12-2016

Task manipulation effects on the relationship between working memory capacity and go/no-go performance

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Graduate School Form 30
Updated 1/15/2015

PURDUE UNIVERSITY
GRADUATE SCHOOL
Thesis/Dissertation Acceptance

This is to certify that the thesis/dissertation prepared

By Elizabeth A. Wiemers

Entitled

Task Manipulation Effects on the Relationship Between Working Memory Capacity and Go/No-Go Performance

For the degree of Master of Science

Is approved by the final examining committee:

Thomas S. Redick
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Approved by Major Professor(s): Thomas S. Redick

Approved by: Christopher R. Agnew 12/1/2016

Head of the Departmental Graduate Program Date

TASK MANIPULATION EFFECTS ON THE RELATIONSHIP BETWEEN WORKING MEMORY CAPACITY AND GO/NO-GO PERFORMANCE

A Thesis

Submitted to the Faculty

of

Purdue University

by

Elizabeth A. Wiemers

In Partial Fulfillment of the

Requirements for the Degree

of

Master of Science

December 2016

Purdue University

West Lafayette, Indiana

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ABSTRACT

Wiemers, Elizabeth A. M.S., Purdue University, December 2016. Task Manipulation Effects on the Relationship Between Working Memory Capacity and Go/No-Go Performance. Major Professor: Thomas S. Redick.

Seemingly minor task manipulations can have large and sometimes unpredicted effects on task performance. Despite this, single tasks are typical in both research and assessment applications. This series of experiments aims to systematically investigate the differences between various perceptual and semantic versions of go/no-go tasks and their relationships with working memory capacity (WMC) with the goal of determining the cause of inconsistencies in the literature. Because these versions of the go/no-go have not previously been systematically studied, the first experiment does so. After determining which performance differences exist based on versions of both task and decision, and noting that these performance measures did not differ in the critical relationship with WMC, other patterns in the literature were examined. Experiment 2 used these patterns to determine a potential cause of the differences in WMC relationships with go/no-go outcome measures, inter-stimulus interval (ISI). Manipulating ISI influenced the relationships with WMC, though the decision type still had effects above and beyond that of the ISI.

INTRODUCTION

Background and Rationale

Cognitive tasks measure performance with the intention of making inferences about the underlying processes involved in completing the task. Attempts have been made to evaluate many processes in this manner such as decision-making, cognitive control, working memory, and attention. These tasks and inferences about the underlying processes based on observed performance develop over time with the push and pull between theory and observation. Theory is used to develop a task. Then, results are examined against expectations. Next, the task is changed in some way or compared to another similar task to evaluate changes in performance due to the critical differences in task structure. When consistent performance differences result from specific task manipulations, the intended underlying process is thought to be measured with some degree of reliability and validity.

For example, to evaluate stages of the decision-making process and the speed at which these sub-processes take place, Donders (1868/1969) used the go/no-go task and the similar two-choice task. The go/no-go task is very similar to the sustained attention to response task (SART; Robertson, Manly, Andrade, Baddeley, & Yiend, 1997), both involving stimuli to which a button press is made (go) and stimuli to which no response is made (no-go). Initially, this task involved a single stimulus as the go stimulus and a single stimulus as a no-go stimulus. For example, Watanabe et al. (2002) used a red square as the go stimulus and a blue square as the no-go stimulus. However, more recent versions have expanded the go and no-go stimuli to sets or categories of stimuli. Digits and letters are frequently used stimuli for this task. For example, participants may be asked to press the button for any digit that is not a 3 but refrain from pressing anything if the digit is a 3 (Seli, Cheyne, Barton, & Smilek, 2012). In another version, participants may be asked to respond to any letter that is not an X and refrain from responding if the letter is an X (Redick, Calvo, Gay, & Engle, 2011). Semantic versions are also used, sometimes asking participants to press the button if a word is in the category ‘animals’ but not if it is in the category ‘foods’ (McVay & Kane, 2009). The two-choice task has the same kinds of stimuli and decisions except, instead of withholding a response, an alternate response is made. Subtracting the response times (RTs) in the go/no-go task from the RTs in the two-choice task, Donders (1868/1969) thought, would indicate the time to make the decision between the two response options was in the two-choice task. Donders was assuming that the processes were completely separate, happening sequentially with no overlap but no delay between them. Others have since explained why these assumptions may render the subtraction method limited and inaccurate in some circumstances (Sternberg, 1969), but the logic of comparing two similar tasks to target an underlying construct is still a common practice in cognitive psychology research.

However, a new problem arises when considering whether a given task can evaluate the various underlying constructs that are targeted by various researchers. For example, the functionally identical go/no-go task and SART are used to measure inhibition and mind-wandering, respectively. That is, failure to inhibit a response to a no-go stimulus is interpreted as a failure in inhibition by some (e.g., Redick et al., 2011) and as an instance of mind-wandering by others (e.g., McVay & Kane, 2009). Small task manipulations may have large effects on performance, calling into question the validity of different interpretations of performance. For example, the comparison between the two-choice and go/no-go paradigms has been thoroughly studied since Donders' comparisons and several variations of each task have been compared to their counterpart task, resulting in striking performance differences. Measso and Zaidel (1990) compared go/no-go and two-choice versions of the lexical decision task, which resulted in substantially faster RTs in the go/no-go task than in the two-choice task when word stimuli were mapped to the go response, but no difference between the tasks when non-words were mapped to the go response. Essentially, participants are asked the same question – whether the item is a word or a non-word, but whether the button press is mapped to the word stimuli or the non-word stimuli affects the speed of responding. This finding illustrates that minor task manipulations that do not have theory-based implications for performance may still affect performance and potentially the way in which the task is relating to underlying constructs it was intended to evaluate. While the go/no-go paradigm continues to be compared to the two-choice task, in recent years, many additional comparisons and applications have been explored in clinical and cognitive psychology.

In clinical settings, the go/no-go task has been typically used to evaluate individuals with ADHD due to high correlations between task performance and inhibition and impulsivity (Bezdjian, Baker, Lozano, & Raine, 2009). However, a recent meta-analysis (Wright, Lipszyc, Dupuis, Thayapararajah, & Schachar, 2014) warned that across studies, correlations between go/no-go performance and symptomology of various diagnoses were not sufficiently large to be used in a diagnostic evaluation. Rather, they posit that the correlations could be indicative of a broader underlying deficit that is related to many disorders and diagnoses.

This warning is indicative of a wider concern involving the distinction between tasks and underlying processes. Comparing performance on a given cognitive task to symptoms of disorders with related deficits involves making some inference about the underlying constructs of which the task is theoretically making use. However, the performance measures on a given task may be interpreted differently depending on the goal of the project, and any one task is not a perfect measure of the underlying construct. In the case of the go/no-go task, responding incorrectly on a no-go trial means responding when the response should have been withheld. This type of error, a commission error, is interpreted as an inhibition failure or a general measure of impulsivity (Bezdjian et al., 2009). Errors on a go trial, conversely, involve withholding a response when a response was appropriate. This type of error, an omission error, is sometimes considered indicative of mind-wandering or attention failures (O'Connell et al., 2009). The strength of the association between the task and the underlying construct may depend on any number of population characteristics or task manipulations. It is for reasons like these that Conway et al. (2005) suggest using more than one version of a task and calculating a composite score or latent variable to capture a better assessment of the underlying processes.

Underlying processes have also been studied via neural mechanisms associated with task performance. The go/no-go procedure in particular has been utilized to examine the neural mechanisms related to inhibition and sustained attention (O'Connell et al., 2009). Specifically, ERP measures provide evidence for the separation of inhibition and sustained attention error processes despite both resulting in the same behavior – a response to a no-go trial. The distinction is made in the no-go trial commission errors on two versions of the task, a fixed and a randomized version. The predictability of the stimuli in this case resulted in differences in the frontal lobe activation during errors.

Go/No-Go Task Manipulations

In previous research, several task manipulations have been thoroughly examined in the go/no-go task and the SART. For example, a frontal-lobe generated negative waveform roughly 200 ms after no-go stimulus presentation has been linked to inhibition in the go/no-go task (N2; Falkenstein, Hoormann, & Hohnsbein, 1999). Stimulus modality effects have been studied via event-related potentials resulting in N2 differences modulated by task difficulty (Nieuwenhuis, Yeung, & Cohen, 2004). Whereas the N2 component was found for a visual version of the task, as is typical, it was not found for the auditory version of the task (Falkenstein, Koshlykova, Kiroj, Hoormann, & Hohnsbein, 1995). Similarly, in behavioral studies, stimulus modality has been examined. Improved performance on an auditory versus a visual version of the SART illustrated the importance of stimulus modality choice (Seli et al., 2012). However, performance was improved only in that accuracy was higher whereas RTs were slower, a pattern evident of a potential speed-accuracy tradeoff. Importantly, this performance difference on tasks using auditory and visual stimuli has no clear theoretical basis. The go/no-go task is used to measure inhibition and mind-wandering, which should not be related to visual versus auditory presentation.

Another thoroughly studied manipulation in the go/no-go literature involves trial type frequencies. Often, the go/no-go task is heavily weighted toward go trials with rare no-go trials or, at the other extreme, the vigilance version of the task has frequent no-go trials and rare go trials (e.g., McVay & Kane, 2012a). The high go-frequency version is used as a measure of sustained attention and response inhibition, but the alternative low go-frequency version changes the task goal, minimizing the inhibition aspect and focusing on sustained attention. The idea is that the prepotency of the go response requires inhibition for infrequent no-go trials, which can only occur if the frequency of go trials is disproportionate enough to develop a prepotency for responding. The vigilance version results in much higher *d*’ scores, a measure of task sensitivity that accounts for both hit and false alarm rates, slower mean RTs, and increased self-reported mind-wandering (McVay & Kane, 2012a). Comparison of versions with different trial frequencies showed consistent changes relating to trial type frequency such that as no-go frequency increased (20 to 50 to 80%), mean RTs increased on go trials and accuracy increased on no-go trials (Jones, Cho, Nystrom, Cohen, & Braver, 2002; Nieuwenhuis, Yeung, van den Wildenberg, & Ridderinkhof, 2003).

Task length can also affect performance in go/no-go tasks. As time-on-task increases, participants tend to self-report more mind-wandering, produce more variable RTs, and show *d*’ decreases (McVay & Kane, 2009). Mind-wandering is often measured in go/no-go tasks via thought probes, administered after a certain percentage of trials during the task to evaluate mind-wandering by asking about recent thoughts and whether or not those thoughts were related to the task. Both subjective thought probes and objective measures such as RTs and accuracy are affected by time-on-task, highlighting the importance of considering the task duration when comparing studies (see below). Additionally, when multiple go/no-go tasks are administered to the same participant, it may be necessary to counterbalance order and consider group differences shown in the first task versus group differences overall or in the second task because there may be effects from continuing with the same type of task similar to the time-on-task effects described above. This becomes an important consideration when many task manipulations have effects on performance, and multiple tasks are desired to measure underlying constructs in a less task-influenced manner.

The nature of the go/no-go decision also has consequences for go/no-go performance. McVay and Kane's (2009) three versions of the task varied in task type, with one perceptual task, one semantic task, and one perceptual-semantic task using the same stimuli. All stimuli were words from the category 'animals' or the category 'foods' and presented in uppercase or lowercase letters. For the semantic task, the go stimuli were words from the category 'animals' and the no-go stimuli were words from the category 'foods', regardless of case. For the perceptual task, the go stimuli were lowercase words and the no-go stimuli were uppercase words, disregarding category. For the perceptual-semantic task, stimuli differed in both dimensions but participants were again asked to make perceptual decisions. Despite the mixed stimuli, the perceptual-semantic version resulted in similar performance to the perceptual version.

More importantly, performance on the perceptual and perceptual-semantic versions varied from the semantic version. In terms of accuracy, the decrease in *d'* seen with time-on-task was shallower for the semantic task compared to the other two versions. For response speed, RTs were much slower on the semantic task than on either of the other two tasks.

Working Memory Capacity and the Go/No-Go Task

In addition to these various considerations and task manipulations, a critical factor to consider is working memory capacity (WMC), an individual differences factor that is related to sustained attention and inhibition (Engle & Kane, 2004). This construct is often measured with complex span tasks. For example, the operation span task (Unsworth, Heitz, Schrock, & Engle, 2005) presents letters one at a time and asks participants to later recall these letters in the order in which they were presented. However, in between the presentation of each letter, the participants are asked to solve an algebraic equation. The task requires both maintenance and processing of information in working memory. Operation span is a verbal version of a complex span task, but there are also spatial versions such as the symmetry span task (Unsworth, Redick, Heitz, Broadway, & Engle, 2009).

Because the go/no-go task measures inhibition and attention, and WMC is highly related to these constructs, the relationships between specific performance outcomes and WMC are indicative of the way the task relates to the underlying mechanisms it is theorized to measure. Thus, all the previously mentioned manipulations causing performance differences on the outcomes measures are concerning for the interpretation of the way the task is measuring these underlying constructs. Concerns about the inconsistent performance between groups or versions would be alleviated should WMC consistently relate to the outcome measures despite the differences. However, correlations between WMC and performance on various versions of the go/no-go task lack this critical consistency. Table 1 shows the variety of relationships between go/no-go performance measures and WMC found in the literature specifically when separated by perceptual versus semantic decision types.

Perceptual versions are inconsistently related to WMC. Redick et al. (2011) found no relationship with WMC in two perceptual versions of the go/no-go task. Reanalyzing their data, McVay and Kane (2009) found a similar pattern of smaller relationships with WMC for their perceptual task alone than they had found for the combined tasks' relationship with WMC reported in the paper. In unpublished follow-up data by McVay and Kane, reported by Redick et al. (2011), the relationship to WMC was no longer present for the perceptual task. However, Stawarczyk, Majerus, Catale, and D'Argembeau (2014) and Jackson and Balota (2012) found relationships between a perceptual go/no-go task and WMC comparable to those found in semantic tasks (McVay & Kane, 2012; Redick et al., 2016). These inconsistent relationships in perceptual versions are focused on the *d*' measure and other accuracy measures. Other WMC relationships are more consistent. As summarized in Table 1, WMC relationships with mean RTs tend to be consistently absent. However, consistent WMC relationships are present with RT (individual standard deviations) ISDs, with high-WMC individuals tending to be less variable in their RTs than low-WMC individuals.

In contrast, relationships in all outcome measures are relatively consistent for semantic versions of the go/no-go. The same lack of a relationship with mean RTs and a negative relationship with RT ISD is found across semantic tasks. Where relationships varied for accuracy measures in the perceptual task, these relationships were invariably positive for semantic tasks. However, comparisons between perceptual and semantic versions are limited by key factors. First, these comparisons are limited by the small number of studies that have included WMC and particularly by the even smaller number that include more than one type of go/no-go task. Second, the task manipulations discussed previously make comparisons between studies even more challenging. For example, the data collected by Redick et al. (2011) may lack a relationship with WMC due to a lack of thought probes. The design also included a smaller sample size and extreme groups for WMC, whereas Stawarczyk et al. (2014) had a larger sample, used the full range of WMC scores, and included thought probes. Importantly, the unpublished data from McVay & Kane used the same design and participant source as the published semantic data, making this inconsistent WMC relationship more compelling.

Similar to stimulus modality, there is no clear theoretical reason for the relationship with individual differences in WMC to be different between task versions if the task is intended to evaluate sustained attention or inhibition. Whether the decision is perceptual or semantic, assuming task demands are equal, inhibition and attention should be affecting performance the same way. To truly investigate this inconsistency, however, the different types of go/no-go must be systematically compared and the respective relationships with WMC must be evaluated.

Present Project

Though many studies have examined the efficacy of the go/no-go task as an inhibition measure and examined the effects of no-go trial frequency on performance, very little has been done to assess the effects of other manipulations in this task. Specifically, two important manipulations have been generally overlooked: stimulus decision type and inter-stimulus interval (ISI). Though many different stimulus versions are used in various tasks, little attention is paid to what effect the choice of stimuli might have on performance. For example, if the decision is perceptual in nature, that decision may have some effect that is different from the effect of a semantic type decision. The few studies that do have different versions of the go/no-go task are not purposefully comparing the versions, usually in favor of comparing go/no-go performance to another type of task such as the two-choice task (e.g., Measso & Zaidel, 1990). Systematic comparisons of variations of the go/no-go task are generally absent from the literature, despite such manipulations having potential implications for what the task is measuring. This absence in the literature raises the question – how different is too different? Given that other task manipulations can have such large effects on performance, it follows that task- and decision-type manipulations may also have large effects. After determining what effects there are, the question becomes whether performance on the various versions can be interpreted the same way and how these differences in performance relate back to individual differences. That is, if differences between perceptual and semantic versions of tasks have large effects on performance to the extent that there are varied relationships with individual differences in WMC, the task has then become so different that it is not measuring the underlying constructs that it was designed to measure in the same capacity that it measured those constructs in other versions of the task.

The present studies systematically compare perceptual and semantic versions of the go/no-go task both between- and within-subjects with task-type, decision-type, and ISI manipulations. Based on the literature, performance on the perceptual tasks was expected to be better, overall, than performance on the semantic tasks in the form of faster mean RTs, smaller RT ISDs, higher no-go accuracy rates, and higher *d*' values. However, this project goes beyond the comparison of task type. Given that these performance differences exist, the purpose of this project is to delve deeper into the specific task manipulations that may influence performance and, critically, to determine why these differences may be occurring. The systematic comparison of multiple versions of each type of task with carefully considered changes, specifically in decision type and ISI, illuminate reasons for performance differences arising from task and decision manipulations.

Specifically, the objective is to determine whether particular manipulations alter the way in which the go/no-go task relates to the underlying constructs the task is intended to measure, and why. Whereas many studies focus exclusively on accuracy on rare no-go trials, the present work will additionally evaluate mean RTs and RT ISDs for go trials and how each of these measures, along with accuracy measures, relates to WMC. Looking at this level of detail is vital to determining the similarity of the task performance between versions. If performance is not different between various versions, then the performance measures derived from the go/no-go task should be a consistent index of the underlying constructs as indicated by similar relationships with

WMC. However, if manipulations of the task change performance in predictable ways, the degree to which the task relates to underlying constructs may also be changing in predictable ways. Alternatively, if performance differences between task versions lead to differences in the relationships between task performance and WMC in inconsistent or unpredictable ways, the relationships between the task and the underlying processes would also be affected. Interpreting the task as a measure of the underlying constructs may subsequently be misleading or inconsistent with interpretations of other versions of the task due to these effects. This project sheds light on the importance of considering task manipulations during the development of a project or assessment and has implications for the use of various versions or multiple versions of the task.

EXPERIMENT 1A

In Experiment 1a (E1a), I compare semantic and perceptual go/no-go tasks within subjects to determine whether the decision made during a go/no-go task has an effect on various measures of performance. The sample is full range for WMC, allowing examination of performance differences related to WMC.

Method

Participants

Purdue University students enrolled in an introductory psychology course participated in this study for course credit. Of the total 125 participants, 3 were excluded for extremely poor go performance, which was considered less than 80% accurate on go trials, and 14 were excluded for extremely poor no-go performance, which was considered less than 11% accurate on no-go trials. Additionally, 1 participant was excluded for having an above-threshold (20%) percent of errors on math for operation span and 2 participants were excluded for being under 18 years old. These constraints left 105 participants in the analyzed sample.

Tasks

Operation span (Redick et al., 2012; Unsworth et al., 2005). This verbal working memory capacity measure alternates presenting letters to be remembered and math problems to solve. Participants indicate whether a number shown is the correct answer to the equation that had been presented on the previous screen. Participants are then shown a letter and then another math problem. The pattern repeats for 3 to 7 items before a recall screen appears. With 3 presentations of each set length, there are a total of 75 items to recall. The partial scoring method is used such that any letter recalled in the correct serial position results in a point regardless of whether the rest of the set is correct.

Symmetry span (Redick et al., 2012; Unsworth et al., 2009). This spatial measure of working memory capacity is similar in structure to operation span but uses symmetry judgements in place of math problems and locations of red squares in a grid instead of letters. Participants respond ‘yes’ or ‘no’ to whether the image on the previous screen was symmetrical about a vertical line and are then shown a 4 x 4 grid with one block colored red. Another image follows and this pattern continues until 2 to 5 red squares have been presented. A blank grid is presented for recall and participants click the locations in the order they appeared. Partial scoring is used for this task as well, with each set size randomly appearing 3 times for a total possible score of 42.

Semantic go/no-go – non-living. Participants were shown a word that was either an exemplar from the “living” category or “non-living” category based on a word list created for this study (See Appendix C). Participants were to press the spacebar if and only if the word shown was an exemplar of the “Non-living” category. Each participant saw 240 go (non-living) trials and 30 no-go (living) trials in a random order. This distribution follows the frequently used 11% no-go trials distribution from the literature going back to the introduction of the SART by Robertson et al. (1997). Half of each of the go and no-go stimuli were presented in uppercase letters and the other half were presented in lowercase letters. No items were repeated during the task. Words were shown for 300 ms before a row of uppercase X's was presented as a mask for 900 ms. Participants were allowed to press the spacebar anytime within those 1200 ms. The next stimulus was immediately presented after the mask. See Figure 1 for the task structure.

Perceptual go/no-go - case. This task was similar to the task described above, including the use of living and non-living words in both uppercase and lowercase presentations. The difference is that participants were asked to press the spacebar if and only if the word was presented in all uppercase letters if they were in group A or if and only if the word was presented in all lowercase letters if they were in group B. As such, the number of exemplars from each category is also different. Here, there were 240 go trials (uppercase/lowercase) and 30 no-go (lowercase/uppercase), and half of each of those groups came from the 'living' word list and the other half came from the 'non-living' word list. No words were repeated between or within tasks. Though repeating stimuli is common in the literature (e.g., McVay & Kane, 2009), stimuli were deliberately not repeated in this study to eliminate the possibility of any confounds from doing so when comparing between- or within-subject performance.

Procedure

Between 1 and 3 participants were simultaneously run in a computer lab and quietly given individual instruction before each task. Participants signed a consent form and then filled out a brief demographic survey. Then, the operation span and symmetry span were completed, in the same order for all subjects. After the working memory tests, participants completed the go/no-go task. Half the participants completed the semantic version and then the perceptual version of the task and the other half of the participants completed the tasks in the opposite order. Within each order, half of the participants completed the uppercase version of the perceptual task as described above and the other half completed the lowercase version of the task as described above. Because this experiment included both a semantic and a perceptual version of the task including two versions of the perceptual task, within- and between-subjects comparisons were examined. The session was typically completed in 45 minutes.

Analyses

ANCOVAs were used to evaluate differences in accuracy, *d'*, mean RTs, and RT ISDs. Between-subjects variables include version of the perceptual task (uppercase or lowercase) and order (perceptual first or semantic first). Composite WMC scores, the average of the z-scores from each task, were the between-subjects covariate. Within-subjects variables include task type (perceptual and semantic) for all analyses and trial type (go and no-go) for accuracy only. Correlations were used to evaluate relationships between WMC and *d'*, RT means, and RT ISDs. All *p*-values discussed as significant are less than .05.

In addition to mean accuracy, *d*' is used to report accuracy in a way that accounts for both correct responses and false alarms (Stanislaw & Todorov, 1999). A logarithmic adjustment was used to ensure the formula would work even where no errors occurred. This adjustment involved adding .5 to every individual's total number of correct trials for both go and no-go trials and dividing by *n* trials + 1. This ensured that no perfect scores existed, but that scores also retained their relationships to each other.

Results

Note that while each of the 105 participants saw both semantic and perceptual tasks, the groups for the versions of the perceptual task are 56 participants for the uppercase letters group and 49 participants for the lowercase letters group. The following section will review these comparisons in terms of both accuracy and RTs after a brief report of WMC measures. Data are summarized in Table 2 and all ANCOVA main effects and interactions are found in Tables 3 through 6.

WMC Measurement

Participants performed very similarly to normed samples (Redick et al., 2012) for both Operation Span and Symmetry Span (Table 2). The two are correlated ($r = .45$, $p < .001$), justifying the composite score used in all further analyses.

Accuracy

As hypothesized, accuracy was significantly higher on the perceptual task than on the semantic task. As expected, go accuracy was significantly higher than no-go accuracy. There was an interaction between task and trial type due to similar go accuracy but higher no-go accuracy for the perceptual task than the semantic task. There was also an interaction between task and version due to similar overall accuracy between the semantic and perceptual tasks when the perceptual task was the lowercase version but higher overall accuracy on the perceptual task than the semantic task when the perceptual task was the uppercase version. Additionally, these main effects and two-way interactions were qualified by an interaction between task, trial type, and version due to similar go accuracy across all conditions and similar no-go accuracy on the semantic task and lowercase version of the perceptual task, but higher no-go accuracy for the uppercase version. There were no effects or interactions involving order in regard to accuracy, as shown in Table 3.

For WMC, there was a significant main effect of WMC on accuracy and an interaction with trial type. This interaction was due to WMC being significantly correlated to no-go performance for both the perceptual task ($r = 0.29$, $p < .01$) and the semantic task ($r = 0.28$, $p < .01$) but not being significantly correlated to go performance for either the perceptual task ($r = 0.17$, $p = .08$) or the semantic task ($r = 0.07$, $p = .46$). However, there were no other interactions involving WMC and accuracy.

As shown in Table 4, the *d*' measure was significantly greater for the perceptual task than the semantic task. This effect also interacted with version of the perceptual task such that a larger difference was observed between the semantic and perceptual *d*' measures when the perceptual task was the uppercase version. Additionally, there was a main effect of WMC, which was correlated with *d*' in both the perceptual ($r = 0.32$, $p < .01$) and semantic ($r = 0.27$, $p < .01$) tasks. However, it is of note that when split by version, WMC was correlated significantly with *d*' on the perceptual task for the uppercase version ($r = 0.44$, $p < .01$) but not the lowercase version ($r = 0.22$, $p = .13$).

Response Times

Participants were significantly faster on the perceptual task than the semantic task. Although there was no main effect of order, there was an interaction between task and order driven by responses to the perceptual task being faster if the perceptual task came first (*M* = 384.52, *SD* = 68.62) than if the perceptual task came second (*M* = 431.79, *SD* = 91.07). There were no effects or interactions involving version of the perceptual task in relation to mean RTs. There was a main effect of WMC on mean RTs that approached traditional significance. This marginal effect is likely due to the positive correlation between mean RT and WMC in both tasks and specifically the marginally significant correlation in the semantic task (perceptual: $r = 0.14$, $p = .16$; semantic: $r = 0.18$, $p = .07$). However, as seen in Table 5, there were no interactions involving WMC.

Participants were significantly less variable on the perceptual task than the semantic task, as is evident in Table 6. In line with the mean RTs, there was no main effect of order for the RT ISDs, but there was an interaction such that the participants were less variable on the perceptual task when the perceptual task was first. Again, there were no effects or interactions involving version of the perceptual task in regard to RT ISDs. Similarly, there was a main effect of WMC on RT ISDs, with higher WMC associated with lower RT ISDs for both perceptual ($r = -0.23$, $p = .02$) and semantic tasks ($r = -0.28$, $p < .01$). Again, similar to the mean RTs, there were no interactions involving WMC.

Discussion

The goal of E1a was to directly compare perceptual and semantic decisions on the go/no-go task by using the same stimuli and a within-subjects design. In addition, the perceptual task had two decision versions. Some participants mapped uppercase words to the go response and the others mapped lowercase words to the go response. For the primary comparison between semantic and perceptual tasks, several differences emerged. The participants were faster and less variable on go trials, were more accurate on no-go trials, and produced higher *d*' values on the perceptual task than the semantic task. The combination of higher accuracy and faster RTs indicates that the performance differences are not due to a speed-accuracy tradeoff, as found in comparisons of stimulus modality (Seli et al., 2012). However, it is possible that the perceptual decision is easier than the semantic decision despite using the same stimuli in both tasks. The slower RTs and lower accuracy on the semantic task despite using the same stimuli as the perceptual task indicates that something about the decision, rather than the specific stimuli, is causing a difference in performance.

Comparing the versions of the perceptual task to each other allows evaluation of performance based on the specific decision within task type. Using the same stimuli between perceptual and semantic tasks produces performance differences, but can the same be said for different decisions on the same stimuli within the perceptual version? Differences in uppercase versus lowercase versions of the perceptual tasks emerged in the no-go trials with accuracy being higher for the uppercase version than the lowercase version. This specific performance difference may be a function of the mask used. Being capital X's, the mask is similar to the uppercase words. Therefore, when the uppercase words are the frequent go stimulus, the task inadvertently becomes similar to a change detection task and a very different goal of "did the letters change height" may become the easier goal to keep in mind. However, the same does not occur when the frequent go stimuli are lowercase words as they would be consistently changing from the mask and the infrequent uppercase words would be less salient. If this were the case, differences might be expected in the RTs, but they are only present in the accuracy.

Perhaps the more interesting performance difference within the perceptual task occurs with order. When the perceptual task was first, performance was quite different from that of the semantic task. However, when the perceptual task was after the semantic task, performance on the perceptual task looked more similar to the performance on the semantic task. This suggests that the processing of the semantic task may influence how the perceptual task is completed. It is possible that it is easier to ignore the semantic element of the stimuli when asked to focus on the perceptual aspects first and more difficult to do so when asked to first evaluate the semantic aspect. Interestingly, the order had no effect on performance for the semantic task, so the interference seems to be specifically from semantic to perceptual.

Turning to the relationships with WMC, consistent with previous research, no significant relationship was found for either task with mean RTs. A relationship with *d'*, less consistently found in the literature, was found in both tasks. This observation is consistent with McVay and Kane (2009), but not with the unpublished perceptual data from McVay and Kane that used very similar WMC and go/no-go tasks as those used in E1a. The literature is also less consistent with showing WMC correlations with RT ISDs, and here there is a significant correlation for the semantic task and the lowercase version of the perceptual task but not for the uppercase version of the task. However, it is important to note that the lack of the relationship there may be due to the smaller sample size (N = 56) as opposed to the semantic task where the whole sample is used.

EXPERIMENT 1B

Two additional perceptual versions of the go/no-go task were used here to investigate whether the stimuli and decision within perceptual versions affects performance on the tasks. Whereas the perceptual tasks in E1a were designed to be closely comparable to the semantic task in E1a, the perceptual tasks in E1b were designed to be closely comparable to the perceptual versions seen most often in the literature to ensure that the results here would be applicable to the broader literature involving this task. Because both tasks were perceptual, we had no strong predictions about differences in performance between the two tasks.

Method

Participants

Participants for E1b were recruited from the same subject pool as E1a but had not participated in E1a. Of the 109 participants, 2 were excluded for extremely poor go performance and 6 were excluded for extremely poor no-go performance, using the same cutoffs described in E1a. The remaining 101 are included in the analyses.

Tasks

Operation span. This task was the same as in E1a.

Symmetry span. This task was the same as in E1a.

Perceptual go/no-go – digits. This task was similar to the go/no-go tasks described in E1a. However, instead of word stimuli, the digits 1 through 9 appeared randomly. Participants were asked to press the spacebar as quickly as possible if and only if the digit was not a 3. This specific version of the task is common in the literature as it closely resembles the SART originally described by Robertson et al. (1997).

Perceptual go/no-go – letters. This task was similar to the task described above. However, instead of digits, letters from the English alphabet were presented. Participants were asked to press the spacebar if and only if the letter was not an X. The non-X letters were B, C, D, G, H, J, L, M, N, P, Q, R, T, V, and Z. Of note, despite similarity to the no-go stimulus, the same mask consisting of 12 capital X's was used. This was done to be consistent with the other tasks in this set.

Procedure

This study was run mostly as described in E1a, except there was only one version. The program still chose the order in which the letter and digit go/no-go tasks appeared based on the subject number entered. This procedure resulted in two groups with one group completing the letters task before the digits task and the other group completing the digits task before the letters task.

Analyses

The analyses were very similar to E1a, except there was no version variable in E1b.

Results

Of the 101 participants included in the analyses, 49 completed the digits task first and the other 52 completed the letters task first. Descriptive statistics for the outcome measures are reported in Table 2.

WMC Measurement

Participants performed very similarly to normed samples for both Operation Span and Symmetry Span (Table 2). The two were correlated ($r = .45$, $p < .001$), justifying the composite score used in all further analyses.

Accuracy

Accuracy was significantly higher overall on the digits task than on the letters task, as seen in Table 3. As expected, go accuracy was significantly higher than no-go accuracy. There was an interaction between task and trial type due to similar go accuracy but higher no-go accuracy for the digits task than the letters task. There were no effects or interactions involving order in regard to accuracy. In regard to WMC, there was a significant main effect and a significant interaction with trial type. This interaction was due to WMC correlations being numerically stronger for go accuracy for both digits ($r = 0.22$, $p = .03$) and letters ($r = 0.33$, $p < .01$) tasks compared to the corresponding correlations with no-go accuracy (digits: $r = 0.19$, $p = .05$; letters: $r = 0.26$, $p = .01$). There were no other significant interactions involving WMC.

The *d*' measure was not significantly different between the two tasks. However, there was a significant main effect of WMC which was significantly correlated with *d*' for both the digits ($r = 0.24$, $p = .01$) and letters ($r = 0.30$, $p < .01$) tasks. As Table 4 shows, there were no significant effects or interactions involving order for *d*'.

Response Times

Mean RTs were not significantly different between the tasks, as shown in Table 5. There was also no main effect of WMC and no interactions involving WMC. There were no effects or interactions involving order for mean RTs. Additionally, there were no significant main effects or interactions for RT ISDs, as shown in Table 6.

Discussion

The goal for E1b was to evaluate two additional perceptual versions that were more similar to those frequently used in the literature. This was done to compare different perceptual decisions to each other to evaluate whether the performance differences were specific to a semantic/perceptual comparison, or if performance differences would be a function of any different decision. There were no significant differences between the tasks for speed, variability, or *d*' indicating that performance was largely consistent between the two tasks. However, there was a significant performance difference in no-go accuracy with accuracy on the digits task being higher than the letters task.

In addition to comparing the tasks to each other, relationships with WMC were examined. For both tasks, significant correlations with *d*' were found. This finding is inconsistent with Redick et al. (2011), who found no relationship between WMC and *d*' despite having a task very similar to the letters task in the present study. Of note, no-go accuracy in Redick et al. (2011) was considerably higher than in the letter go/no-go task in E1b. One variable that differs between the two studies is that the ISI in Redick et al. (2011) was longer than in the current experiment, the importance of which will be discussed later. The associations between WMC and RT measures were more consistent with the literature including Redick et al. (2011), and consistent with E1a, finding no relationship with mean RTs or RT ISDs in either task.

These collective results indicate that while performance is generally similar between different perceptual versions, something about the stimulus set may still affect performance. Specifically, it could be that participants are holding a different goal in mind depending on the size of the stimulus set. The digits task may be more accurate because the list of possible single digits that are not three is a much smaller set than the list of possible letters that are not X. This could make the goal of “press if not 3” easier than the goal of “press if not X”. This would imply that participants are not just comparing each item to the target item and responding to a mismatch. Rather, they may be processing each stimulus first, unable to ignore the meaning of the stimulus despite the irrelevance, and then comparing back to the target. That is, instead of keeping “3 or not-3?” in mind, the participants may keep a broader goal in mind, such as “what is this number? Is it a 3?”. This may become easier for each non-target as it repeats which would explain the difference between the versions, as performance would improve more quickly for the smaller stimulus set. However, if this were the case, it might be expected that RTs would be faster over time for the digits than the letters task, and this is not the case.

EXPERIMENT 1C

To further investigate the effect of stimuli versus the effect of decision, the same stimuli were used from E1a and E1b, but the go and no-go stimuli were switched from the previous versions. E1c serves to both replicate E1a and allow comparison of decision-specific effects. Specifically, E1c replicates the comparison between semantic and perceptual in E1a, but without holding the stimuli the same between the two versions, to determine whether the same patterns hold when the stimuli are not the same between versions. For the decision comparison, in E1a there was already the chance to compare lowercase as ‘go’ to uppercase as ‘go’. E1c allows for the additional decision comparisons for the digits and semantic versions of the task.

This only leaves the letters version in E1b without a direct comparison of this type. However, the letters version in E1b is directly comparable to a letters version with the opposite (X as go) decision mapping from Redick et al. (2011), who compared both mappings in their own work, so no comparison is needed within the present work. Further motivation for E1c involves the findings of Redick et al. when comparing the two opposite decisions. They found both speed and accuracy measure differences between the decision blocks. Importantly, in the present study, the decisions are between-subjects whereas in Redick et al. participants did both for a within-subjects comparison.

Method

Participants

Again, students from the same subject pool who had not participated in E1a or E1b were recruited for this study. A total of 129 participated, though 13 were not included in the analyses due to extremely poor go performance and 12 were not included due to extremely poor go performance the go/no-go tasks. Additionally, 1 participant was excluded due to above threshold math errors on the operation span task, using the same cutoffs described in E1a and 1 participant was not included because they were under 18 years old. The remaining 102 participants were included in all analyses.

Tasks

Operation span. This task was the same as in E1a and E1b.

Symmetry span. This task was the same as in E1a and E1b.

Go/no-go – digits. This task was the same digits go/no-go task described in E1b. However, the task decision was switched such that participants pressed the spacebar if and only if the digit was a 3, not pressing the spacebar if the digit was not a 3.

Semantic go/no-go - living. This task was the same semantic go/no-go task described in E1a. However, the task decision was switched such that the participant was asked to press the spacebar if and only if the stimulus was a living item, and avoid pressing the spacebar if the stimulus was a non-living item.

Procedure

This study was very similar in structure to E1b. The semantic and perceptual order was counterbalanced across subjects, again resulting in two groups. WMC was again continuous and between subjects.

Analyses

The analyses were the same as E1b.

Results

Of the 102 participants included in the analyses, 48 completed the perceptual task first and the other 54 completed the semantic task first. Descriptive statistics for the outcome measures are provided in Table 2.

WMC Measurement

Participants performed very similar to normed samples for both Operation Span and Symmetry Span (Table 2). The two are correlated ($r = .51$, $p < .001$), justifying the composite score used in all further analyses.

Accuracy

Participants were again more accurate on the perceptual task than the semantic task, leading to a main effect of task. As expected, accuracy was again greater for go trials than for no-go trials. Additionally, there was an interaction between task and trial type, due to similar go accuracy but higher no-go accuracy for the perceptual task than the semantic task. In regard to WMC, there was a main effect of WMC that approached traditional significance, likely due to the consistently positive correlations with accuracy. Though, only the correlation with go accuracy for the perceptual task was significant ($r = 0.22$, $p = .03$), as the correlation with no-go accuracy was only marginal (*r* = 0.17, *p* = .09) and the correlations for go and no-go accuracy were non-significant for the semantic task (*r* = 0.08, *p* = .41; *r* = 0.12, *p* = .25). Additionally, there were no significant interactions with WMC, as seen in Table 3.

The *d*' measure was again greater for the perceptual task than the semantic task. Additionally, there was a main effect of WMC, which was significantly correlated with *d*' in both the perceptual (*r* = 0.21, *p* = .03) and semantic (*r* = 0.20, *p* = .05) tasks. As Table 4 shows, there were no significant effects or interactions involving order for *d*'.

Response Times

Again, participants were faster on the perceptual task than the semantic task. There was no significant main effect of order, but there was a significant task by order interaction due to participants being especially fast on the perceptual task when the perceptual task was the first task completed (*M* = 366.58, *SD* = 72.05) compared to when the perceptual task was the second task completed (*M* = 400.68, *SD* = 108.61). There were no significant effects or interactions involving WMC for mean RTs, as seen in Table 5.

RT ISDs were more variable for the semantic task than the perceptual task. There was also a main effect of WMC, which significantly correlated with both perceptual (*r* = -.26, *p* < .01) and semantic (*r* = -.36, *p* < .01) tasks. However, as Table 6 shows, there were no significant interactions involving WMC or order with RT ISDs.

Discussion

The perceptual/semantic comparison in E1c closely replicated E1a with perceptual performance being more accurate, faster, less variable, and producing higher *d*' scores than the semantic task. This replication indicates that whether or not the same stimuli are used between tasks, the performance will be impacted by the task type. This, again, shows that something about the specific decision made during the task is influencing task performance. Additionally, the order of the tasks again affected mean RTs such that responses to the perceptual task were slower when the semantic task had been completed prior to the perceptual task. However, the semantic task, as in E1a, was unaffected by the order of the tasks. Again, this pattern suggests that the semantic quality of the stimuli may be easier to ignore if the first task does not include a semantic decision, but more difficult to ignore when the semantic aspect had previously been the focus.

In regard to WMC, and again consistent with the literature, E1a, and E1b, the correlation with mean RT was not significant. Similar to E1a and E1b, relationships with *d*' were found in both tasks in E1c. Also, similar to E1a, relationships were found with RT ISDs for both tasks. Previous studies have consistently shown no significant relationships with mean RTs, as is replicated across all six tasks in E1. The literature is less consistent with showing relationships between WMC and *d*' and between WMC and RT ISDs. In E1, significant correlations between WMC and *d*' are found, though the relationships to RT ISDs are inconsistent.

BETWEEN-SUBJECTS COMPARISONS

In addition to the analyses within each study, between-subject comparisons were conducted across the studies to investigate the differences in performance based on the go-stimulus decision for otherwise identical tasks. This is possible for the digits (E1b vs. E1c) and semantic (E1a vs. E1c) versions of the task. There was also a decision comparison already discussed in the results of E1a with the uppercase/lowercase versions of the perceptual go/no-go that were between-subjects within E1a. A subset of these data is compared here, in line with the perceptual-digits and semantic decision comparisons.

For the perceptual-digits comparison, the digits task from E1b and the digits task from E1c are compared. The go stimulus for E1b was ‘non-3’ and the go stimulus for E1c was ‘only 3’. For the semantic comparison, the semantic task from E1a and the semantic task from E1c are compared. The go stimuli for E1a were non-living and the go stimuli for E1c were living. Comparisons involving accuracy retain trial type as a within-subjects variable, allowing for ANCOVAs like those used previously. However, the *d*’, mean RT, and RT ISD analyses were univariate ANCOVAs due to the lack of a within-subjects variable. All analyses for the between-subjects comparisons are run only on subjects who completed the given task as the first of the two go/no-go tasks.

Summary statistics of outcome measures from these subgroups are presented in Table 7.

Perceptual-Case Comparison

Because case was a between subjects variable within E1a, and only half of each of those groups of participants completed the perceptual task first, the sample sizes for this comparison are especially reduced (uppercase, $N = 29$; lowercase, $N = 23$). There was not a significant difference in accuracy between the task versions, as shown in Table 8. However, and expectedly, there was a significant difference in accuracy between go and no-go trials, with accuracy being higher on go trials. There was not a significant effect of WMC and no interactions.

The *d*' measure was not different between task versions. A WMC main effect did approach traditional significance, likely due to a significant positive correlation between *d*' and WMC in the uppercase version ($r = .38$, $p = .04$) despite a non-significant correlation in the lowercase version ($r = .15$, $p = .49$).

Mean RTs and RT ISDs were not different between the versions. Additionally, there was no main effect of WMC for mean RTs or RT ISDs.

Perceptual-Digits Comparison

For this comparison, again, only those participants who completed the perceptual task as their first task are included leaving 49 participants in the non-3 group and 54 participants in the only-3 group. There was not a significant difference in accuracy between the task versions, as shown in Table 8. However, and consistent with other comparisons, there was a main effect of WMC and a main effect of trial type, with go accuracy being greater than no-go accuracy. The main effect of WMC, similar to other comparisons, was likely due to positive correlations between accuracy and WMC for both tasks. However, these correlations are only significant in the non-3 task. Additionally, there was an interaction between WMC and trial type, with WMC correlations being numerically stronger with no-go accuracy (non-3: $r = .34$, $p = .02$; only-3: $r = .34$, $p = .01$) than the respective go accuracy (non-3: $r = .29$, $p = .05$; only-3: $r = .21$, $p = .13$).

The *d*' did not differ between task versions, either, as shown in Table 8. However, there was a significant main effect of WMC due to the significant positive correlations for *d*' and WMC in both the non-3 task ($r = .36$, $p = .01$) and the only-3 task ($r = .33$, $p = .01$).

Mean RTs and RT ISDs were not different between task versions. Additionally, there was no significant main effect of WMC for mean RTs or RT ISDs, as seen in Table 8.

Semantic Comparison

For this comparison, again, only those who completed the semantic task as their first task are included leaving 53 participants in the non-living group, from E1a, and 48 participants in the living group, from E1c. There was no difference in accuracy between the task versions, as shown in Table 8. However, and again consistent with previous comparisons, there was a main effect of WMC and a main effect of trial type, with go accuracy being greater than no-go accuracy. There was also an interaction between WMC and trial type, with WMC being significantly correlated with accuracy only in the no-go trials for the non-living task ($r = .39$, $p < .01$). Correlations with no-go accuracy for the living task (*r* = -.003, *p* = .99) and go accuracy for both the non-living (*r* = .07, *p* = .63) and living (*r* = .14, *p* = .33) tasks were not significant.

The *d*' was significantly greater in the non-living version than in the living version, as shown in Table 8. There was also a main effect of WMC due to the positive correlations between WMC and *d*' in both tasks, though only the correlation for the non-living task reached significance (*r* = .33, *p* = .02).

Mean RTs were faster for the Non-living version than for the living version, as shown in Table 8. Again, there was no main effect of WMC for mean RTs. Also indicated in Table 8, the RT ISDs were not different between versions, but there was a significant main effect of WMC as a result of negative correlations between WMC and RT ISDs in both tasks, though the correlation is significant for only the non-living task (*r* = -.31, *p* = .02).

Between-Subjects Comparisons Discussion

The purpose of these decision comparisons was to specifically identify what level of decision affects task performance. Having already shown that differences exist in the perceptual/semantic comparison level, the focus is narrowed here to comparisons of decision mappings (go/no-go) within tasks of the same type (perceptual/semantic). Of note, these comparisons are between-subjects, rather than within-subjects as the perceptual/semantic comparison was. Importantly, in the between-subjects comparisons, only data from those participants who completed the task as their first task were included. This helps to avoid any effects of order and was deemed necessary after finding order effects in E1a and E1c. Though these comparisons are between-subjects, performance on WMC measures were very consistent across all groups, as shown in Table 2. This consistency suggests that differences found in these between-subjects comparisons are not due to WMC differences across samples.

Comparing again the case versions of the perceptual task, this time only for those who completed the task as their first task, resulted in a lack of differences where differences had been previously found. Version effects in the full sample were found in the accuracy and *d*' measures in the previously discussed comparisons in E1a, but no differences were found in the subset of data. This suggests that the order effects may have especially important implications for this task. However, the lack of effects here could also be due to power because the between-subjects comparison includes both order and version, leading to small samples.

The perceptual-digits comparison, like the case comparison, did not result in any significant differences between the tasks. This follows the general pattern of similar performance across perceptual versions of the go/no-go task in these studies.

Interestingly, the semantic task does not only differ from the perceptual task, but the specific stimulus decision also seems to be playing a role. No significant difference was found for accuracy or RT ISDs, but there were significant differences in the mean RT and *d*' measures. Responses were faster and *d*' scores were higher when the go stimulus was non-living than when the go stimulus was living. The stimuli were the same between tasks, making this a strong indication that keeping a different goal in mind between the two versions is leading to different processing.

EXPERIMENT 1 SUMMARY

In E1, two semantic and four perceptual versions of the go/no-go task were compared between- and within-subjects. Some versions of the perceptual task had stimuli identical to those in the semantic task, whereas other versions had different stimuli. Regardless, the perceptual versions produced faster and less variable RTs on go trials and higher accuracy on no-go trials than did the semantic versions. Additionally, WMC was consistently unrelated to mean RTs but was related to *d*'. Less consistent were relationships with RT ISDs. However, the relationships between WMC and the outcome measures were not different between perceptual and semantic versions.

EXPERIMENT 2

In the literature, semantic task outcomes are consistently related to WMC whereas perceptual task outcomes are more inconsistently related to WMC. E1 examined the possibility this distinction in go/no-go outcome relationships with WMC between perceptual and semantic versions had something to do with the task or decision types. The results in E1 show no support for this possibility. Rather, the results of E1 suggest that something else held equal in E1 is likely the cause, as the consistency in the relationships with WMC found in E1 is not typical of the broader literature. The goal of Experiment 2 (E2) was to induce a difference in the relationships between WMC and go/no-go outcomes. As can be seen in Table 1, the differences between semantic and perceptual tasks are not entirely in the performance outcomes. Semantic tasks used in the literature were also more consistently structured than perceptual tasks. Specifically, all tested semantic versions, including the two from E1, had relatively short ISIs with a mask appearing for the length of the interval. However, the perceptual tasks, not including E1, had more variable and longer ISIs usually composed of a blank screen or a mask with an additional blank screen following (e.g., Redick et al., 2011; Stawarczyk et al., 2014; Tan, Zou, Chen, & Luo, 2015). Additionally, the stimulus presentation lengths tend to be longer for the perceptual versions, further adding to the time from the onset of one stimulus to the onset of another.

It is possible that the variation in ISI is influencing the relationship with WMC. This would follow from the literature showing different ISIs resulting in performance differences on various tasks, especially involving mind-wandering outcomes. For example, De Jong, Berendsen, and Cools (1999) found short ISIs produced a smaller Stroop effect despite being only 1800ms faster than the long ISI (see also Jackson & Balota, 2013; Parris, 2014). Short ISIs also led to faster RTs in go/no-go studies, and usually coincided with lower accuracy on no-go trials (Jackson & Balota, 2012; Smallwood et al., 2004; Zamorano et al., 2014). Additionally, Jackson and Balota (2012) found increases in mind-wandering self-reports in the longer ISI version (Experiment 3) compared to the short ISI condition (Experiment 1). A meta-analysis by Metin, Roeyers, Wiersma, van der Meere, and Songua-Barke (2012) looking at differences in participants with ADHD versus control participants showed ISI in go/no-go tasks is also an important factor for special populations. Of note, all of the go/no-go studies examining the role of ISI used perceptual versions of the task.

One potential explanation is that the longer ISIs are less demanding cognitively, and therefore invite more mind-wandering or lapses of attention to occur (e.g., De Jong et al., 1999). This could lead to a stronger relationship with working memory as the need to inhibit mind wandering and enact cognitive control to stay on task becomes greater (e.g., Unsworth, Redick, Lakey, & Young, 2010). This would align with studies on cognitive demand that have found more mind-wandering on longer or more difficult tasks (Feng, D’Mello, & Graesser, 2013; Mason et al., 2007; Seli, Risko, Smilek, &

Schacter, 2016). Interestingly, despite increased self-reports of mind-wandering at longer ISIs, no-go accuracy is typically higher. Accordingly, a lower WMC relationship is another potential outcome at longer ISIs. While a weaker WMC relationship would not follow from the increase in the subjective measure of mind-wandering self-reports, the result would follow from the increase in the objective measure of accuracy. In such a case, mind-wandering may be only perceived to increase or other factors also related to WMC could be influencing the relationship more than increased mind-wandering. Given the potential influence of ISI on go/no-go performance and its possible role in affecting individuals with varying levels WMC, the present study manipulates ISI in an attempt to induce a difference in the working memory relationships with go/no-go outcomes.

Method

Participants

Participants in E2 came from the same subject pool as E1. However, none of the participants from E1 participated in E2. Of the 124 total participants who completed the perceptual versions of the tasks, 1 was unable to complete the study due to an emergency alert disrupting the tasks, 1 was dismissed for being disruptive, 2 were unusable due to being under 18 years old, 1 exceeded the error total limits on the span tasks as described in E1, 3 were unusable due to extremely poor go trial accuracy, and 2 were unusable due to extremely poor no-go trial accuracy in accordance with the cut-offs described in E1. Of the 123 total participants who completed the semantic versions of the tasks, 4 were unable to complete the study due to an emergency alert disrupting the tasks, 5 were unusable due to being under 18 years old, 1 exceeded the error total limits on the span tasks as described in E1, 9 were unusable due to extremely poor go trial accuracy, and 12 were unusable due to extremely poor no-go trial accuracy in accordance with the cut-offs described in E1.These exclusions resulted in a final sample of 114 participants in the Perceptual group and 92 participants in the Semantic group.

Tasks

Operation span. This task was the same as in E1.

Symmetry span. This task was the same as in E1.

Go/no-go – perceptual. This task was similar to the perceptual digits task in E1b. The short ISI version was identical, however the long ISI version included a blank 2000 ms screen between the end of the mask and the start of the next trial. Including the mask, this rendered the short ISI 900 ms and the long ISI 2900 ms. See Figure 1 for the task structure.

Go/no-go – semantic. This task was similar to the semantic task in E1a. The short ISI version was identical, however the long ISI version included a blank 2000 ms screen between the end of the mask and the start of the next trial. Including the mask, this rendered the short ISI 900 ms and the long ISI 2900 ms.

Procedure

The procedure for E2 was very similar to E1 with the order of the two ISI versions of the go/no-go task being counterbalanced across subjects. Half of participants completed the perceptual versions of the tasks and the other half of participants completed the semantic versions of the tasks. Half of each of these groups completed the appropriate short ISI version first followed by the long ISI version and the other half of each group completed the long ISI version before the short ISI version. As in E1, participants completed the two WMC measures before completing the go/no-go tasks.

Analyses

Analyses for E2 are largely similar to those in E1. However, task (perceptual/semantic) was a between-subjects variable and ISI (900ms/2900ms) was a within-subjects variable.

Results

Of the 114 participants in the perceptual task group for E2, 58 participants completed the short ISI task first and the other 56 completed the long ISI task first. Of the 92 participants in the semantic task group, 48 participants completed the short ISI task first and the other 44 completed the long ISI task first. Descriptive statistics for these subgroups are presented in Table 10.

WMC Measurement

Performance on span tasks was consistent with the normed samples (Redick et al., 2012) for both the perceptual group and the semantic group (Table 10). The two are correlated (perceptual: $r = .26$, $p = .01$; semantic: $r = .48$, $p < .001$), justifying the composite scores used in all further analyses.

Accuracy

Accuracy was significantly higher overall on the perceptual task than on the semantic task, as seen in Table 11. As expected, go accuracy was significantly higher than no-go accuracy. There was an interaction between task and trial type due to similar go accuracy but higher no-go accuracy for the perceptual version than the semantic version. Task and task order, the two between-subjects factors, both produced significant main effects and significant interactions with both ISI and trial type. There was also an ISI by task order by trial type interaction because differences were only apparent in the no-go trials and the accuracy on the long ISI task was similar despite order but accuracy on the short ISI task was higher for those who completed that task first as opposed to completing it after the long ISI task. This was true in the overall analysis and held for both the semantic and perceptual task groups when the groups were analyzed separately.

In regard to WMC, there was a significant main effect and a significant interaction with trial type. This interaction was likely driven by the higher correlations with no-go accuracy than with go accuracy particularly in the semantic task. The correlation with no-go accuracy in the semantic task with long ISI reached significance (r = .21, p = .04) and the same correlation for the short ISI approached significance (r = .18, p = .08), as shown in Table 15. Though the same correlations in the perceptual task version were not significant, they were both positive (long ISI: r = .14, p = .14, short ISI: r = .03, p = .76). There were no other significant interactions involving WMC in the overall analysis, including no interaction with ISI. Additionally, the main effect and interaction with trial type only held for the semantic task when the analyses were separated.

The *d*' measure was significantly different between the two tasks with *d*' being larger in the perceptual task than in the semantic task, as shown in Table 12. There was also a main effect of ISI such that the short ISI leads to smaller *d*' than the long ISI. This pattern held within both perceptual and semantic tasks when analyzed separately.

In the overall analysis, ISI interacted with task indicating the difference between the *d*' for short and long ISI tasks was larger in the perceptual version than in the semantic version. There was no main effect of order for the overall or individual analyses, but there was an ISI by order interaction in the overall analysis and the perceptual version analysis. The interaction approached significance in the semantic version analysis. This interaction was due to the difference in *d*' being larger when the long ISI task was completed before the short ISI task.

Additionally, there was a main effect of WMC in the overall analysis for *d*' and the separate semantic analysis due to a significant short ISI semantic task correlation with *d*' (r = .21, p = .04) and a long ISI semantic correlation that approached significance (r = .19, p = .08). This main effect was not present in the separate perceptual analysis likely due to non-significant correlations near zero.

Response Times

A main effect of task, as seen in Table 13, indicated that mean RTs in the perceptual task were faster than those in the semantic task. The main effect of ISI indicated the short ISI resulted in faster mean RTs than the long ISI. There was a main effect of order for mean RTs such that mean RTs were shorter overall when the long ISI task was first, and the interaction with ISI approached significance with the effect of order being larger for the short ISI than the long ISI. There were no other interactions for mean RTs. In regard to WMC, there was no main effect and no interactions. This lack of effect follows from non-significant correlations all near zero between WMC and mean RTs across the tasks and ISIs.

For RT ISDs, as shown in Table 14, there was a main effect of task with the semantic RT ISDs being more variable than the perceptual RT ISDs. There was also a main effect of ISI with the short ISI leading to more variable ISDs than the long ISI. Importantly, there was an interaction between ISI and task, with the difference in RT ISDs between long and short ISI being present only in the semantic task. There was a main effect of order for RT ISDs, but no interactions involving order. Additionally, there was only a marginal main effect for WMC in the overall analysis and in the semantic analysis. Though all the correlations involving RT ISDs were negatively related to WMC, only the long-ISI semantic RT ISDs reached significance ($r = -.21$, $p = .05$). Additionally, there were no interactions with WMC.

Discussion

E2 investigated the effects of manipulating ISI, which resulted in main effects of ISI on all outcome measures. The short ISI produced faster mean RTs on go trials, less accurate performance on no-go trials, and lower *d*' values. There were also order interactions with ISI such that performance on the short ISI task was affected by the long ISI task when the short ISI task came second. This effect was present for both accuracy and *d*' and marginally present for mean RTs. Specifically, accuracy on no-go trials and *d*' are both lower in the short ISI task when the short ISI task is second. The marginal interaction in the mean RTs is due to performance on the short ISI task being particularly fast when it was the second task.

E2 was specifically intended to test whether the manipulation of ISI would induce a difference in the relationships between WMC and the go/no-go outcomes. Such a difference would indicate that ISI was having an effect on the way in which the task was relating to underlying constructs like attention and inhibition that are strongly correlated with WMC. In turn, such differences would help to explain some of the inconsistencies in the literature regarding the relationships between go/no-go performance and WMC.

Specifically, if the varied ISIs were leading to the varied relationships with WMC in the perceptual task version literature, introducing the long ISI into the semantic task version should have resulted in more varied relationships with WMC in the semantic task. This pattern does seem to appear in the present study. Table 16 shows the correlations between WMC and given outcome measures for short and long ISI conditions from E2 and the short ISI comparison from E1, which is identical to the short ISI task in E2. Importantly, the E2 correlations in this table are only from those participants who completed the given task as their first go/no-go task, which was necessary due to the order effects found in E2. The correlations from E2 with short ISI are mostly consistent with the correlations from the matching E1 short ISI comparison. In contrast, the long ISI task outcomes are uncorrelated for both the perceptual and semantic task versions in E2, sometimes even drifting into the opposite direction compared to the short ISI correlations. This pattern of results is clear in the *d*’, no-go accuracy, and RT ISD measures, though less clear in the mean RTs. Importantly, it is the relationships with accuracy measures that normally show such variability in the literature whereas relationships with mean RTs tend to be more consistently absent across tasks.

From the ANCOVAs, WMC is a significant covariate for accuracy, *d*’, and marginally for RT ISDs, but does not interact with ISI for any of the variables. Most interestingly, where WMC was significant as a covariate in the overall analyses and the semantic analysis for the previously mentioned variables, it was not a significant covariate in the separated perceptual task analyses for any of the variables. This echoes the lack of relationships between WMC and perceptual tasks seen elsewhere in the literature as well as non-significant main effects for WMC in E1b, which only included perceptual tasks, for RT outcomes. Despite the lack of WMC main effects, however, the differences in correlations with WMC are informative for the influence WMC has on the various outcome measures. WMC was related to no-go accuracy, *d*', and RT ISD for short ISI tasks in similar patterns to the relationships found in E1. However, these relationships did not appear in the long ISI tasks.

Additionally, in the ANCOVAs, the order variable had a significant main effect for some outcome measures and significant interactions with ISI for some outcome measures. Specifically, it seems no-go accuracy decreased on the short ISI task if the long ISI task was performed first. In mean RTs, when the short ISI task was first, mean RTs on the short ISI task were slower than when the short ISI task was second. Conversely, when the long ISI task was first, mean RTs were faster than when the long ISI task was second. These order effects, while complicating the picture, are not inconsistent with the idea that ISI could cause variability in the relationship to WMC. If the relationship to WMC is stronger in the first task completed, and related constructs like attention and inhibition are being used more, several accounts would propose effects on subsequent tasks. A resource depletion account might suggest worse performance on subsequent tasks, whereas a cognitive control account might posit that cognitive control would increase or be used more efficiently in subsequent tasks. As

WMC is related to long ISI tasks differently than the short ISI tasks, it follows that if the long ISI task is first it may have effects on the subsequent short ISI performance. The short ISI task, if first could also have effects on a subsequent long ISI task for the same reason.

Overall, the patterns found in E2 suggest ISI plays a role in the strength and consistency of relationships between outcome measures and WMC. However, there seem to be additional differences in these relationships based specifically on task type – perceptual versus semantic. This pattern shows smaller or lacking relationships with perceptual tasks versus semantic tasks, unlike E1 but consistent with some of the literature.

CONCLUSIONS

This project provides evidence for the ways in which task manipulations affect the relationships with underlying processes that a task is supposed to be measuring. If the manipulations do not have effects, or have consistent effects, on performance outcomes, then the corresponding connections to underlying processes would be unaffected or affected in a consistent manner. However, should task performance vary in an unpredictable manner depending on different manipulations, the corresponding relationships to underlying processes may also be equally unpredictable or inconsistent.

In the present studies, there are two major findings. First, perceptual versus semantic task performance is consistently different across many task manipulations with perceptual tasks typically resulting in faster and more accurate performance. However, while performance is different, the relationships between outcome measures and WMC are consistent between perceptual tasks and identically structured semantic tasks. Second, as proposed, ISI had an effect on the relationship between WMC and various outcome measures. Importantly, this effect of ISI did not completely explain the differences seen in perceptual versus semantic tasks. So, while ISI does have an effect on the relationships, it must not be the only contributing factor.

These findings do include some limitations. Ideally, in E2, both the ISI critical manipulation and the important task type manipulations would have been within-subjects. However, the time spent doing go/no-go tasks would have so far exceeded the time spent in E1 and been practically incomparable. So, the more important ISI manipulation was chosen as the within-subjects manipulation with task type remaining between-subjects. Importantly, E1 thoroughly investigates the contributions of task type and order of tasks both with similar stimuli and different stimuli such that the necessity of retaining task type in E2 as a between-subjects variable becomes minimal.

Another limitation occurs within the use of *d*’ as a tool to evaluate accuracy in terms of both hit rates and false alarm rates. While this is a more thorough evaluation of accuracy and is used widely in the go/no-go literature, it is important to note the risk associated with using this measure in a task with imbalanced go and no-go trial frequencies, which the measure was not developed to handle (Thomson, Besner, & Smilek, 2016). Specifically, when the frequencies are severely imbalanced, as in the standard go/no-go, the relative contributions of the hits and false alarms are also severely skewed. This imbalance can cause misleading *d*’ values as a small change in hit rate will have a much larger effect on *d*’ than an equal change in false alarms. A more theoretical issue is proposed by Thomson et al. regarding the interpretability of *d*’ in tasks like the go/no-go because the measure may be influenced by moving response criteria as opposed to the hypothesized change in sensitivity. However, this issue is mostly pertinent for studies measuring *d*’ changes with time-on-task. Though changes in *d*’ are not of interest in the present study, the interpretability of the overall *d*’ still must be interpreted cautiously.

Furthermore, future studies may want to consider the implications of the present work for other types of tasks and their relationships with the underlying constructs they are meant to measure. The importance of this investigation is not limited to whether WMC relationships with go/no-go tasks do or do not align with our expectations, but rather extends to the connections between all tasks attempting to measure cognition and the cognitive control constructs such tasks attempt to measure. More importantly the present work illustrates that certain manipulations may be influencing these relationships in impactful and unanticipated ways. Though an important finding, it is not the first instance of such disruptions. Kane and Engle (2003) found that though individual differences in WMC were related to Stroop performance, as would be expected based on executive-attention theory (Engle & Kane, 2004), manipulations such as proportion congruency, presence of feedback, and order of tasks affected this relationship similarly to the effects found in the present work. Additionally, comparing across studies, where Kane and Engle used a vocal response and did not find relationships with WMC in RTs, Unsworth and Spillers (2010) used a button press response in a similar Stroop task and found relationships with WMC and RTs, suggesting response type is another manipulation that affects these relationships.

An additional similarity between the present work and Kane and Engle (2003) is the inconsistency with where the WMC relationships become evident. Kane and Engle (2003) found WMC relationships with the Stroop task primarily in the accuracy measures but not in the RTs. Similarly, in the present work and much of the go/no-go literature, mean RTs were often not related to WMC and RT ISDs were generally inconsistent in their relationships with WMC. This speaks to a wider problem of inconsistency in the literature with WMC relationships and the efforts to determine why relationships are found sometimes and not others and more specifically found in some variables sometimes and other variables other times.

Given the reliance on single tasks throughout the literature, this work has implications for the way in which assessments and studies are designed and carried out for both clinical and research purposes. While the perceptual tasks are advantageous due to the lack of reliance on vocabulary, the semantic tasks are advantageous in that the relationships with working memory are more consistent and are therefore likely getting at the attention and inhibition constructs more clearly. However, extending the ISI was enough to mitigate this advantage and render the tasks equally variable in their relationships with WMC. To conclude, it is advisable to use more than one assessment when attempting to measure a construct and the assessments should be chosen carefully with the effects of various task manipulations in mind.

LIST OF REFERENCES

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Battig, W. F., & Montague, W. E. (1969). Category norms of verbal items in 56 categories: A replication and extension of the Connecticut category norms. *Journal of Experimental Psychology, 80*(3, Pt.2), 1-46. doi:10.1037/h0027577

Bezdjian, S., Baker, L. A., Lozano, D. I., & Raine, A. (2009). Assessing inattention and impulsivity in children during the Go/NoGo task. *British Journal of Developmental Psychology, 27*(2), 365-383. doi:10.1348/026151008X314919

Conway, A. R. A., Kane, M. J., Bunting, M. F., Hambrick, D. Z., Wilhelm, O., & Engle, R. W. (2005). Working memory span tasks: A methodological review and user's guide. *Psychonomic Bulletin & Review*, *12*(5), 769-786. doi:10.3758/BF03196772

De Jong, R., Berendsen, E., & Cools, R. (1999). Goal neglect and inhibitory limitations: Dissociable causes of interference effects in conflict situations. *Acta Psychologica, 101*(2-3), 379-394. doi: 10.1016/S0001-6918(99)00012-8

Donders, F. C. (1869/1969). On the speed of mental processes. *Acta Psychologica, 30*, 412-431. doi:10.1016/0001-6918(69)90065-1

Engle, R.W., & Kane, M.J. (2004). Executive attention, working memory capacity, and a two-factor theory of cognitive control. In B. Ross (Ed.), *The psychology of learning and motivation* (Vol 44, pp 145-199). New York, NY: Academic Press.

Falkenstein, M., Hoorsmann, J., & Hohnsbein, J. (1999). ERP components in Go/Nogo tasks and their relation to inhibition. *Acta Psychologica, 101,* 267-291. doi:10.1016/S0001-6918(99)00008-6

Falkenstein, M., Koshlykova, N. A., Kiroj, V. N., Hoormann, J., & Hohnsbein, J. (1995). Late ERP components in visual and auditory Go/Nogo tasks. *Electroencephalography and Clinical Neurophysiology, 96*(1), 36-43. doi:10.1016/0013-4694(94)00182-K

Faneros, M. A. (2014). *A comparison of contemporary executive function models* (Unpublished doctoral dissertation). University of Oklahoma, Norman, OK.

Feng, S., D'Mello, S., & Graesser, A. C. (2013). Mind wandering while reading easy and difficult texts. *Psychonomic Bulletin & Review*, *20*(3), 586-592. doi:10.3758/s13423-012-0367-y

Jackson, J. D., & Balota, D. A. (2012). Mind-wandering in younger and older adults: Converging evidence from the sustained attention to response task and reading for comprehension. *Psychology and Aging*, *27*(1), 106-119. doi:10.1037/a0023933

Jackson, J. D., & Balota, D. A. (2013). Age-related changes in attentional selection: Quality of task set or degradation of task set across time? *Psychology and Aging*, *28*(3), 744-753. doi:10.1037/a0033159

Jones, A. D., Cho, R. Y., Nystrom, L. E., Cohen, J. D., & Braver, T. S. (2002). A computational model of anterior cingulate function in speeded response tasks: Effects of frequency, sequence, and conflict. *Cognitive, Affective, & Behavioral Neuroscience, 2*(4), 300-317. doi: 10.3758/CABN.2.4.300

Kane, M. J. & Engle, R. W. (2003). Working-memory capacity and the control of attention: The contributions of goal neglect, response competition, and task set to Stroop interference. *Journal of Experimental Psychology: General, 132*(1), 47-70. doi: 10.1037/0096-3445.132.1.47

Kane, M. J., Meier, M. E., Smeekens, B. A., Gross, G. M., Chun, C. A., Silvia, P. J., & Kwapil, T. R. (2016). Individual differences in the executive control of attention, memory, and thought, and their associations with schizotypy. *Journal of Experimental Psychology: General*, *145*(8), 1017-1048. doi:10.1037/xge0000184

Marcusson-Clavertz, D., Cardeña, E., & Terhune, D. B. (2016). Daydreaming style moderates the relation between working memory and mind wandering: Integrating two hypotheses. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 42*(3), 451-464. doi:10.1037/xlm0000180

Mason, M. F., Norton, M. I., Van Horn, J. D., Wegner, D. M., Grafton, S. T., & Macrae, C. N. (2007). Wandering minds: The default network and stimulus-independent thought. *Science, 315*(5810), 393-395. doi:10.1126/science.1131295

McVay, J. C., & Kane, M. J. (2009). Conducting the train of thought: Working memory capacity, goal neglect, and mind wandering in an executive-control task. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *35*(1), 196-204. doi:10.1037/a0014104

McVay, J. C., & Kane, M. J. (2012a). Drifting from slow to 'd'oh!': Working memory capacity and mind wandering predict extreme reaction times and executive control errors. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *38*(3), 525-549. doi:10.1037/a0025896

McVay, J. C., & Kane, M. J. (2012b). Why does working memory capacity predict variation in reading comprehension? On the influence of mind wandering and executive attention. *Journal of Experimental Psychology: General*, *141*(2), 302-320. doi:10.1037/a0025250

Measso, G., & Zaidel, E. (1990). Effect of response programming on hemispheric differences in lexical decision. *Neuropsychologia*, *28*(7), 635-646. doi:10.1016/0028-3932(90)90118-8

Metin, B., Roeyers, H., Wiersema, J. R., van der Meere, J., Sonuga-Barke, E. (2012). A meta-analytic study of event rate effects on Go/No-Go performance in attention-deficit/hyperactivity disorder. *Biological Psychiatry*, 72(12), 990-996. doi: 10.1016/j.biopsych.2012.08.023 pmid:23062355

Morrison, A. B., Goolsarran, M., Rogers, S. L., & Jha, A. P. (2014). Taming a wandering attention: Short-form mindfulness training in student cohorts. *Frontiers in Human Neuroscience*, 7(897). doi: 10.3389/fnhum.2013.00897

Nieuwenhuis, S., Yeung, N., & Cohen, J. D. (2004). Stimulus modality, perceptual overlap, and the go/no-go N2. *Psychophysiology, 41*, 157-160. doi:10.1046/j.1469-8986.2003.00128.x

Nieuwenhuis, S., Yeung, N., van den Wildenberg, W., & Ridderinkhof, K. R. (2003). Electrophysiological correlates of anterior cingulate function in a go/no-go task: Effects of response conflict and trial type frequency. *Cognitive, Affective, & Behavioral Neuroscience, 3*(1), 17-26. doi:10.3758/CABN.3.1.17

O'Connell, R. G., Dockree, P. M., Bellgrove, M. A., Turin, A., Ward, S., Foxe, J. J., & Robertson, I. H. (2009). Two types of action error: Electrophysiological evidence for separable inhibitory and sustained attention neural mechanisms producing error on go/no-go tasks. *Journal of Cognitive Neuroscience*, *21*(1), 93-104. doi:10.1162/jocn.2009.21008

Parris, B. A. (2014). Task conflict in the Stroop task: When Stroop interference decreases as Stroop facilitation increases in a low task conflict context. *Frontiers in Psychology*, *5.* doi: 10.3389/fpsyg.2014.01182

Redick, T. S., Calvo, A., Gay, C. E., & Engle, R. W. (2011). Working memory capacity and go/no-go task performance: Selective effects of updating, maintenance, and inhibition. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *37*(2), 308-324. doi:10.1037/a0022216

Redick, T. S., Broadway, J. M., Meier, M. E., Kuriakose, P. S., Unsworth, N., Kane, M. J., & Engle, R. W. (2012). Measuring working memory capacity with automated complex span tasks. *European Journal of Psychological Assessment*, *28*(3), 164-171. doi:10.1027/1015-5759/a000123

Redick, T. S., Shipstead, Z., Meier, M. E., Montroy, J. J., Hicks, K. L., Unsworth, N., Kane, M. J., . . . Engle, R. W. (2016). Cognitive predictors of a common multitasking ability: Contributions from working memory, attention control, and fluid intelligence. *Journal of Experimental Psychology: General, 145*(11), 1473-1492. doi: 10.1037/xge0000219

Robertson, I. H., Manly, T., Andrade, J., Baddeley, B. T., & Yiend, J. (1997). 'Oops!': Performance correlates of everyday attentional failures in traumatic brain injured and normal subjects. *Neuropsychologia, 35*(6), 747-758. doi: 10.1016/S0028-3932(97)00015-8

Seli, P., Cheyne, J. A., Barton, K. R., & Smilek, D. (2012). Consistency of sustained attention across modalities: Comparing visual and auditory versions of the SART. *Canadian Journal of Experimental Psychology/Revue Canadienne de Psychologie Expérimentale*, *66*(1), 44-50. doi:10.1037/a0025111

Seli, P., Risko, E. F., Smilek, D., & Schacter, D. L. (2016). Mind-wandering with and without intention. *Trends in Cognitive Sciences*, *20*(8), 605-617. doi:10.1016/j.tics.2016.05.010

Smallwood, J., Davies, J. B., Heim, D., Finnigan, F., Sudberry, M., O'Connor, R., & Obonsawin, M. (2004). Subjective experience and the attentional lapse: Task engagement and disengagement during sustained attention. *Consciousness and Cognition*, *13*(4), 657-690. doi:10.1016/j.concog.2004.06.003

Stanislaw, H., & Todorov, N. (1999). Calculation of signal detection theory measures. *Behavior Research Methods, Instruments, & Computers, 31*(1), 137-149. doi:10.3758/BF03207704

Stawarczyk, D., Majerus, S., Catale, C., & D'Argembeau, A. (2014). Relationships between mind-wandering and attentional control abilities in young adults and adolescents. *Acta Psychologica, 148*25-36. doi:10.1016/j.actpsy.2014.01.007

Sternberg, S. (1969). The discovery of processing stages: Extensions of Donders' method. *Acta Psychologica, 30,* 276-315. doi:10.1016/0001-6918(69)90055-9

Tan, T., Zou, H., Chen, C., & Luo J. (2015). Mind wandering and the incubation effect in insight problem solving, *Creativity Research Journal, 27*(4), 375-382. doi: 10.1080/10400419.2015.1088290

Thomson, D. R., Besner, D., & Smilek, D. (2016). A critical examination of the evidence for sensitivity loss in modern vigilance tasks. *Psychological Review, 123*(1), 70-83. doi: 10.1037/rev0000021

Unsworth, N., Heitz, R. P., Schrock, J. C., & Engle, R. W. (2005). An automated version of the operation span task. *Behavior Research Methods, Instruments, & Computers, 37*(3), 498-505. doi:10.3758/BF03192720

Unsworth, N., & McMillan, B. D. (2014). Similarities and differences between mind-wandering and external distraction: A latent variable analysis of lapses of attention and their relation to cognitive abilities. *Acta Psychologica, 150*, 14-25. doi:10.1016/j.actpsy.2014.04.001

Unsworth, N., Redick, T. S., Heitz, R. P., Broadway, J. M., & Engle, R. W. (2009). Complex working memory span tasks and higher-order cognition: A latent-variable analysis of the relationship between processing and storage. *Memory, 17*(6), 635-654. doi:10.1080/09658210902998047

Unsworth, N., Redick, T. S., Lakey, C. E., & Young, D. L. (2010). Lapses in sustained attention and their relation to executive control and fluid abilities: An individual differences investigation. *Intelligence*, *38*(1), 111-122. doi:10.1016/j.intell.2009.08.002

Unsworth, N., & Spillers, G. J. (2010). Working memory capacity: Attention control, secondary memory, or both? A direct test of the dual-component model. *Journal of Memory and Language, 62*, 392-406. doi: 10.1016/j.jml.2010.02.001

VanArsdall, J. (2016) *Exploring animacy as a mnemonic dimension.* (Unpublished doctoral dissertation). Purdue University, West Lafayette, IN.

Watanabe, J., Sugiura, M., Sato, K., Sato, Y., Maeda, Y., Matsue, Y., . . . Kawashima, R. (2002). The human prefrontal and parietal association cortices are involved in no-go performance: An event-related fMRI study. *NeuroImage*, *17,* 1207-1216. doi:10.1006/nimg.2002.1198

Wright, L., Lipszyc, J., Dupuis, A., Thayapararajah, S. W., & Schachar, R. (2014). Response inhibition and psychopathology: A meta-analysis of go/no-go task performance. *Journal of Abnormal Psychology*, *123*(2), 429-439. doi:10.1037/a0036295

Zamorano, F., Billeke, P., Hurtado, J. M., López, V., Carrasco, X., Ossandón, T., & Aboitiz, F. (2014). Temporal constraints of behavioral inhibition: Relevance of inter-stimulus interval in a go-nogo task. *PLoS ONE, 9*(1): e87232. doi:10.1371/journal.pone.0087232

APPENDICES

Appendix A

Table 1

Previous WMC & Go/No-Go Studies

					r			
Authors	*N*	Task	Stimulus Duration	ISI	No-Go ACC	*d'*	*RT* Mean	*RT* ISD
McVay & Kane, 2012a	142	Semantic	250	950	—	0.32	0.04	-0.37
McVay & Kane, 2012b	225	Semantic	300	900	—	0.20	—	-0.17
Unsworth & McMillan, 2014	241	Semantic	300	900	0.12	0.12	—	-0.18
Unsworth, unpublished	211	Semantic	300	900	0.09	—	0.01	-0.13
Redick et al., 2016	534	Semantic	300	900	0.21	0.22	0.03	-0.26
Kane et al., 2016	545	Semantic	300	1500	—	0.18	—	-0.18
McVay & Kane, 2009	83	Perceptual	300	900	—	0.18	—	-0.33
McVay & Kane, unpublished	82	Perceptual	300	900	—	-0.05	0.04	-0.15
Stawarczyk et al., 2014	87	Perceptual	500	2000	0.41	—	-0.15	-0.32
Faneros, 2014	306	Perceptual	300	700	—	0.15	—	—
Marcusson-Clavertz et al., 2016	111	Perceptual	500	2000	0.00	—	—	-0.02
Morrison et al., 2014	58	Perceptual	250	900	0.06	—	0.14	0.01
Tan et al., 2015	17	Perceptual	1000	1000	-0.30	—	0.38	0.38

(*table continues*)

					r			
Authors	*N*	Task	Stimulus Duration	ISI	No-Go ACC	*d'*	*RT* Mean	*RT* ISD
Jackson & Balota, 2012, E1	47	Perceptual	200	900	0.18	—	-0.20	-0.04
Jackson & Balota, 2012, E2	32	Perceptual	200	900	-0.02	—	-0.17	-0.36

Note. *r* = correlation with WMC. Redick et al., 2011, E1 & E2 not listed due to extreme groups design, but no WMC differences were found for the perceptual task for *d'*, mean *RT*, or *RT* ISDs.

Table 2

E1 Descriptive Statistics

	E1a			E1b		E1c	
	Upper	Lower	Non-living	Non-3	Non-X	Only 3	Living
Ospan		59.58		56.97		60.25	
M (SD)		(10.73)		(13.53)		(9.75)	
Sspan		30.99		30.14		31.07	
M (SD)		(6.46)		(7.35)		(7.38)	
Go ACC	98.70	98.58	98.19	98.46	98.94	99.04	95.95
M (SD)	(0.03)	(0.02)	(0.02)	(0.03)	(0.02)	(0.02)	(0.05)
No-go ACC	61.61	54.01	52.98	59.70	53.10	63.69	53.50
M (SD)	(0.20)	(0.21)	(0.21)	(0.23)	(0.25)	(0.20)	(0.18)
Go Mean *RT*	404.61	412.68	509.35	396.51	402.19	382.51	576.14
M (SD)	(88.78)	(83.79)	(87.42)	(105.67)	(105.47)	(92.25)	(92.96)
Go *RT* ISD	113.14	116.25	136.53	108.27	106.26	108.99	142.32
M (SD)	(36.94)	(32.49)	(34.45)	(41.60)	(40.56)	(41.07)	(33.22)
d'	2.80	2.44	2.32	2.68	2.61	2.88	2.00
M (SD)	(0.77)	(0.88)	(0.81)	(1.03)	(1.02)	(0.89)	(0.68)

Note. Ospan = Operation span, Sspan = Symmetry span, ACC = accuracy, RT = response time, ISD = individual standard deviation, WMC = working memory capacity

Table 3

ANCOVA Output – Accuracy E1

	E1a			E1b			E1c		
	F	*p*	η_p^2	*F*	*p*	η_p^2	*F*	*p*	η_p^2
Main Effects									
Task	10.42	.002	.09	11.99	.001	.11	56.62	<.001	.36
Trial	582.10	<.001	.85	397.50	<.001	.80	553.49	<.001	.85
WMC	11.63	.001	.10	6.85	.010	.07	3.44	.067	.03
Order	0.62	.434	.01	0.46	.499	.01	0.16	.687	.00
Version	0.84	.361	.01	—	—	—	—	—	—
2-Way Interactions									
Task x Trial	6.91	.010	.07	20.02	<.001	.17	16.38	<.001	.14
Task x WMC	0.09	.771	.00	1.18	.280	.01	0.39	.536	.00
Task x Order	0.27	.606	.00	0.48	.488	.01	1.73	.192	.02
Task x Version	7.20	.009	.07	—	—	—	—	—	—
Trial x WMC	10.45	.002	.10	4.79	.031	.05	1.98	.163	.02
Trial x Order	0.73	.394	.01	0.49	.488	.01	0.00	.959	.00
Trial x Version	0.80	.373	.01	—	—	—	—	—	—
Order x Version	0.05	.824	.00	—	—	—	—	—	—

(*table continues*)

	E1a			E1b			E1c		
	F	*p*	η_p^2	*F*	*p*	η_p^2	*F*	*p*	η_p^2
3-Way Interactions									
Task x Trial x Order	1.06	.305	.01	0.33	.566	.00	0.99	.322	.01
Task x Trial x WMC	0.00	.984	.00	1.38	.243	.01	0.35	.556	.00
Task x Trial x Version	7.23	.008	.07	—	—	—	—	—	—
Task x Version x Order	0.00	.981	.00	—	—	—	—	—	—
Trial x Version x Order	0.36	.550	.00	—	—	—	—	—	—
4-Way Interaction									
Task x Trial x Version x Order	0.04	.835	.00	—	—	—	—	—	—

Table 4

ANCOVA Output – d' E1

	E1a			E1b			E1c		
	F	*p*	η_p^2	*F*	*p*	$_p^2$	*F*	*p*	η_p^2
Main Effects									
Task	20.28	<.001	.17	0.78	.379	.01	122.19	<.001	.55
WMC	12.65	.001	.11	9.04	.003	.08	6.11	.015	.06
Order	0.74	.391	.01	0.77	.383	.01	0.28	.600	.00
Version	1.74	.190	.02	—	—	—	—	—	—
2-Way Interactions									
Task x WMC	0.64	.424	.01	0.45	.505	.01	0.26	.609	.00
Task x Order	0.03	.860	.00	0.01	.918	.00	2.66	.106	.03
Task x Version	6.78	.011	.06	—	—	—	—	—	—
Order x Version	0.00	.979	.00	—	—	—	—	—	—
3-Way Interactions									
Task x Version x Order	0.91	.342	.01	—	—	—	—	—	—

Table 5

ANCOVA Output – Mean RT E1

	E1a			E1b			E1c		
	F	*p*	η_p^2	*F*	*p*	η_p^2	*F*	*p*	η_p^2
Main Effects									
Task	214.81	<.001	.68	0.81	.369	.01	444.57	<.001	.82
WMC	3.66	.059	.04	1.49	.224	.02	0.09	.762	.00
Order	1.35	.249	.01	0.18	.675	.00	0.33	.567	.00
Version	0.11	.736	.00	—	—	—	—	—	—
2-Way Interactions									
Task x WMC	0.10	.759	.00	3.31	.072	.03	1.13	.290	.01
Task x Order	20.65	<.001	.17	2.27	.135	.02	7.26	.008	.07
Task x Version	0.02	.904	.00	—	—	—	—	—	—
Order x Version	0.31	.579	.00	—	—	—	—	—	—
3-Way Interactions									
Task x Version x Order	2.40	.125	.02	—	—	—	—	—	—

Table 6

ANCOVA Output – RT ISDs E1

	E1a			E1b			E1c		
	F	*p*	η_p^2	*F*	*p*	η_p^2	*F*	*p*	η_p^2
Main E									
Task	36.10	<.001	.27	0.30	.585	.00	50.43	<.001	.34
WMC	11.02	.001	.10	1.16	.284	.01	18.11	<.001	.16
Order	0.06	.806	.00	0.08	.775	.00	0.73	.395	.01
Version	0.58	.449	.01	—	—	—	—	—	—
2-Way Interactions									
Task x WMC	0.48	.491	.01	0.01	.929	.00	0.02	.890	.00
Task x Order	15.01	<.001	.13	0.25	.617	.00	2.71	.103	.03
Task x Version	0.25	.620	.00	—	—	—	—	—	—
Order x Version	0.06	.806	.00	—	—	—	—	—	—
3-Way Interactions									
Task x Version x Order	0.87	.354	.01	—	—	—	—	—	—

Table 7

First Task Only Descriptive Statistics E1

	Case		Digits		Semantic	
	Upper	Lower	Non-3	Only-3	Non-living	Living
Go ACC	99.18	98.46	98.47	99.15	98.33	95.52
M (SD)	(0.01)	(0.02)	(0.02)	(0.01)	(0.02)	(0.05)
No-go ACC	59.31	52.61	58.44	62.78	53.52	52.22
M (SD)	(0.19)	(0.22)	(0.20)	(0.17)	(0.22)	(0.17)
Go Mean *RT*	383.07	387.50	386.68	366.35	501.98	567.16
M (SD)	(69.94)	(67.60)	(87.81)	(72.05)	(91.06)	(89.97
Go *RT* ISD	106.09	110.46	108.69	104.26	131.00	139.47
M (SD)	(31.08)	(29.64)	(43.79)	(36.95)	(32.62)	(30.67)
d'	2.73	2.42	2.58	2.84	2.37	1.91
M (SD)	(0.73)	(0.96)	(0.92)	(0.80)	(0.88)	(0.60)

Table 8

Between Subjects Tests E1

	Case			Digits			Semantic		
	F	p	η_p^2	F	p	η_p^2	F	p	η_p^2
Accuracy									
Main Effects									
Version	1.73	.194	.03	0.96	.329	.01	1.66	.201	.02
Trial	245.72	<.001	.83	517.85	<.001	.84	516.38	<.001	.84
WMC	2.54	.118	.05	13.25	<.001	.12	6.30	.014	.06
Interactions									
Version x Trial	1.20	.279	.02	0.54	.463	.01	0.03	.874	.00
Trial x WMC	2.01	.162	.04	11.93	.001	.11	4.87	.030	.05
d'									
Main Effects									
Version	1.83	.182	.04	1.47	.229	.01	11.01	.001	.10
WMC	3.65	.062	.07	13.53	<.001	.12	5.44	.022	.05

(*table continues*)

	Case			Digits			Semantic		
	F	*p*	η_p^2	*F*	*p*	η_p^2	*F*	*p*	η_p^2
Mean *RT*									
Mean Effects									
Version	0.05	.820	.00	2.00	.160	.02	12.21	.001	.11
WMC	0.35	.558	.01	1.62	.206	.02	0.89	.348	.01
***RT* ISD**									
Main Effects									
Version	0.26	.612	.01	0.17	.685	.00	2.75	.101	.03
WMC	0.50	.484	.01	2.20	.141	.02	7.47	.007	.07

Table 9

Correlations With WMC E1

	E1a			E1b		E1c	
	Upper	Lower	Non-living	Non-3	Non-X	Only 3	Living
N =	56	49	105	101		102	
No-go ACC	.38*	.21	.28*	.19	.26*	.17	.12
d'	.44*	.22	.27*	.24*	.30*	.21*	.20*
Mean *RT*	.13	.16	.18	.06	.17	.05	-.09
RT ISD	-.19	-.29*	-.28*	-.10	-.10	-.26*	-.36*

Note. * indicates $p < .05$

Table 10

Descriptive Statistics E2

	E2 – Perceptual		E2 – Semantic	
	Short	Long	Short	Long
Ospan	59.93		58.29	
M (SD)	(9.68)		(11.03)	
Sspan	30.36		31.42	
M (SD)	(6.84)		(6.55)	
Go ACC	98.83	98.87	98.28	97.79
M (SD)	(1.70)	(2.33)	(2.21)	(2.97)
No-go ACC	55.99	78.07	47.93	69.86
M (SD)	(19.58)	(17.42)	(18.89)	(16.20)
Go Mean *RT*	369.17	452.37	514.58	606.58
M (SD)	(74.46)	(89.98)	(82.55)	(73.18)
Go *RT* ISD	109.16	108.23	140.36	129.22
M (SD)	(38.78)	(33.59)	(37.29)	(22.31)
d'	2.56	3.34	2.21	2.73
M (SD)	(0.77)	(0.86)	(0.73)	(0.75)

Table 11

ANCOVA Output – Accuracy E2

	E2 – Combined			E2 – Perceptual			E2 – Semantic		
	F	*p*	η_p^2	*F*	*p*	η_p^2	*F*	*p*	η_p^2
Main Effects									
ISI	306.64	<.001	.60	176.17	<.001	.61	134.23	<.001	.60
Trial	1125.15	<.001	.85	451.52	<.001	.80	727.10	<.001	.89
WMC	4.99	.027	.02	1.42	.236	.01	4.50	.037	.05
Order	4.69	.032	.02	0.24	.623	.00	6.71	.011	.07
Task	16.85	.000	.08	—	—	—	—	—	—
2-Way Interactions									
ISI x Trial	349.15	<.001	.64	190.30	<.001	.63	160.55	<.001	.64
ISI x WMC	0.51	.478	.00	1.07	.302	.01	0.01	.917	.00
ISI x Order	21.71	<.001	.10	9.87	.002	.08	11.58	.001	.12
ISI x Task	0.04	.839	.00	—	—	—	—	—	—
Trial x WMC	4.65	.032	.02	0.76	.384	.01	5.61	.020	.06
Trial x Order	6.52	.011	.03	0.51	.476	.01	8.62	.004	.09
Trial x Task	12.47	.001	.06	—	—	—	—	—	—
Order x Task	2.11	.148	.01	—	—	—	—	—	—

(*table continues*)

	E2 – Combined			E2 – Perceptual			E2 – Semantic		
	F	*p*	η_p^2	*F*	*p*	η_p^2	*F*	*p*	η_p^2
3-Way Interactions									
ISI x Trial x Order	19.48	<.001	.09	8.32	.005	.07	10.95	.001	.11
ISI x Trial x WMC	0.86	.356	.00	0.97	.326	.01	0.06	.808	.00
ISI x Trial x Task	0.06	.815	.00	—	—	—	—	—	—
ISI x Task x Order	0.20	.652	.00	—	—	—	—	—	—
Trial x Task x Order	2.30	.131	.01	—	—	—	—	—	—
4-Way Interaction									
ISI x Trial x Task x Order	0.30	.586	.00	—	—	—	—	—	—

Table 12

ANCOVA Output – d' E2

	E2 – Combined			E2 – Perceptual			E2 – Semantic		
	F	*p*	η_p^2	*F*	*p*	η_p^2	*F*	*p*	η_p^2
Main Effects									
ISI	148.21	<.001	.42	111.88	<.001	.50	46.71	<.001	.34
WMC	5.94	.016	.03	1.81	.181	.07	5.07	.027	.05
Order	0.42	.519	.00	0.04	.845	.00	1.23	.271	.01
Task	27.05	<.001	.12	—	—	—	—	—	—
2-Way Interactions									
ISI x WMC	0.49	.486	.00	1.15	.287	.01	0.04	.852	.00
ISI x Order	9.74	.002	.05	6.98	.009	.06	3.18	.078	.04
ISI x Task	5.53	.020	.03	—	—	—	—	—	—
Order x Task	0.82	.366	.00	—	—	—	—	—	—
3-Way Interactions									
ISI x Task x Order	0.28	.599	.00	—	—	—	—	—	—

Table 13

ANCOVA Output – Mean RTs E2

	E2 – Combined			E2 – Perceptual			E2 – Semantic		
	F	*p*	η_p^2	*F*	*p*	η_p^2	*F*	*p*	η_p^2
Main Effects									
ISI	325.21	<.001	.62	156.97	<.001	.59	170.21	<.001	.66
WMC	0.06	.815	.00	0.74	.392	.01	0.39	.533	.00
Order	12.68	<.001	.06	3.36	.062	.03	9.98	.002	.10
Task	224.96	<.001	.53	—	—	—	—	—	—
2-Way Interactions									
ISI x WMC	0.00	.993	.00	0.15	.700	.00	0.25	.619	.00
ISI x Order	3.86	.051	.02	0.24	.625	.00	4.91	.029	.05
ISI x Task	0.93	.335	.01	—	—	—	—	—	—
Order x Task	0.83	.364	.00	—	—	—	—	—	—
3-Way Interactions									
ISI x Task x Order	1.65	.200	.01	—	—	—	—	—	—

Table 14

ANCOVA Output – RT ISDs E2

	E2 – Combined			E2 – Perceptual			E2 - Semantic		
	F	*p*	η_p^2	*F*	*p*	η_p^2	*F*	*p*	η_p^2
Main Effects									
ISI	7.07	.008	.03	0.12	.731	.00	9.82	.002	.10
WMC	3.30	.071	.02	0.88	.351	.01	3.00	.087	.03
Order	5.00	.027	.02	5.66	.019	.05	0.61	.437	.01
Task	40.68	<.001	.17	—	—	—	—	—	—
2-Way Interactions									
ISI x WMC	0.00	.948	.00	0.03	.867	.00	0.00	.953	.00
ISI x Order	1.06	.304	.01	2.58	.111	.02	0.00	.996	.00
ISI x Task	4.91	.028	.02	—	—	—	—	—	—
Order x Task	1.52	.219	.01	—	—	—	—	—	—
3-Way Interactions									
ISI x Task x Order	1.09	.299	.01	—	—	—	—	—	—

Table 15

Correlations With WMC E2

	Perceptual		Semantic	
	Short	Long	Short	Long
N =	92		114	
No-go ACC	.03	.14	.18	.21*
d'	.06	.16	.21*	.19
Mean RT	-.11	-.06	.09	.04
RT ISD	-.09	-.09	-.12	-.21*

Note. * indicates $p < .05$

Table 16

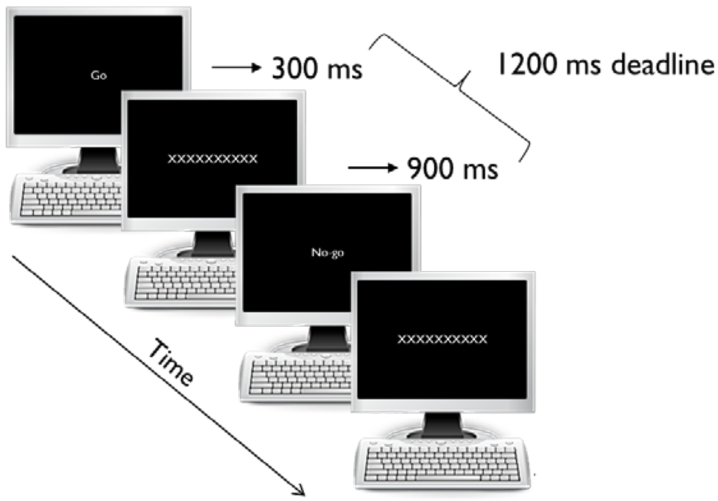
Correlations With WMC Comparison From E1 to E2

	Perceptual			Semantic		
	E1b	E2 - Short	E2 - Long	E1a	E2 - Short	E2 – Long
N =	49	58	56	53	48	44
No-go ACC	.33*	.27*	-.02	.39*	.25	.06
d'	.35*	.28*	.00	.33*	.42*	-.02
Mean *RT*	.17	.07	-.13	.28*	-.02	.08
RT ISD	-.03	.02	-.01	-.31*	-.40*	-.14

Note. * indicates $p < .05$, Correlations for first task only

Appendix B

E1 and E2 - Short



E2 - Long

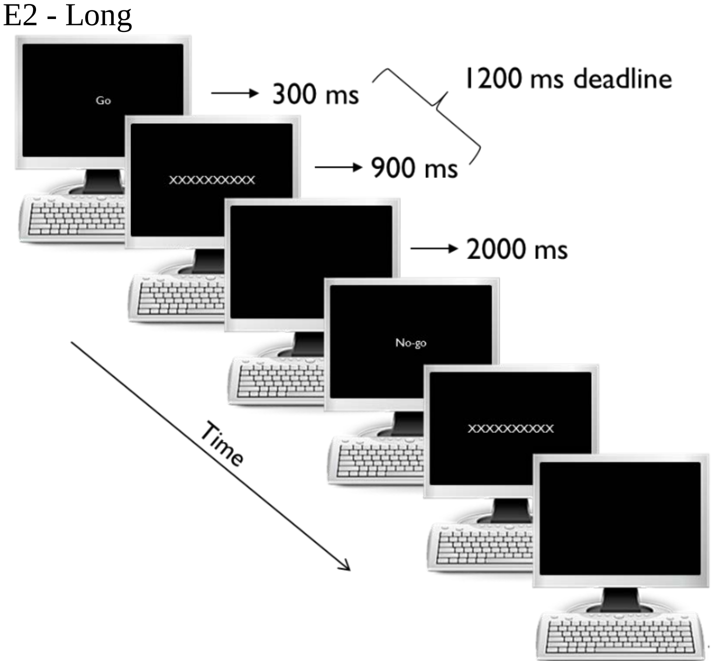


Figure 1. Task structure.

Appendix C

The word list created for E1a and E1c consists of parts of lists from multiple sources (Battig & Montegue, 1969; McVay & Kane, 2012; D. Schneider, personal communication, December 4, 2015; VanArsdall, 2016). Words were randomly selected to appear in uppercase or lowercase. See full list below:

aardvark	bottle	ceiling	cube	fork	hospital
alley	bowl	centipede	cup	fort	house
alligator	box	cereal	deck	fountain	hyena
ambulance	bracelet	certificate	decoration	fox	icicle
anaconda	bread	chair	deer	frame	iguana
animal	breakfast	chalk	desk	frog	incense
ant	brick	cheetah	dice	furnace	ink
antelope	bridge	chicken	dinner	furniture	insect
antique	broom	chimney	dirt	garage	instrument
apartment	brownie	chimpanzee	disc	gas	interior
ape	bubble	chinchilla	dock	gazelle	invitation
appliance	bucket	chipmunk	doe	gerbil	island
apron	buffalo	chocolate	dog	gift	jacket
armadillo	building	chrome	doll	gingerbread	jar
arrow	bull	circle	dollar	giraffe	jeep
auditorium	bunny	clam	dolphin	glass	jelly
baboon	butter	clasp	dome	glitter	journal
background	butterfly	clay	donkey	goat	jug
badge	button	clock	door	gold	juice
bag	cabin	closet	dorm	goldfish	kangaroo
balcony	cable	clothing	dove	gopher	key
ball	cage	cloud	drain	gorilla	kite
bandage	cake	club	dress	graph	kitten
bank	calculator	coast	drill	grasshopper	knot
barn	calf	coat	drum	ground	ladder
basement	camel	cockatoo	duck	guitar	lamb
basin	camera	coin	eagle	gym	lantern
basket	canal	comb	earthworm	hall	latch
bathtub	canary	compass	eel	hammer	lemonade
beach	candle	cone	elephant	hammock	leopard
bear	candy	cord	engine	hamster	letter
beaver	cane	costume	envelope	handkerchief	library
bed	canoe	cottage	equipment	hare	lighthouse
bee	cap	couch	escalator	harmonica	lion
beetle	capsule	cougar	fabric	hat	liquid
belt	card	coupon	factory	hawk	lizard
bench	cardinal	court	fawn	helmet	llama
bicycle	cargo	cow	feast	hen	lobster
billboard	caribou	coyote	fence	herring	lock
binoculars	carp	crab	fireplace	highway	locomotive
bird	carpet	cradle	fish	hill	locust
biscuit	cart	crayon	flag	hippo	lodge
bison	case	cricket	flamingo	hog	lotion
blanket	cash	crocodile	flashlight	hole	luggage
board	castle	crow	flea	home	macaroni
bolt	cat	crown	floor	honey	machine
book	caterpillar	crumb	food	hornet	magazine
booth	catfish	crutch	footballs	horse	magnet

mail
mall
mansion
mantle
map
market
mat
match
mattress
meal
menu
metal
metronome
mice
microscope
milk
minnow
mirror
mite
mitten
mixture
moat
mole
money
monkey
monument
moose
mop
mosquito
motel
moth
motor
motorcycle
movie
mud
mule
muskrat
nail
necklace
neighbourhood
newspaper
nightingale
note
novel
oar
oatmeal
octopus
office
oil
opossum
ornament
ostrich
otter
outfit
oven
owl
oxen
oyster
package
palace
panda
panther
pants
paper
parachute
parrot
passport
patio
peacock
pebble
pen
pencil
penguin
phone
photograph
piano
picture
pig
pigeon
pillow
pin
plate
platform
platter
pocket
pony
pool
porch
porpoise
postcard
primate
prize
propeller
pudding
puppy
purse
puzzle
python
quail
quilt
rabbit
raccoon
radio
raft
railroad
rainbow
ram
rat
rattlesnake
raven
refrigerator
reptile
restaurant
rhinoceros
ribbon
ring
roach
road
robin
roof
room
rooster
rope
rubble
rug
sail
salamander
sandal
satin
sauce
school
scissors
scorpion
screwdriver
seat
serpent
shampoo
shark
shed
sheep
sheet
shirt
shoe
shop
shore
shrimp
sign
silk
silver
sink
skillet
skunk
skyscraper
sleeve
slide
slipper
snail
snake
soap
sock
soda
sofa
softball
soup
sparrow
spatula
spider
spool
spoon
square
squirrel
stadium
stair
stallion
stamp
staple
star
statue
steam
stone
stork
stove
street
string
suds
sugar
sun
surfboard
swan
table
taxi
teapot
telephone
telescope
tent
termite
thermometer
ticket
tiger
tire
toad
toaster
toilet
tool
toothbrush
tortoise
towel
tower
toy
trash
treadmill
treat
trout
trumpet
trunk
tunnel
turtle
typewriter
umbrella
uniform
university
utensil
vacuum
vase
vault
vest
vinegar
violin
vulture
wall
wallaby
wallet
walrus
warbler
warehouse
wasp
water
wax
weasel
whale
wheel
whistle
windmill
window
wolf
wolverine
worm
wren
wrench
yak
zebra
zipper

Appendix D

The word list created for E2 consists of parts of lists from multiple sources (Battig & Montegue, 1969; McVay & Kane, 2012; D. Schneider, personal communication, December 4, 2015; VanArsdall, 2016). Words were randomly selected to appear in uppercase or lowercase. See full list below:

academy
accordion
ambulance
ant
antelope
antique
apartment
appliance
apron
arch
armadillo
armor
arrow
article
auditorium
avenue
baboon
background
badge
bagpipe
balcony
ball
ballot
bandage
bank
banner
barn
basement
basket
bathtub
beach
beam
bedroom
bell
belongings
belt
bench
beverage
bicycle
binoculars
bird
blanket
block
board
bolt
book
boot
booth
bottle
bowl
box
bracelet
bread
breakfast
brick
bridge
broom
brownie
brush
bubble
bucket
buckle
building
bunny
butter
butterfly
button
cabinet
cable
cafe
cage
cake
calculator
camel
camera
camp
candle
candy
canoe
cap
card
cargo
caribou
carp
carpet
cart
cash
cassette
castle
cave
ceiling
cereal
certificate
chair
chalk
chart
chicken
chimney
chimpanzee
chinchilla
chocolate
chrome
circle
city
clam
clarinet
clay
clock
closet
clothing
cloud
club
coast
coat
cockatoo
coin
college
comb
compass
concrete
cone
cord
corridor
costume
cottage
couch
court
coyote
cradle
crayon
cream
cricket
crown
crutch
cube
cup
dart
deck
decoration
deer
desk
dice
dinner
disc
display
dock
dog
doll
dollar
dome
door
dormitory
drain
dress
dresser
drill
drum
dryer
dungeon
earthworm
edge
engine
entrance
envelope
equipment
eraser
escalator
exterior
fabric
factory
fawn
fence
ferry
fiddle
film
fireplace
flag
flashlight
flea
floor
flute
footballs
fork
frame
frog
furnace
furniture
fuse
garage
garment
gate
gauntlet
gazelle
gear
gift
glass
glitter
glove
goat
gold
graph
ground
guitar
gym
hairpin
hall
hammer
hammock
handkerchief
harbor
harmonica
hat
hawk
helmet
herring
highway
hill
hippo
hole
home
honey
hose
hospital
hotel
house
icicle
iguana
incense
ink
insect
instrument
interior
invoice
iron
island
item
jacket
jail
jar
jeep
jelly
jet
jewel
journal
jug
juice
kettle
key
kite
kitten
knob
knot
labyrinth
ladder
lamb
lamp
lantern
latch
lease
lemonade
letter
lever
library
lighter
lighthouse
linen
liquid
lock
locomotive
lodge
lotion
luggage
lumber
macaroni
machine
magazine
magnet
mail
mall
mansion
mantle
map
marble
market
mat
match
material
mattress
medal
medicine
menu
metal
microscope
milk

mirror
mitten
moat
mole
money
monument
moose
mop
motel
motorcycle
movie
mud
mug
mule
muskrat
nail
napkin
necklace
neighbourhood
net
newspaper
nightgown
noodle
note
oar
oatmeal
object
octagon
octopus
office
ornament
outfit
outpost
oven
overcoat
package
paint
palace
panorama
pants
paper
paperclip
parachute
parcel
park
parrot
passage
passageway
passport
pen
pencil
periodical
phone
photograph
piano
picture
pier
pigeon
pillow
pin
plank
plate
platform
pocket
pole
pool
porch
porpoise
portrait
primate
prize
product
projector
propeller
property
puck
pudding
puddle
purse
puzzle
pyramid
python
quarter
quill
quilt
rabbit
raccoon
rack
railroad
rainbow
ram
receipt
reel
refrigerator
register
reptile
resort
restaurant
ribbon
ridge
ring
road
robin
rock
roof
room
rooster
rope
rowboat
rubble
rug
saddle
sail
salamander
salt
sandal
satin
sauce
saucer
saxophone
school
scissors
scorpion
screwdriver
seat
shadow
shampoo
shark
shed
sheet
shelter
shirt
shoe
shoes
sign
silk
silo
silver
sink
sketch
skillet
skirt
skunk
skyscraper
sleeve
sleigh
slipper
soap
sock
sofa
softball
soil
spatula
sphere
spool
spoon
square
stadium
stair
stamp
staple
star
station
statue
steamboat
steel
step
stethoscope
stocking
stone
stove
street
stretcher
string
substance
suds
sugar
suite
sun
surface
surfboard
swan
table
tack
taxi
teapot
telephone
telescope
tent
termite
thermometer
thimble
thread
ticket
tin
tire
toaster
toilet
tool
toothbrush
towel
tower
toy
trapeze
trash
tray
treadmill
treat
triangle
trombone
trumpet
trunk
tuba
tunnel
tweezers
typewriter
umbrella
uniform
university
utensil
vacuum
vapour
vase
vault
velvet
vest
village
vinegar
violin
wall
wallaby
warehouse
wasp
water
wax
weasel
whale
wheel
whistle
windmill
window
wolverine
worm
wrench
zipper
zone