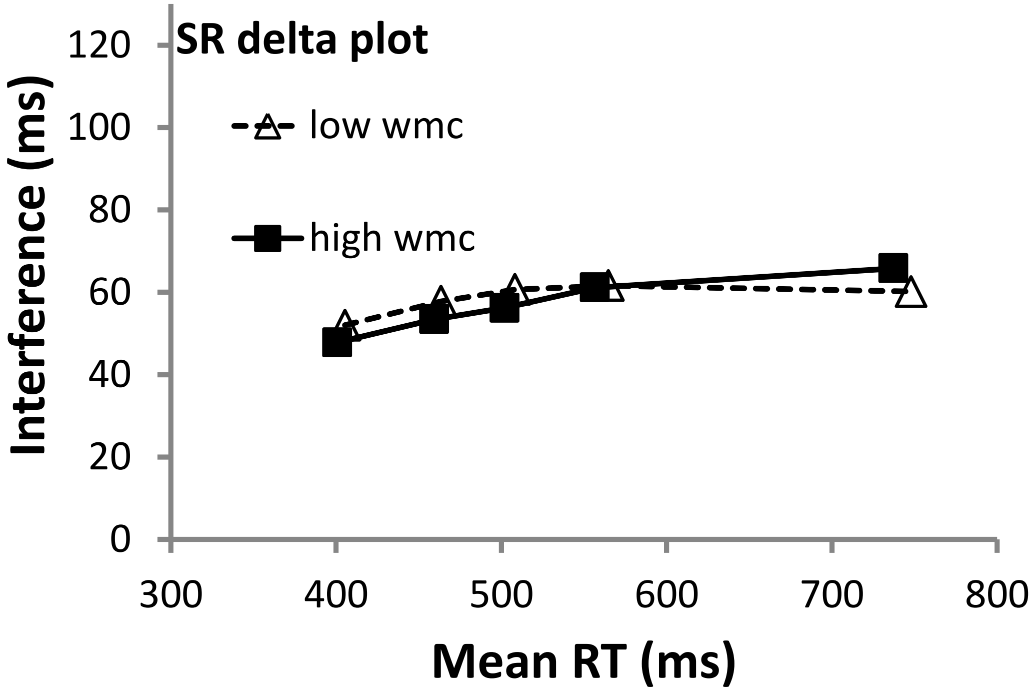
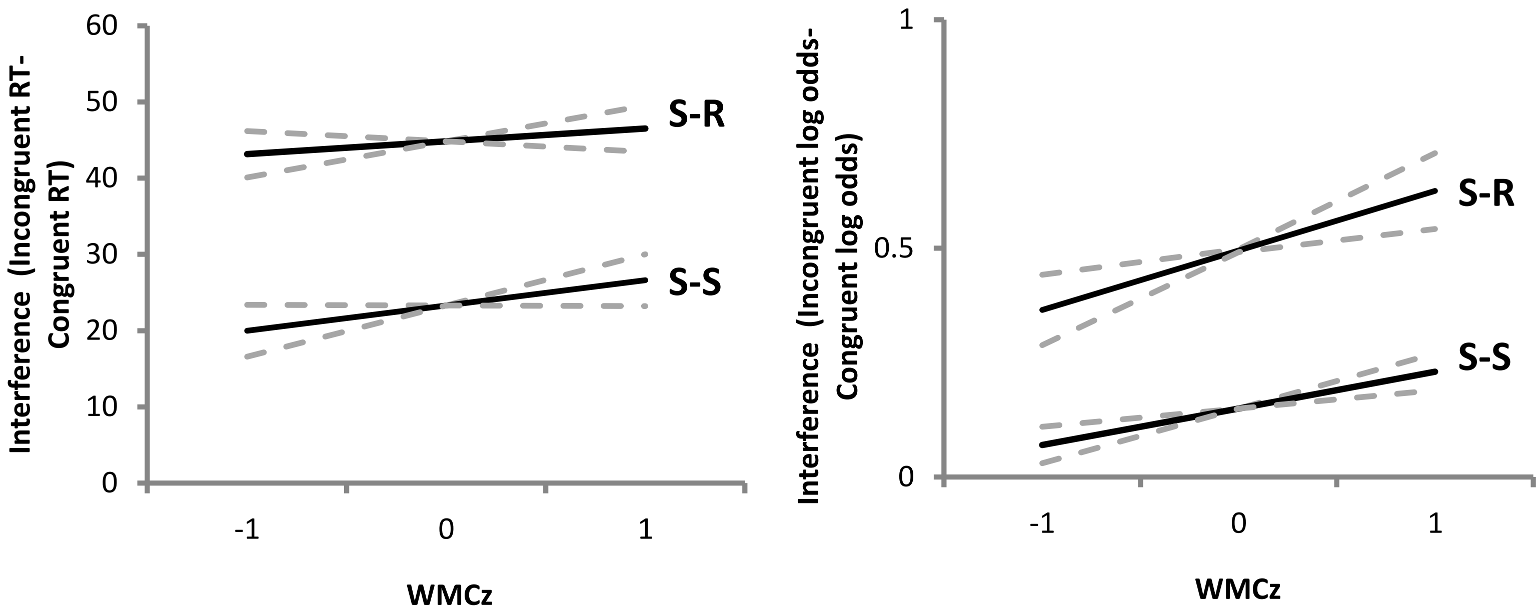


Figure 14. Delta Plot of Stimulus-Response (S-R) Interference as a Function of Upper (High) and Lower (Low) Tercile of Composite Working Memory Capacity Z-score (WMC) in Experiment 3 Joystick Replication task.



a) RTs

b) Errors

Figure 15. Experiment 3 Axis-shifted task Model Parameters of Stimulus-Response (S-R) and Stimulus-Stimulus (S-S) Interference from Combination S-S/S-R Trials as a Function of Composite Working Memory Capacity Z-score (WMCz) in Response Times (RTs; panel A) and Errors (panel B). The dotted lines represent the standard error of the estimate.

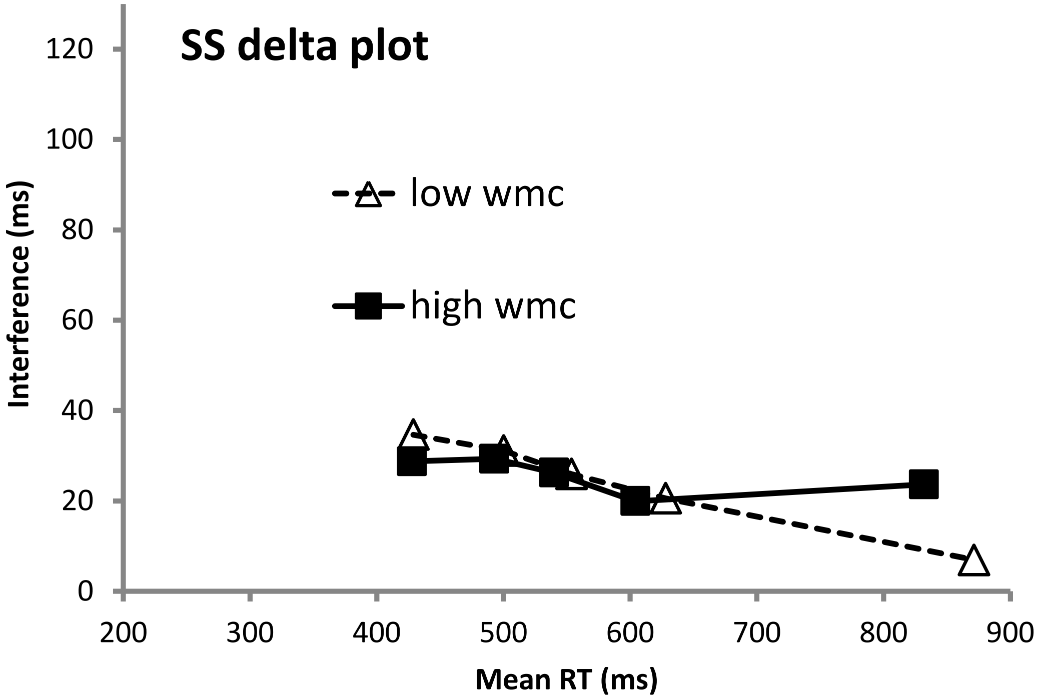


Figure 16. Delta Plot of Stimulus-Stimulus (S-S) Interference as a Function of Upper (High) and Lower (Low) Tercile of Composite Working Memory Capacity Z-score (WMC) in the Experiment 3 Axis-shifted task.

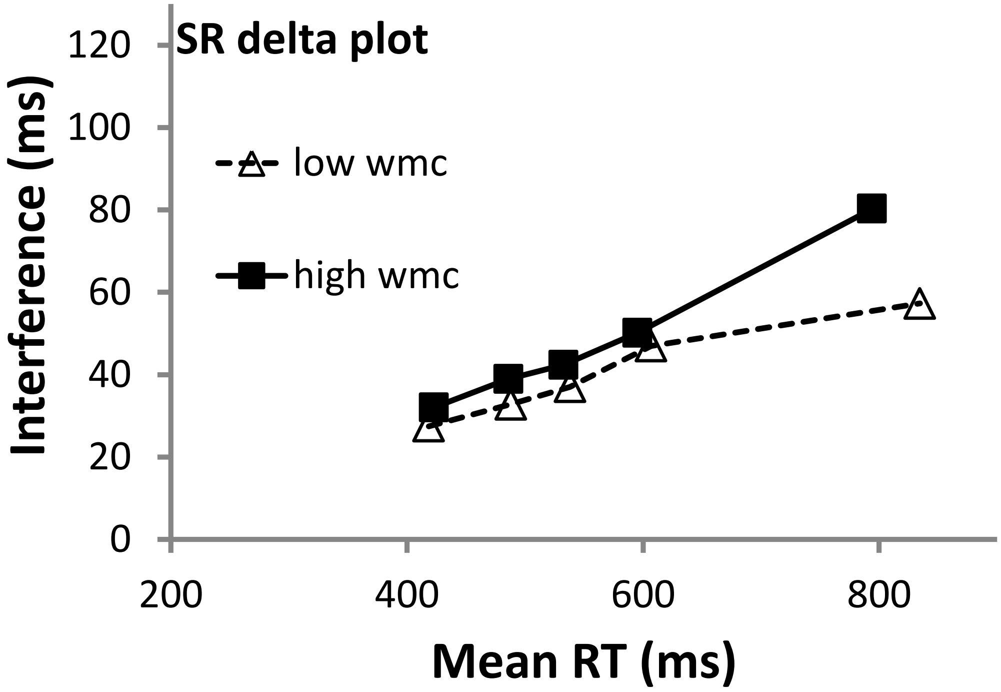
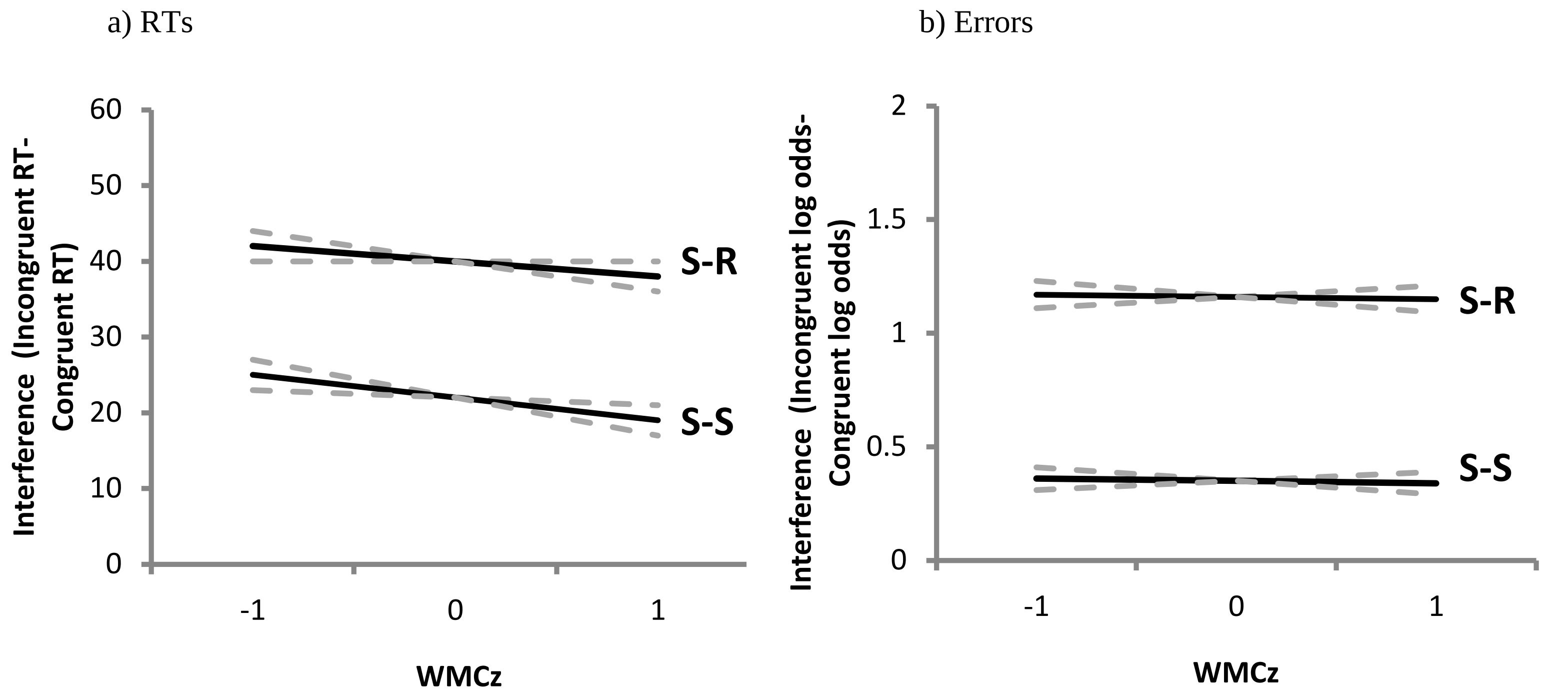


Figure 17. Delta Plot of Stimulus-Response (S-R) Interference as a Function of Upper (High) and Lower (Low) Tercile of Composite Working Memory Capacity Z-score (WMC) in the Experiment 3 Axis-shifted task.


a) RTs

b) Errors

Figure 18. Experiment 3 Up-down Numerosity task Model Parameters of Stimulus-Response (S-R) and Stimulus-Stimulus (S-S) Interference from Combination S-S/S-R Trials as a Function of Composite Working Memory Capacity Z-score (WMCz) in Response Times (RTs; panel A) and Errors (panel B). The dotted lines represent the standard error of the estimate.

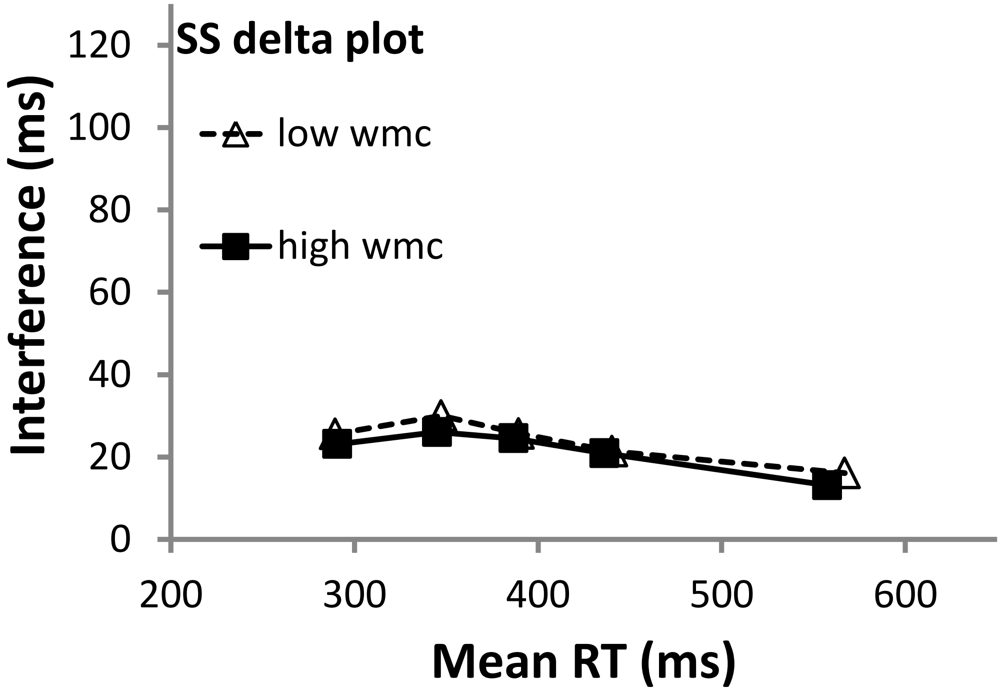


Figure 19. Delta Plot of Stimulus-Stimulus (S-S) Interference as a Function of Upper (High) and Lower (Low) Tercile of Composite Working Memory Capacity Z-score (WMC)in Experiment 3 Up-Down Numerosity task.

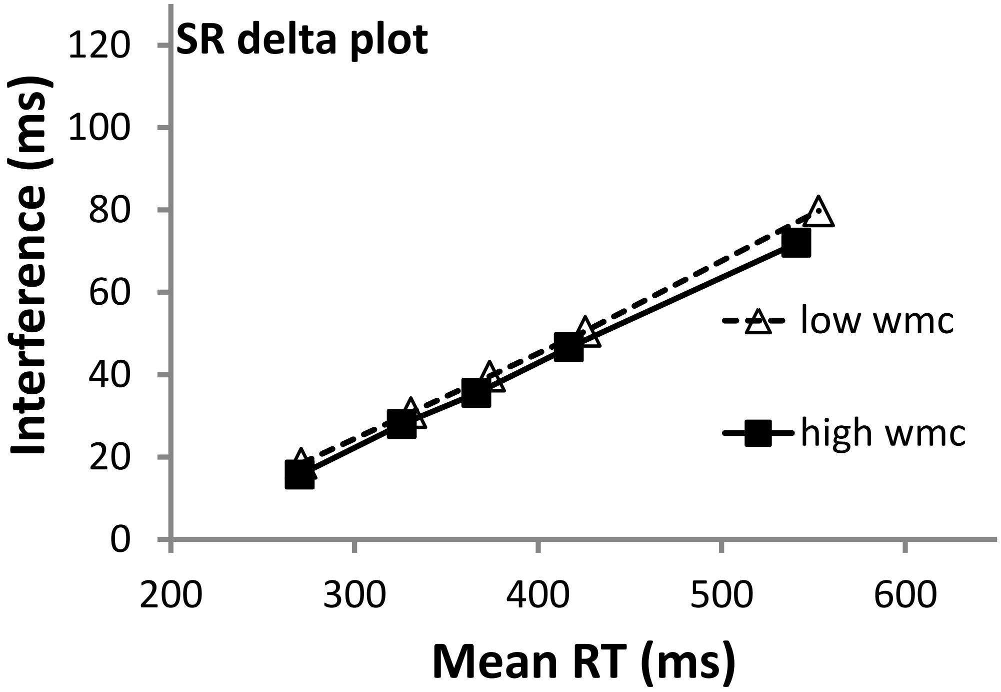
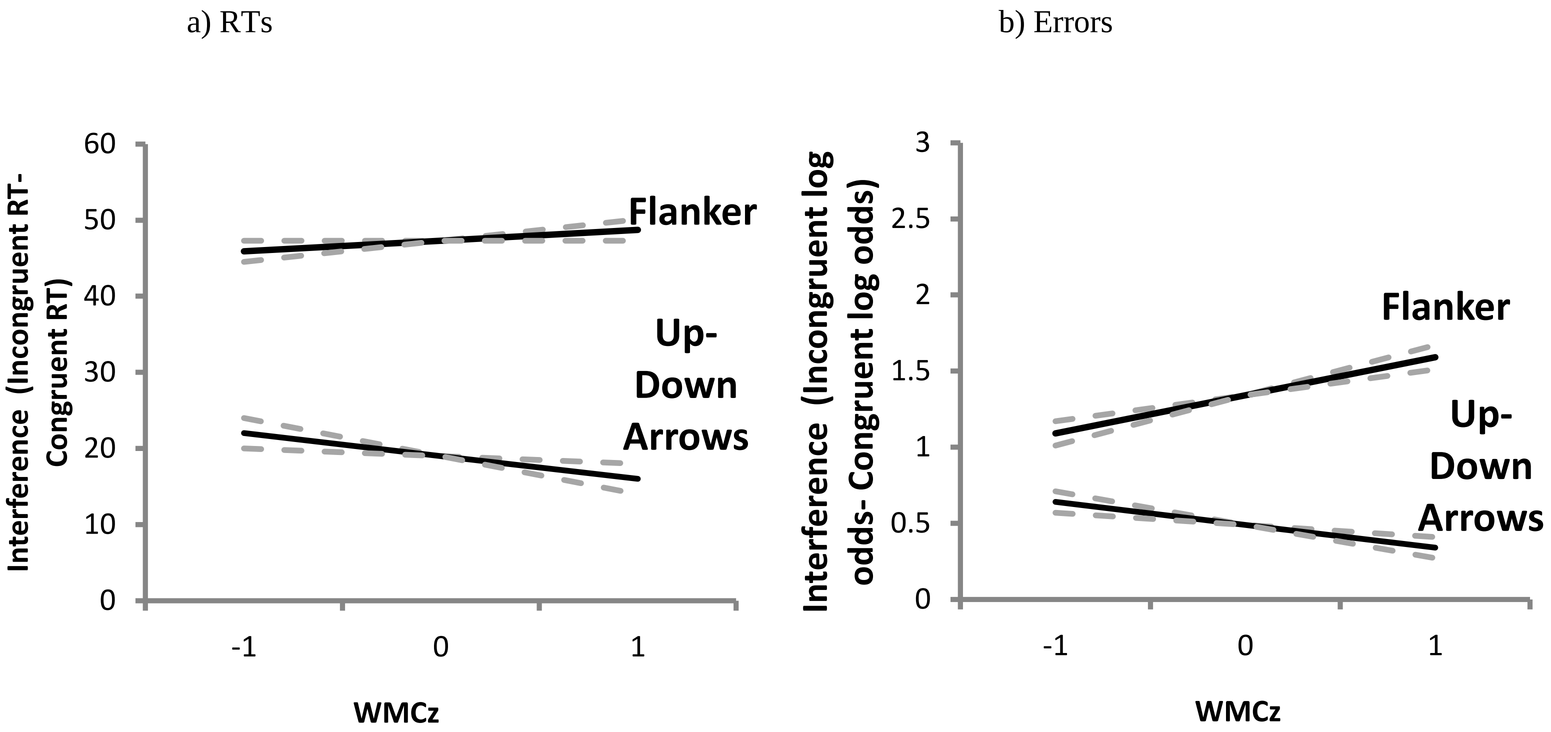


Figure 20. Delta Plot of Stimulus-Response (S-R) Interference as a Function of Upper (High) and Lower (Low) Tercile of Composite Working Memory Capacity Z-score (WMC) in Experiment 3 Up-Down Numerosity task



a) RTs

b) Errors

Figure 21. Experiment 3 Single-conflict task Model Parameters of Stimulus-Stimulus (S-S) Interference as a Function of Composite Working Memory Capacity Z-score (WMCz) in Response Times (RTs; panel A) and Errors (panel B). The dotted lines represent the standard error of the estimate.

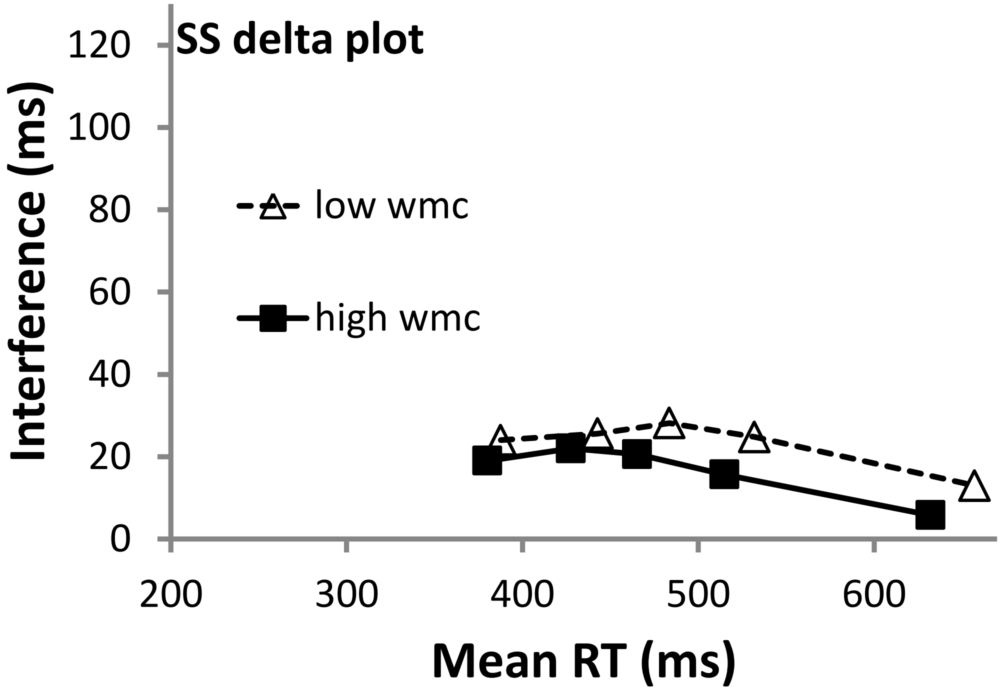


Figure 22. Delta Plot of Stimulus-Stimulus (S-S) Interference as a Function of Upper (High) and Lower (Low) Tercile of Composite Working Memory Capacity Z-score (WMC) in the Experiment 3 single-conflict up-down arrows task.

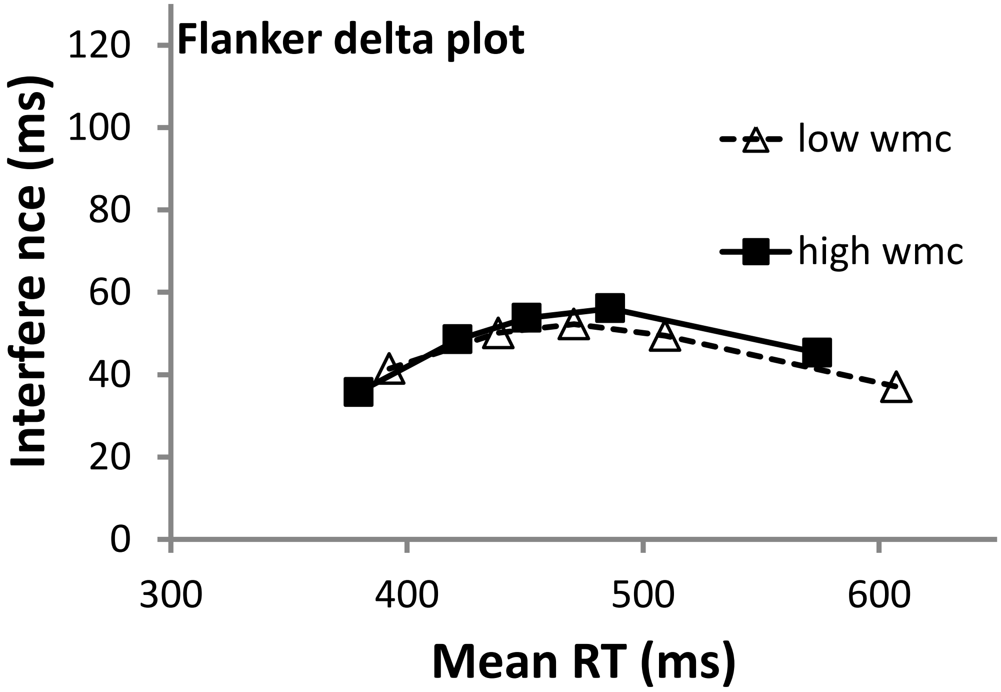


Figure 23. Delta Plot of Stimulus-Stimulus (S-S) Interference as a Function of Upper (High) and Lower (Low) Tercile of Composite Working Memory Capacity Z-score (WMC) in the Experiment 3 Single-Conflict Flanker task

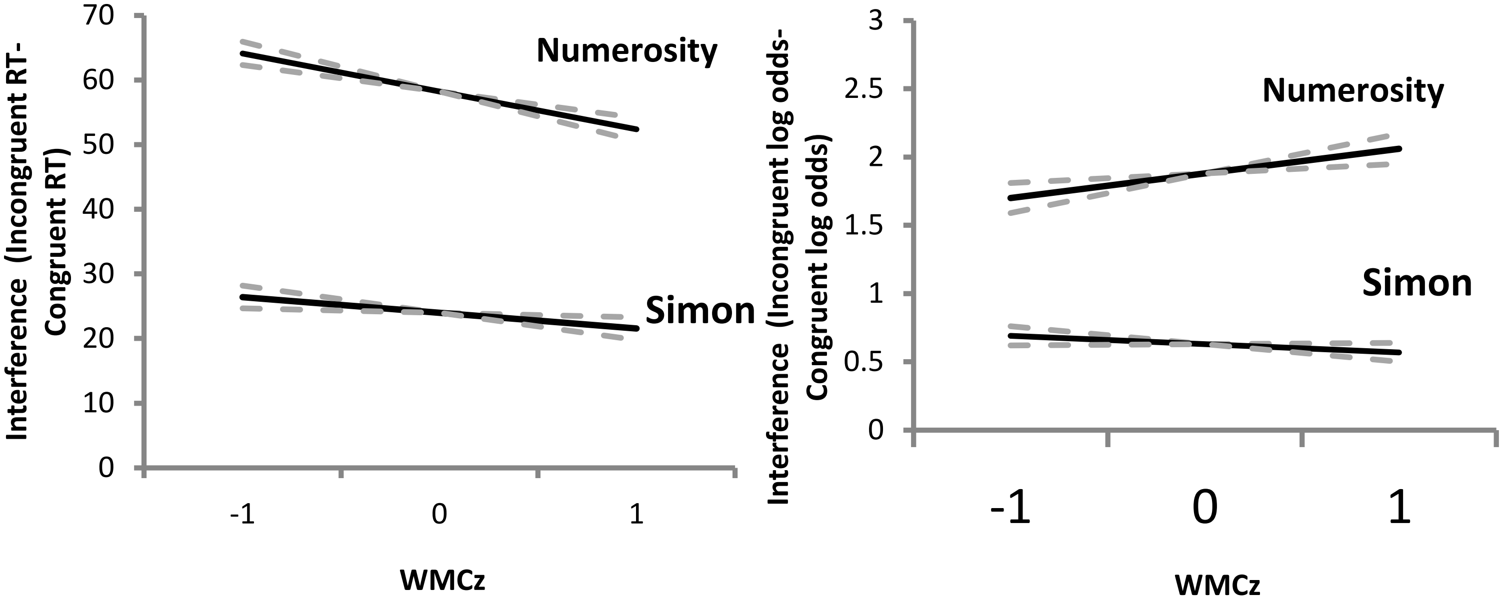


Figure 24. Experiment 3 Single-Conflict task Model Parameters of Stimulus-Response (S-R) Interference (Incongruent RTs/Errors – Congruent RTs/Errors) as a Function of Composite Working Memory Capacity Z-score (WMCz) in Response Times (RTs; panel A) and Errors (panel B). The dotted lines represent the standard error of the estimate.

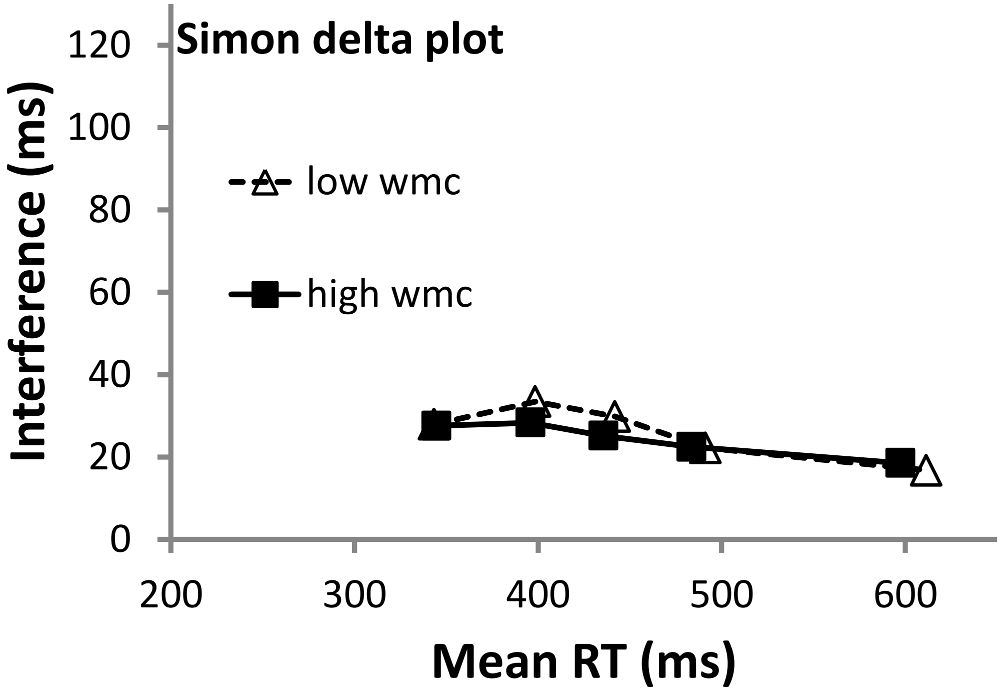


Figure 25. Delta Plot of Stimulus-Response (S-R) Interference as a Function of Upper (High) and Lower (Low) Tercile of Composite Working Memory Capacity Z-score (WMC) in the Experiment 3 single-conflict Simon task.

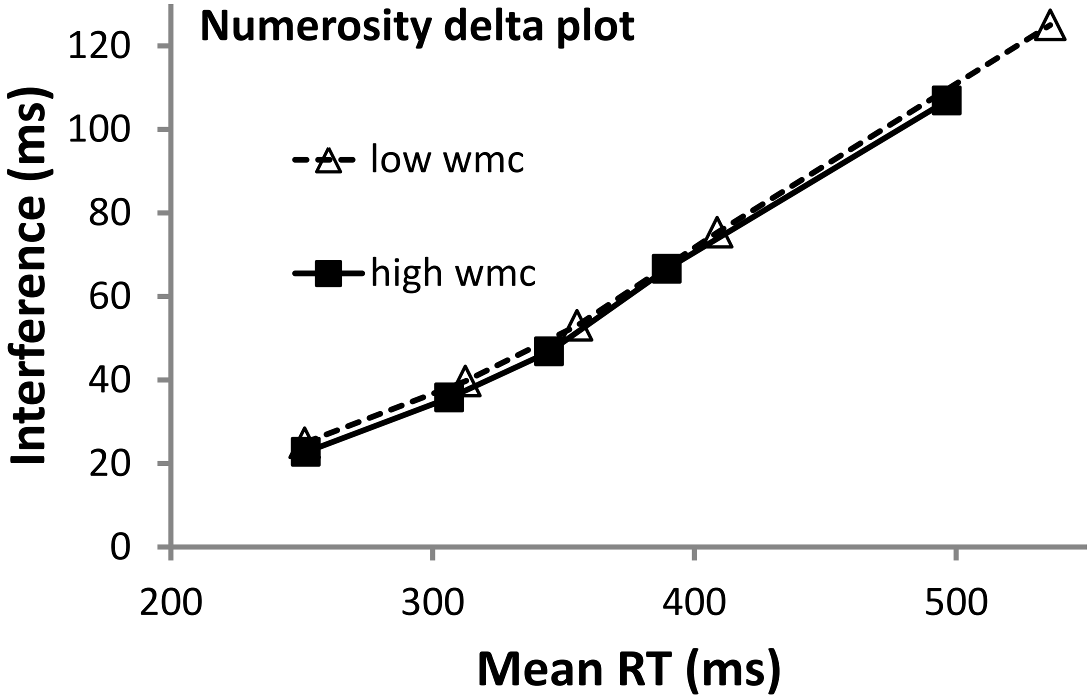


Figure 26. Delta Plot of Stimulus-Response (S-R) Interference as a Function of Upper (High) and Lower (Low) Tercile of Composite Working Memory Capacity Z-score (WMC) in the Experiment 3 single-conflict Numerosity task.

FOOTNOTES

1. All analyses were also run with mapping covariates, in these analyses none of the parameters of interest changed. This is not surprising because the LMMs are random intercept models. The random intercept accounts for between-subject variation in RTs.