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The SNARC effect as a tool to Examine Crosstalk during Numerical Processing in a PRP paradigm

by

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Abstract

The phenomenon where small numbers produce faster left than right responses and large numbers produce faster right than left responses (The SNARC effect) has been used as evidence for obligatory activations of magnitude. In two experiments, I used the SNARC effect to examine crosstalk using a psychological refractory period (PRP) paradigm. In Experiment 1, subjects made a parity judgment to the second number, while ignoring the first number in session 1 or performing a magnitude judgment on the number in session 2. In Experiment 2, subjects performed a magnitude judgment on the second number. They ignored the first number in session 1 or performed a parity judgment on the number in session 2. The results supported two conclusions. First, presentation of a number produced obligatory representations of magnitude even if the number was to be ignored. Second, early representations of magnitude resulted in crosstalk on processing of the subsequent number.

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Introduction

Numbers have always been an essential part of our life. Mostly we use numbers to communicate information about order and magnitude. In addition, numbers also convey a plethora of other information that could involve semantic facts (e.g., whether a number is a prime number) or purely nominal information (e.g., the bus route from the airport to central terminal). In the latter cases, magnitude information is not always a relevant feature. However, research has suggested that the magnitude of a number can be encoded even though it is not relevant to the task (Sheperd, Kilpatrick, & Cunnngham, 1975; Dehaene, Bossini, & Giraux, 1993). This research focuses on the nature of the interference between two numbers presented in quick succession. The line of research presented by Logan and Schulkind (2000) shows robust evidence that interference occurs when participants perform an identical task to two numbers presented in quick succession However, they also found no evidence of interference between two non-identical tasks. In their experiments, Logan and Schulkind were not specifically looking for interference caused by obligatory encoding of irrelevant information. Rather they examined interference between processes involved in response selection to both tasks. In the current research, I review the possibility of interference between two non-identical tasks as a result of obligatory activation of irrelevant information. This will be done by looking at the spatial numerical association of response codes (SNARC) effect in the context of the psychological refractory period (PRP) paradigm.

The SNARC effect, first observed by Dehaene, Bossini and Giraux (1993), has been taken as evidence that magnitude is represented in the form of an analog mental number line that is spatially oriented from left to right, with small numbers on the left and large numbers on the right. In Dehaene et al., subjects made parity judgments to single digit numbers. Analysis of response times showed that left responses were faster than right responses for small numbers. Conversely, right responses were faster than left responses for large numbers. This particular interaction between hand and space, otherwise known as the SNARC effect further suggests that the magnitude of single-digit numbers is associated with left-right spatial codes. Technically, magnitude is irrelevant to successful performance of the required task. Thus, the SNARC effect has also been used as evidence for obligatory activation of magnitude representation when numerical stimuli are presented. The capability of the SNARC effect to tap into the obligatory representation of magnitude makes it possible to examine interference as a result of processes that activate early magnitude representations especially in tasks where magnitude is irrelevant such as parity judgment.

Evidence that magnitude information was activated before parity comes from Sudevan and Taylor (1987). Subjects were cued by the phrases “HI-LO” or “OD-EV” to perform either a magnitude judgment or a parity judgment respectively. In a typical magnitude judgment, participants are asked to determine whether a presented number is larger or smaller than a comparison number of 5. In a parity judgment, participants are asked to determine whether a presented number is odd or even. With limited practice, responses for magnitude judgments were found to be faster than parity judgments. In addition, subjects responded slower for parity judgments if the correct response was inconsistent with the response that would have been used for magnitude. Sudevan and Taylor suggested that magnitude was processed at an earlier stage of processing relative to parity processing. This finding further suggests that performing a magnitude judgment interfered with parity judgments, while conversely, there was no evidence that parity judgments interfered with magnitude judgments. It follows that a magnitude representation of a presented number is present even for parity judgments. During parity judgments, a response might be activated based on the number's magnitude but is inhibited if the required response is inconsistent with this activated response. Sudevan and Taylor suggested that interference can occur between two non-identical tasks. I build on their results to examine whether interference can be localized to processes that activate obligatory magnitude representations. Observations of the SNARC effect is dependent on obligatory representations of magnitude in tasks where magnitude is known to be irrelevant. This means that in tasks that involve focus of attention on a number; for example in a parity judgment task, presenting a number is sufficient to encode the magnitude of the number. In the coming experiments, I use the SNARC effect to examine interference from obligatory representations between two tasks. This will be done by using the psychological refractory period (PRP) paradigm, which has been used to localize the origin of effects (Müller & Schwarz , 2007; Oriet, Tombu & Jolicoeur, 2005).

In the PRP procedure, subjects are presented with two stimuli in succession and are required to perform a different task with each stimulus. The stimuli are separated by a variable stimulus onset asynchrony (SOA). Typically, manipulating SOA has little effect on response time to the first task. However, for the second task, response time is long when SOA is short and decreases substantially as SOA increases, with the slope often approximating -1 at short SOAs (Pashler, 1994). Responses to the second stimulus require more time if the second stimulus immediately follows the first stimulus as compared to longer SOAs where a longer delay is present between the two stimuli. This pattern of results can be explained by a central bottleneck model in which information processing is assumed to be divided into three stages: an early stage, a central stage, and a late stage. In this bottleneck model, early and late processes for both tasks can be performed in parallel. However, central processing can be performed for only one of the tasks at a time. The central stage thus functions as a bottleneck, and central processing for the second task can only be performed after completion of central processing for the first task. This account predicts a long response time for task 2 at short SOAs because central processing for the first task delays central processing of the second task. Early processes involved in the second task could still occur, but further processing is temporarily halted at the bottleneck, producing cognitive slack (waiting time) in the second task. Response times for task 2 at long SOAs are faster than at short SOAs. According to the central bottleneck model this indicates that central processing of task 1 has already been completed before central processing is required for task 2. Hence, central processing for the second task does not require a waiting period at long SOAs.

Models of PRP processing commonly assume that processing for the two tasks is independent during the early and late stages, although crosstalk has been observed under some conditions. I use “crosstalk” to refer to the interaction between the processing for two tasks. In one demonstration of crosstalk, Logan and Schulkind (2000) presented subjects with two numbers at varying SOAs in a PRP paradigm and asked them to perform either a parity or magnitude judgment for each. The two tasks were either identical (e.g., both were parity judgments) or were different (one task was a parity judgment and the other was a magnitude judgment). Subjects were required to respond to the first task with their right hand and to perform the second task with their left hand. A "category match" occurred when responses for the two numbers used the same fingers for both hands, and a "category mismatch" occurred when the required response finger for the two stimuli was different. They reasoned that if crosstalk were present, then response times would be faster when the required responses for task 1 and task 2 were homologous than when responses for the two tasks differed. Logan and Schulkind found that when both tasks were identical, effects of category match affected response times for task 1. However, when task 1 and 2 differed, response times for task 1 were unaffected. Logan and Schulkind inferred that crosstalk occurred only when the two tasks were identical.

The PRP paradigm has recently been used to determine the locus of the SNARC effect. In one experiment, Müller and Schwarz (2007) requested subjects to perform a tone-discrimination task prior to a parity judgment task. They reasoned that if the locus of the SNARC effect were at an early stage, then no SNARC effect should occur at short SOAs, as processes responsible for the SNARC effect would occur in parallel with processing of the tone. However, if the locus of the SNARC effect were at either the central (bottleneck) or late stages, a SNARC effect would be observed at all SOAs, as processes responsible for the SNARC would occur only after the bottleneck. Müller and

Schwarz observed no difference in magnitude of the SNARC effect across long and short SOAs and concluded that the locus of the SNARC effect was after the early processing stage.

In a subsequent experiment, subjects performed a parity judgment before the tone discrimination task. It was assumed in this case that central processing of the tone could occur only after central processing of magnitude due to the bottleneck. If the SNARC effect were to occur during the early or central processing stage, the effect would propagate to the second task at short SOAs, and the time taken to select the correct response in the tone-discrimination task would be shorter for compatible numbers than for incompatible numbers. They termed this phenomenon the “SNARC-like effect.” This phenomenon would be absent if the SNARC effect was localized at the late stage. In this case, processing of the tone would occur concurrently with late processing of the number. Müller and Schwarz (2007) did indeed find a SNARC-like effect. These results together suggested that the SNARC effect occurred during central processing.

In related research, Oriet, Tombu and Jolicoeur (2005) used the PRP paradigm to examine the locus of the symbolic-distance effect in a numerical comparison task in which subjects decided whether a presented number was larger or smaller than 5. The symbolic-distance effect refers to the decrease in response time as the difference between the presented number and the comparison standard increases. Oriet et al presented subjects with a pitch-identification task followed by this magnitude-judgment task and found that the effects of numerical distance and SOA were under-additive. In other words, as SOA decreased, the difference between response times to numbers with magnitude far from 5 and those with a magnitude near to 5 decreased. These results suggest that one possible locus of the distance effect occurs at the early stage and that this effect was absorbed into cognitive slack at short SOAs. However, a distance effect was also present even at an SOA of 50 ms. This implies that the effect was not completely absorbed into cognitive slack as one might expect if the locus of the effect were entirely in the early processing stage. Instead, the pattern of results suggests that the distance effect occurs during both early and subsequent processing.

Based on these previous results, I propose a tentative information processing framework of how a numerical task might be performed. At the early stage, the number is perceived and its magnitude is represented internally. This representation is generally thought of as preverbal in nature (Dehaene, 1997) and is assumed to remain active during central processing. In addition, the SNARC effect suggests that presenting numbers also activates “left-right” spatial codes which can affect response selections. At the central stage, the task-specific category is retrieved and represented. Central stage processing also involves selecting a response based on that category. The initiation of the motor response to the stimulus occurs in the late stage of processing.

The Present Research

In this thesis, the aim is to determine whether crosstalk occurs during early stage processing when two numbers are processed in the context of the PRP paradigm. In the framework described earlier, early stage processing of numbers produce obligatory representations of magnitude and spatial codes. There is a growing body of evidence that numbers produce obligatory activation of magnitude codes (Dehaene, 1993, Dehaene, Bossini, &

Gireaux, 1993). Furthermore, there is also evidence that numbers also produce obligatory activation of spatial codes. For example, a study by Fischer, Castel, Dodd, and Pratt (2003) demonstrated that when participants were cued with a number, it briefly drew attention to spatial locations that were consistent with the underlying spatial representation of its magnitude. In their experiment, subjects were first presented with a number and were asked to detect the presence of a target that would appear either to the left or right of the number after variable SOA. Responses were faster if the target appeared in a location that was consistent with the position of the number on the number line. Fischer and his colleagues inferred that the mere act of attending to numbers was capable of producing spatial codes in a manner consistent with the SNARC effect. The aim of the article is therefore to determine whether early processing of numbers that produce obligatory activation of magnitude and spatial codes produced crosstalk in the processing of a subsequent number.

Given that obligatory activation of numbers occurs during the early stage, my focus will be on the short SOAs. At short SOAs, the onset of the second number coincides with early stage processing of the first number. According to the assumptions of the central bottleneck, two stimuli can be processed in parallel at the early stage. This would suggest that both the magnitude and the associated spatial codes of the two numbers are activated and the processes involved in representing these codes are a potential source of crosstalk.

To investigate the nature of crosstalk at the early stage, two experiments were conducted. Participants performed a single-task and a dual-task session for each experiment. For the dual-task session in Experiment 1, subjects made a vocal magnitude judgment of the first stimulus followed by a manual parity judgment of the second. In Experiment 2, the tasks were reversed, with subjects performing the manual parity judgment before the vocal magnitude judgment. In the single-task sessions, participants were required to ignore the first number while performing the required task on the second number (the parity judgment for Experiment 1 and the magnitude judgment for Experiment 2). If numerical stimuli produce magnitude representations at an early stage, then I assume that obligatory early-stage perceptual processing of the first stimulus may interact with obligatory early-stage processing of the second stimulus, even if the first stimulus was irrelevant. The single-task sessions were thus introduced to determine whether simply presenting a number was sufficient to produce crosstalk with obligatory processing of a subsequent number or whether additional central processing was required.

To determine whether crosstalk occurs as a result of early stage processes that activate left-right codes, I examined the SNARC effect in Experiment 1 and the *SNARC-propagation effect* in Experiment 2. [The SNARC-propagation effect was termed the “SNARC-like” effect by Müller and Schwarz (2007)]. When the magnitude task follows the parity judgment, central stage processing for the magnitude judgment can only proceed after central stage processes for the first task have completed. It follows that central processing of the second number such as response selection can only proceed after the response for the first stimulus has been selected. When responses were faster for the first stimulus in the SNARC-consistent trials (left hand response to small numbers and right hand response to large numbers), central stage processing for the second stimulus is initiated earlier than for SNARC-inconsistent trials (left hand response to large numbers and right hand response to small numbers). This suggests that the SNARC effect from the parity judgment propagates onto central and motor stage processing for the second task, resulting in a SNARC-propagation effect for response times of the second task.

I also examined the effects of magnitude match to determine whether crosstalk can be traced to processes that activate magnitude codes. In the following experiments, magnitude match occurs when both stimuli are less than or greater than 5 while magnitude mismatch occurs when one of the stimulus is less than 5 and the other greater than 5. If crosstalk is a function of magnitude match, I expect to see facilitation of processes that activate magnitude codes in magnitude match conditions resulting in faster response times. In magnitude mismatch conditions, the obligatory activations of conflicting codes requires that the irrelevant magnitude code be inhibited for a response to be made to the required magnitude task. This should result in longer response times.

The interaction between activated spatial code for the first and second stimuli could also be a source of crosstalk. In parity judgment tasks, the spatial codes (“left” or “right”) that are spontaneously associated with magnitude interact with processes involved in response selection to produce a SNARC effect. Activated spatial codes that are consistent with the required response could facilitate processes involved in response selection. In contrast, when activated spatial codes are inconsistent with the required response, additional processes are required to associate the manual response to the required instructions. The SNARC effect is thus a result of the difference in response times between consistent and inconsistent spatial code/response selection associations. In the context of the PRP paradigm, both numbers are capable of activating spatial codes. This suggests that the magnitude of both numbers can affect response selection. Since activated spatial codes are intimately connected with the magnitude of the numbers, I expect to see larger SNARC effects for the magnitude match conditions than in the magnitude mismatch conditions.

Although stimuli for both tasks were presented visually, subjects were required to respond vocally for the magnitude judgments and to respond manually for the parity judgments. As manual responses involve physical motor movements to specific locations in space, introducing the requirement that participants respond verbally to magnitude judgments minimizes interference due to motor responses and late-stage processing between the two tasks.

Experiment 1

In this experiment, subjects in the dual task session were required to make a vocal magnitude judgment to the first stimulus and a manual parity judgment to the second stimulus. In the single-task condition, subjects were asked to ignore the first stimulus and perform a manual parity judgment with the second stimulus. Differences in response times between magnitude match and mismatch conditions would suggest crosstalk between processes involved in magnitude coding. Differences in magnitude of the SNARC effect between magnitude match and mismatch conditions for single and dual-parity judgment tasks would indicate crosstalk between processes involved in obligatory coding of magnitude.

Method

Subjects. Twenty students were recruited from University of Alberta. Subjects performed the experiment in return for either course credit or an honourarium of $20.00 for completing the experiment.

Procedure. Sessions were run on iMac computers with a 55.8 cm LCD display with 1650 by 1050 resolution. Subjects initiated each trial by pressing the space bar on the keyboard. Each trial began with a fixation display consisting of two rows of two dashes separated by a horizontal distance of 2.0 cm and centered at the middle of the screen. The two rows were separated by a vertical distance of 3.0 cm. This display remained on the screen for 500 ms before being replaced by the first stimulus centered in the top row. After an SOA of 100 ms, 300 ms, or 700 ms, the second stimulus was presented in the bottom row, directly under the position of the first stimulus. The stimuli were the digits 1, 2, 3, 4, 6, 7, 8, and 9 presented in 24-point Arial font in black against a white background. At a typical viewing distance of 50 cm, the stimuli subtended a visual angle of 1° vertically, and the two stimulus positions were separated by an angle of 6°.

Each participant attended two sessions. Each session consisted of two blocks. Each block consisted of 32 practice trials. These practice trials were performed to familiarize the subject with the required sequence of tasks and responses. Data for the practice trials were not used in the analysis. The practice trials were followed 168 by non-identical combinations of the first and second stimulus and SOA presented in a random order. These trials consisted of all possible combinations of number pairs with the constraint that both numbers were not identical.

In Session 1, subjects were instructed to ignore the first, upper digit and to perform a parity judgment with the second, lower digit. They were told to press the “a” key for odd digits and the “l” key for even numbers for one of the blocks and were given the reverse mapping for the other block. Participants were always instructed to press the “a” key with their left hand and the “l” key with their right hand. Half of the participants performed the blocks in one order and half performed the blocks in the reverse order. If the parity judgment was incorrect, the word “ERROR” along with the correct response appeared on the screen for 500 ms.

In Session 2, subjects were instructed to perform the magnitude judgment with the first stimulus and a parity judgment with the second stimulus. Subjects were instructed to say the word “tap” if the first digit was less than the number 5 and “teep” if the digit was greater than 5. Responses and response times were measured with the speech recognition routines built into the Mac OS X system. (These responses were selected during pilot testing to maximize the speech recognition accuracy.) They were instructed specifically to perform the magnitude judgment before performing the parity judgment. If the response to either the magnitude or parity judgment was incorrect, the word “ERROR” along with the correct response appeared on the screen for 500 ms. In addition, if the subjects failed to make a magnitude response, a message prompting them to respond to the for the magnitude judgment appeared on the screen for 500 ms.

Data analysis. For both sessions, I excluded all trials on which either the response time to stimulus 1 was less than 150 ms or greater than 2000 ms and on which the response time to stimulus 2 was smaller than 150 ms and larger than 2500 ms. (The response time cutoff for stimulus 2 was longer as the second task is typically slower in the PRP paradigm.). This amounted to 0.9 % of the trials in session 1 and 4.0 % of the trials in session 2 being excluded from the analysis. In session 2, participants were required to respond to the magnitude task before the parity task. This instruction was crucial for assumptions based on the central bottleneck model. Consequently, all trials on which the second-task response occurred prior to the first-task response were discarded. This amounted to 0.4% of the trials. 4.1% of the trials in the dual-task session were lost due to the failure of the speech recognition system to record an appropriate response. All the above trials were excluded from the analysis.

In order to assess the evidence for different interpretations of results, nested linear models were compared using likelihood ratios. The likelihood ratio indicates how likely the data are given the best fit of one model relative to how likely the data are given the best fit of the other model. Following the suggestion of Glover and Dixon (2004), the likelihood ratio was adjusted for the differing degrees of freedom in the two models based on the Akaike Information Criterion (Akaike, 1973); I refer to this statistic as λ_{adj}. This approach provides an intuitive index of the evidence for different interpretations of the results without the well-known problems with null-hypothesis significance testing. However, by way of comparison, a statistically significant result in most typical hypothesis testing situations would correspond to an adjusted likelihood ratio of about 3. In the following models, the SNARC effect was operationalized as the linear component of the interaction between magnitude and response hand for parity judgments. To assess early stage interference of magnitude between the first and second stimulus, the global SNARC effect was calculated. The global SNARC effect was operationalized as the linear component of the interaction between response hand for parity judgments and the average magnitude of the first and second stimulus.

Linear mixed-effects analysis was used to fit the models using the program lmer in the R package lme4 (Bates, Maechler, & Dai, 2008; R Development Core Team, 2008). In mixed-effects analysis, the structure of the random effects must be specified explicitly. For analysis of response times, initial exploratory analysis suggested that optimal models for both single- and dual-task parity judgments included effects of SOA that varied across subjects. Optimal models for single-task judgments were obtained when the magnitude of the stimulus was assumed to vary across subjects.

Accuracy data was analyzed similarly but using generalized linear mixed-effects analysis using a binomial link function (Faraway, 2006; Dixon, 2008), an approach tantamount to logistic regression. Optimal models for single- and dual-task parity judgments were assumed to include effects of SOA that varied across subjects.Optimal models for magnitude judgments were obtained when the magnitude of the stimulus was assumed to vary across subjects. These random effect structures were identical to those used in the response time analysis.

All of the models for response time and errors assumed the above random-effects structures and varied only in the fixed effects.

Results

Analysis of Response Times

Overall there was a substantial PRP effect in the dual-task parity judgment and a smaller effect of SOA in the single-task parity judgments. There was also strong evidence for a global SNARC effect in both dual and single-task-parity judgments. Finally, there were effects of magnitude compatibility for both magnitude and parity judgments in the dual-task session.

Response times for dual-task parity judgments. Response times across SOAs for dual-task parity judgments in session 2 are shown in Figure 1. This pattern of results shows declines with SOA. To examine this effect, I started with an initial model with a main effect of parity response and compared this with a model that contained an additional main effect of SOA and found strong evidence in favor of the latter model ($\lambda_{adj} > 1{,}000$). Table 1 shows mean response times as a function of stimulus magnitude in the dual-parity task. Responses to small stimuli were faster than large numbers. However, adding a main effect of the magnitude of the second stimulus provided only a slight improvement to the model fit ($\lambda_{adj} = 2.16$).

Figure 2 shows the difference between left- and right-hand response time as a function of the average magnitude of the first and second stimulus. This pattern of results suggests that both the first and second stimulus contribute to the SNARC effect. Adding this global SNARC effect indeed provided a better model for the data ($\lambda_{adj} = 8.13$). This model was better than a model with a SNARC effect for just the parity judgment ($\lambda_{adj} = 5.56$). However, there was no evidence that adding an interaction between the global SNARC effect and SOA improved the model ($\lambda_{adj} = 0.23$).

Table 1 also suggests that response times were faster when the magnitude of the first and second stimuli were compatible. Indeed, adding a main effect of magnitude match improved the model somewhat ($\lambda_{adj} = 3.13$).

Response times for dual-task magnitude judgments. I started with an initial model with a main effect of magnitude (large versus small) of the second stimulus and compared this to a model containing an additional main effect of the magnitude of the first stimulus. Table 2 suggests that large numbers were responded to faster than small numbers. There was clear evidence in favour of the model that included an effect of first stimulus magnitude (λ_{adj}=21.4). Table 2 further suggests an effect of magnitude match might be present. However, adding an effect of magnitude match improved the model only slightly (λ_{adj}=2.23).

Response times for single-task parity judgments. I started with an initial model with no main effects. This model was compared to a model including a main effect of SOA. The model including an effect of SOA was a better fit to the data (λ_{adj}= 13.53). Table 3 suggests that small numbers were responded to faster than large numbers. Adding a main effect of the second stimulus provided a better model fit (λ_{adj}>1,000). Figure 3 shows the difference between left- and right-hand response times as a function of the average magnitude of the first and second stimuli. This pattern of results is similar to the the global SNARC effect observed in the dual-task condition. Adding the global SNARC effect provided a better model fit to the obtained data (λ_{adj}=11.59). This model was also a better fit than a model with a SNARC effect for just the parity judgment (λ_{adj}= 8.33).

Analysis of Errors

There was little change in accuracy across SOA for all tasks. The pattern of results for magnitude judgments suggested that participants were more accurate for smaller numbers than larger numbers.

Error analysis for dual-task parity judgments. Table 4 suggests little change in accuracy over SOA and magnitude match. However, participants seemed to be more accurate for large numbers with their left hand than with their right hand. I started with an initial model that only included a parity for the second stimulus. Adding the interaction between hand and magnitude of the second stimulus improved the model substantially ($\lambda_{adj} > 1{,}000$), but there was little evidence for a global SNARC effect ($\lambda_{adj} < 0.001$). Adding an effect of magnitude match failed to improve the model ($\lambda_{adj} = 0.61$).

Error analysis for dual-task magnitude judgments. Table 5 suggested that participants were more accurate with smaller numbers than larger numbers. I started with an initial model of magnitude response and compared this with the optimal model from the response time analysis containing effects of magnitude match and magnitude response. The model including only an effect of magnitude response was better ($\lambda_{adj} = 90.02$).

Error analysis for single-task parity judgments. Table 6 suggested little change in accuracy over SOA and magnitude match. However, participants seemed to respond more accurately with their left hand than with their right hand to large numbers. I started with an initial model of parity for the second stimulus. Adding the interaction between magnitude and and response hand improved the model substantially (λ_{adj} = 1096.63), but there was little evidence for a global SNARC effect (λ_{adj} =0.03). Adding an effect of magnitude match failed to improve the model (λ_{adj} = 0.37).

Discussion

Experiment 1 provided evidence for a global SNARC effect in both the single and dual-task sessions. Specifically, participants responded faster with their left hand when the average of the two stimuli was small and faster with their right hand when the average of the two stimuli was large. The global SNARC effect suggests that when a number is presented before the parity judgment, the magnitude of this number is also represented and affects response selection. The global SNARC effect was observed even in the single-task session in which participants were told to ignore the first stimulus, suggesting that magnitude encoding is obligatory.

In Experiment 1, response times in the second task declined with SOA, while response times in the first task remained fairly uniform. This pattern of results is consistent with the assumptions of the central bottleneck theory: Central stage processing for the second task cannot be initiated until central stage processing for the first task is completed.

Experiment 1 also provided evidence for effects of magnitude compatibility in the dual-task session but not in the single-task session. This provides further evidence for obligatory activations of magnitude representations. In the dual-task session, participants responded to a magnitude judgment followed by a parity judgment. Effects of magnitude compatibility suggest that the magnitude of the second stimulus is also encoded at its onset. When the magnitude of both stimuli are incompatible, two magnitude codes (big" and "small") will also be present. Hence, additional time is required to associate the stimulus for the magnitude judgment with the appropriate magnitude code.

The effects of magnitude match for the parity judgment could be interpreted as a delay of central stage processing for the second task. Given that central stage processing cannot proceed until central stage processing of the first task is completed, the shorter time required to complete the first stimulus in magnitude match trials results in central stage processes being initiated earlier when compared to magnitude mismatch trials.

Experiment 2

In Experiment 2, the order of the tasks used in Experiment 1 was reversed. In the dual-task condition, participants were asked to perform a manual parity judgment of the first stimulus and a vocal magnitude judgment of the second stimulus. In the single-task condition, they were asked to perform a vocal magnitude judgment of the second stimulus while ignoring the first stimulus. Experiment 2 allowed me to investigate the extent to which the magnitude code for the first stimulus (the parity judgment) interfered with processing of magnitude for the second stimulus (the magnitude judgment). As in Experiment 1, I expected faster responses for magnitude match trials than magnitude mismatch trials. This pattern of results would suggest that obligatory activation of magnitude for the first stimulus facilitated processes involved in coding the magnitude of the second stimulus. In Experiment 2, crosstalk between spatial codes was based on examining the SNARC-propagation effect described in the Introduction.

I assume that parity judgments produce a SNARC effect, localized at the central processing stage. At short SOAs, the SNARC effect from the first task propagates to the duration of the second task because central stage processing of the second stimulus cannot proceed until central stage processing of the first stimulus is completed. However, at longer SOAs, central stage processes for the first task will have been completed before central stage processes for the second task have been initiated. The SNARC-propagation effect is thus expected to be absent at long SOAs. While no crosstalk is expected between spatial processing at the longer SOAs, crosstalk can be examined at the shorter SOAs by examining the magnitudes of the SNARC effect for parity judgments and the SNARC propagation effect for magnitude judgments. As in Experiment 1, differences in the SNARC effect between match and mismatch conditions is indicative of crosstalk between processes involved in spatial coding at short SOA. The difference in the SNARC effect for match/mismatch conditions should propagate into the SNARC-propagation effect.

Method

Subjects. Twenty students from the introductory psychology course were recruited from the University of Alberta to participate in the experiment. Subjects performed the experiment in return for partial course credit.

Apparatus and stimuli. The apparatus and stimuli were identical to those used in Experiment 1.

Procedure. As in Experiment 1, participants performed the experiment in two sessions of about 45 minutes each. In the first session, participants were instructed to ignore the first stimulus and to judge the magnitude of the second stimulus. Participants were instructed to say “tap” if the lower number was less than 5 and “teep” if the second number was more than 5.

In the second session, participants were instructed to judge the parity of the first stimulus and the magnitude of the second stimulus. Participants performed the parity judgment by pressing the “a” or “l” key on a computer keyboard. Participants performed two blocks of 168 trials each. In one block, participants pressed “a” for odd numbers and “l” for even numbers. The other block had the reverse mapping. Half of the participants performed the blocks in one order, and half had the reverse order. Participants were given the same instructions as the first session for magnitude judgment. In addition, participants were specifically instructed to perform the first task before the second task.

Data analysis. For both sessions, I excluded all trials on which either response time to stimulus 1 was smaller than 150 ms or larger than 2000 ms and where response times to stimulus 2 was smaller than 150 ms and larger than 2500 ms. This amounted to 0.6% of the trials in session 1 and 7.2% of the trials in session 2 being excluded from the analysis. In session 2, participants were required to respond to the parity task before the magnitude task. This instruction was crucial for assumptions based on the central bottleneck model. Consequently, all trials in which first-task responses were made before second-task responses were discarded. This amounted to 0.40% of the trials. 5.3% of the trials were lost due to the failure of the speech recognition device to record an appropriate response. All the above trials were excluded from the analysis. Table 4 shows the average error rates for dual-task magnitude, dual-task parity, and single-task magnitude trials as a function of SOA.

Model fits were compared as in Experiment 1. All effects and interactions were calculated as in Experiment 1. The only additional interaction in Experiment 2 was a SNARC-propagation effect, calculated as the difference in response times to the second task as a function of the interaction between the response hand and magnitude of the first stimulus. Initial exploratory analysis suggested that optimal fits were found when the effect of SOA was assumed to vary over subjects for parity and magnitude judgments in the dual-task session. Optimal fits in single-task magnitude judgments were obtained when the effects of magnitude were assumed to vary over subjects. All of the models compared assumed the above random-effects structures and varied only in the fixed effects. Accuracy data were analyzed similarly but using generalized linear mixed-effects analysis using a binomial link function (Faraway, 2006; Dixon, 2008), an approach tantamount to logistic regression.

Results

Analysis of Response Times

There was a large PRP effect for the dual-task magnitude judgments and a smaller PRP effect for the single-task magnitude judgment. In addition, there was a SNARC effect for parity judgments and a SNARC-propagation effect for 100 ms but not at 300 ms and 700 ms for dual-task magnitude judgments. In addition, there was an effect of magnitude match for single and dual-task magnitude judgments. However, in this experiment, participants were faster to respond when the two stimuli were incompatible.

Dual-task parity judgments. I started with an initial model with an effect of parity and examined the effects of SOA. Response times for parity judgments across SOA can be found in Figure 4. Adding a main effect of SOA provided only a slight improvement to the model (λ_{adj} =2.58). Figure 5 shows the difference in response times between left and right hand as a function of the parity task stimulus. Adding the SNARC effect variable to the model further improved the model ($\lambda_{adj} > 1{,}000$). However, a model where the SNARC effect was replaced with the global SNARC effect (calculated as in Experiment 1), failed to provide a better fit ($\lambda_{adj} <0.001$). Table 7 shows the magnitude of the parity judgment by hand response. There was little evidence for an interaction between SOA and the SNARC effect.

Dual-task magnitude judgments. Figure 3 shows strong evidence for an effect of SOA. I thus started with an initial model with no main effects and compared this with a model containing a main effect of SOA ($\lambda_{adj} > 1{,}000$). Table 8 shows that participants responded faster to smaller numbers than to larger numbers. Adding an effect of the magnitude of the second stimulus did further improve the fit ($\lambda_{adj} > 1{,}000$).

Figure 6 shows a SNARC-propagation effect at 100 ms. This effect was absent at 300 ms and 700 ms. A model with SNARC-propagation effect to 100 ms SOA was substantially better ($\lambda_{adj} = 38.00$).

Table 8 also shows response times for magnitude match and mismatch conditions as a function of SOA and tasks. Responses were faster on trials on which one of the stimuli was large and the other small. Indeed, adding an effect of magnitude match improved the model substantially ($\lambda_{adj} = 72.53$). However, there was no evidence for an interaction of SOA with magnitude match ($\lambda_{adj} = 0.43$).

Single-task magnitude judgments. Figure 3 shows a modest decrease in response times as SOA increased. I started with an initial model with no main effects and compared this to a model containing a main effect of SOA ($\lambda_{adj} > 1{,}000$). Table 9 suggests participants responded faster to smaller numbers than to larger numbers. Adding an effect of the magnitude of the second stimulus improved the fit still further ($\lambda_{adj} > 1{,}000$). Table 9 also shows that overall, participants were faster in magnitude mismatch conditions than in magnitude match conditions. Adding an effect of magnitude match to this model further produced a better fit to the data ($\lambda_{adj} = 26.71$), but there was no evidence that an interaction between SOA and magnitude match improved the model ($\lambda_{adj} = 0.25$).

Analysis of Errors

Overall analysis suggested little change in accuracy across SOA for the magnitude judgments. However, responses to smaller numbers were more accurate than larger numbers for magnitude judgments.

Error analysis for dual-task parity judgments. Table 10 suggested a modest decrease in accuracy as SOA increased. I started with an initial model containing no main effects. Adding an effect of SOA improved the model(λ_{adj} = 20.09). In addition, table 10 also suggest that participants were more accurate with their left hand to large numbers and with their right hand to small numbers. Adding the interaction between magnitude and response hand further improved the model (λ_{adj} = 665.14). However, adding an effect of magnitude match failed to improve the model(λ_{adj} = 0.61).

Error analysis for dual-task magnitude judgments. Table 11 suggested that participants were more accurate to small numbers than to large numbers. I started with an initial model with a main effect of response to the magnitude stimulus. I then added the the interaction between the magnitude of the parity judgment and its manual response. A model with this interaction provided a better fit to the data (λ_{adj} = 403.43).

Error analysis for single-task magnitude judgments. Table 12 suggests that participants were more accurate for smaller numbers than for larger numbers.. I first started with a model containing no main effects. Adding a main effect of stimulus for the magnitude task improved the fit (λ_{adj} = 12.18).

Discussion

In Experiment 2, participants performed the magnitude judgment after either a parity judgment (in the dual-task session) or a to-be-ignored digit (in the single-task session). Although a SNARC effect was obtained for parity judgment, there was no evidence for a global SNARC effect – that is, the magnitude of the second stimulus did not influence response selection for the first stimulus. This seems to contradict the conclusion from Experiment 1 that numbers produce obligatory activation of magnitude. For example, if the magnitude of the second stimulus were activated at the early stage, we would also expect to see a global SNARC effect for the parity judgment. However, the failure to observe the effect does not preclude the possibility of obligatory activation of the magnitude for the second stimulus, which is subsequently inhibited. At longer SOAs, the onset of the second stimulus could occur after a response to the first stimulus had been selected. As a result, no crosstalk was observed because there was no overlap between the relevant processes. The global SNARC effect arises when there is an interaction between process that activate magnitude representations of the first and second stimuli. The lack of an overlap between early/central processing for the first stimuli and early processing of the second stimuli might also explain the failure to observe the global SNARC effect.

There was evidence for an overall SNARC effect for parity judgments. This propagated to the second task at SOAs of 100 ms but not at the longer SOAs. As described in Müller and Schwarz (2007), the SNARC effect arises at short SOAs as a result of differences in response selection times between SNARC compatible and incompatible trials. When the magnitude of the first stimulus is compatible with its associated response, the time taken to select a response would be faster than if the magnitude and the associated response is incompatible. Given the assumption of the central bottleneck mode, central stage processing for the second task can only be performed after central stage processing for the first task has been completed. Central stage processes of the second task would be initiated earlier in conditions where response selection for the first stimulus had been completed earlier. The SNARC-propagation effect can be explained by the fact that when activated spatial codes and parity responses for the first stimulus were incompatible, additional central stage processes were required to dissociate the spatial code from the parity response. As a result, central stage processing for these trials was slower than trials where central stage processing for the first task for parity responses and spatial codes for the first stimulus were compatible. The additional central stage process for incompatible trials resulted in initiation of central stage processes occurring at a later stage than for compatible trials.

Support for the claim that crosstalk is present between the two tasks comes from the pattern of results for the magnitude match/mismatch factor. Differences in performance between match and mismatch trials suggests that processes activating magnitude codes for the parity stimulus interacted with processing of the magnitude stimulus. In this experiment, participants responded faster in both single and dual-task magnitude judgments when the magnitude of the first and second stimuli were incompatible. This is surprising because processes were facilitated when the magnitude of the first and second stimuli were incompatible. One possibility is that participants were also encoding and representing the magnitude of the second stimulus relative to the first stimulus. In magnitude mismatch trials, such relative magnitude coding would have been consistent with the response. For example, when a “2” was followed by an “8, participants may have encoded that the second stimulus as larger, consistent with the required response of “large.”

I speculate that crosstalk can also be produced between processes involved in coding the numerical relation between stimuli and activation of magnitude codes for the second number.

General Discussion

The primary purpose of this project was to examine the nature of the crosstalk between magnitude and spatial representations when two numbers are presented in succession. This was done by presenting participants with two numbers in a PRP paradigm. Subjects were requested to make vocal magnitude judgments and manual parity judgments. In Experiment 1, subjects performed the parity judgment after either ignoring or performing the magnitude judgment. In Experiment 2, subjects performed the magnitude judgment after ignoring or performing the parity judgment. Evidence for crosstalk between tasks was assessed by looking for differences in the SNARC effect, the SNARC-propagation effect, and effects of magnitude compatibility between the two stimuli. Based on these experiments, I postulate three possible sources of crosstalk.

First, these experiments suggest crosstalk could occur as a result of the activation of spatial codes for both numbers. A large body of research has argued that magnitude is obligatorily activated when numbers are presented (Dehaene, 1992, Dehaene, Bossini & Gireaux, 1993). Several other studies demonstrated that magnitude and spatial codes are intimately related (Fias & Fischer, 2005, Fisher, Castel, Dodd & Pratt, 2003). The global SNARC effect from Experiment 1 confirms that magnitude of a presented number is activated and encoded during the early stage of processing. Activation of the magnitude code seems to be an obligatory process even if it is irrelevant to the task. Activation of magnitude also activates spatial codes that are associated with the number. The spatial code in turn facilitates response selection if it is consistent with the spatial code associated with the required manual response. However, Experiment 2 suggests that some other form of interference might have prevented obligatory activation of the magnitude representation of the second stimulus from having an effect on response selection in the first task at short SOAs. There was also no global SNARC effect in Experiment 2. At short SOAs, this might suggest that some form of interference other than spatial-based crosstalk was present, resulting in a failure to observe the SNARC effect.

Another source of crosstalk could occur between processes that activate magnitude representations. Various studies have shown effects of priming where processes involved in encoding and representing magnitude from one stimulus have the ability to facilitate magnitude processing of a subsequent stimulus (Dehaene et al, 1998; Koechlin, Naccache, Block & Dehaene, 1999). Experiment 1 shows some support for magnitude priming of the second number, demonstrating that when the first number was encoded and its magnitude represented, processes involved in this task were able to facilitate magnitude processing for a subsequent number. The global-SNARC effect observed in Experiment 1 also provides some evidence that obligatory activation of the first number can facilitate magnitude processing of the second number.

I further postulate that another potential source of crosstalk is based on processes encoding the numerical relation between the two stimuli. In Experiment 2, I speculated that participants were slower to respond if the magnitude for the magnitude judgment was inconsistent with the magnitude of the second number relative to the first number. This resulted in facilitation of the magnitude code if the numerical relation associated with that code was also activated. However, in Experiment 1, participants were faster to respond if the two stimuli were compatible in terms of magnitude than if they were incompatible. In Experiment 1, the magnitude judgment was performed first and the parity second. Therefore, if participants were shown “2” before “8” the magnitude of the first stimulus was coded as “small”. However, the numerical relation between the two stimulus would have been coded as “larger”. The numerical relation code would be inconsistent with the required response of “small”. Overall, this would lead to much slower responses than for congruent trials. In congruent trials, there would be occasions where the coding between the magnitude of the first stimulus and the numerical relation would have been consistent. Overall, this would result in faster response times as processes required to reconcile inconsistent semantic codes would not be required.

Previous research has demonstrated that when people are presented with two identical tasks in succession, they could retrieve relevant information for the second task while simultaneously performing the first task (Logan & Schulkind, 2000). Research from the current experiments suggest obligatory activation of spatial and magnitude codes when numbers are presented (Fischer, et al, 2003). These codes seem to produce crosstalk with a subsequent task. Furthermore, effects of magnitude compatibility indicate that magnitude codes can also produce interference during processing of a subsequent number. I postulate further that crosstalk can occur as a result of participants encoding the semantic relation between the two stimuli. While earlier experiments demonstrate that crosstalk occurs when a representation is required for other tasks in the PRP paradigm, these experiments indicate a more subtle kind of crosstalk where codes that are not required are able to facilitate or interfere with relevant representations in a subsequent task.

To summarize, the current results provide evidence that encoding of magnitude is an obligatory process. The experiments also provide evidence that crosstalk does occur when participants are required to perform two different tasks in succession. Furthermore, I have also speculated that crosstalk can either facilitate or interfere with processes involved in magnitude categorization and further specified the conditions when this crosstalk could potentially occur.

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Table 1. *Mean Response Times and Standard Errors (in ms) across Magnitude of Stimulus, SOA, Response Hand and Magnitude Compatibility for Dual-Task Parity Judgments in Experiment 1*

		SOA (ms)					
		100		**300**		**700**	
Magnitude	**Magnitude compatibility**	**Left**	**Right**	**Left**	**Right**	**Left**	**Right**
small	match	**1374 (26)**	**1398 (26)**	**1202 (25)**	**1186 (25)**	**922 (26)**	**929 (26)**
small	mismatch	**1398 (20)**	**1436 (20)**	**1224 (18)**	**1207 (19)**	**909 (19)**	**905 (20)**
large	match	**1390 (26)**	**1375 (26)**	**1235 (25)**	**1154 (25)**	**925 (26)**	**907 (26)**
large	mismatch	**1385 (20)**	**1380 (20)**	**1254 (18)**	**1221 (18)**	**930 (20)**	**947 (19)**

Table 2. *Mean Response Times and Standard Errors (in ms) across Magnitude of Stimulus, SOA and Magnitude Compatibility for Dual-Task Magnitude Judgments in Experiment 1. All responses were given vocally.*

			SOA (ms)	
Magnitude	**Magnitude compatibility**	**100**	**300**	**700**
small	match	**959 (10)**	**947 (10)**	**958 (10)**
small	mismatch	**941 (9)**	**975 (9)**	**966 (9)**
large	match	**945 (10)**	**933 (10)**	**934 (10)**
large	mismatch	**949 (9)**	**959 (9)**	**944 (9)**

Table 3. *Mean Response Times and Standard Errors (in ms) across Magnitude of Stimulus, SOA, Response Hand and Magnitude Compatibility for Single-Task Parity Judgments in Experiment 1*

		SOA (ms)					
		100		**300**		**700**	
Magnitude	**Magnitude compatibility**	**Left**	**Right**	**Left**	**Right**	**Left**	**Right**
small	match	**676 (14)**	**688 (14)**	**659 (14)**	**662 (14)**	**638 (14)**	**670 (14)**
small	mismatch	**702 (13)**	**692 (13)**	**686 (12)**	**656 (12)**	**649 (12)**	**667 (12)**
large	match	**732 (14)**	**685 (14)**	**704 (14)**	**699 (14)**	**675 (14)**	**646 (14)**
large	mismatch	**714 (13)**	**685 (13)**	**684 (12)**	**667 (12)**	**677 (12)**	**674 (12)**

Table 4. *Mean Percentage of Correct Responses and Standard Errors across Magnitude of Stimulus, SOA, Response Hand and Magnitude Compatibility for Dual-Task Parity Judgments in Experiment 1*

		SOA (ms)					
		100		300		700	
Magnitude	**Magnitude compatibility**	**Left**	**Right**	**Left**	**Right**	**Left**	**Right**
small	match	**94.0 (1.3)**	**95.3 (1.4)**	**95.7 (1.8)**	**94.7 (1.3)**	**90.4 (2.5)**	**94.4 (1.6)**
small	mismatch	**93.1 (1.3)**	**92.7 (1.2)**	**91.4 (1.7)**	**95.7 (1.2)**	**88.5 (2.1)**	**93.0 (1.4)**
large	match	**94.9 (1.5)**	**93.4 (1.3)**	**94.9 (1.3)**	**92.9 (1.5)**	**96.7 (1.1)**	**94.0 (1.1)**
large	mismatch	**94.7 (1.3)**	**92.1 (1.2)**	**97.5 (0.9)**	**94.1 (1.3)**	**95.7 (0.9)**	**92.4 (1.4)**

Table 5. *Mean Percentage of Correct Responses and Standard Errors across Magnitude of Stimulus, SOA and Magnitude Compatibility for Dual-Task Magnitude Judgments in Experiment 1. All responses were given vocally.*

		SOA (ms)		
Magnitude	**Magnitude compatibility**	**100**	**300**	**700**
small	match	**96.4 (0.8)**	**97.5 (1.2)**	**99.1 (0.4)**
small	mismatch	**98.1 (0.6)**	**98.0 (0.7)**	**97.4 (0.7)**
large	match	**97.4 (1.1)**	**97.6 (0.8)**	**97.3 (0.6)**
large	mismatch	**98.0 (0.7)**	**97.7 (0.7)**	**97.3 (0.8)**

Table 6. *Mean Percentages of Correct Responses and Standard Errors across Magnitude of Stimulus, SOA, Response Hand and Magnitude Compatibility for Single-Task Parity Judgments in Experiment 1*

		SOA (ms)					
		100		300		700	
Magnitude	**Magnitude compatibility**	**Left**	**Right**	**Left**	**Right**	**Left**	**Right**
small	match	**96.8 (1.0)**	**96.5 (1.3)**	**93.2 (1.6)**	**97.3 (0.9)**	**96.2 (1.5)**	**97.9 (1.0)**
small	mismatch	**94.8 (1.2)**	**95.9 (1.1)**	**94.0 (1.4)**	**98.3 (0.7)**	**97.7 (1.1)**	**97.0 (0.8)**
large	match	**97.1 (0.9)**	**96.0 (1.1)**	**97.9 (1.0)**	**97.1 (1.1)**	**98.4 (1.0)**	**94.2 (1.2)**
large	mismatch	**96.1 (1.2)**	**96.2 (0.9)**	**97.7 (1.1)**	**95.4 (1.2)**	**98.4 (0.8)**	**95.9 (0.7)**

Table 7. *Mean Response Times and Standard Errors (in ms) across Magnitude of Stimulus, SOA, Response Hand and Magnitude Compatibility for Dual-Task Parity Judgments in Experiment 2*

		SOA (ms)					
		100		**300**		**700**	
Magnitude	**Magnitude Compatibility**	**Left**	**Right**	**Left**	**Right**	**Left**	**Right**
small	match	**802 (22)**	**861 (22)**	**851 (21)**	**755 (20)**	**859 (21)**	**826 (22)**
small	mismatch	**803 (19)**	**795 (19)**	**838 (18)**	**812 (18)**	**877 (19)**	**793 (20)**
large	match	**842 (21)**	**831 (22)**	**819 (20)**	**830 (20)**	**846 (22)**	**859 (22)**
large	mismatch	**803 (19)**	**806 (19)**	**810 (18)**	**812 (18)**	**877 (20)**	**834 (19)**

Table 8. *Mean Response Times and Standard Errors (in ms) across Magnitude of Stimulus, SOA and Magnitude Compatibility for Dual-Task Magnitude Judgments in Experiment 2. All Responses were given Vocally*

		SOA (ms)		
Magnitude	**Magnitude compatibility**	**100**	**300**	**700**
small	match	**1520 (15)**	**1347 (15)**	**1174 (15)**
small	mismatch	**1480 (13)**	**1340 (13)**	**1170 (14)**
large	match	**1546 (15)**	**1386 (14)**	**1202 (16)**
large	mismatch	**1503 (13)**	**1354 (13)**	**1170 (14)**

Table 9. *Mean Response Times and Standard Errors across Magnitude of Stimulus, SOA and Magnitude Compatibility for Single-Task Magnitude Judgments in Experiment 2. All Responses were given Vocally*

			SOA (ms)	
Magnitude	**Magnitude compatibility**	**100**	**300**	**700**
small	match	**1001 (10)**	**961 (10)**	**954 (10)**
small	mismatch	**1002 (9)**	**957 (9)**	**927 (9)**
large	match	**1020 (10)**	**985 (10)**	**958 (10)**
large	mismatch	**1002 (9)**	**957 (9)**	**927 (9)**

Table 10. *Mean Percentages of Correct Responses and Standard Errors across Magnitude of Stimulus, SOA, Response Hand and Magnitude Compatibility for Dual-Task Parity Judgments in Experiment 2*

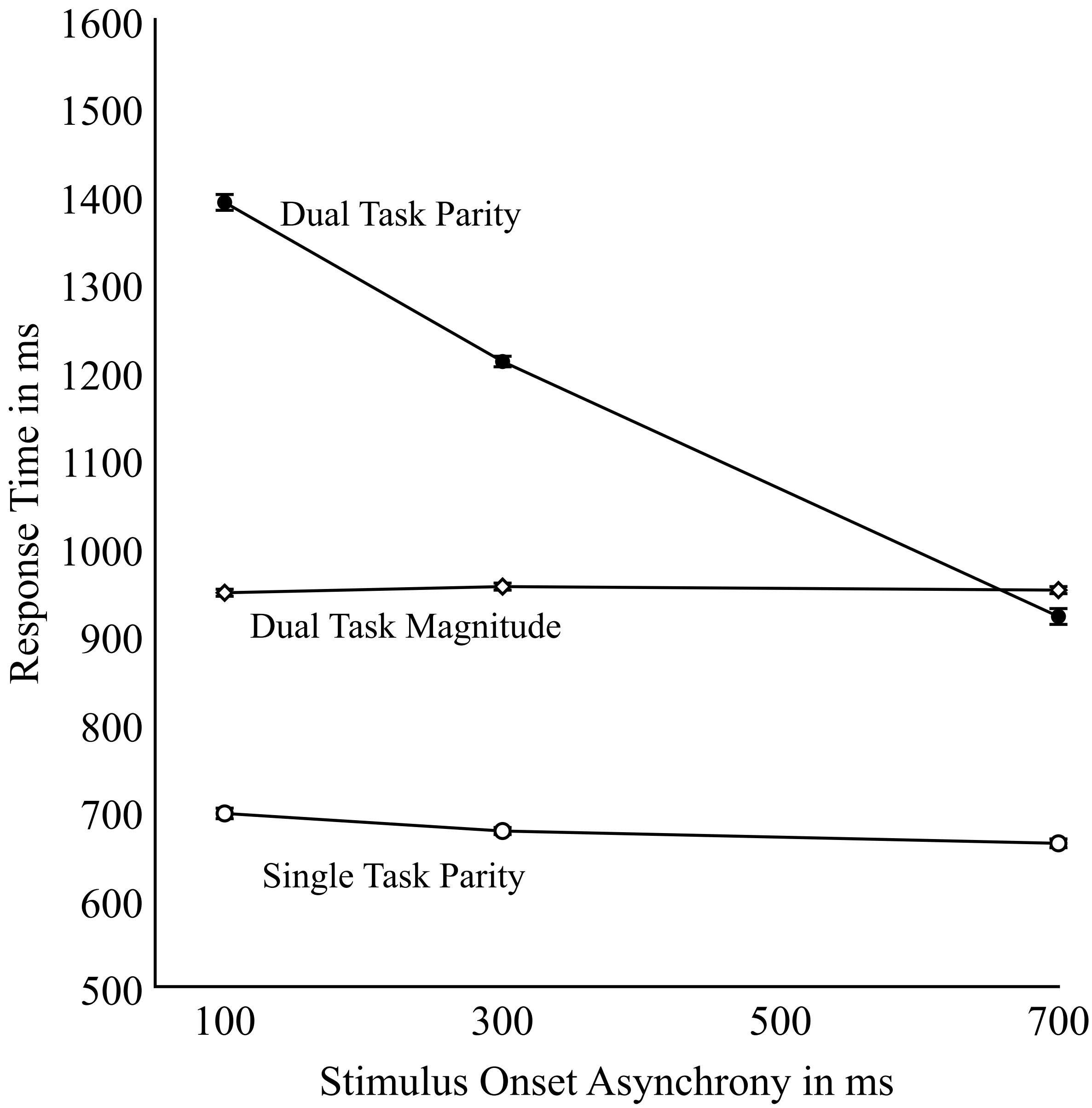
		SOA (ms)					
		100		**300**		**700**	
Magnitude	**Magnitude compatibility**	**Left**	**Right**	**Left**	**Right**	**Left**	**Right**
small	match	**97.1 (1.5)**	**98.7 (0.9)**	**95.5 (1.6)**	**97.2 (1.2)**	**94.9 (1.3)**	**98.2 (1.3)**
small	mismatch	**97.2 (1.0)**	**98.5 (0.9)**	**96.9 (1.5)**	**97.3 (1.5)**	**94.6 (1.4)**	**95.7 (1.5)**
large	match	**99.7 (0.4)**	**98.7 (0.7)**	**99.0 (0.7)**	**96.3 (1.4)**	**97.1 (1.3)**	**94.0 (2.1)**
large	mismatch	**99.0 (0.5)**	**97.7 (0.8)**	**97.7 (1.2)**	**97.4 (1.3)**	**98.1 (0.9)**	**95.1 (1.1)**

Table 11. *Mean Percentages of Correct Responses and Standard Errors across Magnitude of Stimulus, SOA and Magnitude Compatibility for Dual-Task Magnitude Judgments in Experiment 2. All Responses were given Vocally.*

		SOA (ms)		
Magnitude	**Magnitude compatibility**	**100**	**300**	**700**
small	match	**98.2 (0.8)**	**96.5 (1.1)**	**98.8 (0.6)**
small	mismatch	**98.1 (0.7)**	**97.5 (0.6)**	**98.9 (0.4)**
large	match	**96.8 (0.9)**	**98.0 (0.8)**	**96.5 (1.9)**
large	mismatch	**97.3 (0.8)**	**98.1 (0.7)**	**97.4 (0.7)**

Table 12. *Mean Percentages of Correct Responses and Standard Errors across Magnitude of Stimulus, SOA and Magnitude Compatibility for Single-Task Magnitude Judgments in Experiment 2. All Responses were given Vocally.*

		SOA (ms)		
Magnitude	**Magnitude compatibility**	**100**	**300**	**700**
small	match	**98.9 (0.6)**	**98.2 (0.6)**	**99.3 (0.5)**
small	mismatch	**99.1 (0.5)**	**99.5 (0.3)**	**99.1 (0.4)**
large	match	**97.8 (0.8)**	**98.0 (0.6)**	**98.3 (0.8)**
large	mismatch	**97.8 (0.5)**	**98.2 (0.5)**	**99.2 (0.4)**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Response Time in ms
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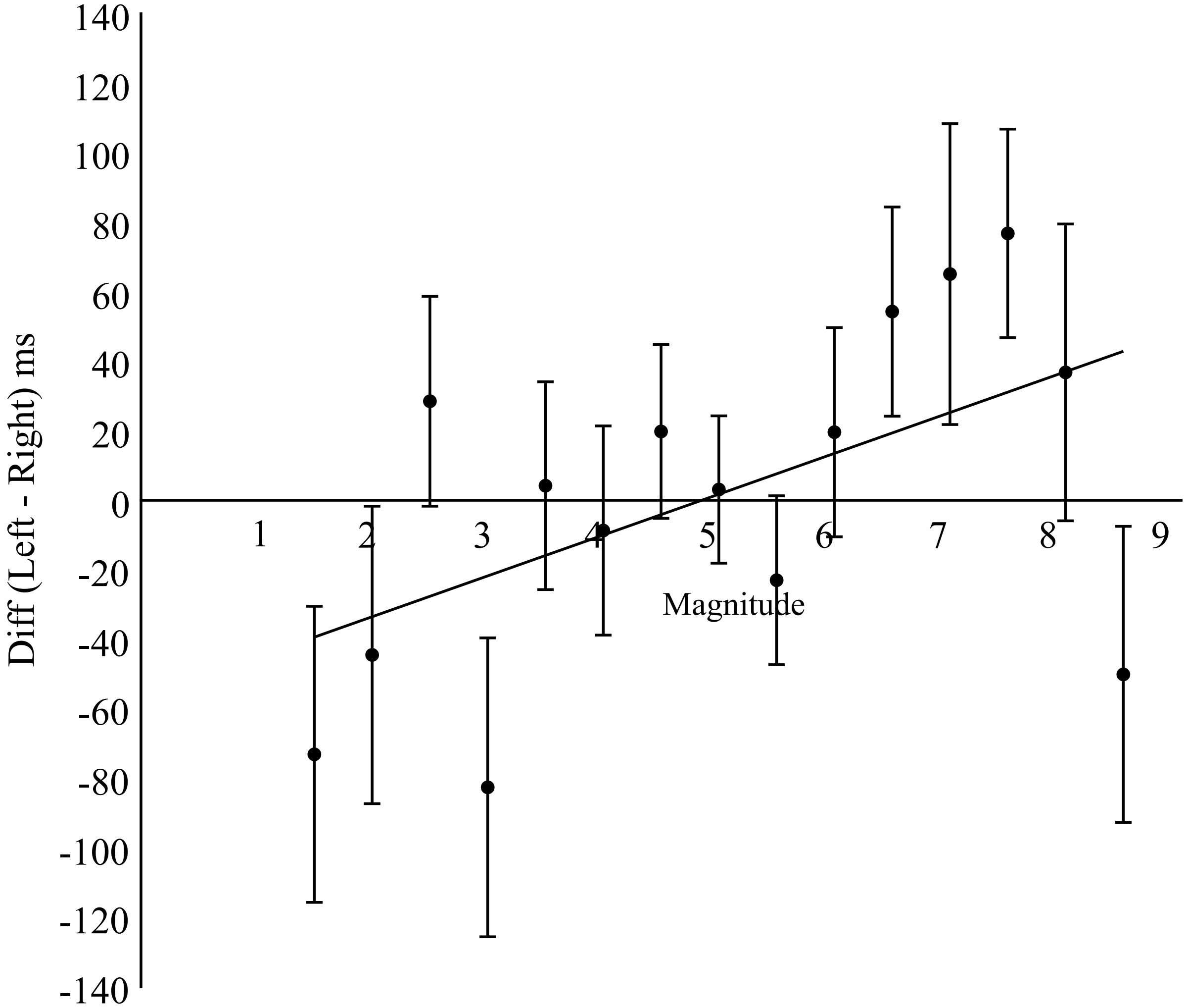
Stimulus Onset Asynchrony in ms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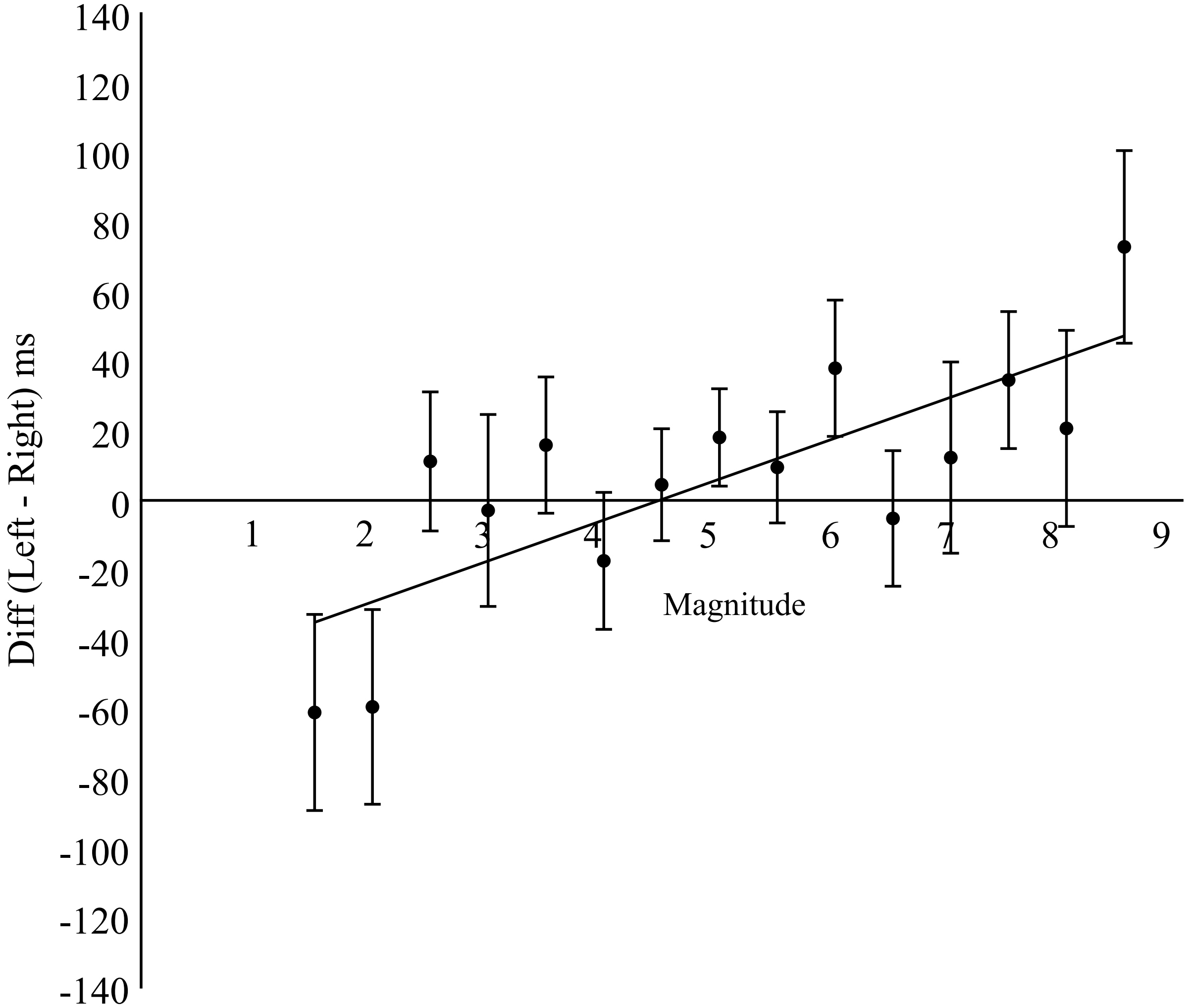
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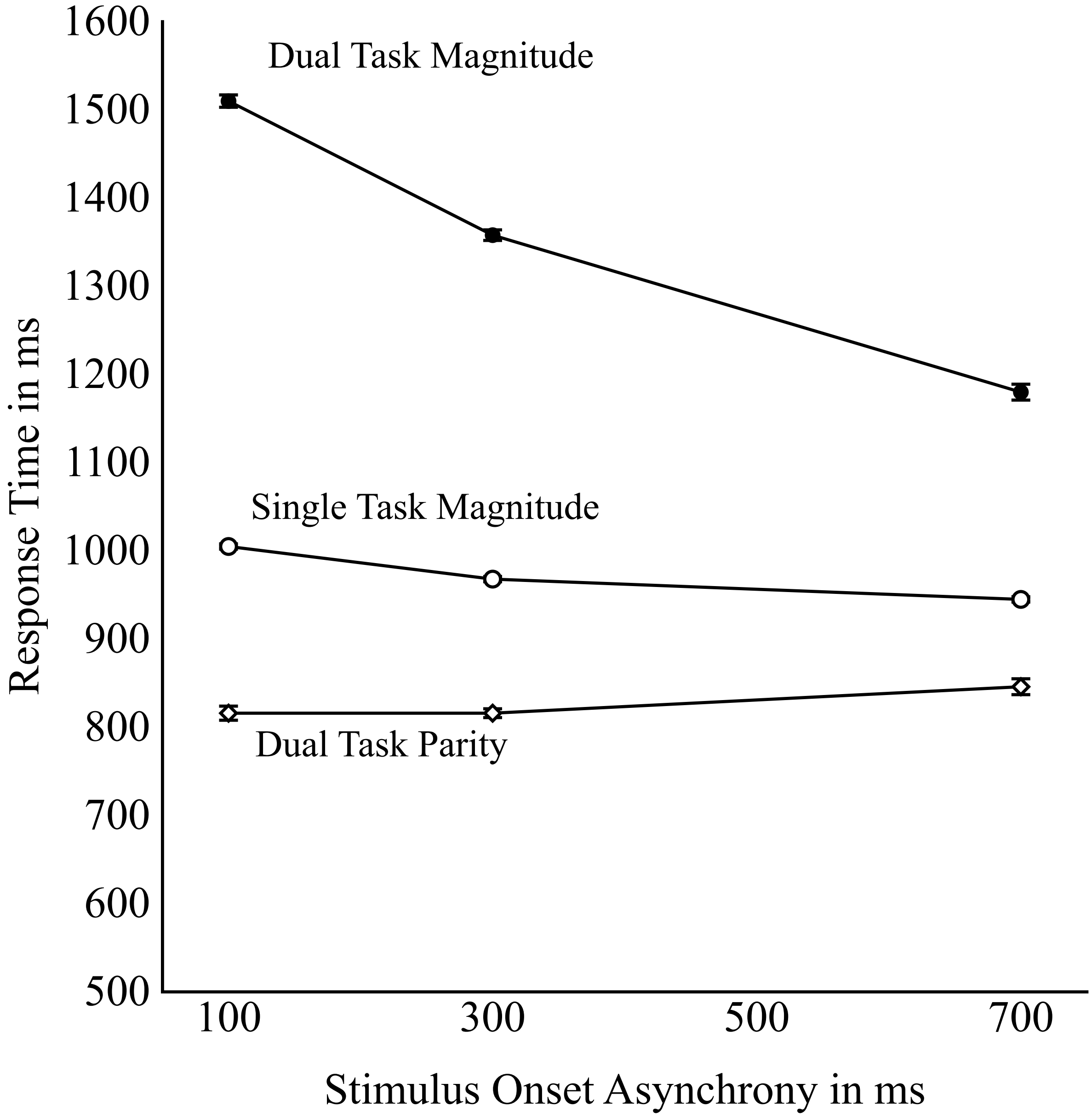
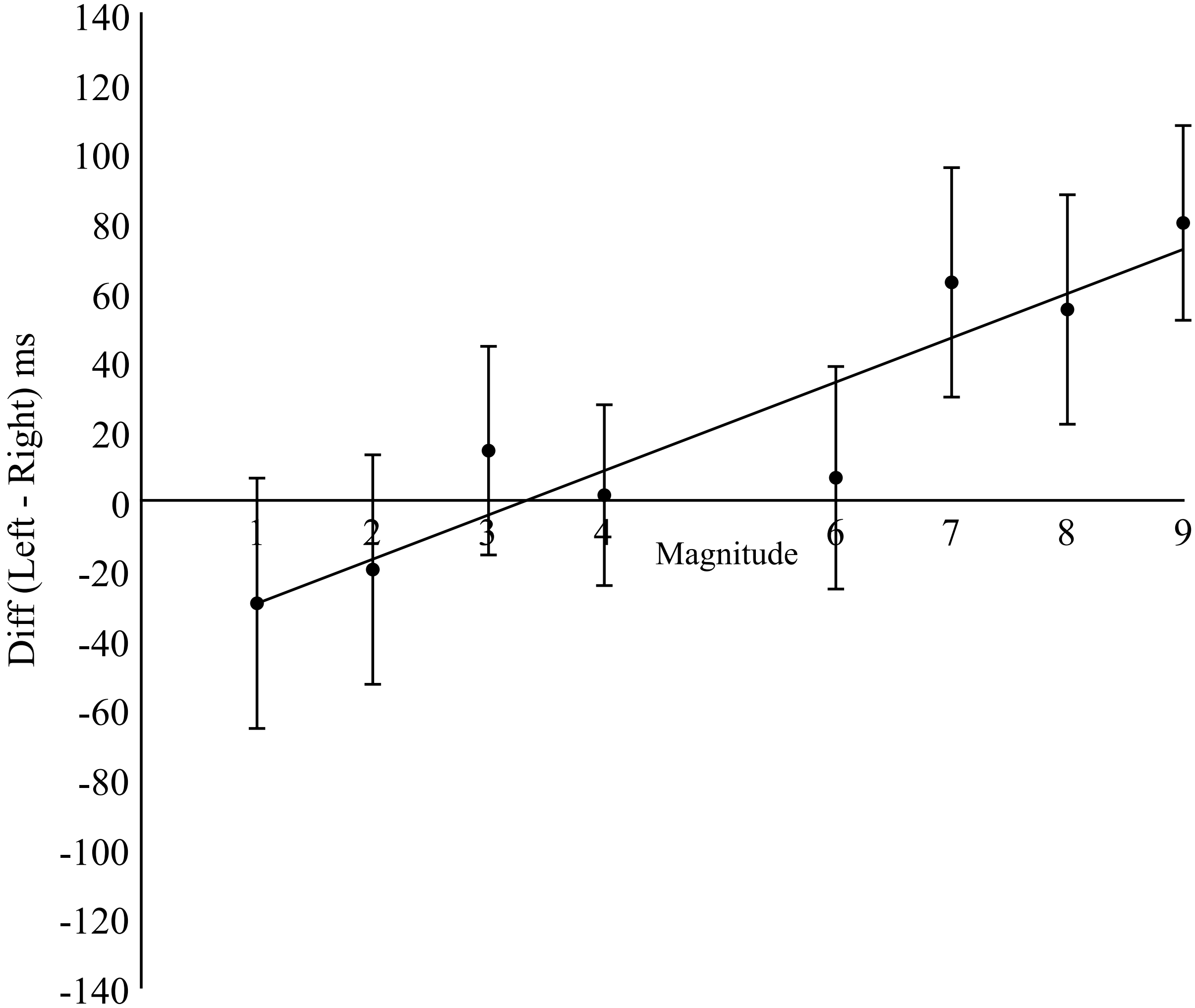
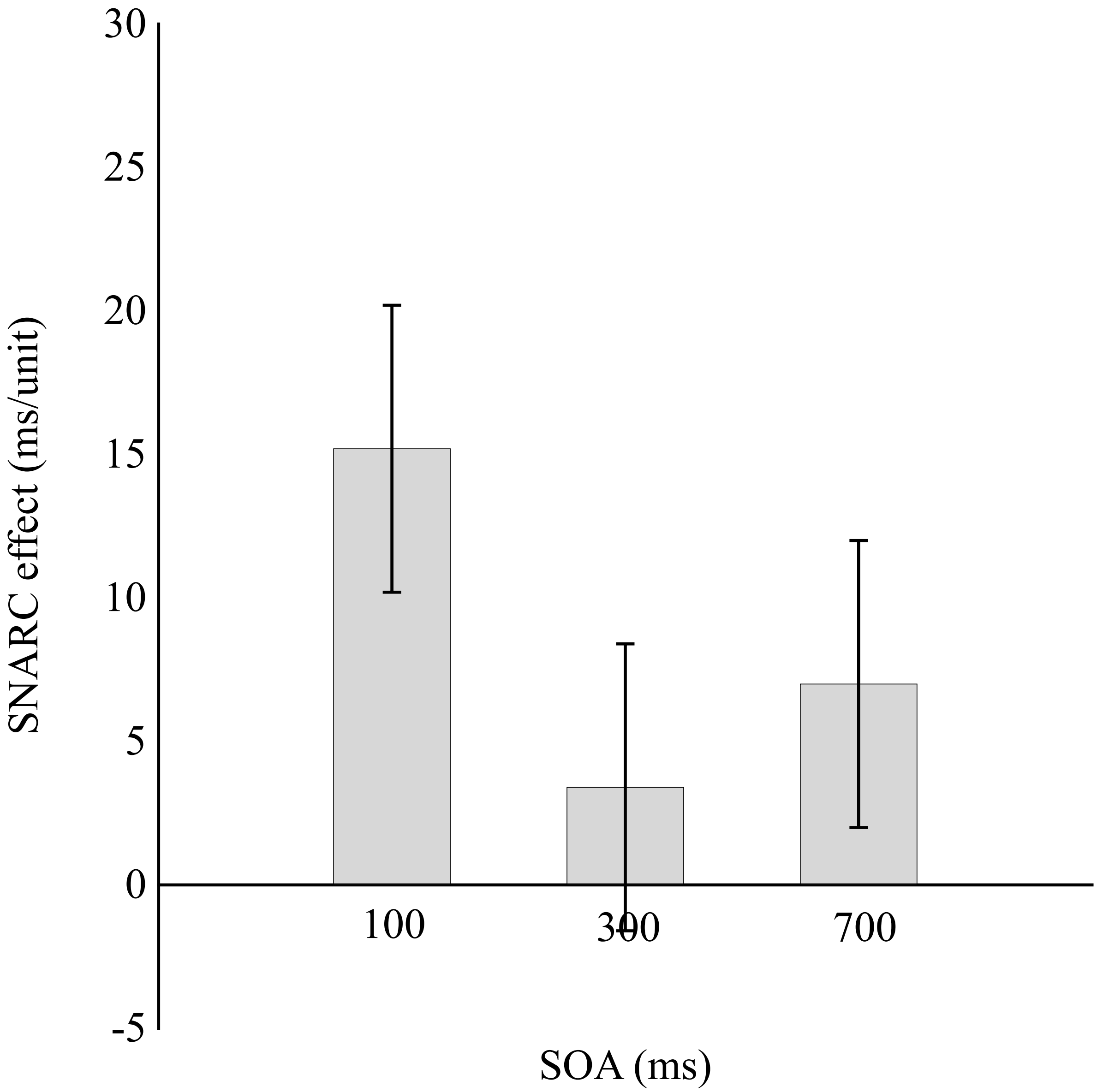
2
3
4
5
6
7
8
9
Magnitude


1600
1500
1400
1300
1200
1100
1000
900
800
700
600
500
Response Time in ms
Dual Task Magnitude
Single Task Magnitude
Dual Task Parity
100
300
500
700
Stimulus Onset Asynchrony in ms


Diff (Left - Right) ms
140
120
100
80
60
40
20
0
-20
-40
-60
-80
-100
-120
-140
1
2
3
4
6
7
8
9
Magnitude


30
25
20
15
10
5
0
-5
SNARC effect (ms/unit)
100
300
700
SOA (ms)