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ON THE LOCUS OF DUAL-TASK INTERFERENCE DURING ENCODING

by

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ABSTRACT

Jolicoeur & Dell'Acqua (1998) demonstrated that encoding a few briefly presented masked characters for later report can produce significant interference in a concurrent speeded tone task. This result implies that encoding requires a capacity limited cognitive mechanism also required for the tone task. Six experiments explore the nature of this capacity limited cognitive mechanism using the locus of cognitive slack logic (Pashler & Johnston, 1989; McCann & Johnston, 1992). The combined results indicate that the capacity limited cognitive mechanism involved in encoding takes the form of a processing bottleneck that affects a stage after rudimentary perceptual processing but before response selection. A model is proposed which assumes a processing bottleneck at the stage where implicitly coded stimulus information is explicitly coded by the observer, a stage referred to as 'short-term consolidation' (STC). The implications of these findings on other phenomena in the dual-task literature are also discussed.

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My sincerest thanks to Pierre Jolicoeur for his support and guidance throughout the years. I would also like to thank Marg Ingleton and the other members of the Jolicoeur lab, past and present, for helping make even the biggest crisis seem surmountable.

For my parents

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Introduction

Most cognitive tasks require encoding and for this reason there are obvious incentives for psychologists to understand not only how encoding operates, but how it may be affected by concurrent processing demands. The present work explores both the extent of the involvement of capacity limited cognitive mechanisms in encoding, and the nature of these capacity limitations.

The role of capacity limited cognitive mechanisms in encoding

The results from several of the earlier experiments conducted in this area indicated that encoding does not involve a capacity limited cognitive mechanism. In an experiment that has since become a classic, Posner and Boies (1971) examined the role of a capacity limited cognitive mechanism in letter encoding. Participants were presented with two letters, separated by a short interval, and were required to decide whether the letters were the same or different (letter matching task). The first letter remained on the screen throughout the trial. A probe tone was presented at various stages during the letter matching task to which participants made a simple speeded response. Posner and Boies (1971) argued that if letter encoding required a capacity limited cognitive mechanism also required for the tone task, simple RTs to the tone would be elevated during the encoding interval immediately following the onset of the first letter, as compared to at other points during the trial. The results from this experiment, however, showed tone RTs to be shorter during the encoding interval than in the inter-trial interval before the first letter was presented, which served as the baseline measure. Posner and Boies (1971) concluded that letter encoding does not require a central capacity limited cognitive mechanism. Posner and Boies' (1971) finding has been replicated a number of times (e.g. Posner & Klein, 1973; Proctor & Proctor, 1979).

Other researchers have provided support for Posner and Boies' (1971) conclusions using different experimental paradigms. For example, Pashler (1993a) presented participants with a high or low pitched tone followed, at an SOA of 50, 150, or 650 ms, by a Phillips display (so called because it was first employed by Phillips, 1974), consisting of a random 4 x 4 array of eight black and eight red squares. Participants made a speeded response to the tone and encoded the array. The Phillips display was presented for either 100 or 300 ms and then masked for 100 ms by a 4 x 4 array of alternating black and red squares. After an interval of 500 ms another Phillips display was presented which was either identical to the first or different by one square and participants indicated at their leisure whether it was the same or different as the one presented earlier in the trial. Pashler's (1993a) logic was similar to that of Posner and Boies (1971); if encoding requires the same capacity limited cognitive mechanism required for the tone task then the tone task will postpone encoding, and because the array is presented briefly and masked, ultimately reduce accuracy in the matching task. Pashler (1993a) found no effect of SOA on accuracy for the matching task and concluded that the encoding of visual information up to and including short-term memory does not require the same capacity limited cognitive mechanism associated with response selection.

However the conclusions of Posner and Boies (1971) and Pashler (1993a) are undermined by the results of several other experiments. Ogden, Martin, and Paap (1980), Comstock (1973), and Johnson, Forester, Calderwood, and Weisgerber (1983) used the same basic paradigm as Posner and Boies (1971) but presented the first letter only briefly and followed it with a mask, thus forcing participants to encode the letter as soon as it was presented. Ogden et al. (1980), Comstock, (1973), and Johnson et al. (1983), all found probe RTs during the encoding intervals to be significantly longer than baseline, implying that encoding does indeed involve a capacity limited cognitive mechanism. It seems plausible that Posner and Boies (1971) failed to find interference between the encoding task and the tone task because the first letter remained on the screen until the response, and participants were able to avoid encoding the letter and responding to the tone simultaneously. In addition, Ogden et al. (1980) found that probe RT during the inter-trial interval (ITI), which served as a baseline in Posner & Boies (1971), is sensitive to the probability that a tone will be presented during this interval, and thus the presence or absence of interference in the paradigm used by Posner & Boies (1971) may be more dependent on participant alertness than on the processing demands of the primary task (Paap & Ogden, 1981).

When Jolicoeur and Dell'Acqua (in press) used the same paradigm as Pashler (1993a) they found a significant effect of SOA on Pashler's Phillips display matching-task accuracy, with accuracy 7% higher at the longest SOA than at the shortest SOA. In addition, when Jolicoeur and Dell'Acqua (in press) made the first task more difficult by increasing the tone task from a 2 alternative discriminations (2AD) task to a 3 alternative discrimination (3AD) task the effect of SOA on accuracy was even greater, accuracy rose 20% across SOAs. Jolicoeur and Dell'Acqua (in press) hypothesized that Pashler (1993a) may have failed to find an effect of SOA on matching task accuracy because the tone task was not sufficiently difficult to interfere with encoding.

Thompson (1987) found converging evidence that encoding requires a capacity limited cognitive mechanism. In Thompson (1987) participants performed a visual search task (sometimes searching for a single feature, sometimes for a conjunction of features) while performing a concurrent simple response to a tone. At the end of the trial participants were presented with two stimulus arrays and had to decide which array they had just seen. As with Ogden et al. (1980, Exp. 3), Comstock (1973), and Johnson, et al. (1983), Thompson (1987) found simple RT to the tone was slowest when the tone was presented immediately following the presentation of the first array, and fastest prior to the presentation of the first array, again implying that a capacity limited cognitive mechanism is involved in encoding.

Although the results of Ogden et al. (1980), Comstock (1973), Johnson et al., (1983), Jolicoeur and Dell'Acqua (in press) and Thompson (1987) indicate that a capacity limited cognitive mechanism is involved in the encoding task, a number of other unrelated cognitive processes, such as anticipating the second stimulus, preparing to perform the match, or preparing to respond, could also be contributing to the observed interference. Thus corroborating evidence from experiments with better controlled paradigms is needed before these results can be considered evidence that encoding requires a capacity limited cognitive mechanism.

Jolicoeur and Dell'Acqua (1998) developed a paradigm that avoids many of the interpretive pitfalls inherent to earlier experiments that have examined the role of capacity limited cognitive mechanisms in encoding. Jolicoeur and Dell'Acqua's (1998) paradigm is adapted from the well known and widely used psychological refractory period (PRP) dual-task paradigm (Welford, 1952, 1980).

The Psychological Refractory Period (PRP) Paradigm

The PRP paradigm was originally designed to examine basic performance deficits incurred under dual-task conditions but has since been developed into a powerful tool not only for detecting the involvement of capacity limited cognitive mechanisms, but also for assessing how the capacity limited cognitive mechanism constrains processing. In the PRP paradigm (Welford, 1952, 1980) participants are presented with two stimuli, (S1 and S2) at varying SOAs and are required to make a speeded response to each (R1 and R2). Results from PRP paradigm experiments consistently show increases in task 2 response times (RTs) with decreasing SOA, a phenomenon referred to as the 'PRP effect' (see Pashler, 1994, for a review). Because RTs increase with increased task overlap, the PRP effect shows that the same capacity limited cognitive mechanism is required for some aspect of the processing for both tasks.

Three different descriptions of the capacity limited cognitive mechanism responsible for the PRP effect have been proposed in the literature: Processing bottleneck models, capacity sharing models, and strategic bottleneck models. Proponents of processing bottleneck models conceptualize the capacity limited cognitive mechanism responsible for the PRP effect as a processing bottleneck that can only process information relevant to one task at a time. When two concurrent tasks must complete a stage of processing that requires the capacity limited cognitive mechanism, or bottleneck, processing of the bottleneck stage in task 2 must wait until processing at the bottleneck stage for task 1 has been completed (Pashler, 1994; 1998). Because increasing task overlap increases the likelihood that task 2 processes will encounter a busy bottleneck , mean task 2 RTs are longer at shorter SOAs than at longer ones, which would explain the PRP effect.

Proponents of capacity sharing models (e.g. Kahneman, 1973) instead conceptualize the capacity limited cognitive mechanism as a limited resource that can be allocated to various processing requirements. It is assumed that when less of the resource is allocated to a given task, processing efficiency for that task is reduced. When two tasks simultaneously require this capacity limited resource for one or more stages of processing less of the resource is allocated to each task and processing of both tasks may be slowed to some degree. There are a number of different variations on this basic theme, some capacity sharing models assume that capacity is divided equally between concurrent tasks while others assume that the division of the resource between tasks is flexible and may vary according to a number of factors, such as instructions or the objectives of the participants[1]. In both types of capacity sharing models some slowing will be observed for both task 1 and task 2, and the amount of slowing will be proportional to task overlap, and thus capacity sharing models are also consistent with the basic PRP effect.

Meyer and Kieras (1997) instead propose a 'strategic bottleneck' explanation of dual-task interference. Meyer and Kieras (1997) argue that although the cognitive system is capable of processing any combination of stages in parallel, participants may 'lock-out' task 2 processing during specific stages in order to cope with the specific demands of a given paradigm. Meyer and Kieras (1997) argue that because PRP paradigm experiments require a response to task 1 before a response to task 2, participants may 'lock-out' task 2 processing around response selection to ensure that a response to task 1 is made before a response to task 2. According to Meyer and Kieras (1997) the lock-out point may occur at any point during processing and will depend upon specific task instructions, a participant's goals, an prior experience. Meyer and Kieras (1997) thus argue that the PRP effect is the result of participants strategically postponing task 2 response selection so as to guarantee that task 1 is always responded to first. At short SOAs, task 2 response selection will be 'locked out' for longer, and hence response times will be larger than at longer SOAs.

Because all three classes of models predict increased task 2 RTs with decreasing SOAs, it is necessary to look to more complex effects to distinguish between the three accounts of the PRP effect. Each type of model makes different predictions about how manipulations of the duration of various stages of processing will affect task 2 RTs in a PRP paradigm experiment, which can be compared to the results of actual experiments employing the PRP paradigm.

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[1] Note that a processing bottleneck model is essentially a capacity sharing model that devotes 100% of capacity to the first task.

The basic logic behind the main predictions of processing bottleneck models is shown in Figure 1. In all panels of Figure 1 a processing bottleneck is assumed to affect stage B of both tasks such that processing of stage B in task 2 must wait for processing of stage B of task 1 to be complete. The first, and arguably the most diagnostic, prediction made by processing bottleneck models is that manipulating the duration of a pre-bottleneck stage of task 2 processing will result in an underadditive interaction with decreasing SOA (see Panel A of Figure 1). In the present context an interaction is considered to be underadditive when the shape of the function converges as SOA is decreased, and when the function instead diverges as SOA is decreased the interaction is considered to be overadditive. The basic logic behind this prediction is shown in Panel A of Figure 1, where the duration of stage A processing for task 2 is manipulated. At short SOAs the bottleneck produces a period of 'cognitive slack' during which task 2 processing of stage A must wait for task 1 processing of stage B to be complete. This period of cognitive slack effectively absorbs the durational difference in the processing of stage A such that task 2 response times for the two conditions are the same. At long SOAs, however, there is no period of cognitive slack to absorb the durational difference in stage A processing, and the full extent of durational differences in the two conditions of task 2 will be reflected in task 2 RTs. Thus, if a pre-bottleneck stage of processing is manipulated there will be no difference in RTs between the two conditions at short SOAs accompanied by differences in the two conditions at long SOAs, which will result in an underadditive interaction with decreasing SOA.

A second prediction of processing bottleneck models is that manipulating the duration of a post-bottleneck stage of task 2 will have additive effects across SOAs. In Panel B of Figure 1 the duration of processing for stage B of task 2 is manipulated. Because there is no period of cognitive slack when a stage at or after the bottleneck is manipulated, the full extent of

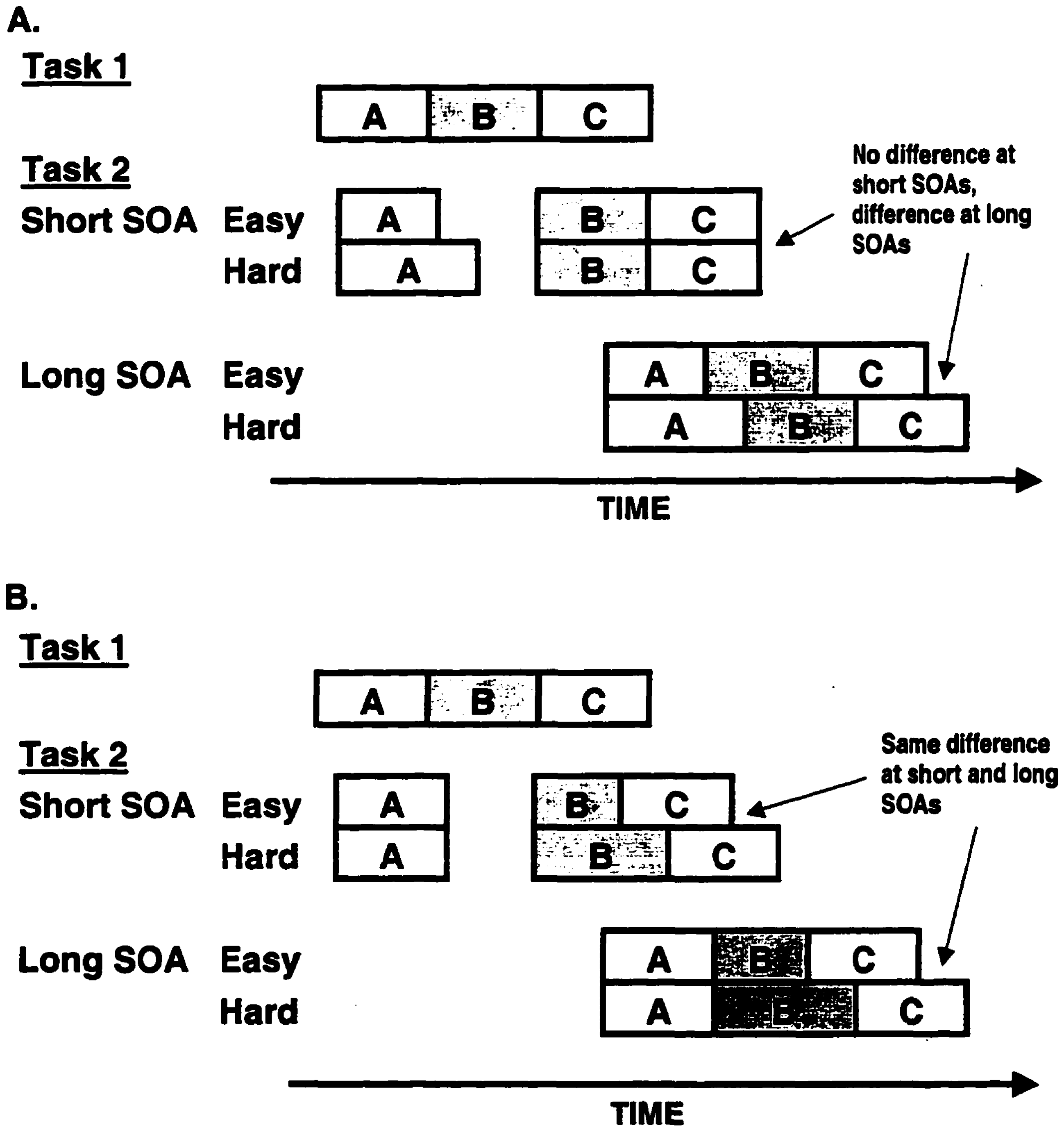

Figure 1. Predictions made by processing bottleneck models based on the locus of cognitive slack logic. Stage B is assumed to constitute a processing bottleneck. Panel A illustrates the predicted outcome of manipulating a pre-bottleneck stage of processing. At short SOAs differences in processing time are absorbed into the period of 'cognitive slack', leading to an underadditive interaction with decreasing SOAs. Panel B illustrates the predicted outcome of manipulating a stage at or after a processing bottleneck. Here the manipulation affects a stage after the period of cognitive slack and thus the full extent of processing time differences are reflected in tone RTs at all SOAs, producing additive effects.

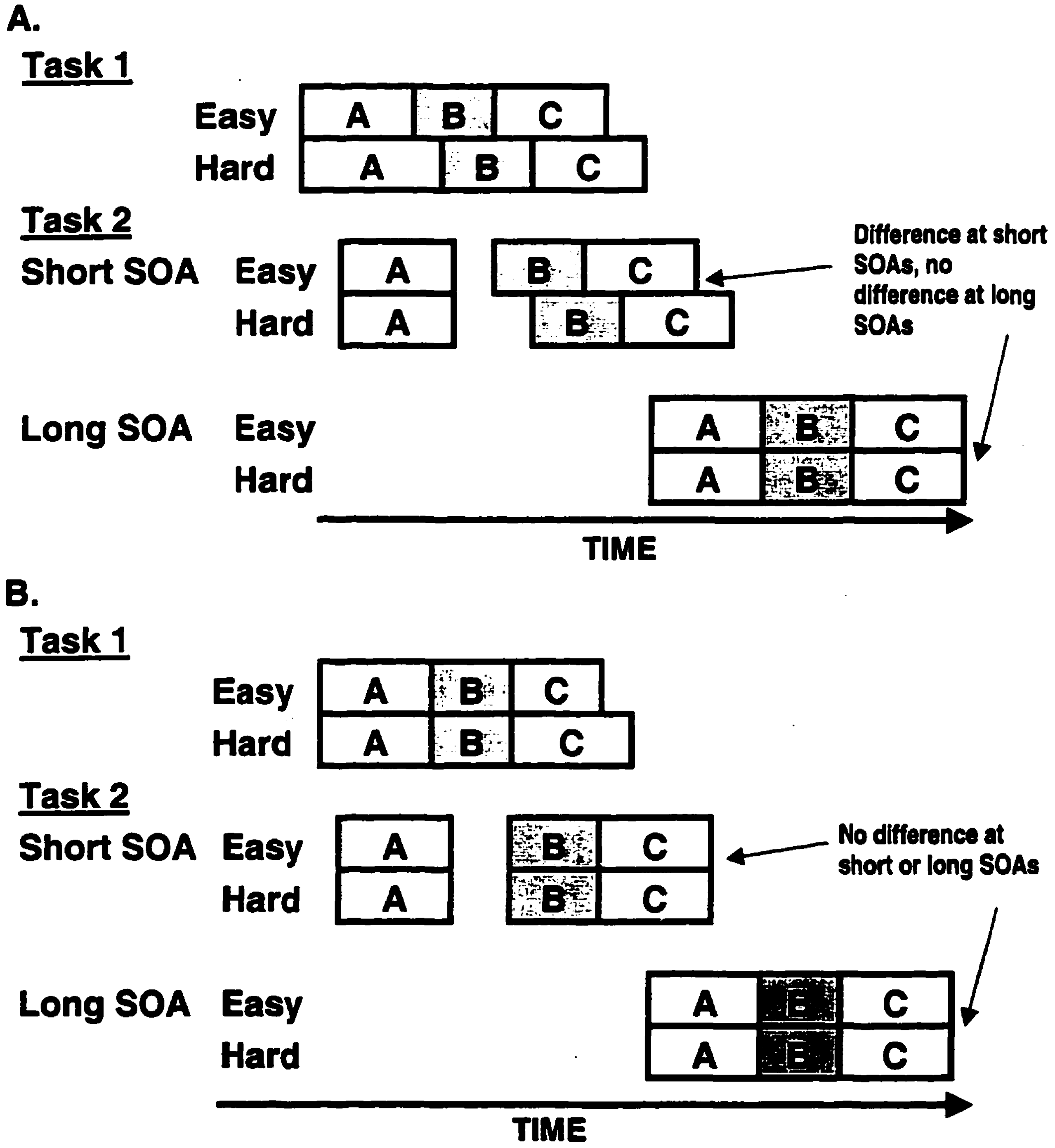

Figure 2.. Predictions made by processing bottleneck models based on the locus of cognitive slack logic. Stage C is assumed to constitute a processing bottleneck. Panel A illustrates the predicted outcome when a pre-bottleneck stage of task 1 is manipulated. At short SOAs the manipulation will propagate onto tone RTs, whereas at long SOAs the manipulation will not affect task 2 RTs. Panel B illustrates the predicted outcome of manipulating a stage at or after the bottleneck in task 1. Because the manipulation will not affect task 2 postponement, the manipulation will not affect task 2 RTs.

processing time differences between the two conditions will be reflected in task 2 RTs at all SOAs resulting in additive effects.

A third prediction stemming from processing bottleneck models is that increasing the duration of a pre-bottleneck or bottleneck stage of task 1 processing will result in an overadditive interaction with decreasing SOA in task 2 RTs (see Panel A of Figure 2). In panel A of Figure 2 the duration of stage B in task 1 is manipulated. At short SOAs stage B of task 2 will be postponed until all pre-bottleneck and bottleneck processing of task 1 has been completed, and hence any manipulation which increases the duration of pre-bottleneck or bottleneck processing of task 1 will be propagated onto task 2 RTs. At long SOAs, however, task 1 processing will be complete before task 2 processing begins and hence a manipulation of the duration of task 1 processing will have no effect on task 2 RTs.

Finally, processing bottleneck models predict that increasing the duration of a post-bottleneck stage of task 1 processing will result in increases in task 1 RTs but not task 2 RTs (see Panel B of Figure 2). In Panel B of Figure 2 the duration of stage C of task 1 processing is manipulated. Because increasing the duration of post-bottleneck stages of task 1 does not add to the postponement of task 2, no difference in task 2 processing times will be observed under these conditions. Processing bottleneck models also predict that there will be no effect of SOA on task 1 accuracy or response times in any conditions because task 1 processing is not affected by the demands of performing task 2.

The prediction made by capacity sharing models as to how a task 2 difficulty manipulation will affect RT depends upon the extent to which the stage of task 2 processing affected by the difficulty manipulation overlaps with task 1 processing.

Figure 3 illustrates the predictions of capacity sharing models when the duration of a stage of task 2 processing is manipulated. Panel A illustrates the predicted outcome when the

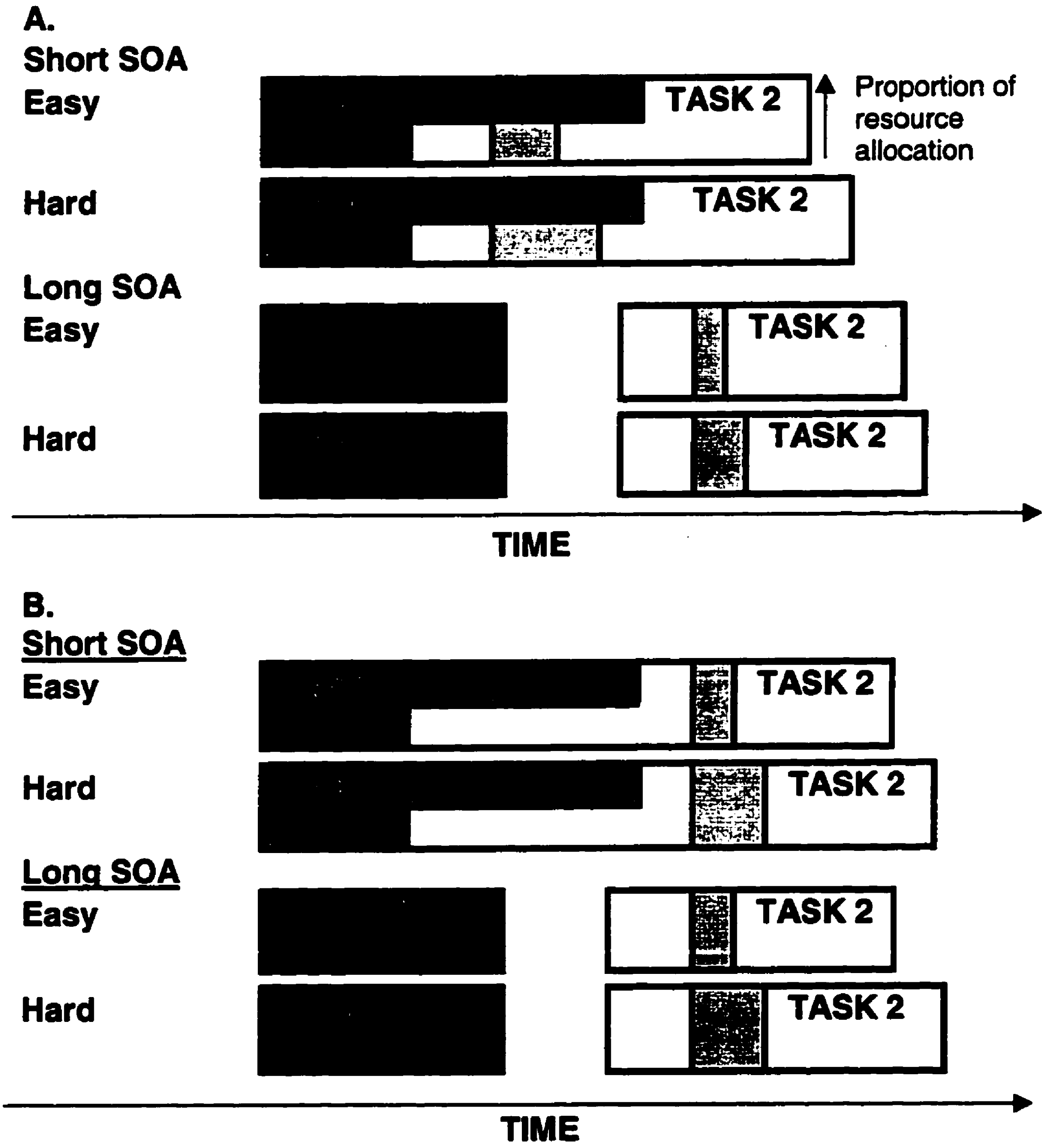

Figure 3. Predictions made by capacity sharing models when a difficulty manipulation is employed in task 2. Th areas labeled 'task 1' and 'task 2' represent the total resources required for the task. The height of each area represents the proportion of resources allocated to that task and the width represents the amount of time needed for task completion. The light gray area represents the manipulated stage. Panel A: the predicted outcome when the manipulated stage overlaps completely with task 1 at short SOAs. At short SOAs the durational difference will be exaggerated compared to at longer SOAs because more time is needed for processing when less resources are available. Panel B illustrates the predicted outcome when the task 2 difficulty manipulation affects a stage that do not overlap with task 1. Here the effect of the difficulty manipulation will be the same regardless of SOA and additive effects are instead predicted.

manipulated stage completely overlaps with task 1 processing at short SOAs while Panel B illustrates the predicted outcome when the manipulated stage of task 2 never overlaps with task 1 processing. The enclosed areas labeled "Task 1" and "Task 2" represent the total amount of processing resources required for the completion of each task. The height of these regions represents the proportion of resources assigned to the task, and the width represents the amount of processing time required. Because it is assumed that completing a given task always requires the same total amount of resources, the area of the region representing each task (calculated by multiplying the proportion of resources allocated to the task by time) must remain constant across conditions. Thus reducing the proportion of resources allocated to a given task must be matched by an increase in the amount of processing time required for the task (and vice versa). The light gray areas represents the stage of task 2 processing affected by the difficulty manipulation. When S1 is presented, the capacity limited resources are allocated exclusively to task 1 processing until S2 is presented. At short SOAs processing of task 1 will not be complete at the onset of S2, and the resources must be divided between the two tasks. This results in a reduction in the proportion of resources allocated to task 1 (represented by the decrease in height of the region) with a simultaneous increase in the proportion of resources allocated to task 2. When task 1 processing is complete, all of the resources are allocated to task 2. At long SOAs both task 1 and task 2 are completed with exclusive access to the full extent of the resources. Panel A illustrates the predicted outcome when the stage of task 2 processing affected by a difficulty manipulation completely overlaps with task 1 processing at short SOAs but not at long ones. There is a larger effect of the difficulty manipulation at short SOAs than at longer ones because the duration of processing time for the manipulated stage must be increased at short SOAs to compensate for the decrease in the proportion of the resources allocated to task 2. Thus an overadditive interaction with decreasing SOA is predicted by capacity sharing models when the stage of task 2 processing that is manipulated completely overlaps with task 1 processing. Panel B illustrates the predicted outcome when the manipulated stage of task 2 processing never overlaps with task 1 processing.. Here, the difference in processing time for the two conditions is the same at all SOAs, because the manipulated stage of task 2 is always completed when task 2 has exclusive access to the resources. This results in additive, instead of overadditive, effects with SOA. Thus depending on whether the manipulated stage overlaps with task 1 processing (Panel A) or does not (Panel B) different patterns may be observed in task 2 RTs[2].

One important distinction between the capacity sharing account that predicts additive effects between a task 2 difficulty manipulation and SOA (Panel B of Figure 3) and the account submitted by processing bottleneck models is that this capacity sharing account predicts significant effects of SOA on task 1 RTs, while the processing bottleneck model predicts no effect of SOA on task 1 processing when additive effects on task 2 processing are observed. A capacity sharing account which predicts a decrease in resources assigned to each task during the period where both tasks require the capacity limited mechanism necessarily predicts an increase in task 1 RTs at short SOAs, because RTs will be slowed as a result of having fewer resources assigned to task 1 processing, and the probability of such slowing increases as SOA decreases. Processing bottleneck models, on the other hand, predict that in all situations, including when additive effects are observed, task 1 processing will be unaffected by all task 2 manipulations, and thus task 1 RTs should remain constant across SOAs. Thus when additive effects are observed, we argue that an examination of the corresponding pattern in task 1 RTs may be used to

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[2] The intermediate case, where there is partial overlap between the manipulated stage of task 2 and task 1 processing, which is not illustrated, can produce either additive effects like in the no overlap condition or partial overadditivity.

distinguish between a processing bottleneck account and a capacity sharing account of the interference. It is important to note that although a capacity sharing model may be used to account for either an overadditive interaction or additive effects between a task 2 difficulty manipulation and SOA, a capacity sharing model cannot be reconciled with an underadditive interaction with decreasing SOA.

One clear prediction of Meyer and Kieras (1997) is that if response order constraints are removed in a PRP paradigm experiment, such that participants may respond to each stimuli in the order they please, that no interference will be observed. This is because inherent to Meyer and Kieras' (1997) model is the assumption that "lock-out" points, which produce bottleneck-like interference, are only imposed in the PRP paradigm because of strict response-order instructions given to participants before the experiment. However, in a recent study conducted in our lab participants were presented with a letter and a tone in random order at varying SOAs and were required to make a speeded forced choice response to each. Participants were given no instructions to respond to one task stimulus before the other. In fact because stimulus order was random participants had an incentive to respond to the first stimulus that was presented, rather than the letter first on all trials or the tone first on all trials. Meyer and Kieras (1997) clearly predict no interference in this paradigm, because response order is not specified. The results from two experiments of this type show clear and substantial PRP effects for both stimulus order conditions. Participants responded to the first stimulus that was presented on 90% of the trials, and hence were clearly not pre-imposing a strategic "lock-out" point at response selection for a specific stimulus, and yet clear evidence of dual-task interference was still observed. This finding cannot be reconciled with Meyer and Kieras (1997) who predict no interference under these circumstances, and for this reason Meyer and Kieras' (1997) model of the PRP effect may be rejected.

The vast majority of empirical evidence indicates that the capacity limited cognitive mechanism responsible for the PRP effect takes the form of a processing bottleneck. All of the predictions that stem from processing bottleneck models have been borne out empirically. The best evidence for a processing bottleneck comes from the large number of experiments that have produced underadditive interactions between a task 2 difficulty manipulation and decreasing SOA, implying that the capacity limited cognitive mechanism responsible for the PRP effect takes the form of a processing bottleneck. Such interactions could not be produced if capacity sharing was the source of the PRP effect, because these models predict additive or overadditive (depending on the specific instantiation of the model), but not underadditive, effects with increased task overlap.

The pattern of additivity and interactions across a wide variety of PRP paradigm experiments further implies that the processing bottleneck responsible for the PRP effect occurs sometime after the completion of rudimentary perceptual processing and before the completion of response selection. Experiments in which the duration of task 2 perceptual processing is manipulated consistently produce underadditive interactions with decreasing SOA, placing the locus of the bottleneck sometime after this perceptual processing has been completed (see Panel A of Figure 1). Experiments in which a variable believed to affect the duration of task 2 response selection is manipulated, however, typically produce additive effects with SOA. McCann and Johnston (1992) manipulated the compatibility of the S-R mapping in a PRP paradigm experiment. On each trial participants were presented with a high or low pitched tone followed, at varying SOAs, by either an arrow pointing left or right (easy condition), or the letter M or T (hard condition) at fixation. Participants made a speeded response to the pitch of the tone followed by a speeded response to the visual stimulus. In the easy S-R mapping condition participants pressed the left hand key if the arrow pointed left, and the right hand key if the arrow pointed right. In the hard S-R mapping condition participants pressed the left hand key if the letter was an T, and the right hand key if the letter was a M. McCann and Johnston (1992) found the S-R mapping manipulation to produce additive effects with SOA, implying that the locus of the PRP bottleneck precedes the completion of response selection. Pashler and Johnston (1989), who manipulated response repetition in task 2 and Pashler (1989), who manipulated response modality (vocal/manual) in task 2 also found additive effects with SOA. These patterns of additivity between manipulations of the duration of response selection and SOA imply that the processing bottleneck occurs at or before response selection (see Panel B of Figure 1).

However, there is some debate in the literature as to whether the processing bottleneck affects a stage before the completion of response selection, or later at the response execution stage. Some researchers have argued against a response execution bottleneck based on the additive effects of response selection manipulations and SOA (e.g. Pashler, 1989; Pashler & Johnston, 1989; McCann & Johnston, 1992) because if the postponement was occurring later, at response execution, then manipulations that affect the duration of response selection should produce underadditive, not additive, effects with decreasing SOA. In addition, although response selection manipulations for task 1 variables have been found to propagate onto task 2 RTs in a number of experiments, response execution manipulations for task 1 have not, implying that response selection occurs at or before the PRP bottleneck, whereas response execution occurs after the PRP bottleneck (Pashler, 1994). Karlin and Kestenbaum (1968) manipulated the number of response alternatives in task 1 and found the manipulation to produce roughly equivalent increases in task 1 and task 2 processing, however Van Selst and Jolicoeur (1997) failed to replicate this result. Other experiments which have manipulated the difficulty of executing the task 1 response (e.g. Pashler & Christian, 1994), have found only a slight impact of these manipulations on task 2 RTs. Because processing bottleneck models clearly stipulate that increasing the duration of pre-bottleneck or bottleneck stages of task 1 processing will be reflected in task 2 RTs whereas manipulations of post-bottleneck stages will not, the results of Karlin and Kestenbaum (1968) indicate that the processing bottleneck is at or before response selection and the results of Pashler and Christian (1994) indicate that the processing bottleneck occurs before, but not at, response execution.

When Karlin and Kestenbaum (1968) manipulated the number of response alternatives in task 2 of a PRP paradigm experiment, such that task 2 involved simple RT in some blocks and a 2AD in other blocks, an underadditive interaction between the response selection manipulation and decreasing SOA was observed, implying that the response selection manipulation affected a stage before a processing bottleneck. However there is experimental evidence that strongly suggests that Karlin and Kestenbaum's (1968) result may have been an artifact of using simple RT. Van Selst and Jolicoeur (1997) and Schubert (1996) replicated the paradigm utilized by Karlin and Kestenbaum (1968) but included a 3AD condition in task 2 in addition to simple RT and 2AD. Although there was some suggestion of an underadditive interaction with decreasing SOA between the simple RT and 2AD conditions (as was found in Karlin and Kestenbaum's experiment) the results from the 2AD and 3AD conditions were clearly additive. Van Selst and Jolicoeur (1997) speculate that Karlin and Kestenbaum's (1968) observation of underadditivity may have resulted from participants making anticipatory responses to the tone in the simple RT condition at long SOAs (when the participant could be certain that the presentation of the tone was imminent). Indeed Van Selst and Jolicoeur (1997) found a dramatic increase in the number of anticipatory responses made in the simple RT condition at long SOAs. The authors argue that such anticipatory responses could have reduced mean RTs for the simple RT condition at long SOAs in Karlin and Kestenbaum's (1968) experiment, resulting in a larger difference between the simple RT and 2AD conditions at long SOAs and an underadditive interaction with decreasing

SOA. In 2AD and 3AD conditions, however, anticipatory responses are rare (the stimulus must be presented before an appropriate response can be made in tasks involving choice) and thus the results from these conditions are more likely to reflect actual processing constraints. Van Selst and Jolicoeur (1997) thus conclude that Karlin and Kestenbaum's (1968) finding of underadditivity between a response selection manipulation and decreasing SOA are not reliable.

Better evidence for a processing bottleneck at response execution is provided by De Jong (1993). De Jong (1993) conducted four PRP paradigm experiments in which participants made a speeded response on some trials ('go' trials) and no response on other trials ('no-go' trials). The identity of S1 determined whether a given trials was a 'go' trial or a 'no-go' trial (for example, in Experiment 1 participants made a speeded response when S1 was a 'B' and no response when S1 was a 'D'). De Jong (1993) reasoned that if response execution, like response selection, required a capacity limited cognitive mechanism then more interference will be observed on a 'go' trial, where response execution is required, than on a 'no-go' trial where response execution is not engaged. Indeed, in all four experiments De Jong (1993) observed smaller PRP effects on 'no-go' trials than on 'go' trials indicating that response execution contributes to the interference observed in PRP paradigm experiments. In order to reconcile this finding with others in the literature which clearly show response selection manipulations to be additive with SOA (implying that the last encountered bottleneck is at response selection where the S-R manipulation exerts its effect) De Jong (1993) developed a dual-bottleneck model that includes a processing bottleneck at both response selection and response execution. Because the response selection bottleneck and the response execution bottleneck are assumed to affect consecutive stages, the dual-bottleneck model predicts that the response execution bottleneck will only be encountered when the duration of task 1 response execution is longer than the duration of task 2 response selection (see Figure 4). Thus an underadditive interaction between a response selection manipulation and decreasing SOA is predicted when task 1 response execution takes more time than task 2 response selection, and additive effects between a response selection manipulation and SOA are predicted when task 1 response execution takes the same or less time than task 2 response selection. Assuming that the model shown in Figure 4 is accurate, the duration of response execution can be estimated by calculating the average inter-response interval when the second task involves simple RT. Based on the results of Karlin and Kestenbaum, De Jong (1993) calculates the average inter-response interval to be about 200 ms. Thus according to De Jong (1993) response selection must take less than 200 ms in order for the response execution bottleneck to be encountered and underadditive effects with decreasing SOA observed. De Jong (1993) notes that while Karlin and Kestenbaum (1968) clearly satisfy this condition, with average simple RTs of 199 ms (indicating that response selection must have taken less than 200 ms), Pashler (1989), Pashler and Johnston (1989), and McCann and Johnston (1992) all found total RTs in the simplest condition to be in excess of 500 ms, making it unlikely that response selection took less than 200 ms to complete. De Jong (1993) thus concludes that a dual-bottleneck model is completely consistent with all the effects observed in PRP paradigm experiments and that it may be premature to argue that response execution does not constitute a bottleneck simply because response selection manipulations do not, typically, go underadditive with decreasing SOA.

In summary, work using the PRP paradigm reveals that a capacity limited cognitive mechanism, in the form of a processing bottleneck, is involved in some aspect of the period of processing between rudimentary perceptual processing and the completion of the response selection stage. In the PRP paradigm this processing bottleneck typically postpones task 2 response selection, resulting in increased task 2 RTs at short SOAs. If De Jong (1993) is correct, there is also a subsequent processing bottleneck at response execution, however this bottleneck

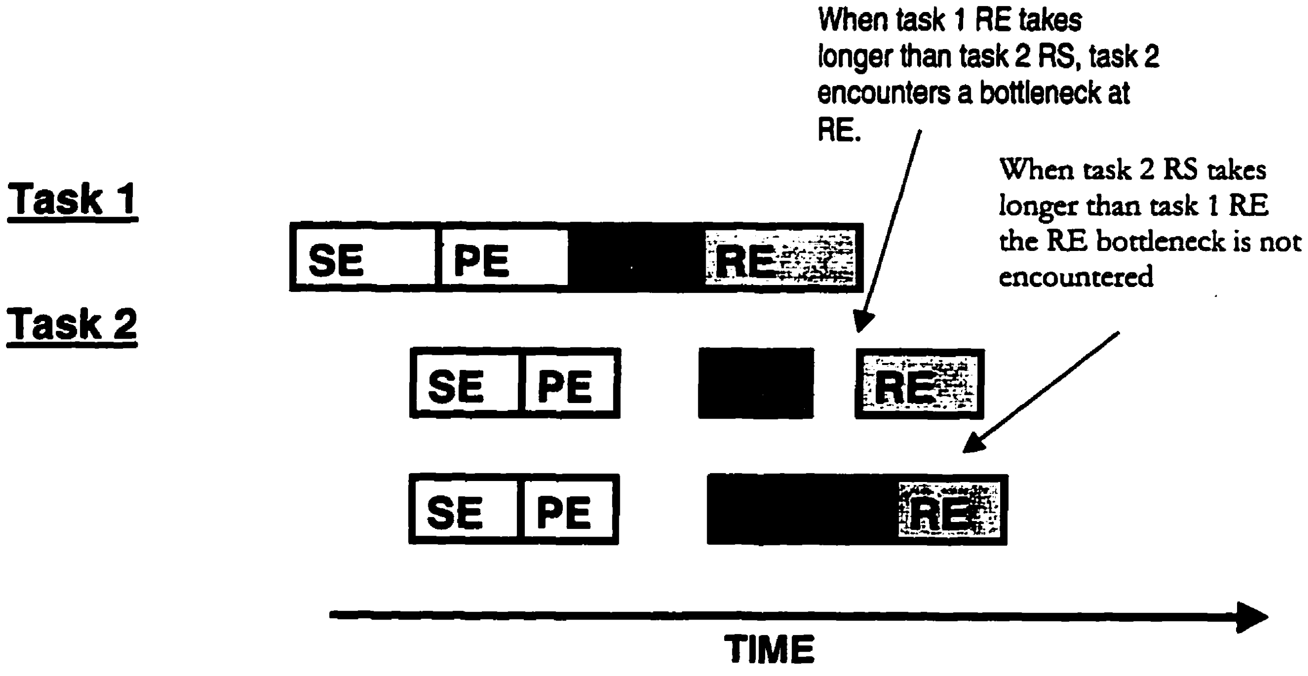

Figure 4. The logic behind De Jong's (1993) argument that the bottleneck at response execution (RE) will only be encountered when task 1 RE takes longer than task 2 response selection (RS). De Jong (1993) uses this logic to explain why some experimenters have found RS difficulty manipulations to produce underadditive interactions with decreasing SOAs (indicating a processing bottleneck after RS) while others have found additive effects (indicating that the bottleneck at or before RS).

will only affect task 2 processing in those cases where task 2 response selection is very short, and will therefore not be relevant in the vast majority of PRP paradigms where task 2 involves a choice response.

Jolicoeur and Dell'Acqua (1998)

By simply switching the first task from a speeded choice response task to a delayed report encoding task Jolicoeur and Dell'Acqua (1998) adapted the PRP paradigm to study the role of capacity limited cognitive mechanisms in encoding. There were a number of reasons for their choice. First, this type of paradigm controls for the pitfalls of earlier letter matching experiments, including the influence of extraneous factors such as anticipating the second stimulus or preparing to make a match, and the possibility that simple RT is not sensitive enough to detect interference. Second, Jolicoeur and Dell'Acqua (1998) were curious to see if the same capacity limited cognitive mechanism that produces interference in the PRP paradigm was involved in encoding, and by using the same second task as in the PRP paradigm, this comparison would be possible.

Jolicoeur and Dell'Acqua's (1998) basic paradigm, shown in Figure 5, is similar to the PRP paradigm, except that instead of a speeded first task, participants encoded or ignored a few simple characters which they report at the end of the trial. Like in most PRP paradigms, the second task was a speeded response to the pitch of a tone. Relatively long SOAs were utilized to help ensure that perceptual processing of the first stimulus was completed by the time that the second stimulus was presented. Jolicoeur and Dell'Acqua (1998) argued that this paradigm helps ensure that the only processes that will be active following the presentation of the first stimulus will be directly involved in encoding, and hence any interference observed in the tone task can be attributed to a capacity limited cognitive mechanism required both for encoding and for the tone task.

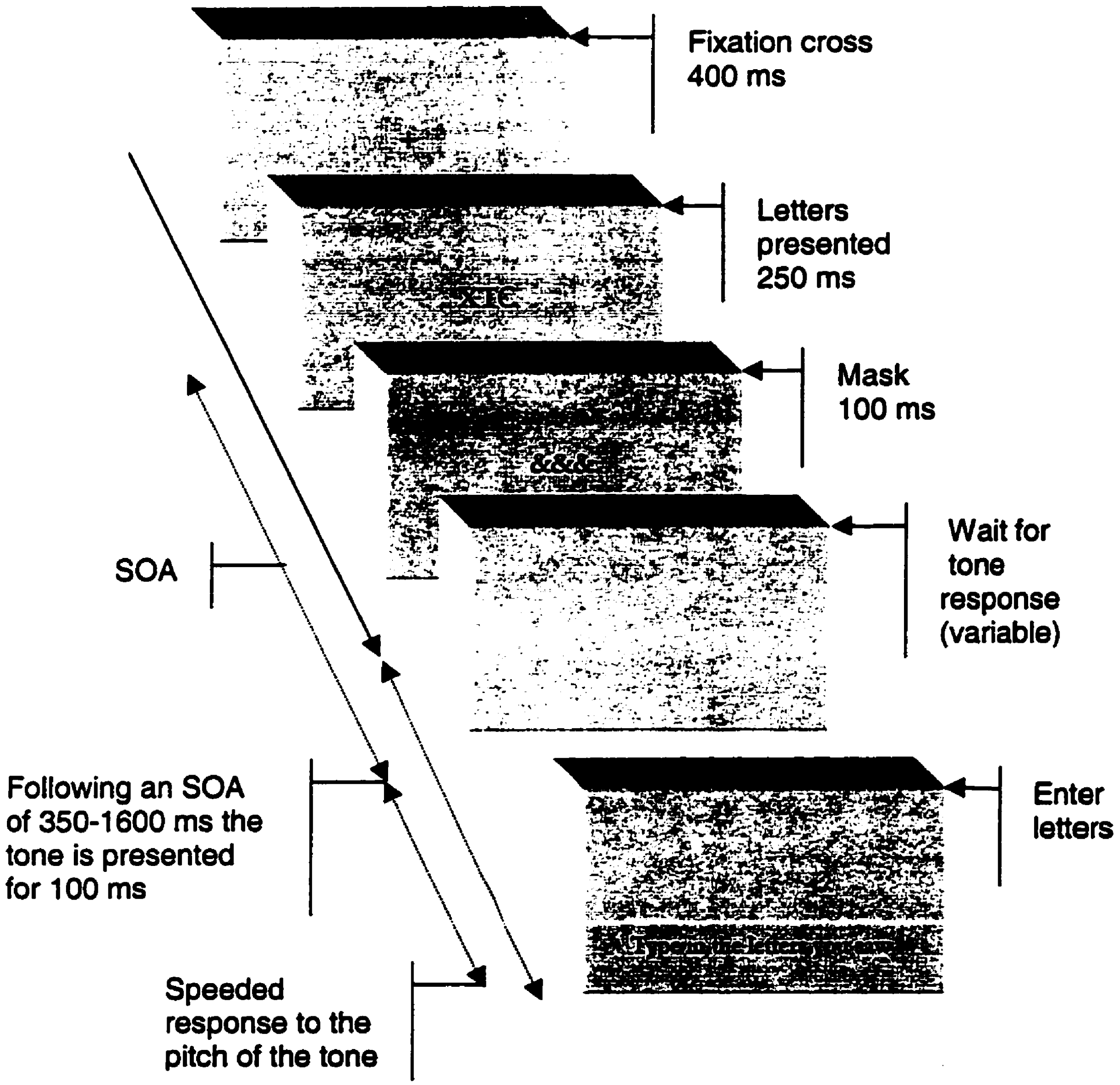

Figure 5. The paradigm used in Experiment 4 of Jolicoeur and Dell'Acqua (1998)(encode condition shown).

In Experiment 4 Jolicoeur and Dell'Acqua (1998) presented participants with a 250 ms masked display of one or three items (letters on half the trials, keyboard symbols on the other half of the trials) followed, at an SOA of 350, 500, 650, 800, or 1200 ms, by a high or low pitched tone. Half of the participants encoded the letters and ignored the symbols while the other half encoded the symbols and ignored the letters. On every trial participants made a speeded response to the pitch of the tone. If it was an encode trial participants then typed in the letters or keyboard symbols they had seen, if it was an ignore trial participants simply pressed the space bar. Mean RTs to the tone served as the main dependent variable.

The results from Jolicoeur and Dell'Acqua (1998, Experiment 4) support the claim that encoding requires a capacity limited cognitive mechanism also required for the tone task. The significant three-way interaction between encode/ignore, SOA, and number of items is shown in Figure 6. When participants had to encode the items, the effect of SOA on tone responses was greater in the three item condition than in the one item condition. When participants instead ignored the items, however, the effect of SOA was much smaller and did not differ in the three and one item conditions. Very similar results were found in the other experiments conducted by Jolicoeur and Dell'Acqua (1998). In every experiment in Jolicoeur and Dell'Acqua (1998) task 2 RTs were slower on encode trials than on ignore trials and the effect of SOA was always greater on encode trials than on ignore trials. In addition, task 2 RTs always showed an effect of number of items on encode trials but not on ignore trials. Further, similar results were found when letters, digits, or keyboard symbols were encoded. Because the interference is greater on encode trials than on ignore trials, and because more encoding results in more interference in this paradigm, the results from this experiment imply that the process of encoding is producing the majority of interference with the tone task.

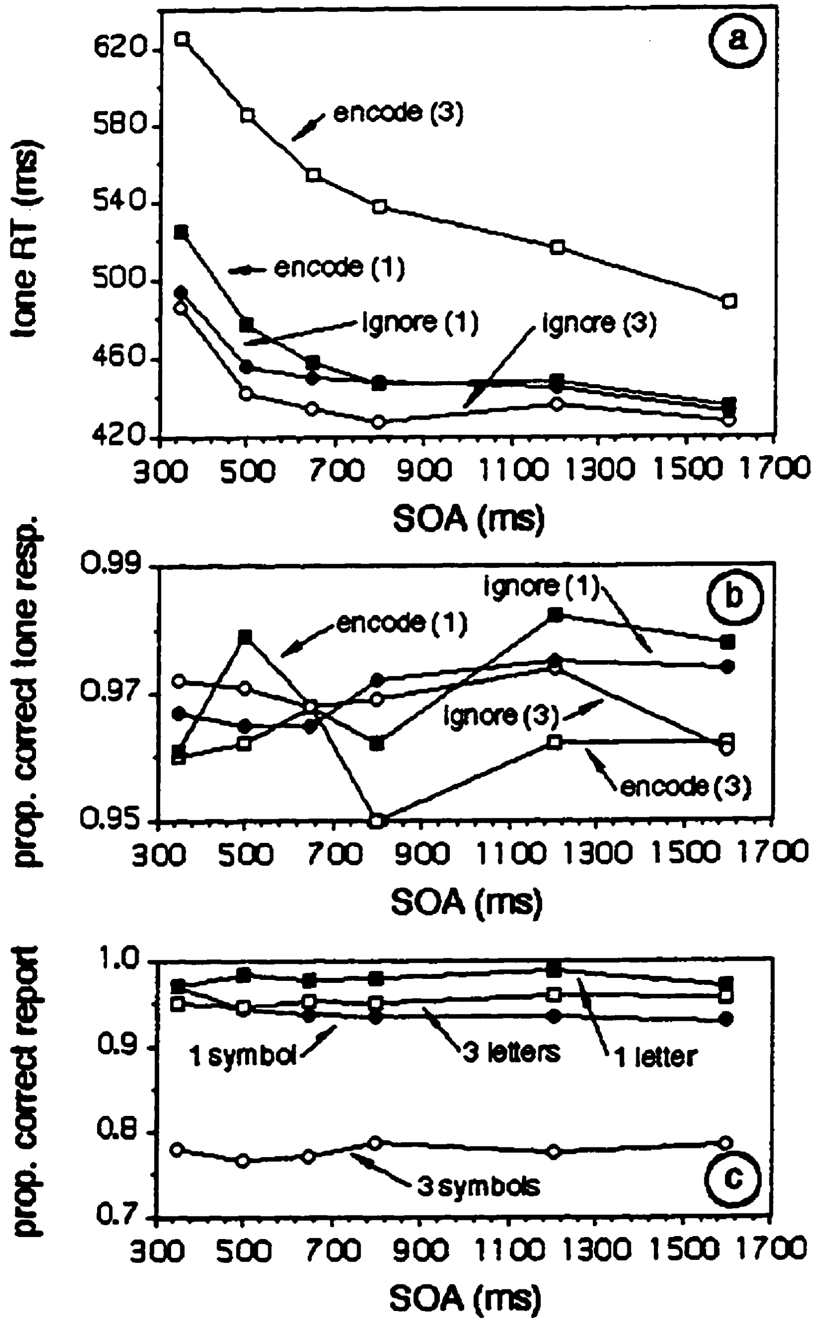

Figure 6. Results from Jolicoeur & Dell'Acqua (1998, Experiment 4).

Jolicoeur and Dell'Acqua (1998) argue that a number of other possible sources for the interference can also be ruled out. First, early perceptual processing is not likely the source of the interference both because the letter presentation was always complete before the tone was presented and because S1 and S2 were presented in different modalities. Also, early sensory processing presumably took place on ignore trials of Experiment 7 but the effects of SOA were negligible in that experiment. Second, response selection can be ruled out as the source of the interference because no online response was needed for the encoding task. Third, the retention of the material is an unlikely source for the interference because retaining material produces a constant demand on cognitive resources, yet task 2 RTs decrease significantly with increasing SOA. Thus Jolicoeur and Dell'Acqua (1998) concluded that their results are most consistent with the locus of interference at the encoding stage, which they refer to as 'short-term consolidation.'

Note, however, that there is a small but significant effect of SOA on ignore trials in Jolicoeur and Dell'Acqua (1998, Experiment 4) (see Figure 6). To establish that this effect was not the result of participants accidentally encoding the items on a small proportion of ignore trials, Jolicoeur and Dell'Acqua (1998) conducted Experiment 4a in which participants were unexpectedly asked to report the identity of the items on their very last trial, which was always an ignore trial. Participants performed at chance for letter report and only slightly above chance for symbol report[3]. In both cases report was significantly less than in the encode condition. The results imply that accidental encoding on some trials is not a likely source for the interference in the ignore condition of Experiment 4. Jolicoeur and Dell'Acqua (1998) found converging evidence for the conclusion that a process other than accidental encoding on some trials was

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[3] Mean number of letters reported = .58, chance = .48, 95% confidence interval for chance letter report was .14 to 1.02; mean number of symbols reported = 1.38, chance = 1.0, 95% confidence interval for chance symbol report was 1.11 to 1.64. Ten of sixteen participants performed at chance in the symbol report.

responsible for the effect of SOA observed for ignore trials in Experiment 4 in Experiment 7, where blocking encode and ignore trials eliminated the effect of SOA for ignore trials. Jolicoeur and Dell'Acqua (1998) also argue that the interference is not occurring at a perceptual level because the results from a number of pilot experiments show no effect of SOA on ignore trials when the visual stimulus was never encoded. Jolicoeur and Dell'Acqua (1998) suggest that the effect of SOA observed for ignore trials is the result of the decision to encode or ignore a given stimulus, a process they refer to as 'selective control' (SC). Further, based on the results from the PRP literature, Jolicoeur and Dell'Acqua (1998) conclude that the same capacity limited cognitive mechanism required for selective control and short-term consolidation is also required for response selection in speeded tasks. These conclusions are formalized in Jolicoeur and Dell'Acqua's (1998) Central Interference Theory.

Central Interference Theory (Jolicoeur &Dell'Acqua, 1998)

Jolicoeur and Dell'Acqua (1998) propose a model of task interactions termed 'Central Interference Theory', shown in Figure 7, to account for the results from their experiments as well as the existing literature. The component stages for this model are sensory encoding, perceptual encoding, selective control, short-term consolidation, durable storage, response selection, and response execution. Three of these stages, selective control, short-term consolidation, and response selection, are assumed to require the same capacity limited cognitive mechanism which Jolicoeur and Dell'Acqua (1998) refer to as 'central mechanism.' Processing of one of these stages in one task will interfere with processing of any of these stages in any concurrent tasks. Which stages are encountered during the completion of a given task depend on the specific task requirements.

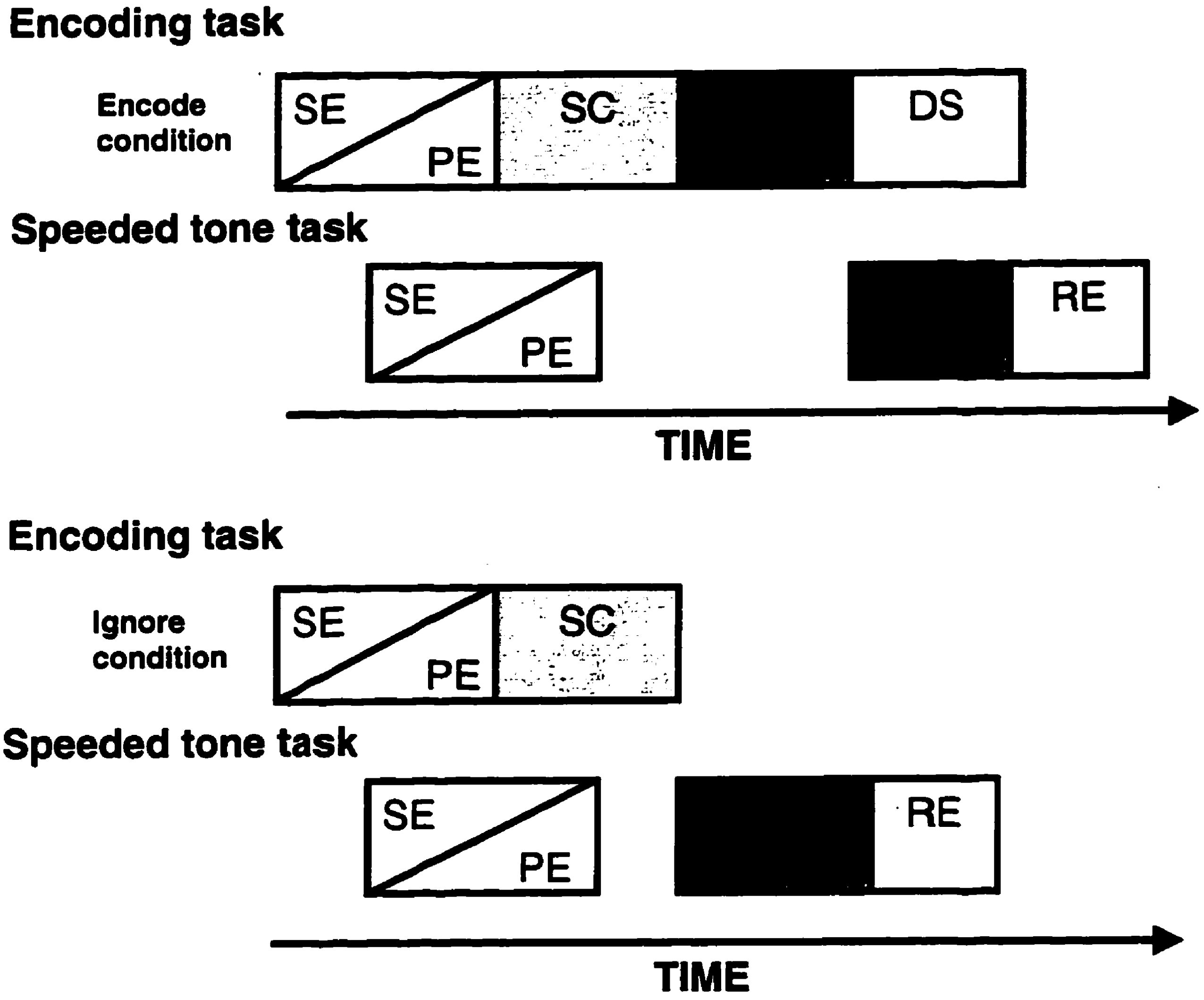

Figure 7. Jolicoeur and Dell'Acqua's (1998) Central Interference Theory applied to the paradigm used in Experiment 4 Panel A illustrates the encode condition, Panel B, the ignore condition. In the visual encoding task (task 1) the stimulus first passes through sensory encoding (SE) and perceptual processing (PE) and then selective control (SC) evaluates the output of PE in order to determine whether the stimulus is to be encoded. If selected, the output of PE is passed on to short-term consolidation (STC), STC then produces a copy of the output of PE in durable storage (DS). SC and STC require a central mechanism which prevents response selection for task 2 while SC and STC are engaged.

Sensory encoding

Sensory encoding (SE) is assumed to be a massively parallel stage that provides the input for subsequent stages of processing. Basic perceptual features including colour, motion, and stereopsis result from SE (e.g. Zeki, 1993; Cavanaugh, 1988; Treisman & Gelade, 1980). Representations at this stage are susceptible to masking but are not susceptible to interference from other sensory modalities.

Perceptual encoding

The output from sensory encoding is subjected to perceptual encoding (PE). Output from this stage includes pattern information, such as letter identities, and likely the activation of associated long-term memories (see Pashler & Carrier, 1996). The output of PE is no longer maskable but will fade rapidly without continued bottom-up support (e.g., Chun & Potter, 1995; Potter, 1976, 1993).

Selective control

Selective control (SC) determines which outputs from PE will be encoded into short-term memory. Perceptual items that are selected by SC will be subjected to short-term consolidation, perceptual items that are not selected will decay quickly. Selective control is one of the three stages assumed to require the central mechanisms. Jolicoeur and Dell'Acqua (1998) argue that it is interference between task 1 selective control and task 2 response selection that produced the effect of SOA observed for ignore trials in Experiment 4, based primarily on their finding of null effects of SOA in Experiment 7, where encode and ignore trials were blocked.

Short-term consolidation

Short-term consolidation (STC) is only engaged when the stimulus must be encoded. Output of PE selected for encoding is subjected to short-term consolidation (STC). Short-term consolidation copies the selected material into durable storage (DS), the short-term memory store (Coltheart, 1982, 1984). Once in DS material must be rehearsed or it will be lost. The results from Jolicoeur and Dell'Acqua (1998) show that STC takes time, that STC takes more time when more items need to be encoded, and that STC requires the same capacity limited cognitive mechanism required for the tone task, the so-called central processor.

Response selection

Response selection is engaged when a speeded response is required. Output from PE is subjected to response selection (RS) whenever a speeded response is required. The duration of RS will depend on the complexity of the contingency between stimulus and response. Response selection is assumed to require central processing mechanisms.

Response execution

Response execution follows response selection when a speeded response is needed. Output from RS is subjected to response execution (RE) where the appropriate motor pathways are recruited and the overt response made.

Figure 7 illustrates the assumed stages of processing for an unspeeded encoding task such as that used for task 1 in Jolicoeur and Dell'Acqua (1998, Experiment 4). The visual stimulus first passes through SE and PE, where simple and complex perceptual features are extracted. Selective control uses the output of PE to determine whether to encode a given stimulus or ignore it (based on category membership). If the stimulus is to be ignored no further cognitive operations are performed on the output of PE and the representation simply decays. If the stimulus is to be encoded, however, the output of PE is copied into DS where is can be maintained until the end of the trial. According to the Central Interference Theory, the completion of selective control and short-term consolidation will both require central mechanisms and will interfere with the processing of any stages of a concurrent task that also require central mechanisms, namely selective control, short-term consolidation, or response selection.

Figure 7 also illustrates the assumed stages of processing for a speeded tone task such as that used for task 2 in Jolicoeur and Dell'Acqua (1998, Experiment 4). Like with unspeeded tasks, the stimulus is first processing through SE and PE. However, when the task is speeded, and the stimulus does not need to be stored in durable storage (DS), processing instead proceeds directly to RS and RE. According to the Central Interference Theory, the completion of response selection will require the central processing mechanism and will interfere with the processing of any stages of a concurrent task that also require central processing.

Jolicoeur and Dell'Acqua (1998) used computer simulations to test whether the pattern in mean RTs observed in Experiments 4, 6, and 7 were consistent with a processing bottleneck account of dual-task interference (see Jolicoeur & Dell'Acqua, 1998, for details). The results of simulations of Experiments 4, 6, and 7 all provide an excellent fit to Jolicoeur and Dell'Acqua's (1998) data, implying that a processing bottleneck account of the interference is consistent with the experimental data.

However the success of Jolicoeur and Dell'Acqua's (1998) simulations do not provide proof that the capacity limited cognitive mechanism involved in encoding constitutes a processing bottleneck, they merely show that a processing bottleneck account is consistent with the existing data. Indeed Jolicoeur and Dell'Acqua (1998) concede that their experiments provide no actual test as to the precise nature of the capacity limited cognitive mechanism involved in encoding. In Experiments 2 through 6 of this thesis the nature of the capacity limited cognitive mechanism involved in encoding is explored in great detail using the locus of cognitive slack logic (Pashler & Johnston, 1989; McCann & Johnston, 1992).

First, however, we test the validity of Jolicoeur and Dell'Acqua's (1998) conclusion that the decision to encode or ignore requires a capacity limited cognitive mechanism. The reasons for this are twofold. First, Jolicoeur and Dell'Acqua (1998) provide no direct evidence for a capacity limitations in the selective control stage, and thus a test of their assumption is desirable. Second, what we may conclude about encoding using the locus of cognitive slack logic will be greatly reduced if selective control and short-term consolidation both require a capacity limited cognitive mechanism also required for a speeded choice tone task. Figure 8 shows that if selective control is capacity limited in some way, then it will be difficult to use the locus of cognitive slack logic effectively, because the pattern in the data could potentially reflect either the nature of the limitation at selective control or the nature of the limitation at short-term consolidation. For example, Figure 8 illustrates how an underadditive interaction between a manipulation of an early stage of task 2 processing and decreasing SOA could reflect a bottleneck at selective control, short-term consolidation, or both. Similarly, additive effects could reflect a bottleneck at selective control, short-term consolidation, or both. The same problem with interpretation does not arise if capacity sharing is the source of the interference, however because the PRP effect has been shown to be the result of a processing bottleneck, and because the encoding paradigm is very similar to the PRP paradigm there is a very real possibility that the capacity limited cognitive mechanism involved in encoding constitutes a processing bottleneck as well. It is therefore critical that we employ experimental controls that will permit an accurate depiction of the locus of a processing bottleneck in the event that evidence for one is found.

Recall that Jolicoeur and Dell'Acqua (1998) came to the conclusion that selective control, the stage at which decisions to encode or ignore specific outputs from perceptual encoding are made, involves a capacity limited cognitive mechanism because of the appearance of effects of SOA on ignore trials in the experiments they conducted in which encode and ignore trials were mixed.

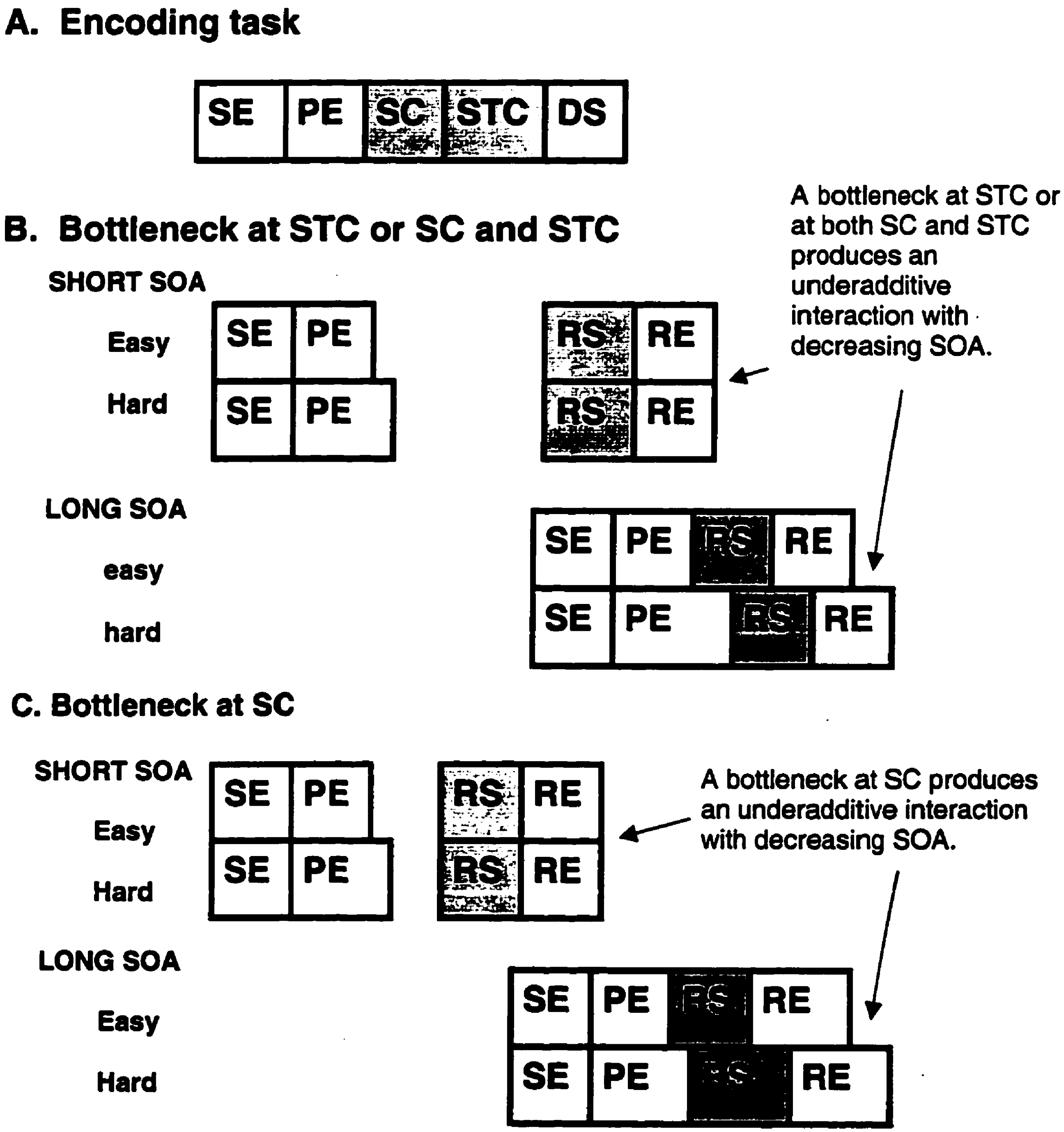

Figure 8. Predicted impact of a processing bottleneck at selective control (SC), short-term consolidation (STC) or both on task 2 response times (RTs). Stages of processing are sensory encoding (SE), perceptual encoding (PE), selective control (SC), short-term consolidation (STC, response selection, (RS) and response execution (RE). Shaded stages are postponed by a processing bottleneck. Panel A shows the putative stages of processing for the encoding task used in Jolicoeur and Dell'Acqua (1998, Experiment 4). Panel B illustrates that an underadditi interaction is predicted if the duration of PE is manipulated if either STC or both STC and SC require central mechanisms. Panel C illustrates that an underadditive interaction is also predicted if only SC requires the central mechanism.

Jolicoeur and Dell'Acqua (1998) argued that the effect of SOA on ignore trials was not the result of occasionally accidentally encoding stimuli on ignore trials. Jolicoeur and Dell'Acqua (1998) concluded that because participants had to decide whether to encode or ignore on both encode and ignore trials, a capacity limited cognitive mechanism may be involved at the decision, or selective control, stage. However it is also plausible that having to switch between two sets of task protocols may have produced the effect of SOA observed for ignore trials, as a number of researchers have found evidence for interference due to task switching (e.g. Rogers & Monsell, 1995). Experiment 1 examined Jolicoeur and Dell'Acqua's (1998) claim that a capacity limited cognitive mechanism is involved in selective control by comparing the extent of interference on trials where online selection was required to performance on trials where no online selection was required. A brief overview of all of the present experiments is shown in Appendix B.

Experiment 1

In Experiment 1 Jolicoeur and Dell'Acqua's (1998) hypothesis that selective control requires a capacity limited cognitive mechanism is tested. The basic paradigm, shown in Figure 9, is the same as that used by Jolicoeur and Dell'Acqua (1998), however whether or not selective control was required was manipulated across blocks.

In 'Selection' blocks participants must make an online decision to encode or ignore one, two, or three briefly presented and masked red or green random consonants based on their colour while simultaneously performing a speeded choice tone task. After responding to the tone, participants typed the letters they saw if it was an encode trial or simply press the space bar if it was an ignore trial. In 'Control' blocks participants were informed ahead of time, by the presentation of either a solid or dashed fixation box before each trial, whether to encode or ignore the red or green random consonants while performing the same speeded tone task as in 'Selection' blocks. If the fixation box was solid participants encoded the letters and reported them at the end of the trial, if the fixation box was dashed participants ignored the letters and pressed the space bar after making their tone response. In 'Selection' blocks selective control must have occurred during the trial whereas in 'Control' blocks the decision was made before the onset of the letters. If the decision to encode or ignore requires a capacity limited cognitive resource also required for the tone task, as proposed by Jolicoeur and Dell'Acqua (1998), then tone response times should be different in 'Selection' blocks, where an online decision was made, and 'Control' blocks, where it was not. If, on the other hand, selective control does not required a capacity limited cognitive mechanism also required for the tone task then tone response times should instead be similar in 'Selection' and 'Control' blocks. The purpose of this experiment was to assess the capacity demands of online selective control.

Method

An illustration of the paradigm used in Experiment 1 is shown in Figure 9.

Participants

Sixteen University of Waterloo students were paid $6.00 for their participation in this experiment. All participants reported normal hearing and normal or corrected-to-normal vision.

Apparatus

Visual stimuli were presented on a black background on a SVGA colour computer screen controlled by a 386 or 486 CPU. Tones were presented through the computer speaker. A standard computer keyboard was used to collect responses.

Visual Stimuli

The visual stimuli consisted of one, two, or three consonants (excluding Y and Z) randomly selected without replacement on every trial, such that a letter was not repeated within a given trial. On half the trials the letters were red and on the other half of the trials the letters were green. Red letters had a luminance of 8.8 cd/m^2 and green letters had a luminance of 9.5 cd/m^2.

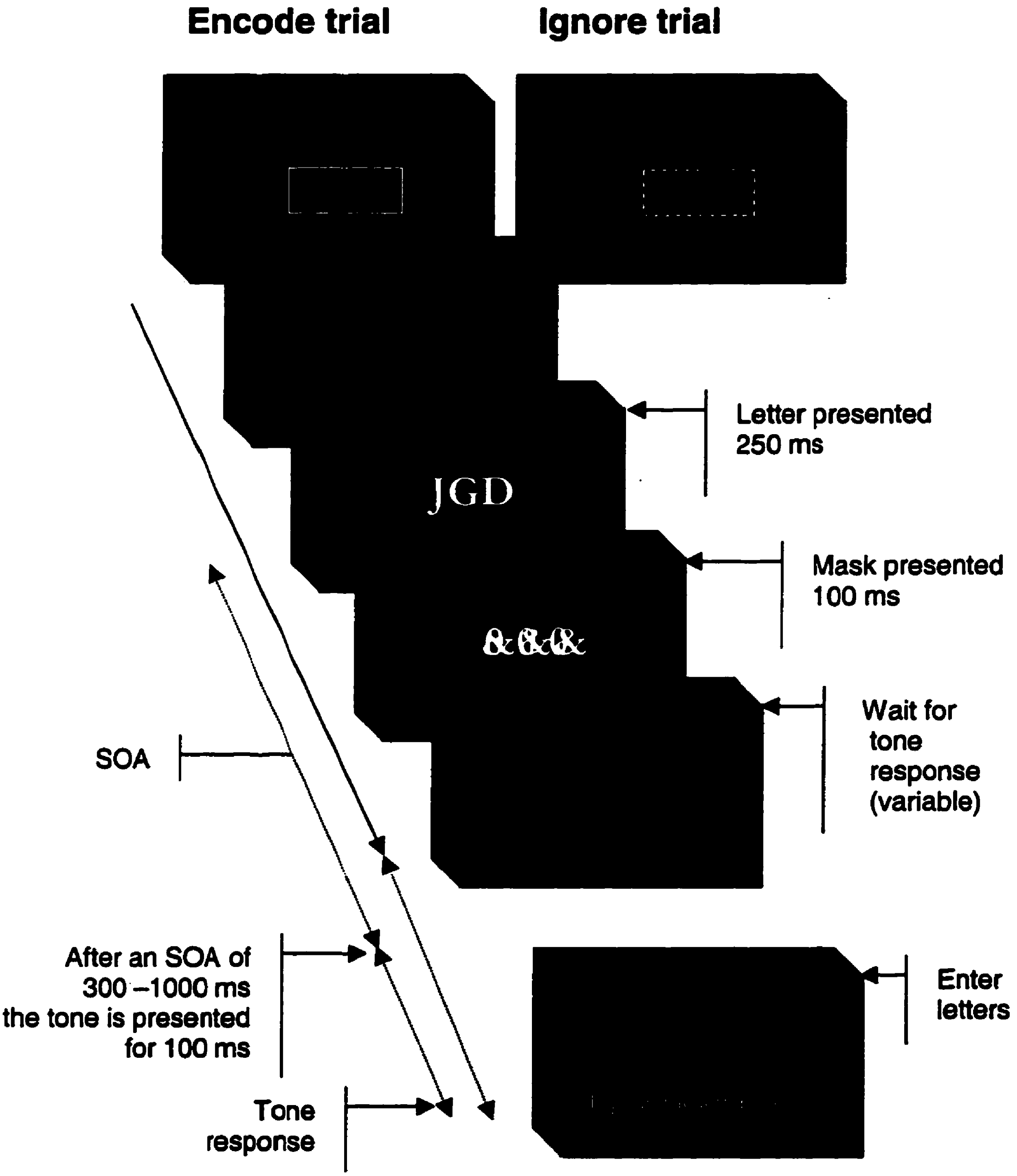

Figure 9. The paradigm used in Control blocks of Experiment 1 One, two, or three red or green letters are presented and masked. Participants encode the letter(s) that follow a solid-line fixation box and ignore the letter(s, that follow a dashed fixation box for report at the end of the trial. In Selection blocks (not shown) trials are identical except the fixation box is always solid and participants encode or ignore the letters based on their colour (red or green). Participants make a speeded response to the pitch of the tone and then report the letters (or press th space bar on ignore trials)

The mask consisted of '0's superimposed onto '$'s and was presented in the same colour as the stimulus. Each letter subtended 0.66 degrees of visual angle in width and 1.00 degrees of visual angle in height. The letters on each trial were centred at fixation. The fixation box extended 0.53 degrees of visual angle to the left and right of the letters and 0.50 degrees of visual angle beyond the top and bottom of the letters.

Auditory stimuli

The auditory stimuli consisted of a 400 Hz tone ('low' tone) and a 1200 Hz tone ('high' tone) presented through the computer speaker. There were an equal number of trials for each tone condition.

Procedure

Participants were seated approximately 60 cm from the computer monitor in a dark room with a computer keyboard situated in front of them.

There were two block types in this experiment. In 'Control' blocks participants encoded or ignored the letters based on the style of the fixation box. Participants were instructed to encode the letters that followed a fixation box composed of solid lines and ignore the letters that followed a dashed fixation box. In 'Selection' blocks participants encoded or ignored the letter(s) depending on their colour. Half of the participants were instructed to encode the red letters and ignore the green ones ('red' group), and the other half of the participants were instructed to encode the green letters and ignore the red one ('green' group). Fixation boxes in 'Selection' blocks were always composed of solid lines.

Each trial began with the presentation of a fixation box in the centre of the screen. Participants initiated each trial by pressing the space bar which caused the fixation box to disappear. After a 400 ms delay the visual stimulus was presented for 250 ms and then masked for 100 ms. The tone was presented at a stimulus onset asynchrony (SOA) of 300, 400, 500, 600, entered into a 5 (SOA) x 2 (tone localization difficulty) repeated measures ANOVA. The main effect of tone localization difficulty was significant, $F(1,13) = 5.2$, $p < .05$, $MSE = 0.00137$. Tone responses were more accurate in the easy tone localization condition than in the hard tone localization condition.

Discussion

The results from Experiment 5 replicate those from Experiment 3. The effect of tone localization difficulty was additive with SOA and there was no effect of SOA on task 1 accuracy, which provides converging evidence for the claim that the capacity limited cognitive mechanism involved in encoding takes the form of a processing bottleneck. What's more, the finding that a second perceptual difficulty manipulation produced additive effects with SOA undermines Jolicoeur and Dell'Acqua's (1998) claim that only short-term consolidation is subject to a processing bottleneck in the encoding paradigm, because the additive effects imply that some perceptual processing is also being postponed by the bottleneck.

Experiment 6

The main evidence that a perceptual factor is affecting the bottleneck stage comes from the additive effects observed in Experiments 3 and 5. One possibility, however, is that we observed additivity in these experiments because the SOAs used were not sufficiently short. In Experiments 3 and 5 we made the shortest SOA 200 ms to avoid any interference that may result from the abrupt onset of the tone when the letters were still visible. However, in our PRP paradigm experiments, most of the convergence in the underadditive interactions between task 2 difficulty manipulations and decreasing SOA occurs within the first 150 ms; if the two shortest SOAs were removed the pattern in the results from Experiments 2 and 4 would appear additive (see Figures 12 and 16). Thus we may observe additive effects in the encoding paradigm simply because we were not probing early enough during the encoding process. In Experiment 6 we

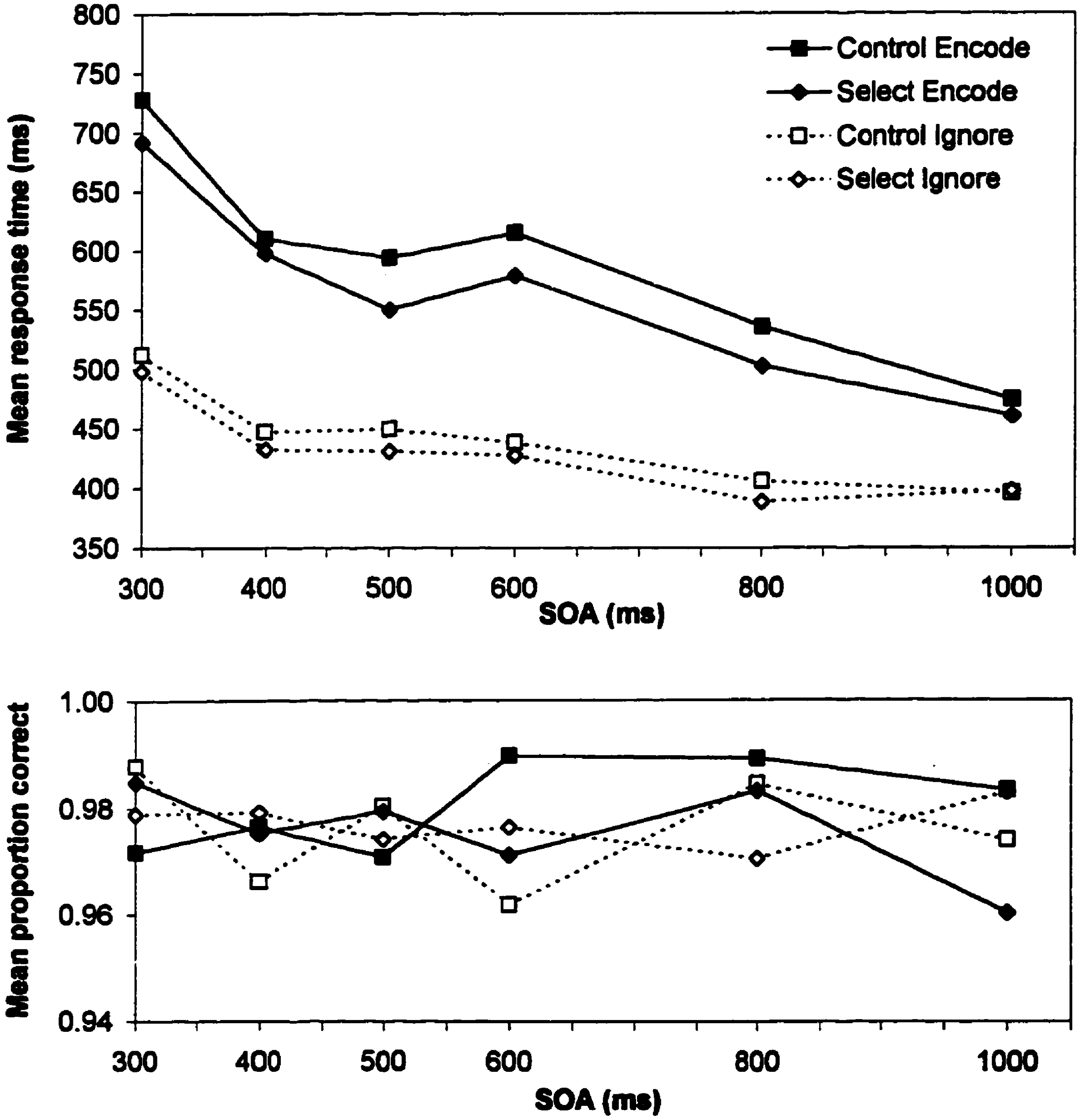

Figure 10. Mean resonse times (top panel) and proportions correct (bottom panel) as a function of block type, encode/ignore, and stimulus onset asynchrony (SOA) for the tone task in Experiment 1.

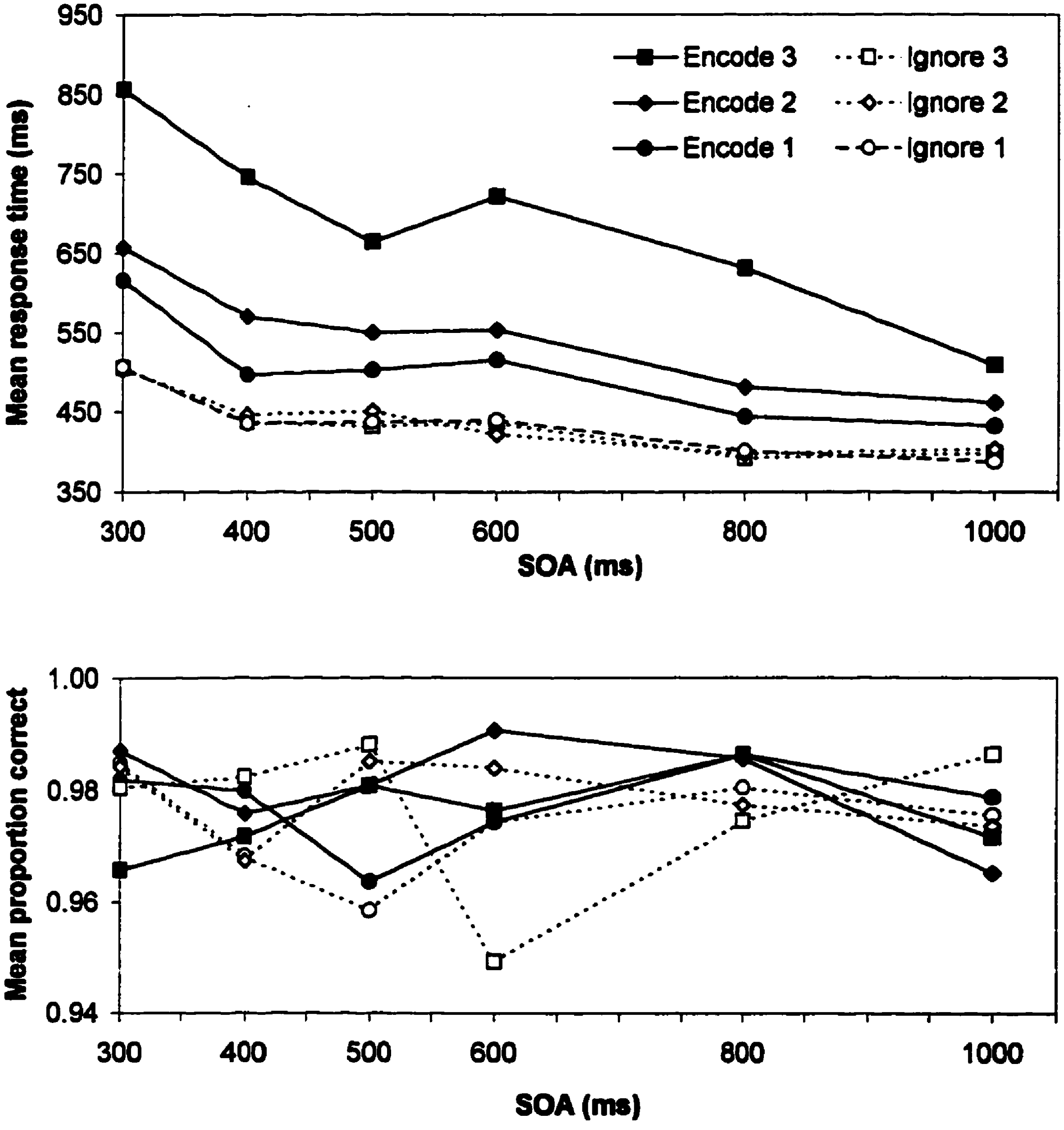

Figure 11. Mean resonse times (top panel) and proportions correct f(bottom panel) as a function of encocde/ignore, number of letters, and stimulus onset asynchrony (SOA) for the tone task in Experiment 1.

lower boundaries. These boundaries are established based on the number of observations in a cell, the adjusted cell mean, and cell variance. This analysis removed 2.89 % of the data.

Mean RTs and corresponding proportions of correct tone responses are shown in Table 1. Mean tone RTs were entered into a 2 (control/select) x 2 (encode/ignore) x 3 (number of letters) x 6 (SOA) repeated measures analysis of variance (ANOVA). The main effect of block type was significant, F(1,15) = 5.46, p < .05, MSE = 13965.10, tone responses were 10 ms slower on Control trials than on Selection trials, however block type did not interact with any other factor (see Figure 10). There was a significant 3-way interaction between SOA, encode/ignore, and number of letters, F(2,30) = 2.80, p < .0001, MSE = 5458.72 which is shown in Figure 11. Increasing the number of letters increased the effect of SOA for encode trials but not for ignore trials. The 2-way interaction between encode/ignore and number of letters was significant, F(2,30) = 23.9, p < .0001, MSE = 38935.22. Mean tone RT increased with the number of letters for encode trials but not for ignore trials. There was a significant 2-way interaction between SOA and number of letters, F(10,150) = 4.86, p < .0001, MSE = 3759.37. The effect of SOA on tone RT was greater when more letters were presented. There was also a significant 2-way interaction between SOA and encode/ignore, F(5,75) = 10.94, p < .0001, MSE = 6507.11. The effect of SOA was greater for encode trials than for ignore trials. Tone responses were slower at shorter SOAs than at longer ones (F(5,75) = 30.56, p < .0001, MSE = 12518.63), slower on encode trials than on ignore trials (F(1,15) = 29.85, p < .0001, MSE = 196896.93) and slower when more letters were presented (F(2,30) = 19.64, p <.0001, MSE = 45563.35).

Accuracy Results

All experimental trials were included in the accuracy analyses.

Letter task

Mean proportions of correctly reported letters across conditions are shown in Table 2. The mean proportion of letters correctly identified were entered into a 2 (control/select) x 3 (number of letters) x 6 (SOA) repeated measures ANOVA. This analysis revealed a significant 2-way interaction between block type and number of letters, $F(2,30) = 5.02$, $p < .05$, $MSE = 344.21$. For Control blocks the mean proportion of letters correctly reported increased as the number of letters increased, while in Selection blocks the mean proportion of letters correctly reported decreased as the number of letters increased.

Tone task

Mean proportion of correct tone responses are shown in Table 1. The mean proportion of correct tone responses were entered into a 2 (control/select) x 2 (encode/ignore) x 3 (number of letters) x 6 (SOA) repeated measures ANOVA. There was a significant 4-way interaction between block type, SOA, encode/ignore and number of letters, $F(10,150) = 2.19$, $p < .05$, $MSE = 0.00253$. There was also a significant 3-way interaction between block type, SOA, and encode/ignore, $F(5,75) = 2.35$, $p < .05$, $MSE = 0.002943$.

Discussion

The results of Experiment 1 replicate Jolicoeur and Dell'Acqua (1998, Experiment 4). There is a significant three-way interaction in task 2 RTs in which the effect of SOA increases significantly with the number of letters on encode trials but not on ignore trials. Most importantly, however, tone responses on Selec trials are not significantly slower than tone responses on Control trials (see Figure 10). In fact, task 2 RTs are slightly slower in Control blocks, where no online decision was needed, as compared to Selection blocks where participants decided to encode or ignore based on the colour of the letters. When taken together these results imply that selective control does not require a capacity limited cognitive mechanism, and that it is some aspect of processing that follows the decision to encode or ignore in the encoding task (in other words some aspect of encoding) that is producing the interference. This conclusion is inconsistent with Jolicoeur and Dell'Acqua's (1998) claim that selecting material for encoding requires a capacity limited cognitive mechanism, and suggests that their Central Interference Theory should be modified to exclude selective control as requiring the central mechanism. In addition, there was a significant effect of SOA on ignore trials in Control blocks, implying that the effect of SOA on ignore trials observed in Jolicoeur and Dell'Acqua (1998, Experiment 4) was not the result of the online decision to encode or ignore requiring the same capacity limited cognitive mechanism required for the tone task.

Experiment 2

The nature of the capacity limited cognitive mechanism involved in encoding

In Experiment 2 and the next several experiments the locus of cognitive slack logic was applied to a combination of PRP paradigm and encoding paradigm experiments to determine the source of the interference observed during the encoding task. According to the locus of cognitive slack logic, the most diagnostic finding is a task 2 difficulty manipulation that results an underadditive interaction with decreasing SOA, which can only be produced when the task 2 difficulty manipulation affects the duration of a stage of processing that precedes a bottleneck (see Introduction). It is thus desirable to use a task 2 difficulty manipulation that affects an early stage of processing because such a manipulation is most likely to produce an underadditive interaction with decreasing SOA if the capacity limited cognitive mechanism producing the interference constitutes a processing bottleneck. One way to establish that the manipulation affects an early stage is to first employ it in a PRP paradigm experiment. A myriad of PRP paradigm experiments have revealed a processing bottleneck that affects a stage at or around response selection. Thus if a task 2 difficulty manipulation produces an underadditive interaction with decreasing SOA in a PRP paradigm experiment it may be concluded that the manipulation affects a relatively early stage before the onset of response selection (see Introduction). In Experiment 2 a task 2 tone loudness manipulation was employed in a PRP paradigm experiment.. A perceptual difficulty manipulation (loudness) was chosen for task 2 because, according to CIT, perceptual processing is complete before the locus of the capacity limited cognitive mechanism at STC in the encoding paradigm. Loudness was chosen as the perceptual difficulty manipulation because PRP paradigm experiments in which the contrast of the second stimulus is manipulated typically result in underadditive interactions with decreasing SOA (e.g., De Jong, 1993; Pashler, 1984; Pashler & Johnston, 1989).

In Experiment 2 participants were presented with an H, O, or S at fixation followed, at an SOA of 50, 111, 245, 542, or 1200 ms by a high or low pitched tone presented through headphones. On half the trials the loudness of the tone was reduced to slightly above threshold. Participants made a speeded response to the identity of the letter followed by a speeded response to the pitch of the tone. If the loudness manipulation produces an underadditive interaction with decreasing SOA we may conclude that both tasks require the same capacity limited cognitive mechanism that constitutes a processing bottleneck at a stage after the locus of the loudness manipulation. Such a finding would be particularly diagnostic because underadditivity with decreasing SOA cannot be reconciled with a capacity sharing account of dual-task interference. If the loudness manipulation produces an overadditive interaction with decreasing SOA we may account for the interference using a capacity sharing model. If the loudness manipulation instead produces additive effects with SOA we will use the pattern in task 1 RT across SOAs to determine whether a processing bottleneck account or a capacity sharing account is most appropriate. If no effect of SOA is observed on task 1 RTs, we may conclude the additive effects were the result of a processing bottleneck at or before the locus of the tone difficulty manipulation. If task 1 RTs are instead significantly longer at short SOAs, and postponed to a degree comparable to task 2 RTs, we will instead conclude that the observed interference is the result of capacity sharing.

Method

Participants

Eight University of Waterloo students were paid $6.00 for their participation in this experiment. All participants reported normal hearing and normal or corrected-to-normal vision.

Apparatus

The apparatus used in Experiment 2 was identical to that of Experiment 1 except that tones were presented to participants through a standard pair of stereo headphones

Visual Stimuli

The visual stimuli consisted of the letters H, O, or S presented individually at fixation. The letters were always gray with a luminance of 21 cd/m^2 and each subtended 0.76 by 0.86 degrees of visual angle.

Auditory stimuli

The auditory stimuli consisted of a 400 Hz tone ('low' tone) and a 1200 Hz tone ('high' tone) presented through headphones. There were two loudness conditions. In the 'loud' condition the tones were clearly audible. In the 'quiet' condition the loudness was calibrated for each individual participant prior to the beginning of the experiment.

Procedure

Participants were seated approximately 60 cm from the computer monitor in a dark room with a computer keyboard situated in front of them. Subjects were given headphones and adjusted them until they were comfortable. Participants were presented with high and low pitched tones at the normal loudness until they were familiar with them. Participants then began the loudness calibration phase.

Loudness calibration

Participants were told that the goal of the calibration was to reduce the loudness of the tone to the quietest possible level where the participant could still accurately identify the pitch. Participants pressed the space bar to hear a sample tone. After hearing the tone they could choose to make it louder, quieter, to hear it again, or to accept it. To accept the tone they simply pressed the space bar. If they chose to make the tone louder, the control value used to control loudness in MEL was increased by 2% relative to the loudness control value of the tone used in the 'loud' condition, if they chose to make it quieter the loudness control value was reduced by 2%, relative to the loudness of the tone used in the 'loud' condition, and if they chose to hear it again the loudness was not altered. A tone was then presented at the chosen loudness level. This procedure was repeated until the participant determined the minimum loudness level where they could still discriminate between the high and low pitched tones. After selecting that loudness the participant was presented with detailed instructions concerning how each trial would progress.

Each trial began with a fixation marker in the centre of the computer screen. Participants pressed the space bar to initiate the trial. The fixation marker disappeared and following a 400 ms delay an H, O, or an S, was presented in the centre of the screen. Participants were instructed to indicate the identity of the letter as quickly and accurately as possible by pressing the '<,' key with the index finger of their right hand if the letter was an H, the '>.' key with the middle finger of their right hand if the letter was an O, or the '?/' key with the third finger on their right hand if the letter was an S. The letter remained on the screen until a valid response was made. The tone was presented to both ears through the headphones at an SOA of 50, 111, 245, 542, or 1200 ms from the onset of the letter. Each of the five SOAs, three letters, two tone difficulty conditions, and two tone pitches were utilized an equal number of times. Participants were instructed to indicate the pitch of the tone as quickly and accurately as possible by pressing the 'A' key for the high tone and the 'Z' key for the low tone. Participants had to enter a response to the letter before they could enter a response to the tone. After a valid response was given for both letter and the tone, the fixation marker for the next trial was presented. The marker consisted of two variable symbols which reflected letter and tone accuracy on the previous trial. The symbol on the left described letter accuracy with a '+' or '-' and the symbol on the right described tone accuracy with a '+' or '-'. Participants completed one block of thirty practice trials and eight blocks of sixty experimental trials.

Results

Preliminary analyses revealed no effect of tone pitch on mean RT, letter accuracy, or tone accuracy. Data were collapsed across these variables in the following analyses.

RT Results

Only trials in which both responses were correct were included in the RT analyses. Correct letter RT data and correct tone RT data and letter RT data were subjected, sequentially, to the modified recursive outlier analysis suggested by Van Selst and Jolicoeur (1994) (see Experiment 1). This analysis removed 2.65 % of the data based on tone responses, and a further 3.052 % of the remaining data was removed based on letter responses. When an RT, in either task, was rejected as an outlier, the entire trial was rejected (i.e., both RTs were rejected).

Tone task

Mean RTs to the tone and the corresponding proportions of correct tone responses are shown in Figure 12 and Table 3. Mean RTs to the tone were entered into a 2 (tone difficulty) x 5 (SOA) repeated measures ANOVA. There was a significant 2-way interaction between tone difficulty and SOA, $\underline{F}(2,5) = 8.04$, $\underline{p} < .0001$, $\underline{MSE} = 1057.63$ which is plotted in Figure 12. This

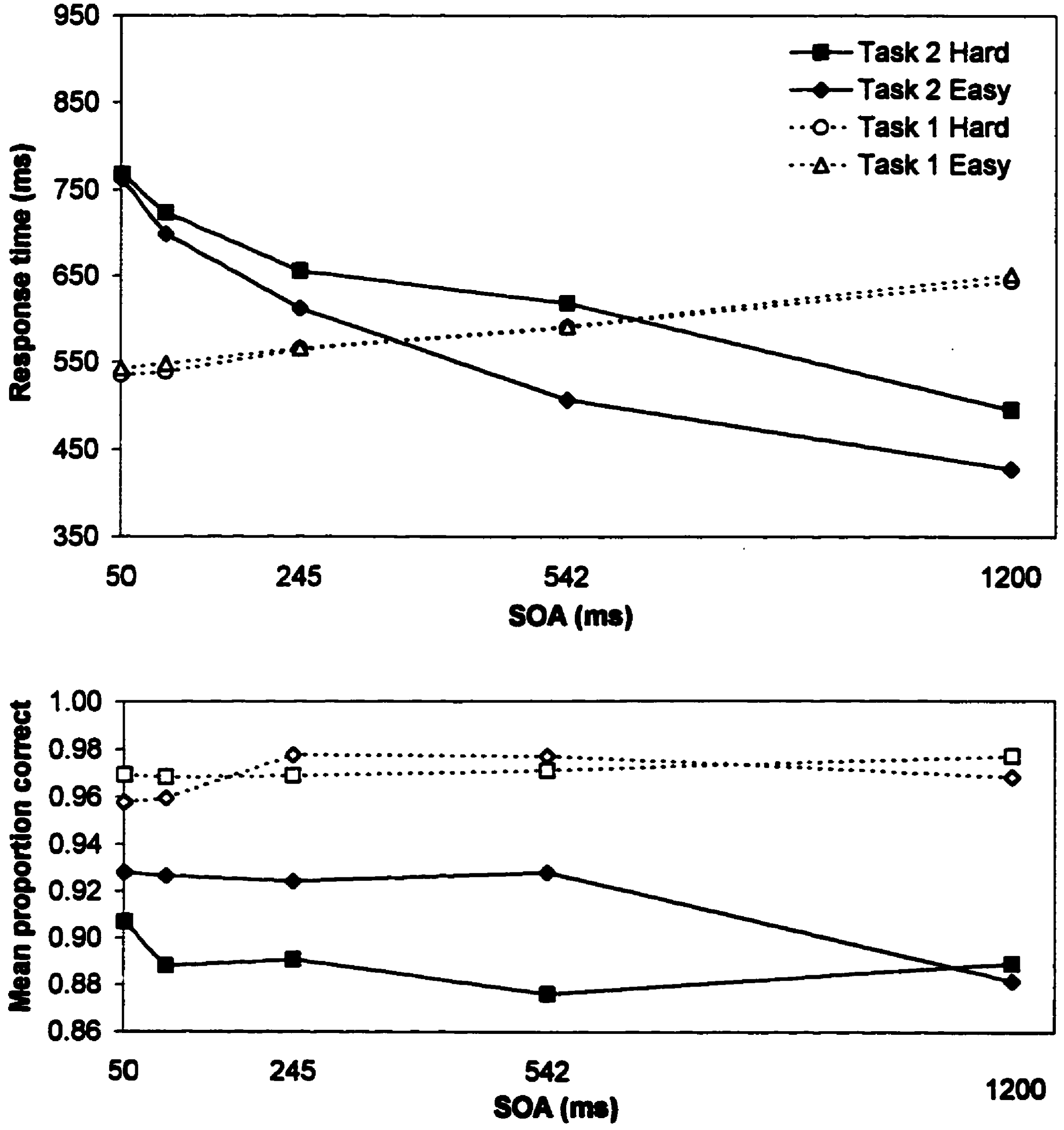

Figure 12. Mean resonse times (upper panel) and proportions correct (lower panel) as a function of tone task difficulty and stimulus onset asynchrony (SOA) or the letter task (task 1) and the tone task (task 2) in Experiment 2.

interaction is clearly underadditive with decreasing SOA; the difference in tone RTs for the easy and the hard tone conditions increases from only 6 ms at the shortest SOA to 46 ms at an SOA of 1200 ms. Tone responses were slower in the hard tone difficulty condition than in the easy tone difficulty condition (F(1,10) = 57.16, p < .0001, MSE = 1081.01), slower at shorter SOAs (F(4,10) = 79.76, p < .0001, MSE = 3947.88).

Letter task

Mean RTs to the identity of the letter and the corresponding proportions of correct letter responses are shown in Figure 12 and Table 4. Mean RTs to the letter were entered a 2 (tone difficulty) x 5 (SOA) repeated measures ANOVA. There were no effects of the experimental manipuiation on RTs to the letter.

Accuracy Results

Tone task

Mean proportion of correct tone responses are shown in Figure 12 and Table 3. Mean proportion of correct tone responses were entered into a 5 (SOA) x 2 (tone difficulty) repeated measures ANOVA. The analysis revealed no effect of the experimental manipulations on tone task accuracy.

Letter task

Mean proportions of correct letter responses are shown in Table 4. Mean proportion of correct letter responses were entered into a 5 (SOA) x 2 (tone loudness) repeated measures ANOVA. The analysis revealed no effect of the experimental manipulations on letter task accuracy.

Discussion

The results from Experiment 2 reveal a highly significant underadditive interaction between the task 2 tone difficulty manipulation and decreasing SOA, indicating that the tone difficulty manipulation affected a stage before a processing bottleneck (see Figure 12). Thus in future experiments we can be certain not only that this tone task requires a capacity limited cognitive mechanism, but also that this capacity limited cognitive mechanism affects a stage after the locus of the tone difficulty manipulation in the PRP paradigm.

The purpose of Experiment 2 was simply to confirm both that our tone task required a capacity limited cognitive mechanism, and that the difficulty manipulation was affecting an early stage of processing. We can now use the same tone task in an encoding paradigm experiment to determine if the process of encoding is subject to constraint from a similar capacity limited cognitive mechanism.

Experiment 3

In Experiment 3 participants were presented with one or three red or green letters which they encoded or ignored based on their colour, followed, at varying SOAs, by a loud or quiet high or low pitched tone. Participants made a speeded response to the tone and then entered the letters if it was an encode trial or press the space bar if it was an ignore trial.

If the tone difficulty manipulation produces an underadditive interaction with decreasing SOA we may conclude that encoding requires a capacity limited cognitive mechanism that produces a processing bottleneck sometime after the locus of the tone difficulty manipulation. If the tone difficulty manipulation produces an overadditive interaction with decreasing SOA we may instead conclude that the capacity limited cognitive mechanism involved in encoding slows, but does not halt, processing of all stages of both tasks that require the capacity limited cognitive mechanism. If the effects of SOA and the tone difficulty manipulation are additive, the appropriate conclusion would be less clear. While an overriding assumption of capacity sharing models is that RTs will be slowest when task overlap is greatest (which predicts an overadditive interaction with decreasing SOA), capacity sharing models are also consistent with additive effects under some conditions (see Figure 3). Recall that in the PRP paradigm we are able to distinguish between additive effects resulting from a processing bottleneck and additive effects resulting from capacity sharing by examining the effects of SOA on task 1 RTs; a significant effect of SOA on task 1 RTs is predicted by the capacity sharing account but inconsistent with the processing bottleneck account. In the present encoding paradigm, however, task 1 is not speeded, and therefore task 1 RTs may not be used to discriminate between the models if additive effects are found. However, the pattern in task 1 accuracy may serve to distinguish between the two models in the encoding paradigm. The logic behind this assertion is shown in Figure 13. Suppose that capacity sharing is responsible for the interference between the encoding task and the tone task. The capacity sharing model that would have to be adopted to account for additive effects is shown in Panel B of Figure 13. At short SOAs, when task 1 and task 2 must share the capacity limited resource, less processing of each task can be completed during a given period of time than at long SOAs when each task has exclusive access to the resource. Thus when a stimulus is presented briefly and masked, such as the task 1 stimulus in the encoding paradigm, less processing of the stimulus will be possible at short SOAs, and thus more errors in stimulus report are predicted. Capacity sharing models therefore predict more errors in task 1 report at short SOAs than at long SOAs in the encoding paradigm. Processing bottleneck models, on the other hand, predict no impact of SOA on task 1 processing in the encoding paradigm. Thus if additive effects are observed in the present encoding paradigm, the pattern of task 1 accuracy may be used to determine whether a processing bottleneck or capacity sharing account of the interference is most appropriate.

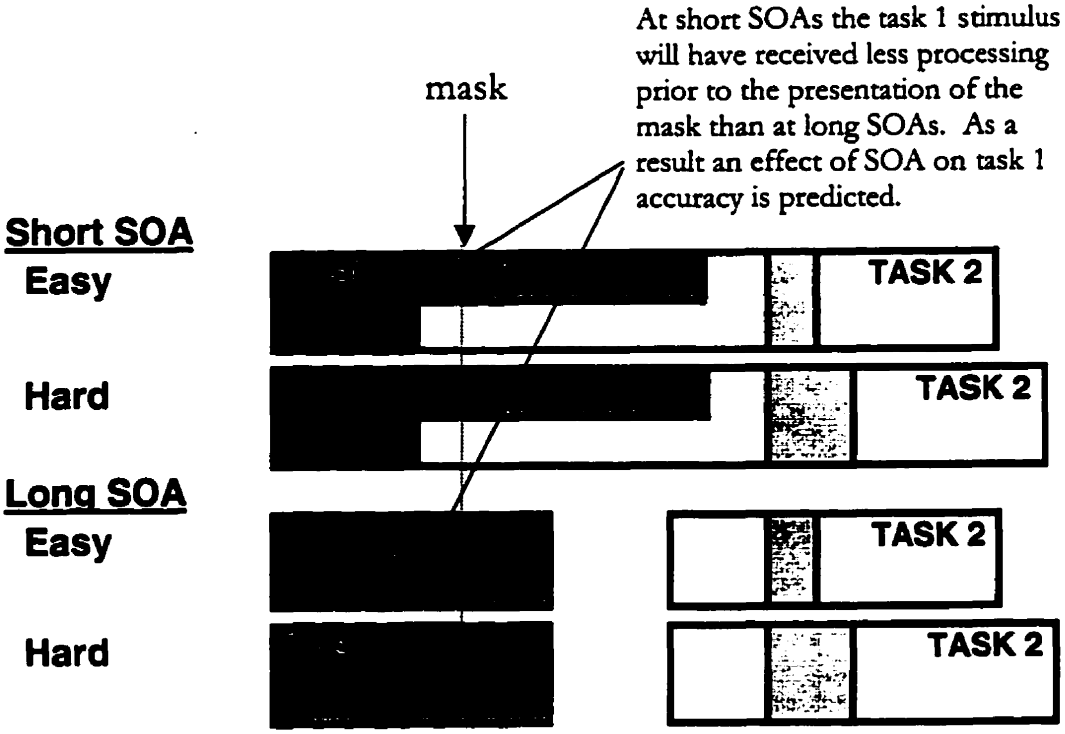

Figure 13. A capacity sharing model adapted to account for additive effects of a task 2 difficulty manipulation in an encoding paradigm experiment. At short SOAs task 1 encoding is interrupted by the onset of task 2, reducing the capacity allotted to task 1 encoding. Because the letters are presented briefly and masked the reduction in capacity allotted to task 1 during encoding results in more errors in letter report..

Method

Participants

Sixteen University of Waterloo students were paid $6.00 for their participation in this experiment. All participants reported normal hearing and normal or corrected-to-normal vision.

Visual Stimuli

The apparatus was identical to that used in Experiment 2. The visual stimuli consisted of 1 or 3 consonants (excluding Y and Z) randomly selected without replacement on every trial. There were an equal number of 1 and 3 letter trials. On half the trials the letters were red while on the other half they were green. Red letters had a luminance of 8.8 cd/m^2 while green letters had a luminance of 9.5 cd/m^2. The mask consisted of '0's superimposed onto '&'s and was presented in the same colour as the stimulus. Each letter subtended 0.76 degrees of visual angle in width and 0.86 degrees of visual angle in height. The visual stimuli was centred at fixation.

Auditory stimuli

The auditory stimuli were identical to those used in Experiments 2. Participants completed a calibration procedure identical to that used in Experiment 2 to determine the appropriate tone intensity for the 'quiet' condition.

Procedure

Half the participants (N =8) were instructed to encode red letter(s) and ignore green letter(s) while the other half of the participants (N = 8) were instructed to encode green letter(s) and ignore red letter(s). The experimental procedure was the same as in 'Selection' blocks in Experiment 1, with the exception of the SOAs which were either 200, 261, 395, 692, or 1350 ms in Experiment 3. Participants completed one block of thirty practice trials and six blocks of eighty experimental trials.

Results

Preliminary analyses revealed no effect of whether subjects were in the 'red' or the 'green' group or tone pitch on mean RT, letter accuracy, or tone accuracy. Data were collapsed across these variables in the following analyses.

RT Results

Only trials on which both responses were correct were included in the RT analyses. Correct tone RT data were first subjected to the modified recursive outlier analysis suggested by Van Selst and Jolicoeur (1994). This analysis removed 3.56 % of the data.

Mean RTs and corresponding proportions of correct tone responses are shown in Table 5. Mean tone RTs were entered into a 2 (encode/ignore) x 2 (number of letters) x 5 (SOA) x 2 (tone difficulty) repeated measures ANOVA. There was a significant 3-way interaction between SOA, encode/ignore, and number of letters, $\underline{F}(4,84) = 7.15$, $\underline{p} < .0001$, $\underline{MSE} = 13331.89$ which is shown in Figure 14. Increasing the number of letters increased the effect of SOA for encode trials but not for ignore trials. There was a significant 2-way interaction between encode/ignore and tone difficulty, $\underline{F}(1,21) = 9.78$, $\underline{p} < .01$, $\underline{MSE} = 8281.26$ which is shown in Figure 15. Increasing the tone difficulty had a larger effect on tone RTs on encode trials than on ignore trials. There was a significant 2-way interaction between SOA and encode/ignore, $\underline{F}(4,84) = 9.16$, $\underline{p} < .0001$, $\underline{MSE} = 15379.39$. The effect of SOA was greater for encode trials than for ignore trials. The 2-way interaction between encode/ignore and number of letters was significant, $\underline{F}(1,21) = 36.42$, $\underline{p} < .0001$, $\underline{MSE} = 64742.69$. Mean tone RT increased with the number of letters for encode trials but not for ignore trials. Finally, there was a significant 2-way interaction between SOA and number of letters, $\underline{F}(4,84) = 9.63$, $\underline{p} < .0001$, $\underline{MSE} = 20767.09$. Increasing the number of letters increased the effect of SOA on tone RT. Tone RTs were longer at shorter SOAs ($\underline{F}(4,84) = 48.83$, $\underline{p} < .0001$, $\underline{MSE} = 32195.37$), longer in the three letter

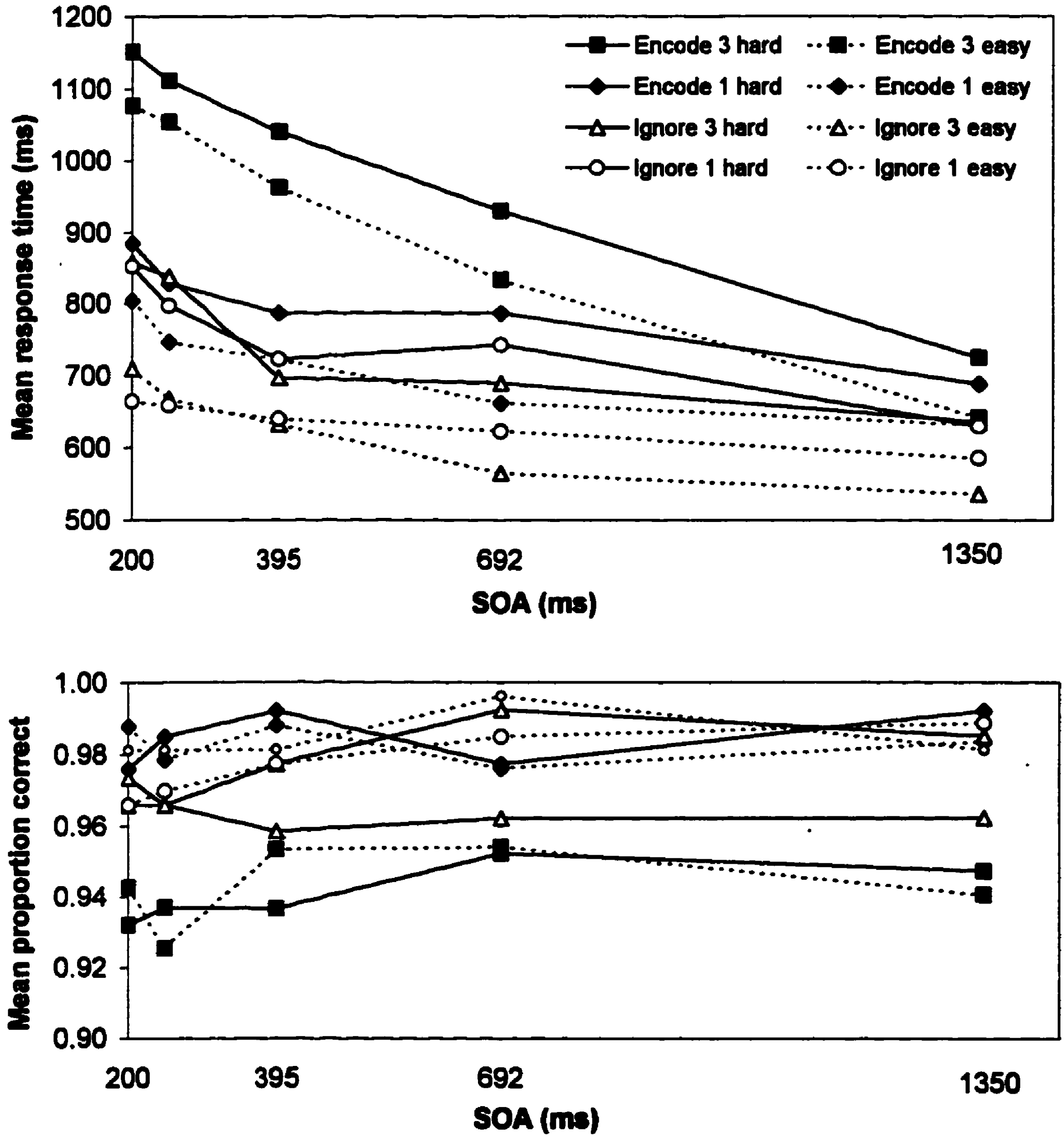

Figure 14. Mean resonse times (top panel) and proportions correct as a function of encode/ignore, number of letters, tone task difficulty, and stimulus onset asynchrony (SOA) for the tone task in Experiment 3.

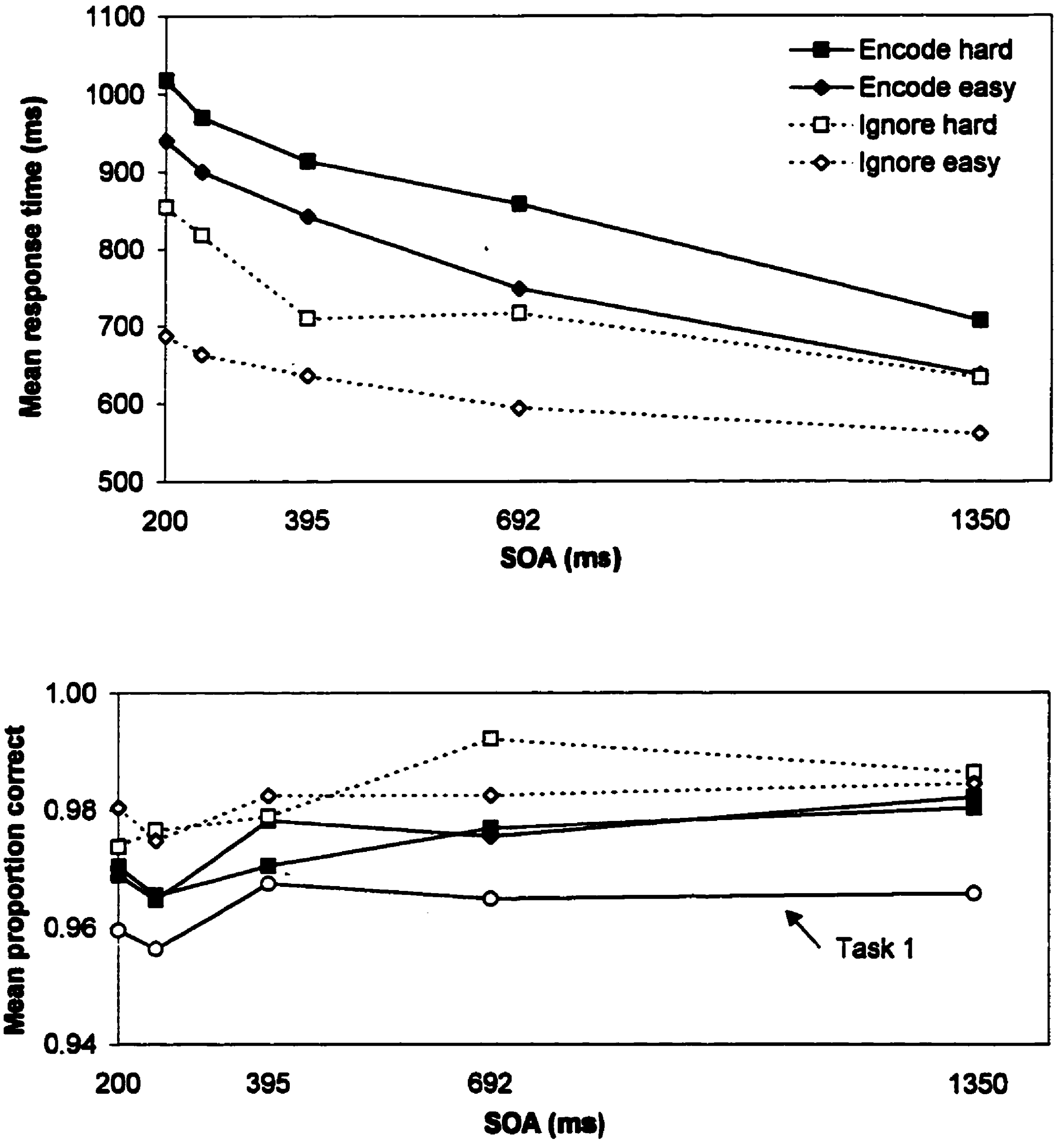

Figure 15. Mean resonse times (top panel) and proportions correct (bottom panel) as a function of encode/ignore, tone task difficulty, and stimulus onset asynchrony (SOA) for the tone task in Experiment 3. Task 1 accuracy is plotted in the bottom panel.

condition than in the one letter condition (F(1,21) = 32.08, p < .0001, MSE = 61549.68), longer in the encode condition than in the ignore condition (F(1,21) = 48.22, p < .0001, MSE = 125747.47), and longer in the hard tone difficulty condition than in the easy tone difficulty condition (F(1,21) = 10.16, p < .01, MSE = 211028.81).

In order to apply the locus of cognitive slack logic we also conducted separate ANOVAs on the encode and ignore trial data. The nature of the capacity limited cognitive mechanism involved on encode trials is of primary interest.

Encode trials

We entered the encode data into a 5 (SOA) x 2 (number of letters) x 2 (tone difficulty) repeated measures ANOVA. The 2-way interaction between SOA and number of letters was significant, F(4,84) = 12.49, p < .0001, MSE = 21587.77. The effect of SOA was greater in the three letter condition than in the one letter condition. Tone responses were slower at shorter SOAs (F(4,84) = 48.53, p < .0001, MSE = 26584.77), slower in the three letter condition than in the one letter condition (F(1,21) = 40.38, p < .0001, MSE = 107080.49), and slower in the quiet condition than the loud condition (F(1,21) = 8.38, p < .01, MSE = 83049.76). There was no indication of a 2-way interaction between SOA and tone difficulty (i.e. the effects were additive, F < 1) (see Figure 15).

Ignore trials

The data from ignore trials was entered into a 5 (SOA) x 2 (number of letters) x 2 (tone difficulty) repeated measures ANOVA. The interaction between SOA and tone difficulty was significant, F(5,2) = 3.43, p < .05, MSE = 12727.73. This interaction was caused by an unusually small difference between tone RTs on quiet and loud trials at an SOA of 395 ms compared to at other SOAs (see Table 5). Tone response times were slower at shorter SOAs (F(1,21) = 8.39, p

$< .01$, $MSE = 83049.76$) and in the hard condition than in the easy tone difficulty condition ($F(1,21) = 11.23$, $p < .01$, $MSE = 136260.31$).

Accuracy results

Letter task

Mean proportions of letters correctly reported are shown in Table 6. Mean proportion of correct letter responses were entered into a 5 (SOA) x 2 (number of letters) x 2 (tone difficulty) repeated measures ANOVA. The effect of SOA on the proportion of letters correctly reported was not significant, $F(4,84) = 1.39$, $p < 0.24$, $MSE = 0.00137$. Letter report accuracy was thus not affected by task overlap. There was a significant effect of number of letters on the proportion of letters correctly reported, $F(1,21) = 13.22$, $p < 0.01$, $MSE = 0.01435$. Participants reported 98% of the letters on one letter trials and 94% of the letters on three letter trials.

Tone task

Mean proportions of correct tone responses are shown in Figure 14 and in Table 5. Mean proportion of correct tone responses were entered into a 5 (SOA) x 2 (encode/ignore) x 2 (number of letters) x 2 (tone difficulty) repeated measures ANOVA. The analysis revealed a significant 2-way interaction between encode/ignore and number of letters, $F(1,21) = 10.52$, $p < .01$, $MSE = 0.00199$. In the one letter condition participants were more accurate on encode trials than on ignore trials, however in the three letter condition participants were more accurate on ignore trials than on encode trials. The main effect of tone difficulty was also significant, $F(1,21) = 6.15$, $p < 0.05$, $MSE = 0.00222$. Participants correctly reported the pitch of the tone 97% of the time on quiet trials and 98% of the time on loud trials.

Separate analyses were also conducted on encode and ignore trials. Mean proportions of correct tone responses for encode trials were entered into a 5 (SOA) x 2 (number of letters) x 2 (tone difficulty) repeated measures ANOVA. The analysis revealed no effect of the experimental manipulations on tone report accuracy. Mean proportions of correct tone responses for ignore trials were entered into a 5 (SOA) x 2 (number of letters) x 2 (tone difficulty) repeated measures ANOVA. There was a significant main effect of number of letters, $\underline{F}(1,21) = 8.67$, $\underline{p} < 0.01$, $\underline{MSE} = 0.00163$. Tone responses were more accurate in the three letter condition (mean = .98) than in the one letter condition (mean = .97). There was also a significant main effect of tone difficulty, $\underline{F}(1,21) = 6.37$, $\underline{p} < 0.05$, $\underline{MSE} = 0.00167$. Tone responses were more accurate in the easy tone condition (mean = .98) than in the hard tone condition (mean = .97)

Discussion

The goal of Experiment 3 was to assess the nature of the capacity limited cognitive mechanism involved in the encoding paradigm using the locus of cognitive slack logic (Pashler & Johnston, 1989). The results of Experiment 3, shown in Figure 15, reveal additive effects of a task 2 tone difficulty manipulation and SOA. Because Experiment 2 revealed an underadditive interaction with decreasing SOA using an extremely similar paradigm, it is argued that Experiment 3 had sufficient power to detect an interaction, and that the absence of the interaction is not likely the result of a type II error. In addition, there was no effect of SOA on letter report accuracy. A capacity sharing model of these additive effects would have to predict an effect of SOA on task 1 accuracy, and thus a capacity sharing account is not, in this case, consistent with the pattern of interference. Meyer and Kieras' (1997) strategic bottleneck model may also be rejected to the extent that peripheral processes, such as phonological recoding and translation of motor codes, are not involved in the interference. The results are instead most consistent with the conclusion that the tone difficulty manipulation affects a stage at or after a processing bottleneck, and that it is this processing bottleneck that produces interference in the encoding paradigm.

The question remains as to the locus of the processing bottleneck in the encoding paradigm. According to Jolicoeur and Dell'Acqua's (1998) Central Interference Theory, the processing bottleneck is at short-term consolidation, the stage that copies selected outputs of perceptual encoding to durable storage, the short-term store, for later report. As it stands, Central Interference Theory asserts that perceptual processing is complete before short-term consolidation begins, and thus cannot easily be reconciled with the result from Experiment 3, which implies that the tone difficulty manipulation affects a stage at or after the bottleneck stage. One possibility is that the tone loudness manipulation used in Experiments 2 and 3 is somehow distinct from other perceptual difficulty manipulations and that typically perceptual factors affect perceptual encoding, a stage before the bottleneck. In this case we should be able to find a task 2 manipulation that produces an underadditive interaction with decreasing SOA in an encoding paradigm. Another possibility is that the encoding stage is not distinct from some complex perceptual processing. Indeed, there is evidence from PRP paradigm experiments that some complex perceptual discriminations occur at stages after initial perceptual encoding (e.g. McCann & Johnston, 1992).

Experiment 4

In Experiment 3 we found a tone loudness manipulation to produce additive effects with SOA in the encoding paradigm, implying that the tone loudness manipulation affects a stage at or after a processing bottleneck. This finding is inconsistent with Jolicoeur and Dell'Acqua's (1998) CIT which predicts that perceptual processing is complete before the bottleneck at STC is engaged. To resolve this issue we replicated Experiments 2 and 3 using a different task 2 perceptual difficulty manipulation. These experiments serve three important purposes. First, and most obviously, we may be able to replicate the results from Experiment 3 and provide further support for our argument that the capacity limited cognitive mechanism involved in encoding takes the form of a processing bottleneck. Second, by using a different perceptual difficulty manipulation in Experiment 5 we can determine if perceptual manipulations typically affect the bottleneck stage in an encoding paradigm, and adjust our conceptualization of the bottleneck stage accordingly. Finally, if our new perceptual manipulation produces an underadditive interaction with decreasing SOA in an encoding paradigm, we will have extremely compelling converging evidence that the capacity limited cognitive mechanism involved in encoding takes the form of a processing bottleneck.

In Experiment 4 we use a PRP paradigm identical to that of Experiment 2, except that the second stimulus was two 800 Hz tones presented at different loudness' to both ears simultaneously. The participant perceived a single tone localized on the side of the louder of the two tones. Participants made a speeded response to the identity of a letter and then a speeded response to the apparent locus (left or right) of the tone. The difficulty of the localization task was manipulated by varying the relative loudness of the two tones; in the 'hard' tone localization condition the loudness of the two tones was more similar than in the 'easy' tone localization condition. If we find an underadditive interaction between the tone localization difficulty manipulation and decreasing SOA we can then use this same task 2 difficulty manipulation in an encoding paradigm to further our understanding of the processing bottleneck involved in encoding.

Method

Participants

Fifteen University of Waterloo students were paid $6.00 for their participation in this experiment. All participants reported normal hearing and normal or corrected-to-normal vision.

Visual Stimuli

The apparatus and visual stimuli were identical to those used in Experiment 2.

Auditory stimuli

The auditory stimuli consisted of a 800 Hz tone presented to both ears simultaneously through headphones. One tone was always presented more loudly than the other, which created the perceptual of a single tone originating from the side of the louder tone. The loudness of the louder of the two tones was constant across trials, on 'easy' tone localization trials the control value for the loudness of the quieter tone was set to 30% of the control value for the loudness of the louder tone, on 'hard' trials the control value for the loudness of the quieter tone was set to 70% of the control value for the loudness of the louder tone. There were an equal number of trials with the louder tone in the right and left ear.

Procedure

The procedure was identical to Experiment 2 with two exceptions. First, there was no loudness calibration phase. Second, task 2 involved making a speeded response to the apparent locus of a tone; participants pressed the 'Z' key with the middle finger of their left hand if they heard a tone to the left and the 'X' key with the index finger of their left hand if they heard a tone to the right.

Results

Preliminary analyses revealed no effect of tone pitch on mean RT, letter accuracy, or tone accuracy. Data were collapsed across these variables in the following analyses.

RT Results

Only trials in which both responses were correct were included in the RT analyses. Correct letter RT data and correct tone RT data were subjected, sequentially, to the modified recursive outlier analysis suggested by Van Selst and Jolicoeur (1994). This analysis removed 3.5% of the data was removed based on tone responses, and a further 2.75% of the remaining data was

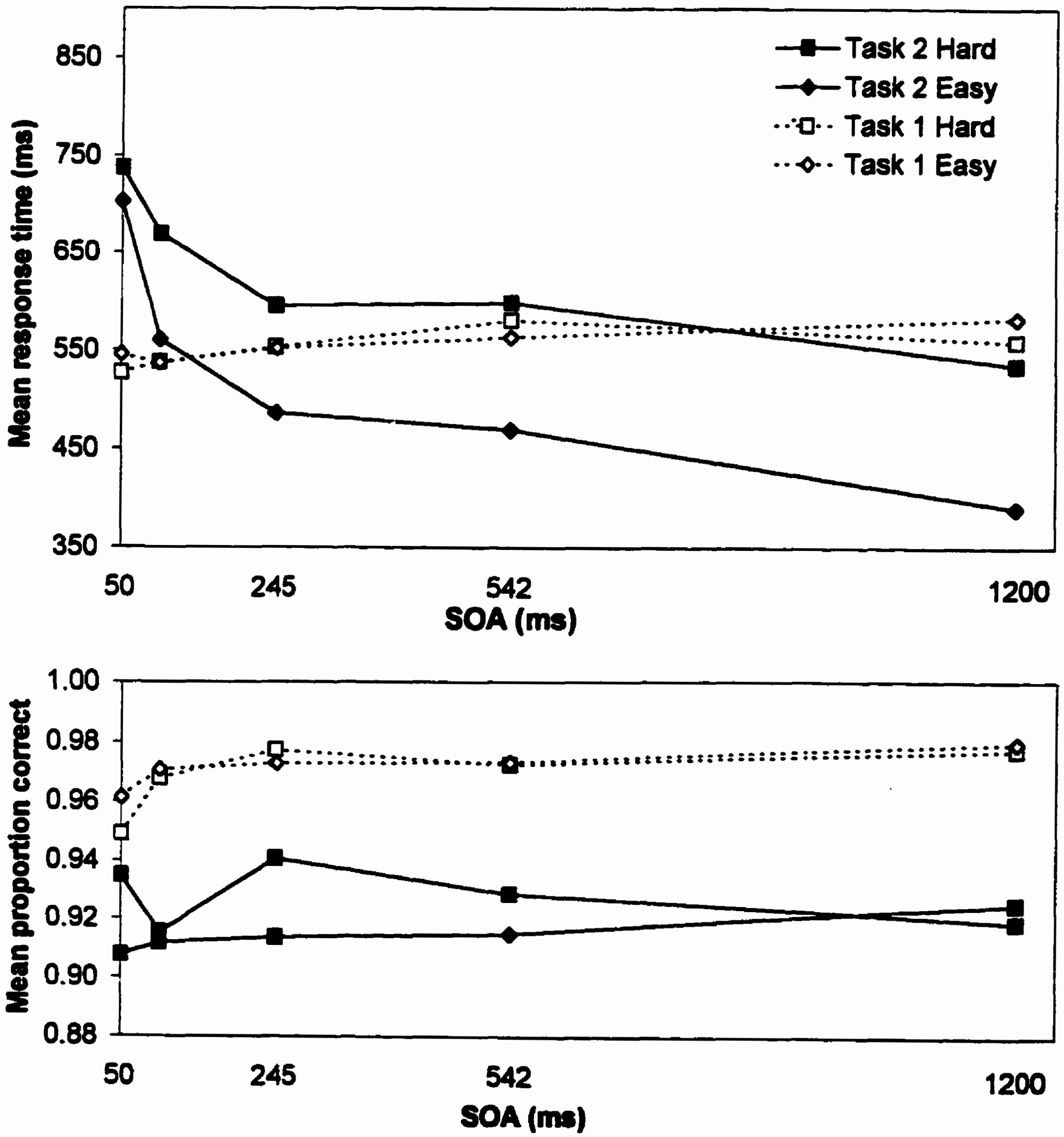

Figure 16. *Mean resonse times (upper panel) and proportions correct (lower panel) fas a function of tone task difficulty and stimulus onset asynchrony (SOA) or the letter task (task 1) and the tone task (task 2) for the tone task in Experiment 4.*

removed based on letter responses. When an RT, in either task, was rejected as an outlier, the entire trial was rejected (i.e., both RTs were rejected).

Tone task

Mean RTs to the tone and the corresponding proportions of correct tone responses are shown in Table 7. Mean RTs to the tone were entered into a 2 (tone localization difficulty) x 5 (SOA) repeated measures ANOVA. There was a significant 2-way interaction between tone difficulty and SOA ($F(4, 56) = 9.43$, $p < .0001$, MSE = 1447.07), plotted in Figure 16, which is clearly underadditive with decreasing SOA; the difference in tone RTs for the quiet and the loud tone conditions increases from only 35 ms at the shortest SOA to 145 ms at an SOA of 1200 ms. Tone responses were slower in the hard tone localization difficulty condition than in the easy tone localization difficulty condition ($F(1,14) = 53.74$, $p < .0001$, MSE = 7763.15), and slower at shorter SOAs ($F(4,56) = 58.09$, $p < .0001$, MSE = 4917.80).

Letter task

Mean RTs to the identity of the letter and the corresponding proportions of correct letter responses are shown in Table 8. Mean RTs to the letter were entered a 2 (tone localization difficulty) x 5 (SOA) repeated measures ANOVA. There was a significant interaction between tone localization difficulty and SOA, $F(4,56) = 6.84$, $p < .0001$, MSE = 664.94. The effect of SOA was greater in the hard tone localization difficulty condition than in the easy tone difficulty condition. Finally, letter responses were slower at shorter SOAs ($F(4,56) = 6.84$, $p = 0.0001$, MSE = 1361.15)

Accuracy Results

Tone task

Mean proportions of correct tone responses are shown in Table 7. Mean proportion of correct tone responses were entered into a 2 x 5 repeated measures ANOVA. There were no effects of the experimental manipulations on tone response accuracy.

Letter task

Mean proportions correct for the letter task are shown in Figure 8. Mean proportion of correct letter responses were entered into a 2 x 5 repeated measures ANOVA. Letter responses were less accurate at shorter SOAs ($\underline{F}(4,56) = 5.28$, $p < .01$, $\underline{MSE} = 0.000450$).

Discussion

The results from Experiment 4 reveal an underadditive interaction between the tone localization difficulty manipulation and decreasing SOA (see Figure 16). This result indicates that the tone localization difficulty manipulation affects a stage before the PRP bottleneck. We can now replicate Experiment 3 in Experiment 5 using this new perceptual difficulty manipulation.

Experiment 5

In Experiment 5 participants encoded or ignored three consonants based on their colour and then make a speeded response to the apparent location of a tone. On half the trials localizing the tone is made more difficult. If we observe an underadditive interaction between the tone localization difficulty manipulation and decreasing SOA we will also have converging evidence for the claim that the capacity limited cognitive mechanism involved in encoding is a processing bottleneck, and the conclusions of Jolicoeur and Dell'Acqua (1998) regarding the processes involved in the bottleneck stage need not be challenged. If additive effects between the tone localization task and SOA are observed in Experiment 5, accompanied by no effect of SOA on letter report accuracy, we will also have converging evidence that the capacity limited cognitive mechanism involved in encoding takes the form of a processing bottleneck, and that the tone localization task affects a stage at or after this bottleneck. However, this evidence that a second perceptual difficulty manipulation affects the bottleneck stage in an encoding task will force the re-evaluation of Jolicoeur and Dell'Acqua's (1998) assumption that the capacity limited stage in encoding is only responsible for copying the output of perceptual encoding to the short-term store. Finally, if an overadditive interaction between the task 2 difficulty manipulation is observed it may be concluded that capacity sharing is responsible for the interference observed in the encoding paradigm.

Method

Participants

Fourteen University of Waterloo students were paid $6.00 for their participation in this experiment. All participants reported normal hearing and normal or corrected-to-normal vision.

Visual Stimuli

The apparatus was identical to that in Experiment 2. The visual stimuli were identical to those used in Experiment 3 except three consonants were presented on every trial.

Auditory stimuli

The auditory stimuli were identical to those used in Experiments 4.

Procedure

Half the participants (N = 7) were instructed to encode the red letters and ignore the green letters while the other half of the participants (N = 7) were instructed to encode the green letters and ignore the red letters. The experimental procedure was identical to that of Experiment 3 except there was no loudness calibration phase.

Results

Preliminary analyses revealed no effect of whether subjects were in the 'red' or the 'green' group, or tone pitch on mean RT, letter accuracy, or tone accuracy. Data were collapsed across these variables in the following analyses.

RT Results

Only trials on which both responses were correct were included in the RT analyses. Correct tone RT data were first subjected to the modified recursive outlier analysis suggested by Van Selst and Jolicoeur (1994). This analysis removed 3.51 % of the data.

Mean RTs and corresponding proportions of correct tone responses are shown in Table 9. Mean tone RTs were entered into a 2 (encode/ignore) x 5 (SOA) x 2 (tone localization difficulty) repeated measures ANOVA. There was a significant 2-way interaction between SOA and encode/ignore, $\underline{F}(4,52) = 2.90$, $\underline{p} < .05$, $\underline{MSE} = 14540.94$, which is shown in Figure 17. The effect of SOA was greater for encode trials than for ignore trials. Tone responses were slower at shorter SOAs ($\underline{F}(4,52) = 14.6$, $\underline{p} < .0001$, $\underline{MSE} = 18667.35$) slower for encode trials than for ignore trials ($\underline{F}(1,13) = 32.87$, $\underline{p} < .0001$, $\underline{MSE} = 60175.47$), and slower in the hard tone localization difficulty condition than in the easy tone difficulty manipulation ($\underline{F}(1,13) = 24.63$, $\underline{p} < .001$, $\underline{MSE} = 102409.40$).

In order to apply the locus of cognitive slack logic we also conducted separate ANOVAs on the encode and ignore trial data. We are primarily interested in the nature of the capacity limited cognitive mechanism involved on encode trials.

Encode trials

Mean response times for encode trials were entered into a 5 (SOA) x 2 (tone localization difficulty) repeated measures ANOVA. Tone responses were slower at shorter SOAs ($\underline{F}(4,52) = 11.55$, $\underline{p} < .0001$, $\underline{MSE} = 22609.983$), and slower in the hard tone localization condition than in

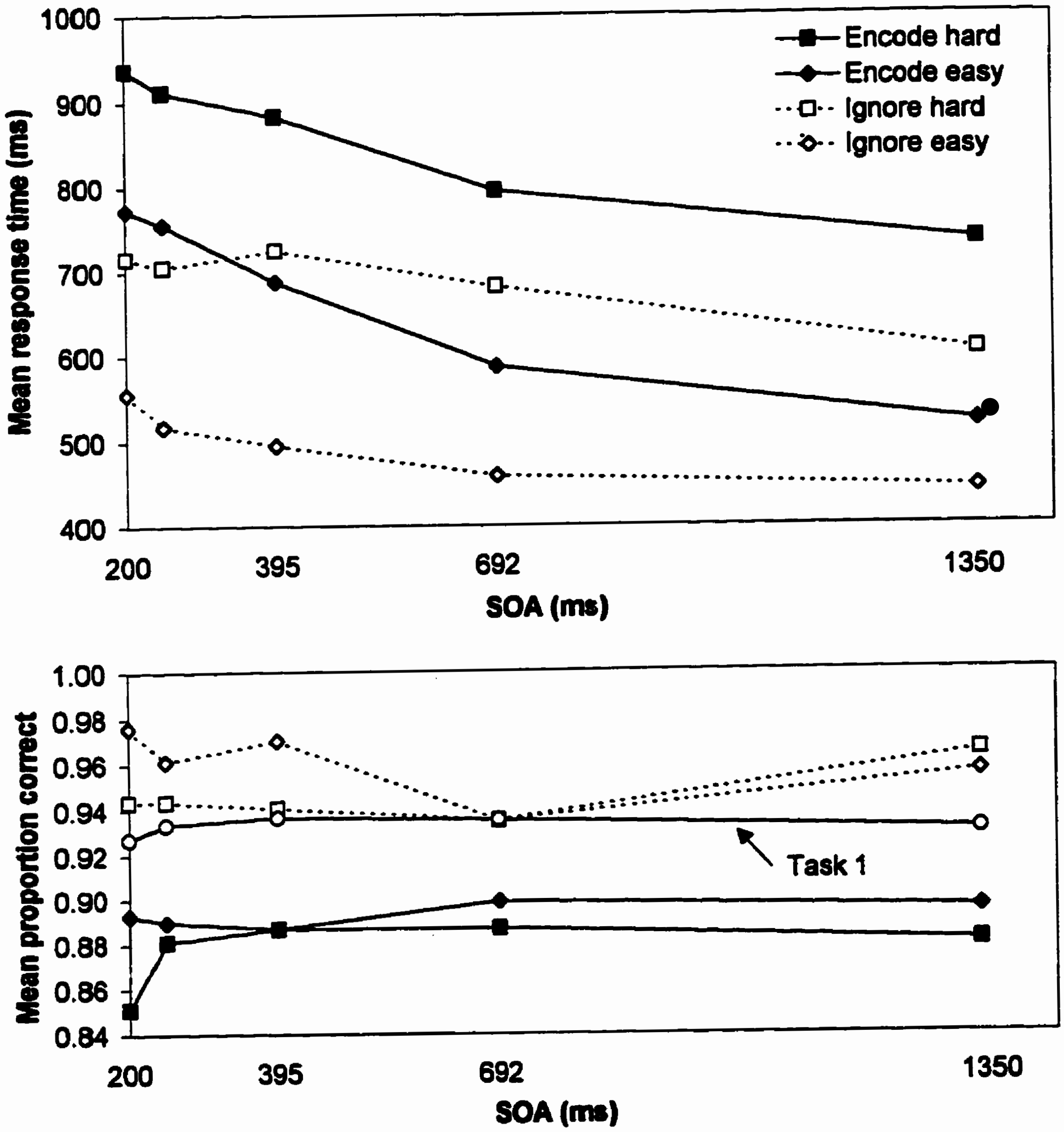

Figure 17. Mean resonse times (top panel) and proportions correct (bottom panel) as a function of encode/ignore, tone task difficulty, and stimulus onset asynchrony (SOA) for the tone task in Experiment 5. Task 1 accuracy is plotted in the bottom panel.

the easy tone localization condition ($F(1,13) = 33.69$, $p < .0001$, $MSE = 474927.62$). The interaction between tone localization difficulty and SOA was not significant (i.e., additive effects were observed, $F < 1$).

Ignore trials

The data from ignore trials was entered into a 5 (SOA) x 2 (tone localization difficulty) repeated measures ANOVA. Tone response times were slower at shorter SOAs ($F(4,52) = 5.05$, $p < 0.01$, $MSE = 10598.32$) and slower in the hard tone localization condition than in the easy tone localization condition ($F(1,13) = 17.23$, $p < .001$, $MSE = 74978.39$).

Accuracy Results

Letter task

Mean proportions of letters correctly reported are shown in Table 10. Mean proportion of correct letter responses were entered into a 5 (SOA) x 2 (tone localization difficulty) repeated measures ANOVA. The analysis revealed no effect of the experimental manipulations on letter task accuracy.

Tone task

Mean proportions of correct tone responses are shown in Table 9. Mean proportion of correct tone responses were entered into a 5 (SOA) x 2 (encode/ignore) x 2 (tone localization difficulty) repeated measures ANOVA. There was a main effect of tone localization difficulty, $F(1,13) = 4.57$, $p < .05$, $MSE = 0.003388$. Tone responses were more accurate in the easy tone localization condition than in the hard localization difficulty condition.

Separate analyses were also conducted on encode and ignore trials. Mean proportions of correct tone responses for encode trials were entered into a 5 (SOA) x 2 (tone localization difficulty) repeated measures ANOVA. There were no effects of the experimental manipulations on tone localization accuracy. Mean proportions of correct tone responses for encode trials were entered into a 5 (SOA) x 2 (tone localization difficulty) repeated measures ANOVA. The main effect of tone localization difficulty was significant, F(1,13) = 5.2, $p < .05$, MSE = 0.00137. Tone responses were more accurate in the easy tone localization condition than in the hard tone localization condition.

Discussion

The results from Experiment 5 replicate those from Experiment 3. The effect of tone localization difficulty was additive with SOA and there was no effect of SOA on task 1 accuracy, which provides converging evidence for the claim that the capacity limited cognitive mechanism involved in encoding takes the form of a processing bottleneck. What's more, the finding that a second perceptual difficulty manipulation produced additive effects with SOA undermines Jolicoeur and Dell'Acqua's (1998) claim that only short-term consolidation is subject to a processing bottleneck in the encoding paradigm, because the additive effects imply that some perceptual processing is also being postponed by the bottleneck.

Experiment 6

The main evidence that a perceptual factor is affecting the bottleneck stage comes from the additive effects observed in Experiments 3 and 5. One possibility, however, is that we observed additivity in these experiments because the SOAs used were not sufficiently short. In Experiments 3 and 5 we made the shortest SOA 200 ms to avoid any interference that may result from the abrupt onset of the tone when the letters were still visible. However, in our PRP paradigm experiments, most of the convergence in the underadditive interactions between task 2 difficulty manipulations and decreasing SOA occurs within the first 150 ms; if the two shortest SOAs were removed the pattern in the results from Experiments 2 and 4 would appear additive (see Figures 12 and 16). Thus we may observe additive effects in the encoding paradigm simply because we were not probing early enough during the encoding process. In Experiment 6 we replicated Experiment 3 using the same SOAs as employed in Experiments 2 and 4. If additive results are again found, our conclusion that some perceptual processing is occurring at the bottleneck stage in the encoding paradigm will be supported. If an underadditive interaction with decreasing SOA is observed we will instead conclude that the processing bottleneck occurs after perceptual processing. Finally, if an overadditive interaction with decreasing SOA is observed, it may be concluded that the interference is the result of capacity sharing.

Method

Participants

Ten undergraduates from the University of Waterloo were paid $6.00 for their participation in this experiment.

Visual stimuli

The apparatus was identical to the one used in Experiment 2. The visual stimuli were identical to those used in Experiment 3.

Auditory stimuli

The auditory stimuli were identical to those used in Experiment 3.

Procedure

The procedure was identical to that of Experiment 3 except that we instead used the SOAs from Experiments 2 and 4, which were 50, 111, 245, 542, and 1250 ms. Unlike in Experiment 3, in Experiment 6 the letters would still be present on the screen when the tone was presented on about half the trials (those trials where the SOA was less than the 250 ms).

Results

Preliminary analyses revealed no effect of whether subjects were in the 'red' or the 'green' group or tone pitch on mean RT, letter accuracy, or tone accuracy. We were therefore able to collapse across these variables in the following analyses.

RT Results

Only trials on which both responses were correct were included in the RT analyses. Correct tone RT data were first subjected to the modified recursive outlier analysis suggested by Van Selst and Jolicoeur (1994). This analysis removed 3.156 % of the data.

Mean RTs and corresponding proportions of correct tone responses are shown in Table 11. Mean tone RTs were entered into a 2 (encode/ignore) x 5 (SOA) x 2 (tone difficulty) repeated measures ANOVA. The 3-way interaction between SOA, encode/ignore, and tone difficulty is significant, $\underline{F}(4,36) = 4.53$, $\underline{p} < .01$, $\underline{MSE} = 1921.94$ (see Figure E6 F1). The effect of SOA was much more dramatic on encode trials, particularly in the hard tone difficulty condition. The 3-way interaction between encode/ignore, number of letters, and SOA was also significant, $\underline{F}(4,36) = 4.0$, $\underline{p} < .01$, $\underline{MSE} = 3583.73$. The effect of SOA was greater in the three letter condition than in the one letter condition for encode trials but not ignore trials. The 2-way interaction between SOA and encode/ignore was significant, $\underline{F}(4,20) = 6.02$, $\underline{p} < .001$, $\underline{MSE} = 4833.67$. The effect of SOA was greater on encode trials than on ignore trials. The 2-way interaction between encode/ignore and number of letters was also significant, $\underline{F}(1,9) = 11.46$, $\underline{p} < .01$, $\underline{MSE} = 13471.8$. Tone RTs were slower in the three letter condition than in the one letter condition for encode trials but not for ignore trials. Tone responses were slower at shorter SOAs ($F(4,20) = 14.5$, $\underline{p} < .0001$, $\underline{MSE} = 18993.43$), slower in the encode condition ($\underline{F}(1,5) = 35.8$, $\underline{p} < .001$, $\underline{MSE} = 31913.900$), and slower in the hard tone difficulty condition ($\underline{F}(1,9) = 19.98$, $\underline{p} < .01$, $\underline{MSE} = 24981.23$).

In order to apply the locus of cognitive slack logic we also conducted separate ANOVAs on the encode and ignore trial data. We are primarily interested in the nature of the capacity limited cognitive mechanism involved on encode trials.

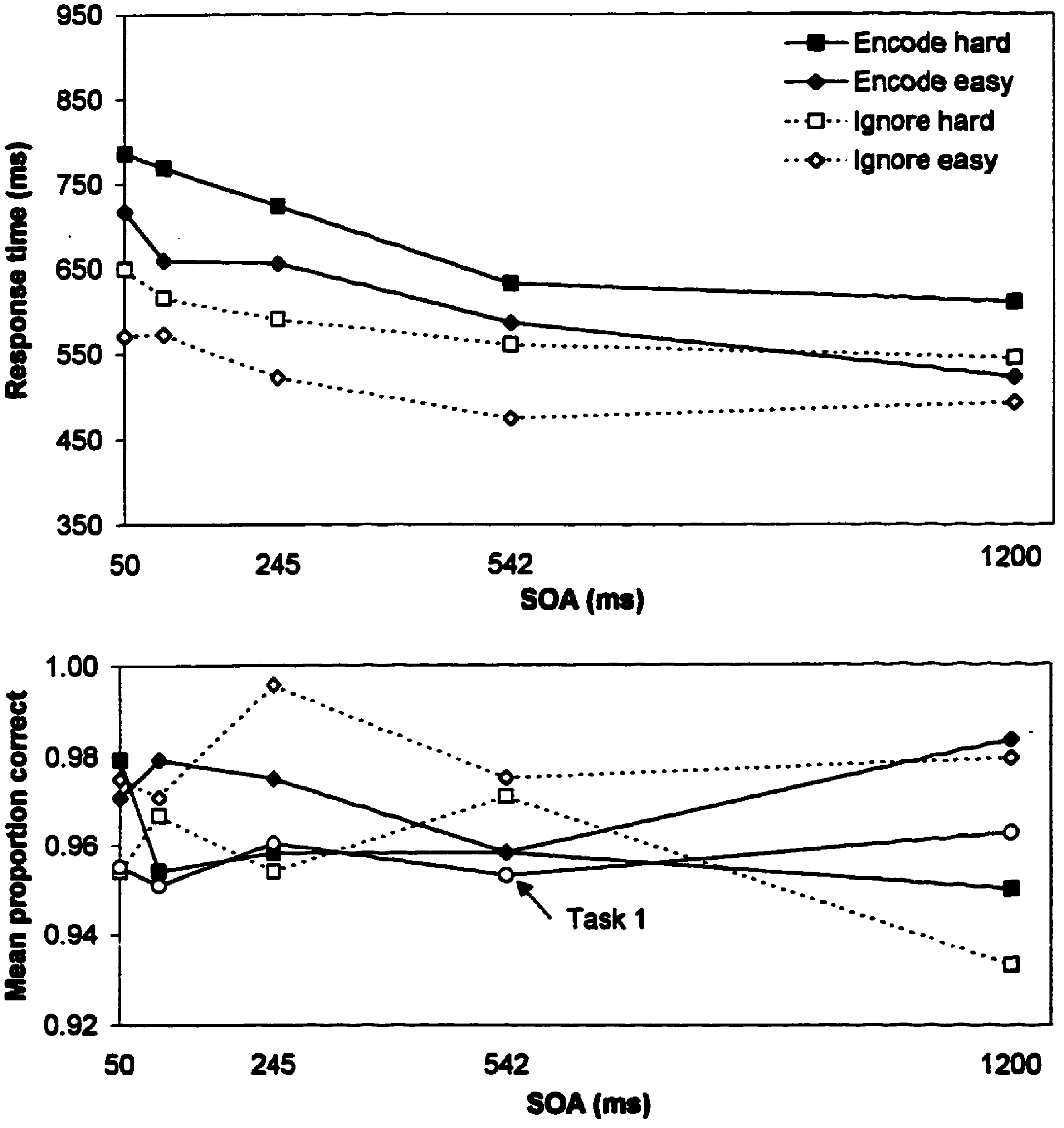

Figure 18. Mean resonse times (top panel) and proportions correct (bottom panel) as a function of encode/ignore, tone task difficulty, and stimulus onset asynchrony (SOA) for the tone task in Experiment 6. Task 1 accuracy is plotted in the bottom pabel.

Encode trials

Mean correct response times were entered into a 5 (SOA) x 2 (number of letters) x 2 (tone difficulty) repeated measures ANOVA. Most importantly, the 2-way interaction between SOA and tone difficulty was not significant (i.e., the effects were additive, $\underline{F}(4,36) = 1.34$, $\underline{p} < 0.27$). The 2-way interaction between SOA and number of letters was also significant, $\underline{F}(4,36) = 3.96$, $\underline{p} < .01$, $\underline{MSE} = 5110.63$. The effect of SOA was greater on three letter trials than on one letter trials. Tone responses were slower at shorter SOAs than at longer SOAs, ($\underline{F}(4,36) = 12.96$, $\underline{p} < .001$, $\underline{MSE} = 17955.54$), slower in the three letter condition than in the one letter condition, $\underline{F}(1,9) = 10.66$, $\underline{p} < .01$, $\underline{MSE} = 28972.13$, and slower in the hard tone difficulty condition than in the easy tone difficulty condition, ($\underline{F}(1,9) = 15.89$, $\underline{p} < .01$, $\underline{MSE} = 18076.01$).

Ignore trials

Mean correct response times were entered into a 5 (SOA) x 2 (number of letters) x 2 (tone difficulty) repeated measures ANOVA. Most importantly, the 2-way interaction between SOA and tone difficulty was not significant ($\underline{F}(4,36) = 1.4$, $\underline{p} < 0.256$). Tone responses were slower at shorter SOAs than at longer SOAs ($\underline{F}(4,20) = 4.79$, $\underline{p} < 0.01$, $\underline{MSE} = 8288.24$), and slower in the hard tone difficulty condition than in the easy tone difficulty condition ($\underline{F}(1,9) = 24.11$, $\underline{p} < .001$, $\underline{MSE} = 8896.04$).

Accuracy Results

Letter accuracy

Mean proportions of letters correctly reported are shown in Table 12. Mean proportion of correct letter responses were entered into a 5 (SOA) x 2 (tone localization difficulty) repeated measures ANOVA. There was a significant effect of number of letters on the proportion of letters correctly reported, $F(1,9) = 19.98$, $\underline{p} < 0.01$. A larger proportion of the letters were reported on three letter trials than on one letter trials.

Tone accuracy

Mean proportion of correct tone responses were entered into a 5 (SOA) x 2 (encode/ignore) x 2 (tone difficulty) repeated measures ANOVA. Tone responses were less accurate in the hard tone difficulty condition than in the easy tone difficulty condition ($F(1,9) = 5.12$, $p < 0.05$).

Encode trials

Mean proportions of correct tone responses for encode trials were entered into a separate 5 (SOA) x 2 (number of letters) x 2 (tone difficulty) repeated measures ANOVA. There were no effects of the experimental manipulations on tone report accuracy for encode trials.

Ignore trials

Mean proportion of correct tone responses for encode trials were entered into a separate 5 (SOA) x 2 (number of letters) x 2 (tone difficulty) repeated measures ANOVA. Tone responses were less accurate in the hard tone difficulty condition than in the easy tone difficulty condition ($F(1,5) = 9.60$, $p < .05$, $MSE = 0.00384$).

Discussion

The results from Experiment 6 show that a task 2 perceptual difficulty manipulation still produces additive effects with SOA even when the SOAs are very short (see Figure 18). Thus it may be concluded that the stage being affected by the perceptual difficulty manipulations occurs at or after, and not before, a processing bottleneck.

The goal of the present series of experiments was to gain an understanding of the role of a capacity limited cognitive mechanism in encoding and to establish a locus for the mechanism. The experiments establish that encoding requires a capacity limited cognitive mechanism and that this mechanism takes the form of a processing bottleneck (Experiments 3, 5, and 6). We now turn to the theoretical implications for these findings.

General Discussion

In Experiments 2 to 6 we found that the same perceptual difficulty manipulations that produced underadditive interactions with decreasing SOA in the PRP paradigm experiments (Experiments 2 and 4) produced additive effects with SOA and no effects of SOA on task 1 accuracy in the encoding paradigm experiments (Experiments 3, 5 and 6). When the locus of cognitive slack logic (Pashler & Johnston, 1989; McCann & Johnston, 1992) is applied, these results imply that the tone difficulty manipulations used in the present experiments exert their effects at or after a processing bottleneck (based on the additivity in Experiments 3, 5, and 6) and that this bottleneck is both *before* the PRP bottleneck at response selection (based on the underadditive interactions with decreasing SOA in Experiments 2 and 4) and *different from* the PRP bottleneck at response selection (based on the fact that the PRP bottleneck is not encountered in the encoding paradigm experiments because no speeded response is required for task 1). In addition the results from Experiment 1 imply that making a decision to encode or ignore based on colour does not require a capacity limited cognitive mechanism and thus some rudimentary sensory processing must occur before the bottleneck stage.

The results from the present experiments thus clearly indicate the presence of a processing bottleneck with a locus somewhere between rudimentary sensory processing and the onset of response selection. Further, the locus of this bottleneck is at or before the locus of the tone difficulty manipulations used in Experiments 3, 5, and 6, as these tone manipulations produced additive effects across SOA in encoding paradigm experiments. A number of recent studies that have employed the attentional blink (AB) paradigm (e.g., Broadbent & Broadbent, 1987; Raymond, Shapiro, & Arnell, 1992) suggest that a capacity limited cognitive mechanism is involved in the conversion of implicitly coded stimulus features into explicitly coded stimulus features. It seems plausible that such a stage could also constitute a processing bottleneck in the encoding paradigm. If so, then Jolicoeur and Dell'Acqua's (1998) Central Interference Theory (CIT) may be adapted to include a processing bottleneck which postpones the translation of implicitly coded stimulus information during short-term consolidation (STC)

Encoding and the Attentional Blink (AB) paradigm

In the attentional blink (AB) paradigm participants are presented with multiple targets embedded among non-targets in a rapid serial visual presentation (RSVP) stream, which displays a succession of brief stimuli in the same location at a rate of about 10 stimuli per second. Targets are typically distinguished from non-targets by colour, shape, or alphanumeric class. Participants are required to make judgments about the targets for report at the end of the trial. Targets are presented with a varying number of intervening non-targets. Results from AB paradigm experiments consistently show marked decreases in target detection accuracy during the 500 ms following the presentation of a preceding target, a phenomenon referred to as the 'attentional blink' (see Figure 19).

Like the PRP effect, the attentional blink may be attributed to a capacity limited cognitive mechanism, as task overlap increases the magnitude of the effect. Originally, the capacity limited cognitive mechanism involved in the attentional blink was assumed to prevent all processing of subsequent stimuli for a brief period of time, much in the same way that visual input is temporarily blocked when we blink our eyes (Raymond, Shapiro, & Arnell, 1992). However subsequent research has revealed that although the attentional blink may indeed serve to interfere with certain types of processing, other types of processing may proceed unhindered during the blink interval.

Shapiro, Driver, Ward, and Sorenson (1997) were among a group of researchers who speculated that the 'eye blink' analogy used to describe the AB phenomenon may be too simplistic and that certain types of implicit stimulus processing may still be possible during the

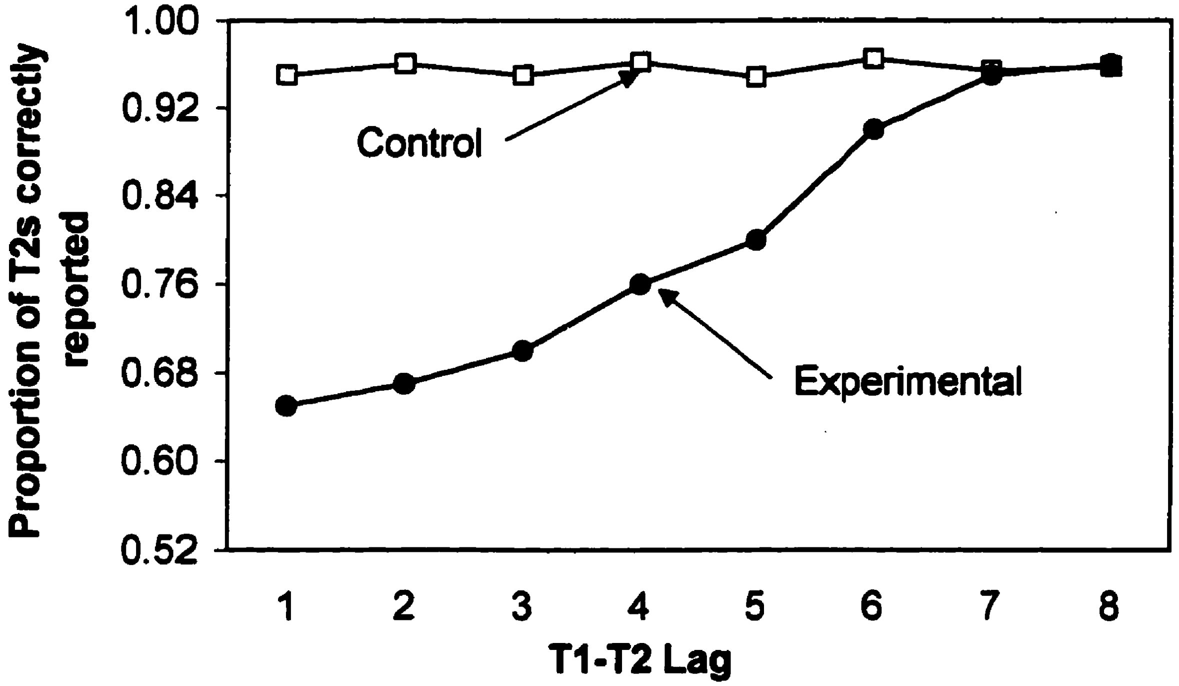

Figure 19. Example of a typical attentional blink (AB) effect (e.g. Raymond et al., 1992). On Control trials only T2 is reported. On Experimental trials both T1 and T2 must be reported. For Experimental trials, but not Control trials, T2 report accuracy is significantly lower when the T1-T2 lag is short than when the lag is long.

blink interval, even if stimuli presented during this interval were not explicitly coded by the observer (for a review of other AB models see Jolicoeur, 1998). To test this hypothesis, Shapiro et al. (1997) studied the extent to which a target presented during the blink interval that can not be accurately reported, serves to prime subsequent targets in an AB paradigm experiment. If all processing of subsequent stimuli is prevented during the blink interval then targets presented during the blink that *cannot* be reported by the participant should not prime subsequent targets.

In Experiment 1, which is illustrated in Figure 20, Shapiro et al. (1997) presented participants with 13 to 23 stimuli in an RSVP stream. Each stimulus was presented for 15 ms, with an inter-stimulus interval (ISI) of 75 ms (11 stimuli/second). In each stream there were three targets referred to as T1, T2, and T3. T1 was a white digit, T2 was a black upper case letter, T3 was a black lower case letter that either had the same name as T2 (match condition) or a different name than T2 (mismatch condition). The remaining non-targets were all black digits. Participants were required to report T1, T2, and T3 at the end of each trial. A random number of distractors, ranging from seven to fifteen, preceded T1. T1 served to produce a 'blink' for T2, which was always the third stimulus that followed T1 (thus T2 was always presented 270 ms after T1) and T3 was always the sixth stimulus to follow T2 (thus T3 was always presented 540 ms after T1). If the original assumption about the attentional blink is accurate, and processing of incoming stimuli is halted during the blink interval, then when T2 is missed T2 should not be sufficiently processed to prime T3 and thus there should be no difference between T3 accuracy on T2-match and T2-mismatch trials (i.e., no priming). If, on the other hand, complex information is implicitly coded during the blink, then missed T2s may still affect T3 processing, and T3 accuracy will be higher on match trials than on mismatch trials (i.e., priming will occur).

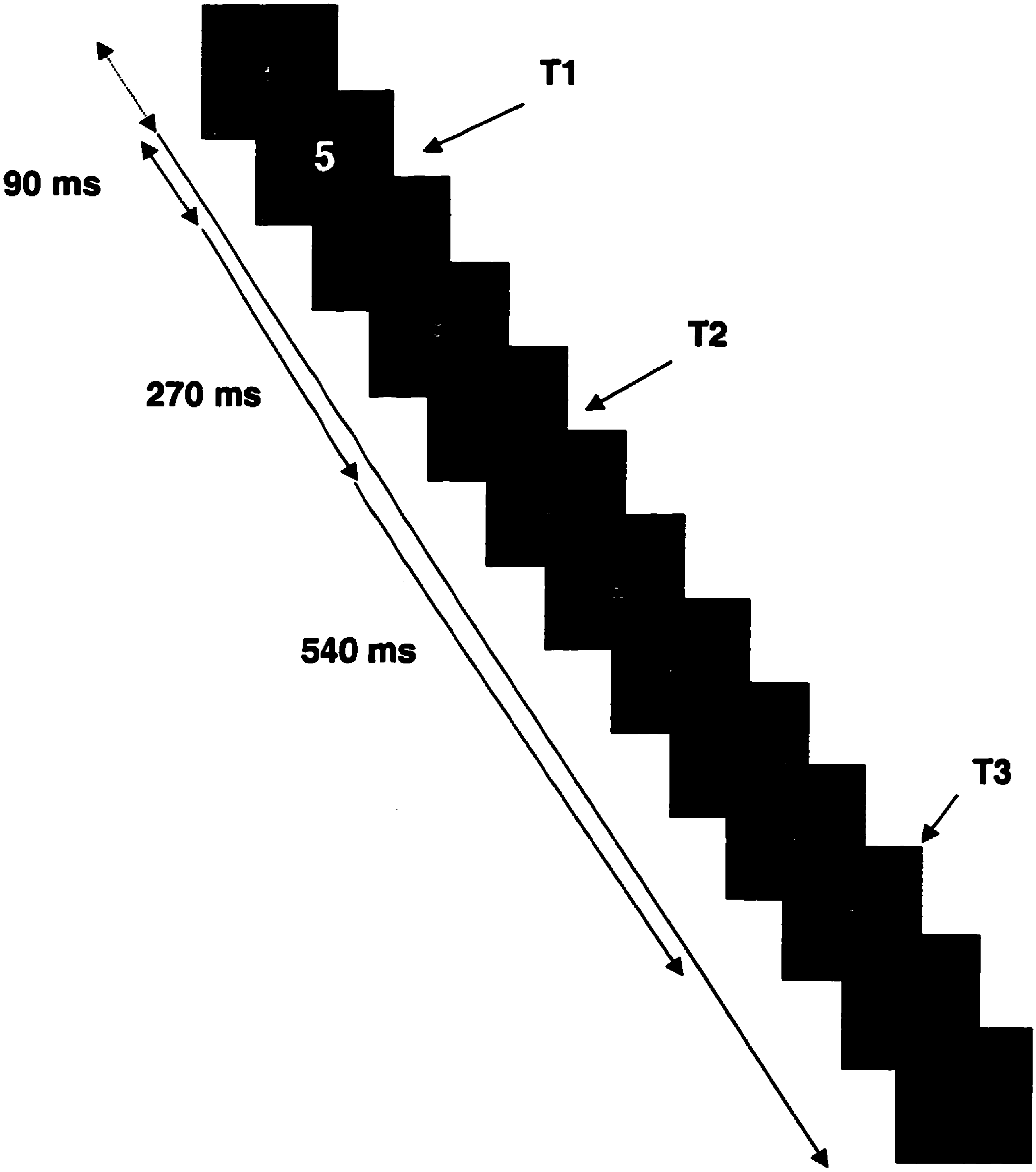

Figure 20. An illustration of the paradigm used in Shapiro et al. (1997, Experiment 1), Each stimulus was presented for 15 ms followed by a 75 ms blank interval. Seven to fifteen stimuli preceded T1. T3 was always the third stimulus to follow T1, T3 was always the sixth stimulus to follow T2. Participants reported the identities of T1 T2, and T3 at the end of each trial. This illustration shows a 'match' trial. On a 'mismatch' trial T3 may instead b a 'b'.

The results from Shapiro et al. (1997, Experiment 1) are shown in Figure 21[4]. As is clear from the figure, Shapiro et al. (1997) found a very different pattern in T3 accuracy when T2 was missed than when T2 was reported accurately. When T2 was missed (33% of the trials), T3 accuracy was significantly higher in the match condition than in the mismatch condition, indicating that T2s that couldn't be reported because of the blink were still able to prime T3. Thus Shapiro et al. (1997) concluded that T2s that were not explicitly coded were still implicitly coded to the level of meaning during the attentional blink.

When T2 was reported accurately (67% of the trials), however, T3 accuracy was higher in the mismatch condition than in the match condition, an effect referred to as 'repetition blindness' (RB). Repetition blindness is often observed in experiments which use RSVP streams consisting of simple alphanumeric characters (Shapiro et al., 1997). Kanwisher (1987) argues that RB results from the participants' inability to create two separate episodic tokens (i.e., specific instances of a category such as the capital letter 'A' or the lower case letter 'b') of stimuli of the same type (i.e., abstract category such as the letter A or the letter B) in rapid succession. Thus Shapiro et al. (1997) speculate that RB was observed in Experiment 1 because coding the token for T2 (e.g.., an upper case 'A'), interfered with coding the token for a subsequent target of the same type (e.g., a lowercase 'a'), which resulted in more errors when T2 and T3 were the same type (had the same name, match condition) than when T2 and T3 were different types (had different names, mismatched condition).

In Experiment 2 Shapiro et al. (1997) used a similar AB paradigm as in Experiment 1, with the exception that in Experiment 2 the stimuli consisted of words instead of letters and digits, and T2

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[4] The data shown in Figure 21 was corrected to allow for possible case-confusion errors (see Shapiro et al., 1997). Although this adjustment reduced accuracy estimates in all conditions, the pattern of significant effects was not changed.

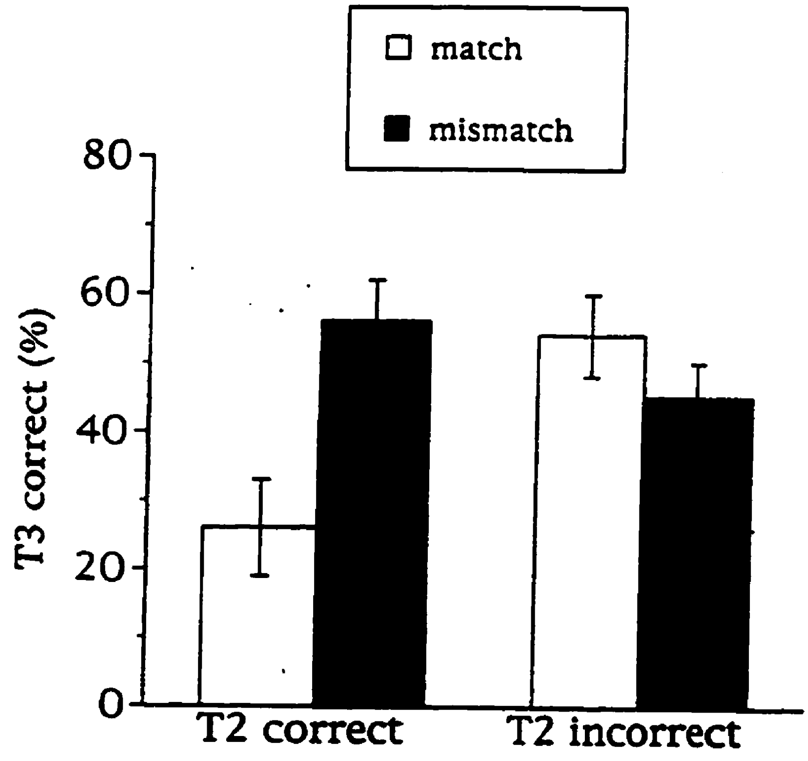


Figure 21. Results from Shapiro, Driver, Ward, & Sorenson (1997, Experiment 1). Proportion of T3s correctly reported across conditions. When T2 was reported correctly, more T3s were reported correctly in the mismatch condition than in the match condition. When T2 was reported incorrectly, more T3s were reported correctly in the match condition than in the mismatch condition.

was either semantically related to T3 (related condition) or not semantically related to T3 (unrelated condition). All related pairs of words were shown to produce significant facilitatory priming in an unrestricted viewing paradigm (Shelton & Martin, 1992). When T2 was missed in Experiment 2, accuracy at detecting T3 was again higher in the related condition than in the unrelated condition, implying implicit semantic coding even in stimuli outside of the participants awareness (see Figure 22). Unlike in Experiment 1, however, when T2 was reported correctly, T3 accuracy was higher in the related condition than in the unrelated condition (i.e., priming occurred). This discrepancy is, however, consistent with Kanwisher (1987) who suggests that RB only occurs when two successive stimuli are different tokens from the same type, because T2 and T3 in Experiment 2 were never of the same type. Shapiro et al. (1997) concluded that stimuli that cannot be reported due to the attentional blink are still implicitly coded to the level of meaning.

Maki, Frigen, and Paulson, (1997) also used an AB-priming paradigm to examine the extent to which stimuli presented during the blink are processed implicitly. Maki et al. (1997) always used words as both the targets and the distractors, and included a condition in some experiments where a semantically related distractor preceded a target. In addition to replicating the basic findings of Shapiro et al. (1997), namely that targets that cannot be reported by the participant can still prime subsequent targets that are semantically related, Maki et al. (1997) demonstrated that semantically related distractors, if presented immediately preceding a target, could also prime the target, although distractor priming only lasted for 100 ms, as compared to 400 ms found when a target primed another target. Thus Maki et al.'s (1997) findings further illustrate that even briefly presented distractors are processed semantically and coded implicitly.

The results from electrophysiological experiments support the claims of Shapiro et al. (1997) and Maki et al. (1997). Luck, Vogel, and Shapiro (1996) examined whether the N400 peak, a

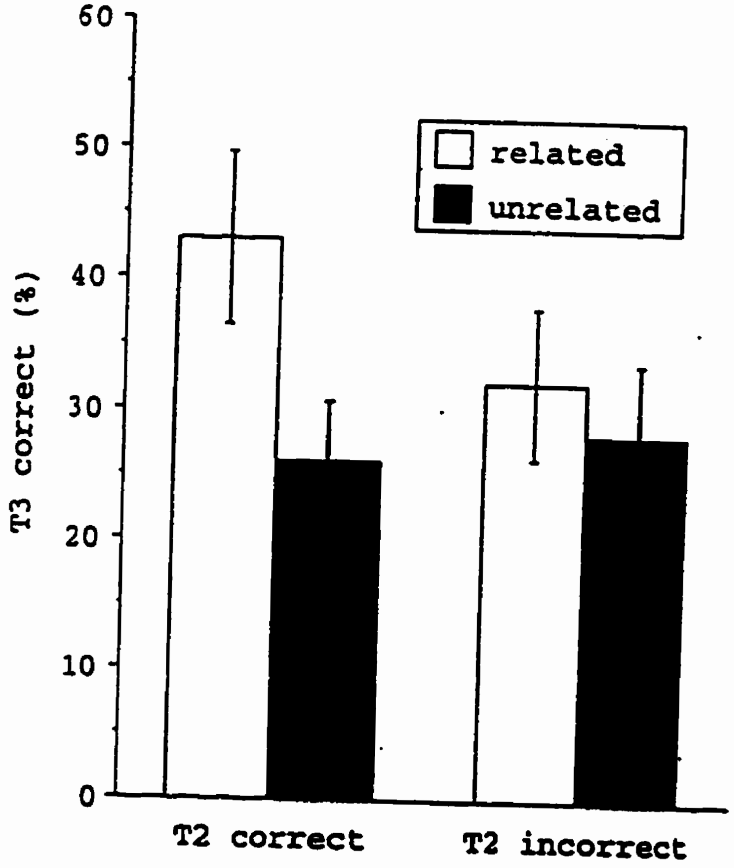


Figure 22. Results from Shapiro, Driver, Ward, & Sorenson (1997, Experiment 2). Proportion of T3s correctly reported across conditions. Even when T2 was reported incorrectly, responses to T3 were still more accurate in the match condition than the mismatch condition.

peak associated with semantic processing, can be elicited during the attentional blink. The N400 peak (which appears 400 ms after the stimulus) is unique in that it is only observed when there is a mismatch between a word and a previously established semantic context (Luck et al., 1996). For example a N400 peak would be produced after the sentence "Giraffes have brown spots and long kettles" but not after the sentence "Giraffes have brown spots and long necks." Because the N400 peak results from semantic processing, a stimulus that evokes an N400 peak must have been processed to semantics. Luck et al. (1996) measured participants' ERPS during trials in an AB experiment which used words as the critical stimuli. At the beginning of each trial participants were presented with a context word (e.g., 'CHAIR') to set the semantic context of the trial. Participants were presented with RSVP streams of twenty seven-character strings of consonants or digits at a rate of one stimulus every 83 ms. The distractors were seven randomly selected consonants presented in blue (e.g., 'GTRWPLK'). T1, which served to produce a 'blink' for T2, was a digit repeated seven times (e.g., '3333333') and T2 was a three to seven letter word presented in red which was either related to the context word (e.g., 'TABLE') or unrelated to the context word (e.g., 'KITE'). T1 was either the first, the seventh or the tenth stimulus in the RSVP stream and T2 was either the third the or seventh string to follow T1. There was both an experimental condition, in which participants reported the identity of T1 and T2 at the end of the trial and a control condition in which participants ignored T1 and only reported T2. ERPs were recorded at fifteen standard electrode sites. Luck et al., (1996) found the typical 'blink' pattern in T2 accuracy for experimental trials, and substantial N400 peaks on unrelated trials in both the experimental and the control conditions. Most importantly, there was no effect of T1-T2 lag on the size of the N400 peaks, indicating that stimuli presented during the blink, indicating which often cannot be reported by the participant, are still processed to semantics. Luck et al.'s (1996) findings were replicated by Vogel, Luck, and Shapiro (1998).

Thus the results from Shapiro et al. (1997), Maki et al. (1997) and Luck et al. (1996) all indicate that complex stimulus information is coded implicitly even when participants possess no explicit code of the stimulus features. In addition, the results indicate that it is the development of explicit codes that is prevented during the attentional blink, implying that the development of explicit codes requires a capacity limited cognitive mechanism. The primary tasks in both the AB paradigms used by Shapiro et al. (1997), Maki et al. (1997), and Luck et al. (1996) and the encoding paradigm used in Experiments 3, 5, and 6 of the present work, are essentially the same; in both paradigms participants must select a stimulus for encoding based on colour or alphanumeric class and must encode it for report at the end of the trial. It is thus reasonable to conclude that the capacity limited cognitive mechanisms involved in target processing in the AB paradigm will also be involved in the encoding task of the encoding paradigm used in Experiments 3, 5, and 6, and thus that the encoding task used in the encoding paradigm also requires a capacity limited cognitive mechanism for the conversion of implicitly coded stimulus information into explicit codes. Because the encoding task in the encoding paradigm interferes with completion of the tone task, the tone task may also be assumed to require this same capacity limited cognitive mechanism for the transformation of implicitly coded tone information into explicit codes.

To account for the results of the present experiments I propose a revised version of Jolicoeur and Dell'Acqua's (1998) Central Interference Theory in which it is assumed that converting implicit codes to explicit codes requires a capacity limited cognitive mechanism that produces a processing bottleneck. One way to modify the model is to modify the definition of short-term consolidation (STC) to include the transformation of implicit codes to explicit codes. Because we also assume that the duration of STC will be directly related to how quickly explicit codes may be formed, the tone difficulty manipulations may be assumed to have their locus at STC; more ambiguous implicit codes formed in the hard tone conditions will take longer to consolidate than a tone with stronger implicitly activated codes (in the easy tone condition). Thus the new model is entirely consistent with the additive effects between the tone difficulty manipulations and SOA found in Experiments 3, 5, and 6.. The model can also account for a wide variety of findings in both the PRP and the AB literatures.

The present model

The present model assumes a similar set of stages as Jolicoeur and Dell'Acqua's (1998) Central Interference Theory (CIT), which are shown in Figure 23. Stimuli are first processed through sensory encoding (SE) and perceptual encoding (PE) which implicitly codes stimulus characteristics up to the level of meaning. At this point stimulus information is not explicitly available to the observer. This assumption is strongly supported by the results of Shapiro et al. (1997), Maki et al. (1997), and Luck et al. (1996), who found that stimuli that could not be reported were coded implicitly to the level of meaning during the attentional blink. It is assumed that explicit coding is required before controlled processes, such as response selection, may be engaged. Selective control (SC) serves to select a subset of the implicit codes to be passed through short-term consolidation (STC) which translates the implicit codes into explicit codes. The results from Experiment 1 imply that the SC stage does not require a capacity limited cognitive mechanism, contrary to the suggestions of Jolicoeur and Dell'Acqua (1998). Selective control may operate on any feature implicitly coding during SE/PE, selectively passing stimuli that meet a preset criteria through short-term consolidation (STC). Short-term consolidation translates the selected subset of the implicit codes into explicit codes, and the output becomes part of short-term memory. Short-term consolidation constitutes a processing bottleneck which postpones STC for subsequent stimuli until STC for the current stimuli has been completed. The duration of STC will depend on the relative strength of the implicit codes being transformed

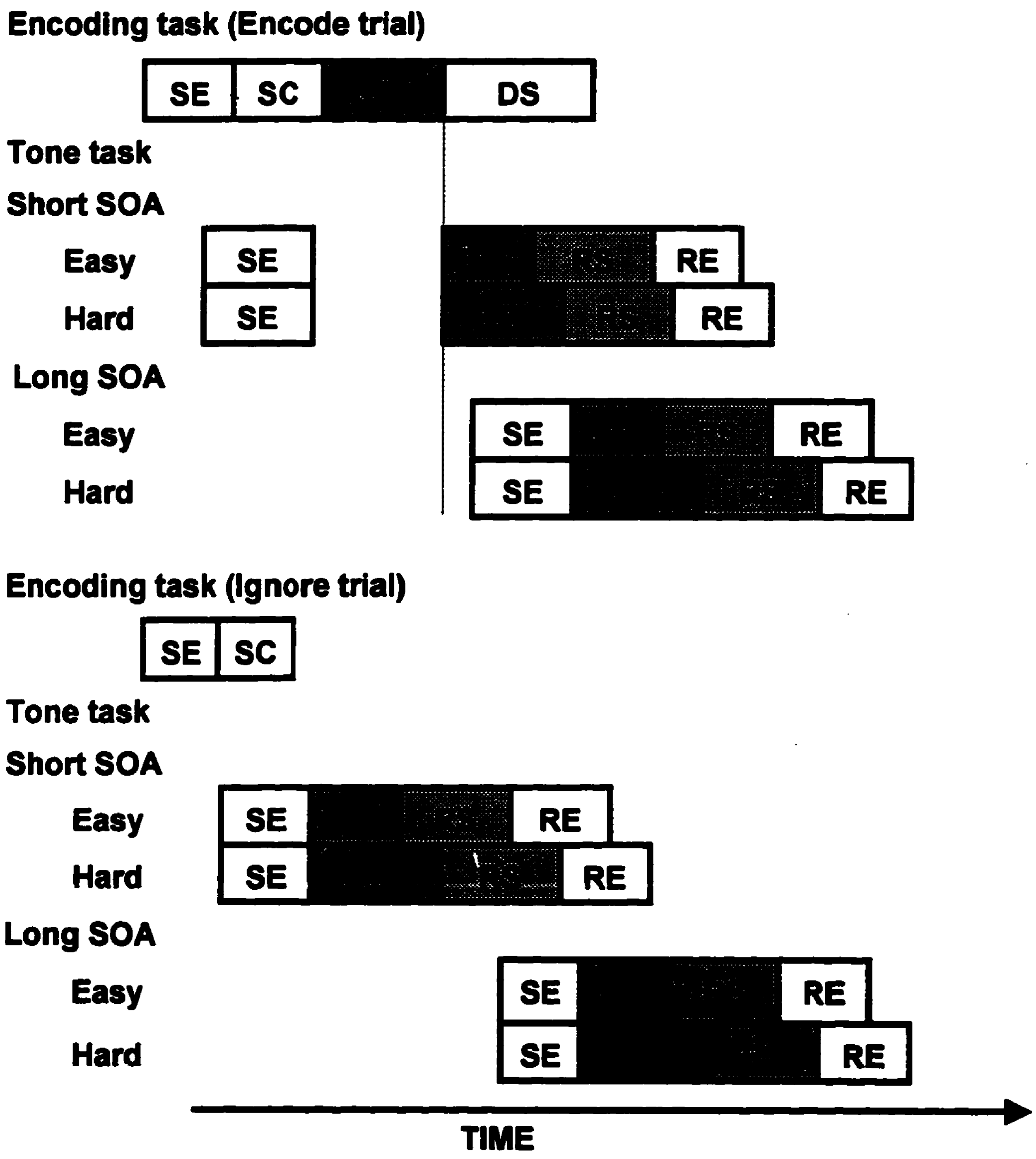


Figure 23. Illustration of the model when applied to the encoding paradigm used in Experiments 3, 5, and 6. The top panel represents the assumed interaction between tasks for an encoding trial. Because the locus of the tone difficulty manipulation is assumed to be at short-term consolidation (STC), the locus of the bottleneck, the tone difficulty manipulation produces additive effects across SOA. No bottleneck on ignore trials (bottom panel) also results in additive effects.

such that more highly activated implicit codes may be translated more quickly than implicit codes with less activation. Thus factors that affect the strength of implicit coding, such as stimulus contrast or loudness, will have their locus at STC. The output of STC becomes part of short-term memory, however active maintenance is necessary for the stimulus to remain part of short-term memory for more than a few seconds. Once a stimulus is coded explicitly, controlled processes may be performed. If it is a speeded task, the output of STC forms the basis for response selection (RS). Response selection also constitutes a processing bottleneck (the 'PRP bottleneck') such that the system can only select a response to one stimulus at a time. After RS is complete, response execution (RE) may be performed. Note that all stimuli whose features must be explicitly known to the participant are assumed to be processed through the bottleneck stage at STC regardless of whether a speeded or unspeeded response is required. Thus this model predicts interference between any two tasks that both require a stimulus to be explicitly coded.

Figure 23 shows the presumed interaction between tasks on an encode trial in the encoding paradigm. The encoding stimulus is presented first. The letters are implicitly coded to the level of meaning in SE and PE. Selective control then selects stimuli matching the pre-set colour criterion for explicit processing. Once selected, the stimulus enters STC and is explicitly coded. While the system is occupied performing STC on the visual stimulus, STC of the tone is postponed. After the completion of STC the visual stimulus is part of short-term memory and may be reported, however ongoing maintenance is required if the delay between encoding and report is more than a few seconds. At short SOAs the tone is presented before STC of the visual stimulus has been completed, and thus STC for the tone is postponed until STC for the visual stimulus has been completed. At long SOAs tone processing may proceed unhindered. As soon as STC is available, STC for the tone takes place and implicit tone features become explicitly available for further processing. Short-term consolidation in the easy tone condition will take less time than STC in the hard tone conditions because tones in the easy condition will have more implicit activation than tones in the hard condition. Because the tone manipulation is affecting a stage at or after the bottleneck, the full extent of processing time differences in the two conditions will be observed in RTs both at short and long SOAs. Thus the model predicts that a tone difficulty manipulation will produce additive effects across SOAs on encode trials. Panel B of Figure 23 shows the presumed interaction between an encoding task and a speeded tone task when participants instead ignores the encoding stimulus. Like on encode trials, the encoding stimulus is implicitly coded up to the level of meaning by SE and PE. However these implicit codes are not selected for explicit coding by SC and simply fade after a few hundred milliseconds. Because no bottleneck is encountered on ignore trials (because STC is not necessary for the ignore task) the tone may be fully processed upon arrival without postponement. The difference in tone RTs in the easy and hard conditions will again be additive, however overall RTs are much faster in the ignore condition than in the encode condition.

The present model and the PRP paradigm

The present model can easily be reconciled with the underadditive interaction between the tone difficulty manipulation and decreasing SOA observed in Experiment 2 and 4 (see Figure 24). The difficulty manipulation produces an underadditive interaction with decreasing SOA because at short SOAs the differences in the duration of STC for the two difficulty manipulations is absorbed in the period of cognitive slack produced by the processing bottleneck at response selection. At longer SOAs both bottlenecks have passed before the presented of the second stimulus and the full extent of durational differences between the two tasks with be reflected in task 2 RTs, and an underadditive interaction between the difficulty manipulation and decreasing SOA is observed. In any dual-task experiment the effect of a difficulty manipulation will always reflect the relationship between the locus of the difficulty manipulation and the *last* processing

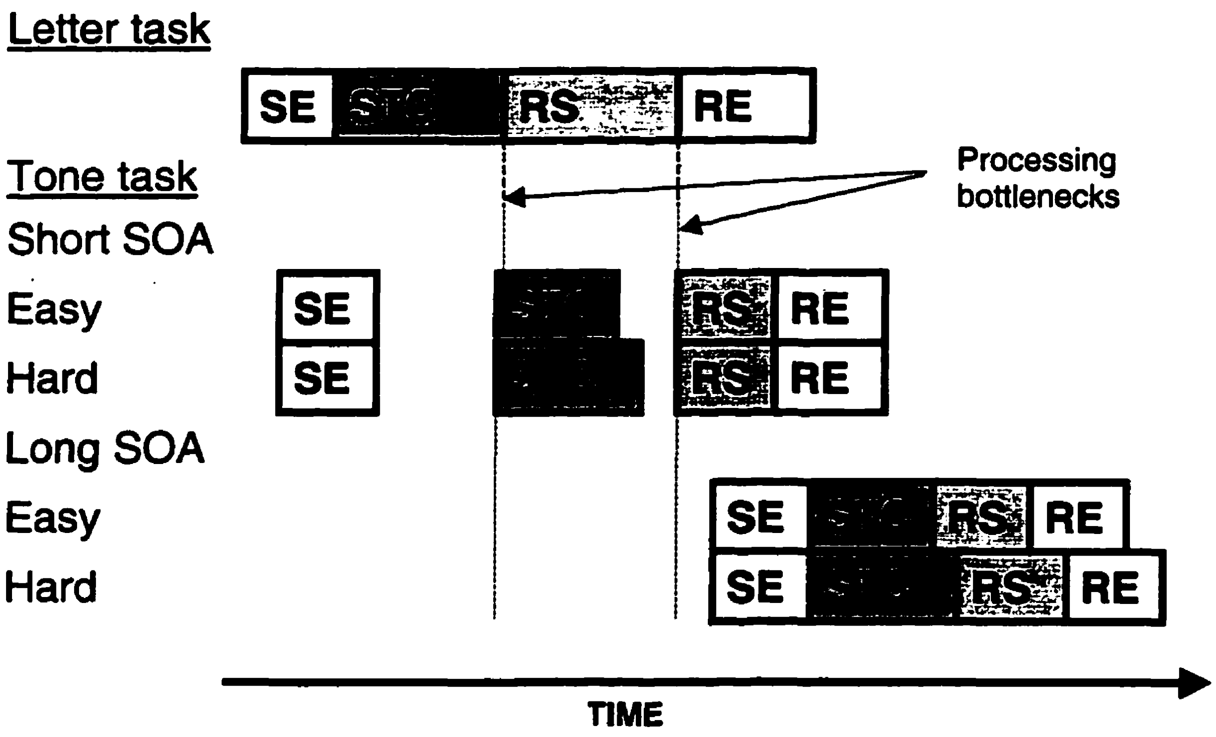
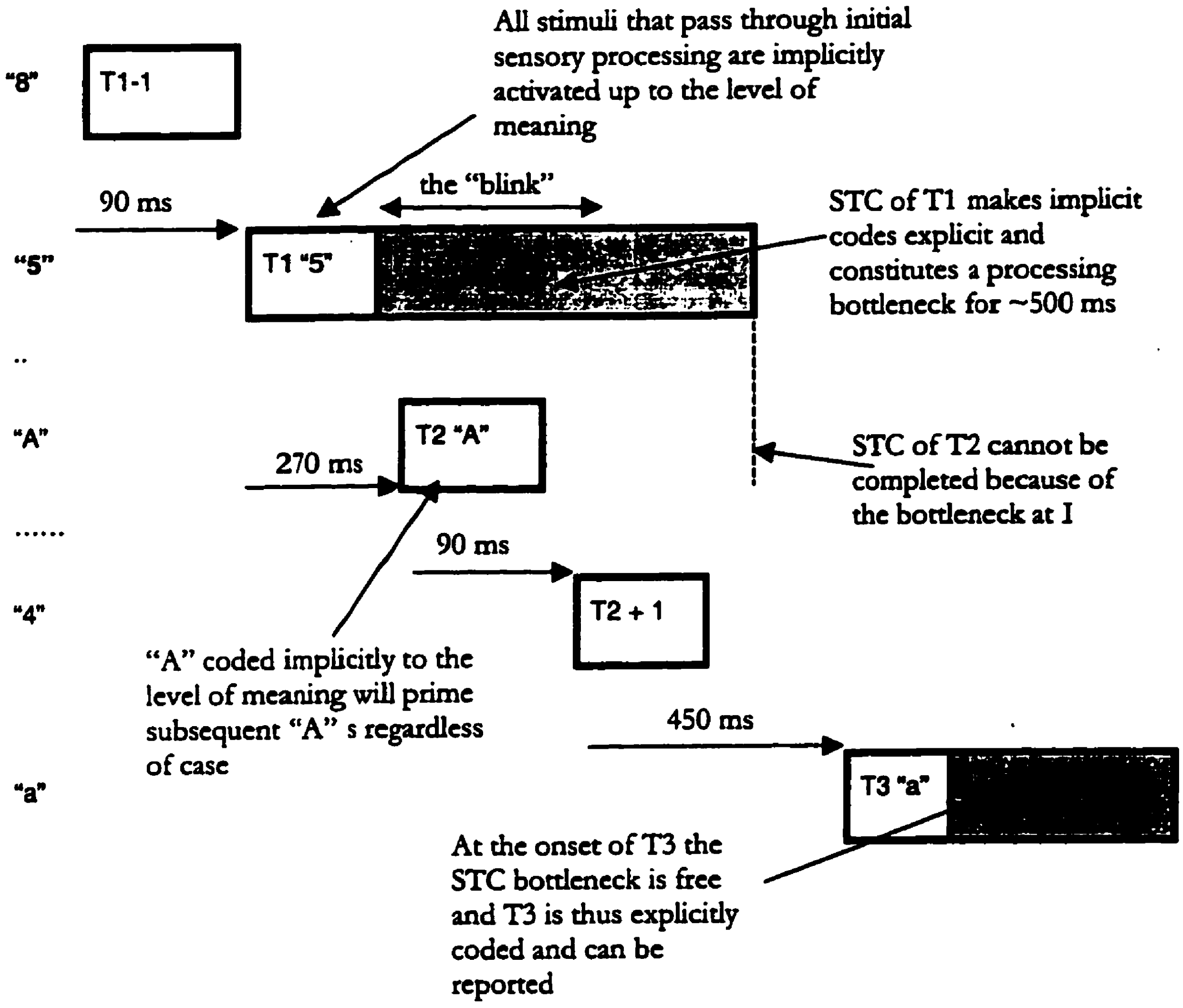


Figure 24. An illustration of the model when applied to the PRP paradigm used in Experiments 2 and 4. Two bottleneck are encountered in the PRP paradigm, one at short-term consolidation (STC) and one at r3esponse selection (RS). The tone difficulty manipulations are assumed to affect STC. At short SOAs, differences in processing time for the easy and hard tone conditions are absorbed into the period of cognitive slack between STC an RS. At long SOAs, both bottlenecks will have passed before the tone is presented and the full extent of processing time differences will be reflected in tone task RTs.. This will result in an underadditive interaction with decreasing SOA.

bottleneck encountered while completing the task. In the PRP paradigm the bottleneck at response selection is always the last bottleneck encountered and thus all manipulations that affect a stage before response selection will produce an underadditive interaction with decreasing SOA, even manipulations such as those in Experiments 2 and 4 which are presumed to affect STC, a stage which produces a processing bottleneck itself. Thus the present model is consistent with the results of Experiments 2 and 4, as well as other results from the PRP literature which show underadditive interactions between pre-response selection factors and decreasing SOA.

The present model and the AB priming paradigm

The revised CIT model is also consistent with the results of Shapiro et al. (1997), Maki et al., (1997), and Luck et al. (1996). An illustration as to how the model can account for the results of Shapiro et al.'s (1997) Experiment 1 is shown in Figure 25. The first few stimuli processed implicitly but are not selected because they do not meet the preset criteria for encoding. Finally, T1 is presented and meets the selection criteria (white digit) and is thus passed to STC for translation into an explicit code and short-term memory. Short-term consolidation produces a processing bottleneck which prevents subsequent stimuli from being translated to explicit codes and be encoded until STC for T1 is complete. This bottleneck is the 'attention blink'. T2 is presented 270 ms after T1. T2 is processed to the level of meaning implicitly, however T1 still occupies STC and thus STC for T2 is prevented and T2 is not coded explicitly and cannot be reported later on. When T3 is presented some 500 ms after T2, the STC bottleneck is free and T3 can be encoded. Previous implicit activation of T3 by a related T2 serves to increase T3 accuracy. At the end of the trial T1 and T3 will have had exclusive access to STC and thus they can be reported. T2, however, was presented while STC was being performed on T1 and thus could not be processed by STC and is not explicitly encoded and consequently cannot be reported.



All stimuli that pass through initial sensory processing are implicitly activated up to the level of meaning

STC of T1 makes implicit codes explicit and constitutes a processing bottleneck for ~500 ms

STC of T2 cannot be completed because of the bottleneck at I

"A" coded implicitly to the level of meaning will prime subsequent "A" s regardless of case

At the onset of T3 the STC bottleneck is free and T3 is thus explicitly coded and can be reported

***Figure 25.** Short-term consolidation (STC) of T1 produces a 'blink' for T2. When T2 is presented features are implicitly coded but cannot be explicitly coded because the system is still performing STC on T1. When T3 is presented, STC is again possible and the stimulus is encoded. Features of T2, although not explicitly available, still prime processing of T3 increasing T3 accuracy when T2 and T3 are semantically related.*

Can RS postpone STC (and vice versa)?

In the present model both short-term consolidation (STC) and response selection (RS) are assumed to constitute processing bottlenecks. One question concerns the extent to which the capacity limited cognitive mechanisms involved in RS and STC are related to one another. Jolicoeur (1998) posits, in an adaptation of CIT to fit AB models, that RS in one task can postpone STC in another. Jolicoeur's (1998) argument for the postponement of STC by RS is based on the results of several AB paradigm experiments which showed larger attentional blinks when T1 was speeded than when T1 was unspeeded (T2 was always unspeeded). Jolicoeur (1998) asserts that because an unspeeded T2 can be affected by requiring RS in T1, RS in T1 must somehow interact with STC in T2. However the combined results of Experiments 2 to 6 of the present work imply that STC and RS produce independent bottlenecks, as a very different pattern in task 2 RTs are observed when both STC and RS are required (underadditive interactions with decreasing SOA in Experiments 2 and 4) compared to when only STC was required (additive effects in Experiments 3, 5, and 6). As is shown in Figure 26, if STC and RS required the same capacity limited cognitive mechanism additive effects of the tone manipulation are predicted in *both* the PRP paradigm experiments and the encoding paradigm experiments, however our PRP paradigm experiments produced highly significant underadditive interactions with decreasing SOA. When the results from Jolicoeur (1998) are carefully examined it appears as though requiring a speeded response to T1 produces a deeper (although not longer) attentional blink. This result indicates that requiring a speeded response to T1 reduced the likelihood of detecting T2 considerably without affecting the duration of the interference. If RS produced additional stage of postponement, however, then the duration of the attentional blink should have been increased. A plausible explanation of the effect of RS on the attentional blink may be that maintaining response mappings in a speeded task reduces processing efficiency at short

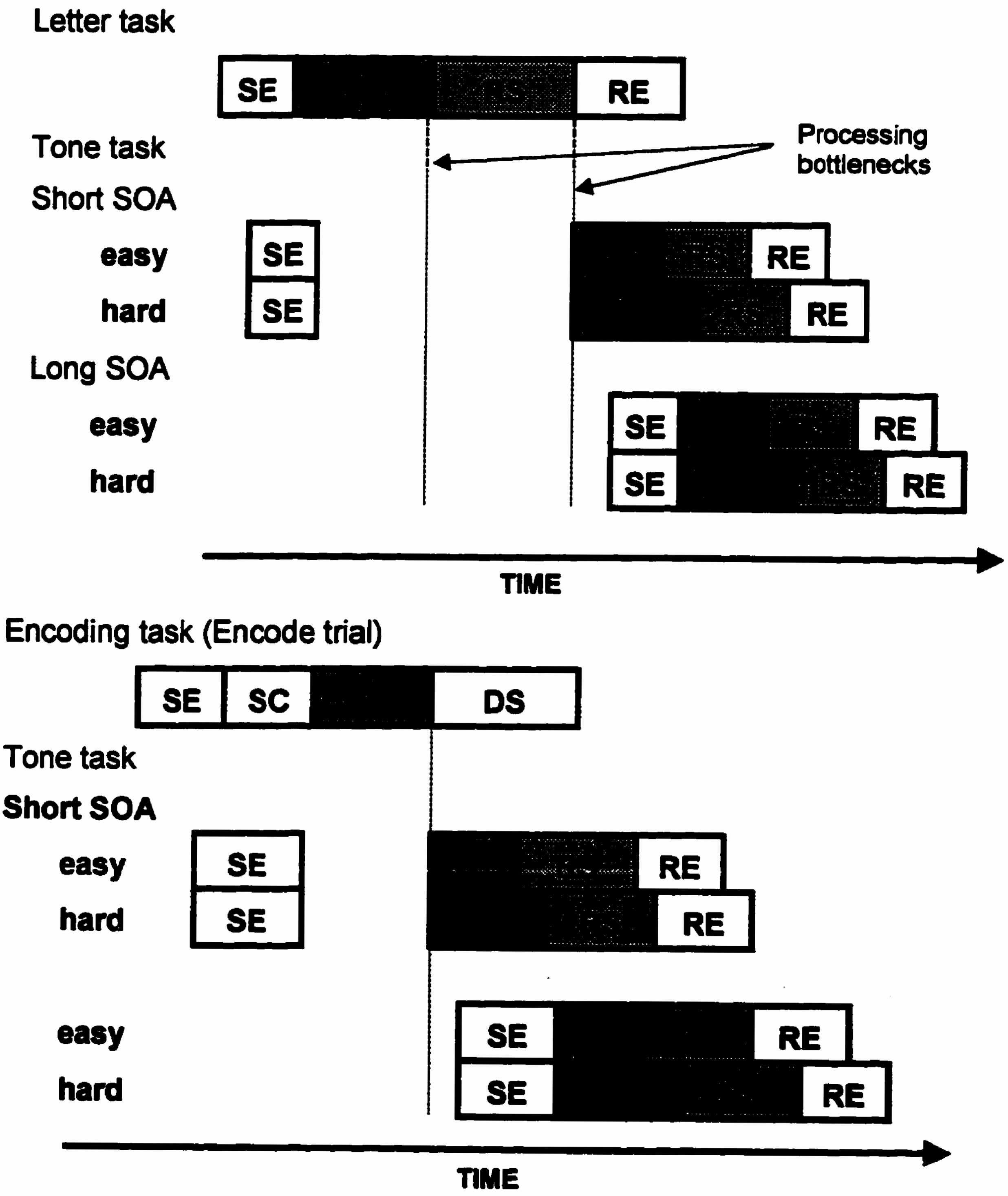


Figure 26. The predicted outcome in a PRP paradigm experiment (top) and an encoding paradigm experiment (bottom) if response selection (RS) could postpone short-term consolidation (STC). The tone manipulation produces additive effects in both paradigms. This prediction is inconsistent with the results of Experiments 2 and 4 which show underadditive interactions in PRP paradigm experiments.

SOAs which results in a general decrease in the likelihood of detecting T2. This argument is supported by a wide variety of dual-task experiments which show mild but consistent interference resulting from increasing the complexity of task preparation (e.g. De Jong, 1993). For the moment we thus maintain that STC and RS require separate capacity limited cognitive mechanisms.

What produces the effect of SOA on ignore trials?

Experiment 1 was designed to determine whether the decision to encode or ignore the stimulus (selective control) produced the significant effect of SOA on ignore trials in Jolicoeur and Dell'Acqua (1998, Experiment 4). As is shown in Figure 10, trials that required online selection ('Select' trials), did not take longer or produce more interference with the tone task than trials where no online selection was required ("Control' trials), indeed 'Select' trials were an average of 10 ms faster than 'Control' trials. This result implies that selection based on colour does not produce postponement, and thus cannot be responsible for the effect of SOA on ignore trials. In addition, even in 'Control' blocks when the decision to encode or ignore was not made on line there was still a significant effect of SOA on ignore trials. This finding strongly suggests that the effect of SOA observed on ignore trials in Jolicoeur and Dell'Acqua (1998, Experiment 4), as well as in the encoding paradigm experiments in this thesis, was not the result of a capacity limited cognitive mechanism being involved in selective control. When Jolicoeur and Dell'Acqua (1998, Experiment 7) blocked encode and ignore trials, the effect of SOA on ignore trials was eliminated. Because the effect of SOA on ignore trials is dependent upon having to perform an encode/ignore task in conjunction with a tone task, it is plausible that the effect of SOA on ignore trials results from having to switch between two different sets of task requirements. There is ample empirical evidence which indicates that switching between tasks can have significant effects on performance (see Rogers & Monsell, 1995).

Implications for our understanding of the relationship between the PRP effect and the AB effect

For a number of years after the attentional blink was first observed, researchers typically assumed that the attentional blink and the PRP effect were unrelated. This conclusion was not wholly unfounded as evidence at that time suggested that the PRP effect occurred solely as the result of a processing bottleneck at response selection, and thus was apparently not relevant to the results of AB paradigm experiments which had always used unspeeded responses. More recent work, however, has found a number of commonalties between the pattern in interference resulting from the AB paradigm and the PRP paradigm. In addition, the results from the experiments reported here suggest that the same bottleneck stage of processing, STC, is required for both the unspeeded tasks used in the AB paradigm and the speeded tasks used in the PRP paradigm.

A final word regarding the issue of selective control

Thus far the present model has been applied to paradigms where the decision to encode or ignore a stimulus is based on highly learned categorical feature of the stimulus, such as the stimulus' colour or its alphanumeric class. In these situations the model predicts that the decision to encode or ignore may be completed by selective control (SC) because the selection feature will be coded by sensory encoding (SE) and perceptual encoding (PE). However if the selection criterion is sufficiently complex, the stimulus may need to pass through short-term consolidation (STC) before the selection feature may be classified. For example, if participants were asked to encode numbers whose name starts with a consonant (e.g. '3', 21') and asked to ignore numbers whose name starts with a vowel (e.g. '1', '18') selective control per se may not be possible, as short-term consolidation (STC) of the number may be needed before the participant would be able to determine if the number's name started with a consonant or a vowel. Because both to-be-encoded and to-be-ignored stimuli will require STC in complex selection situations, the model predicts that a complex selection criterion will produce more similar interference in ignore trials and encode trials than a highly learned selection criterion. However encode trials will likely still show more interference, particularly at long SOAs, because of the capacity demands of maintaining stimuli for later report. The model thus predicts that in complex selection criterion situations irrelevant stimuli (e.g. stimuli that do not need to be encoded) may not be ignored. It may be interesting to test this prediction empirically.

Conclusions

The present series of experiments explored the nature and extent of dual-task interference during encoding. It was found that the same task 2 difficulty manipulations that produced underadditive interactions with decreasing SOA in the PRP paradigm experiments produced additive effects in the encoding paradigm experiments. Because there is no converging evidence for a capacity sharing account of this interference (there was never an effect of SOA on task 1 accuracy in the encoding paradigm experiments), these results are interpreted as evidence for a processing bottleneck at a stage after the completion of rudimentary perceptual processing but before the onset of response selection. In the present model it is proposed that this bottleneck affects short-term consolidation, the stage which translates implicit stimulus codes into explicit form. Because it is assumed that a stimulus must be consolidated to be accessible in short-term memory and available for the application of controlled processing, the present model predicts that a vast number of cognitive tasks will be susceptible to producing or being postponed by this processing bottleneck in dual-task situations.

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Appendix A

Table 1. *Task 2 response times (RTs) and proportions correct for Experiment 1.*

SOA (ms)		300	400	500	600	800	1000	Mean
Control blocks								
RT (ms)	Encode 3	850.02	753.75	700.51	748.95	657.66	526.23	706.19
	Encode 2	670.37	572.02	565.44	582.43	496.11	469.10	559.24
	Encode 1	663.29	505.99	516.31	514.64	452.90	429.33	513.74
	Ignore 3	500.39	448.26	444.43	436.26	392.81	395.76	436.32
	Ignore 2	534.83	455.16	463.46	431.04	404.17	396.67	447.56
	Ignore 1	501.54	438.67	440.81	448.23	420.67	395.44	440.90
Proportion correct	Encode 3	0.938	0.962	0.969	0.988	0.992	0.992	0.974
	Encode 2	0.992	0.992	0.977	0.993	0.983	0.984	0.987
	Encode 1	0.984	0.975	0.966	0.988	0.992	0.973	0.980
	Ignore 3	0.979	0.984	0.987	0.938	0.969	0.973	0.972
	Ignore 2	0.992	0.945	0.993	0.972	1.000	0.973	0.979
	Ignore 1	0.992	0.969	0.961	0.977	0.984	0.977	0.977
Selection blocks								
RT (ms)	Encode 3	863.17	738.40	626.80	695.10	604.20	492.35	670.00
	Encode 2	644.18	568.17	533.58	523.86	467.55	454.01	531.89
	Encode 1	567.87	488.09	488.96	517.29	436.01	436.53	489.13
	Ignore 3	510.01	428.15	420.21	436.58	392.39	402.14	431.58
	Ignore 2	472.70	437.48	438.64	413.79	391.86	411.45	427.65
	Ignore 1	512.83	432.71	433.82	431.94	381.89	381.16	429.06
Proportion correct	Encode 3	0.993	0.982	0.993	0.964	0.980	0.951	0.977
	Encode 2	0.982	0.960	0.984	0.988	0.988	0.946	0.975
	Encode 1	0.979	0.984	0.961	0.961	0.980	0.984	0.975
	Ignore 3	0.982	0.980	0.989	0.961	0.980	1.000	0.982
	Ignore 2	0.977	0.990	0.977	0.996	0.955	0.974	0.978
	Ignore 1	0.978	0.968	0.956	0.972	0.977	0.974	0.971

Table 2. *Task 1 proportions correct for Experiment 1.*

SOA (ms)		300	400	500	600	800	1000	Mean
Proportion Correct	Control 1	0.762	0.985	0.775	0.868	0.988	0.899	0.880
	Control 2	0.923	0.915	0.969	0.872	0.866	0.929	0.912
	Control 3	0.863	0.946	0.986	0.973	0.981	0.950	0.950
	Select 1	0.988	0.982	0.812	0.994	0.898	0.986	0.943
	Select 2	0.926	0.986	0.915	0.889	0.925	0.979	0.936
	Select 3	0.819	0.928	0.982	0.923	0.811	0.911	0.896
	Mean	0.880	0.957	0.906	0.920	0.911	0.942	

Table 3. *Task 2 response times (RTs) and proportions correct for Experiment 2.*

SOA (ms)		50	111	245	542	1200	Mean
RT (ms)	Easy	762.68	698.63	611.82	506.65	428.08	601.57
	Hard	767.52	723.00	655.38	618.15	495.51	651.91
	Mean	765.10	710.81	633.60	562.40	461.80	
Proportion Correct	Easy	0.928	0.927	0.924	0.928	0.882	0.918
	Hard	0.907	0.888	0.891	0.876	0.889	0.890
	Mean	0.917	0.907	0.907	0.902	0.885	

Table 4. *Task 1 response times and proportions correct for Experiment 2.*

SOA (ms)		50	111	245	542	1200	Mean
RT (ms)	Easy	542.83	548.33	566.44	591.28	651.18	580.01
	Hard	535.44	538.70	564.84	589.95	643.86	574.56
	Mean	539.13	543.52	565.64	590.61	647.52	
Proportion Correct	Easy	0.958	0.959	0.977	0.977	0.968	0.968
	Hard	0.969	0.968	0.969	0.971	0.977	0.971
	Mean	0.963	0.964	0.973	0.974	0.972	

Table 5. *Task 2 response times (RTs) and proportions correct for Experiment 3.*

SOA (ms)		200	261	395	692	1350	Mean
RT (ms)	Encode 3 hard	1150.91	1111.28	1040.42	929.08	724.92	955.55
	Encode 3 easy	1076.42	1053.93	962.05	833.25	641.91	913.40
	Encode 1 hard	884.59	828.35	786.57	786.26	688.33	758.68
	Encode 1 easy	804.63	746.19	722.73	662.34	631.54	719.79
	Ignore 3 hard	857.68	838.34	696.34	689.58	635.80	698.74
	Ignore 3 easy	709.24	667.68	632.63	564.86	536.48	676.49
	Ignore 1 hard	852.08	797.14	722.50	742.56	630.32	716.06
	Ignore 1 easy	664.66	658.98	639.62	622.85	585.75	392.65
Proportion correct	Encode 3 hard	0.953	0.957	0.976	0.960	0.980	0.972
	Encode 3 easy	0.981	0.973	0.973	0.985	0.989	0.981
	Encode 1 hard	0.985	0.972	0.980	0.992	0.985	0.980
	Encode 1 easy	0.980	0.977	0.992	0.980	0.980	0.986
	Ignore 3 hard	0.972	0.966	0.977	0.992	0.989	0.979
	Ignore 3 easy	0.985	0.981	0.981	0.996	0.985	0.976
	Ignore 1 hard	0.969	0.966	0.965	0.962	0.972	0.975
	Ignore 1 easy	0.963	0.972	0.977	0.988	0.988	0.583

Table 6. *Task 1 proportions correct for Experiment 3.*

SOA (ms)		200	261	395	692	1350	Mean
Proportion correct	Encode 3 hard	0.943	0.925	0.953	0.954	0.941	0.943
	Encode 3 easy	0.932	0.937	0.937	0.952	0.947	0.941
	Encode 1 hard	0.988	0.979	0.988	0.976	0.983	0.983
	Encode 1 easy	0.976	0.985	0.992	0.977	0.992	0.984
	Mean	0.960	0.956	0.968	0.965	0.966	

Table 7. *Task 2 response times (RTs) and proportions correct for Experiment 4.*

SOA (ms)		50	111	245	542	1200	Mean
RT (ms)	Easy	545.93	537.01	551.45	563.47	583.50	556.27
	Hard	526.54	537.74	552.72	580.98	559.92	551.58
	Mean	536.24	537.37	552.09	572.23	571.71	
Proportion Correct	Easy	0.949	0.968	0.977	0.972	0.977	0.969
	Hard	0.961	0.971	0.973	0.973	0.979	0.971
	Mean	0.955	0.969	0.975	0.972	0.978	

Table 8. *Task 1 response times (RTs) and proportions correct for Experiment 4.*

SOA (ms)		50	111	245	542	1200	Mean
RT (ms)	Easy	545.93	537.01	551.45	563.47	583.50	556.27
	Hard	526.54	537.74	552.72	580.98	559.92	551.58
	Mean	536.24	537.37	552.09	572.23	571.71	
Proportion Correct	Easy	0.949	0.968	0.977	0.972	0.977	0.969
	Hard	0.961	0.971	0.973	0.973	0.979	0.971
	Mean	0.955	0.969	0.975	0.972	0.978	

Table 9. *Task 2 response times (RTs) and proportions correct for Experiment 5.*

SOA (ms)		200	261	395	692	1350	Mean
RT (ms)	Encode hard	937.26	911.23	882.95	794.31	734.61	852.07
	Encode easy	772.70	755.30	687.26	586.30	521.17	664.55
	Ignore hard	715.80	705.22	724.43	681.45	604.52	686.28
	Ignore easy	555.72	517.20	494.79	458.99	444.01	494.14
Proportion correct	Encode hard	0.795	0.851	0.787	0.803	0.856	0.818
	Encode easy	0.991	0.997	0.991	0.997	0.994	0.994
	Ignore hard	0.777	0.804	0.842	0.766	0.804	0.798
	Ignore easy	0.991	0.988	0.991	0.984	0.994	0.990

Table 10. *Task 1 proportions correct for Experiment 5.*

SOA (ms)		200	261	395	692	1350	Mean
Proportion correct	Encode 3 hard	0.933	0.936	0.935	0.941	0.935	0.936
	Encode 3 easy	0.921	0.931	0.938	0.928	0.926	0.929
	Mean	0.927	0.933	0.936	0.935	0.930	

Table 11. *Task 2 response times and proportions correct for Experiment 6.*

SOA (ms)		50	111	245	542	1200	Mean
RT (ms)	Encode 3 hard	817.48	784.33	794.65	682.19	623.05	740.34
	Encode 3 easy	755.88	686.54	717.79	654.31	541.07	671.12
	Encode 1 hard	754.26	753.21	653.05	582.68	598.39	668.32
	Encode 1 easy	679.92	632.13	593.94	519.17	504.66	585.97
	Ignore 3 hard	635.15	620.88	582.21	568.72	547.80	590.95
	Ignore 3 easy	574.37	572.47	522.68	463.91	507.47	528.18
	Ignore 1 hard	664.17	610.39	599.37	552.30	542.10	593.67
	Ignore 1 easy	567.11	573.33	521.61	485.63	479.51	525.44
Proportion correct		50	111	245	542	1200	Mean
	Encode 3 hard	0.983	0.958	0.975	0.950	0.950	0.963
	Encode 3 easy	0.975	0.992	0.975	0.933	0.975	0.970
	Encode 1 hard	0.975	0.950	0.942	0.967	0.950	0.957
	Encode 1 easy	0.967	0.967	0.975	0.983	0.992	0.977
	Ignore 3 hard	0.958	0.958	0.942	0.983	0.942	0.957
	Ignore 3 easy	0.967	0.942	0.992	0.975	0.975	0.970
	Ignore 1 hard	0.950	0.975	0.967	0.958	0.925	0.955
	Ignore 1 easy	0.983	1.000	1.000	0.975	0.983	0.988

Table 12. *Task 1 proportion correct for Experiment 6.*

SOA (ms)		50	111	245	542	1200	Mean
Proportion correct	Encode 3 hard	0.933	0.892	0.929	0.929	0.933	0.923
	Encode 3 easy	0.896	0.917	0.925	0.900	0.917	0.911
	Encode 1 hard	0.996	0.996	0.996	0.992	1.000	0.996
	Encode 1 easy	0.996	1.000	0.992	0.992	1.000	0.996
	Mean	0.955	0.951	0.960	0.953	0.963	

Experiment 1: Mean response times for the tone task (task 2)

```
model is
-->  sj   ( 16 )
     soa   ( 6 )
     blktype   ( 2 )
     rem_ny   ( 2 )
     nlet   ( 3 )

KEY:
      soa       (1) = 300 (2) = 400 (3) = 500 (4) = 600 (5) = 800 (6) = 1000
      blktype   (1) = Control (2) = Select
      rem_ny    (1) = ignore (2) = encode
      nlet      (1) = 1 (2) = 2 (3) = 3

soa  ( 6 )
   607.60064   522.23680   506.08087   515.00898   458.18469   432.51231

blktype   ( 2 )
   517.32365   496.55111

soa  ( 6 )
blktype   ( 2 )
   620.07470   528.97458   521.82735   526.92603   470.71906   435.42020
   595.12658   515.49901   490.33438   503.09193   445.65032   429.60441

rem_ny   ( 2 )
   435.50931   578.36545

soa  ( 6 )
rem_ny   ( 2 )
   505.38400   440.07145   440.22811   432.97335   397.29768   397.10125
   709.81728   604.40214   571.93362   597.04461   519.07170   467.92336

blktype   ( 2 )
rem_ny   ( 2 )
   441.58952   429.42909
   593.05778   563.67312

soa  ( 6 )
blktype   ( 2 )
rem_ny   ( 2 )
   512.25504   447.36585   449.56717   438.51166   405.88294   395.95449
   498.51297   432.77706   430.88904   427.43504   388.71243   398.24802
   727.89436   610.58332   594.08752   615.34040   535.55518   474.88591
   691.74019   598.22095   549.77972   578.74881   502.58822   460.96081

nlet   ( 3 )
   468.20642   491.58445   561.02127

soa  ( 6 )
nlet   ( 3 )
   561.38463   466.36492   469.97730   478.02561   422.87119   410.61486
   580.51781   508.20633   500.27840   487.77865   439.92104   432.80450
   680.89949   592.13914   547.98690   579.22267   511.76185   454.11756

blktype   ( 2 )
```

```
nlet   ( 3 )
   477.32000   459.09284
   503.39875   479.77016
   571.25221   550.79032

soa   ( 6 )
blktype   ( 2 )
nlet   ( 3 )
   582.41754   472.32932   478.56430   481.43471   436.78795   412.38616
   540.35171   460.40052   461.39029   474.61652   408.95443   408.84356
   602.59882   513.58992   514.45061   506.73363   450.13783   432.88170
   558.43679   502.82274   486.10619   468.82366   429.70424   432.72731
   675.20774   601.00452   572.46713   592.60975   525.23140   460.99275
   686.59124   583.27375   523.50667   565.83560   498.29230   447.24237

rem_ny   ( 2 )
nlet   ( 3 )
   434.97728   501.43555
   437.60264   545.56627
   433.94800   688.09453

soa   ( 6 )
rem_ny   ( 2 )
nlet   ( 3 )
   507.18750   435.68977   437.31808   440.08743   401.28404   388.29688
   615.58175   497.04007   502.63651   515.96380   444.45833   432.93285
   503.76319   446.31964   451.04901   422.41276   398.01283   404.05841
   657.27242   570.09302   549.50779   553.14453   481.82924   461.55060
   505.20132   438.20495   432.31723   436.41987   392.59617   398.94847
   856.59766   746.07333   663.65657   722.02548   630.92753   509.28664

blktype   ( 2 )
rem_ny   ( 2 )
nlet   ( 3 )
   440.89518   429.05939
   513.74482   489.12629
   447.55503   427.65025
   559.24247   531.89006
   436.31836   431.57764
   706.18607   670.00300

soa   ( 6 )
blktype   ( 2 )
rem_ny   ( 2 )
nlet   ( 3 )
   501.54100   438.67083   440.81362   448.23289   420.67411   395.43862
   512.83400   432.70871   433.82254   431.94196   381.89397   381.15513
   663.29408   505.98780   516.31499   514.63653   452.90179   429.33371
   567.86942   488.09234   488.95804   517.29107   436.01488   436.53199
   534.82928   455.16384   463.46245   431.03757   404.16964   396.66741
   472.69710   437.47545   438.63557   413.78795   391.85603   411.44940
   670.36836   572.01600   565.43876   582.42969   496.10603   469.09598
   644.17649   568.17004   533.57682   523.85938   467.55246   454.00521
   500.39483   448.26287   444.42545   436.26451   392.80506   395.75744
   510.00781   428.14702   420.20902   436.57522   392.38728   402.13951
   850.02065   753.74617   700.50882   748.95499   657.65774   526.22805
   863.17467   738.40048   626.80432   695.09598   604.19732   492.34524
```

```
soa  ( 6 )
   DF        SS                  MS
    5     3523001.179520         704600.235904
   75     7166427.299777         95552.363997
F(5,75) = 7.373970   p <= 0.000011    ****

blktype  ( 2 )
   DF        SS                  MS
    1     124271.641116          124271.641116
   15     130227.415242          8681.827683
F(1,15) = 14.313995   p <= 0.001803    ****

soa  ( 6 )
blktype  ( 2 )
   DF        SS                  MS
    5     20982.890772           4196.578154
   75     347389.396187          4631.858616
F(5,75) = 0.906025   p <= 0.481832

rem_ny  ( 2 )
   DF        SS                  MS
    1     5877468.779594         5877468.779594
   15     1772866.972700         118191.131513
F(1,15) = 49.728509   p <= 0.000004    ****

soa  ( 6 )
rem_ny  ( 2 )
   DF        SS                  MS
    5     502112.358396          100422.471679
   75     1536702.038947         20489.360519
F(5,75) = 4.901201   p <= 0.000619    ****

blktype  ( 2 )
rem_ny  ( 2 )
   DF        SS                  MS
    1     21360.550964           21360.550964
   15     80363.479153           5357.565277
F(1,15) = 3.986988   p <= 0.064332

soa  ( 6 )
blktype  ( 2 )
rem_ny  ( 2 )
   DF        SS                  MS
    5     6572.156266            1314.431253
   75     355191.124004          4735.881653
F(5,75) = 0.277547   p <= 0.924061

nlet  ( 3 )
   DF        SS                  MS
    2     1789772.837809         894886.418904
   30     954861.844958          31828.728165
F(2,30) = 28.115683   p <= 0.000000    ****

soa  ( 6 )
nlet  ( 3 )
   DF        SS                  MS
```

```
   10     205131.287130        20513.128713
  150     1138998.445012        7593.322967
F(10,150) = 2.701469   p <= 0.004492    ****

blktype   ( 2 )
nlet  ( 3 )
   DF        SS                MS
    2     1414.322455        707.161227
   30     93228.285487        3107.609516
F(2,30) = 0.227558   p <= 0.797838

soa   ( 6 )
blktype   ( 2 )
nlet  ( 3 )
   DF        SS                MS
   10     49132.701326        4913.270133
  150     635712.754774        4238.085032
F(10,150) = 1.159314   p <= 0.322749

rem_ny   ( 2 )
nlet  ( 3 )
   DF        SS                MS
    2     1866208.632332        933104.316166
   30     904858.851235        30161.961708
F(2,30) = 30.936460   p <= 0.000000    ****

soa   ( 6 )
rem_ny   ( 2 )
nlet  ( 3 )
   DF        SS                MS
   10     197743.281510        19774.328151
  150     991875.901201        6612.506008
F(10,150) = 2.990444   p <= 0.001819    ****

blktype   ( 2 )
rem_ny   ( 2 )
nlet  ( 3 )
   DF        SS                MS
    2     7619.134143        3809.567072
   30     184516.373372        6150.545779
F(2,30) = 0.619387   p <= 0.545016

soa   ( 6 )
blktype   ( 2 )
rem_ny   ( 2 )
nlet  ( 3 )
   DF        SS                MS
   10     74429.664290        7442.966429
  150     860548.571858        5736.990479
F(10,150) = 1.297364   p <= 0.236797

-------------------- END ----------------
```

Experiment 1: Mean response times for IGNORE trials (task 2)

```
model is
-->  sj  ( 16 )
     blktype  ( 2 )
     soa  ( 6 )
     nlet  ( 3 )

KEY:
      soa       (1) = 300 (2) = 400 (3) = 500 (4) = 600 (5) = 800 (6) = 1000
      blktype   (1) = Control (2) = Select
      rem_ny    (1) = ignore (2) = encode
      nlet      (1) = 1 (2) = 2 (3) = 3

blktype  ( 2 )
   439.53661   431.48201

soa  ( 6 )
   475.38335   462.97401   426.62439   410.74474   422.76083   414.56853

blktype  ( 2 )
soa  ( 6 )
   475.69260   475.07409
   461.56877   464.37924
   433.89923   419.34955
   420.36496   401.12453
   430.22718   415.29448
   415.46692   413.67014

nlet  ( 3 )
   434.97728   437.60264   433.94800

blktype  ( 2 )
nlet  ( 3 )
   435.50739   434.44717
   446.84865   428.35663
   436.25379   431.64221

soa  ( 6 )
nlet  ( 3 )
   474.88694   472.38798   429.67247   407.30134   418.12612   407.48884
   482.93343   443.24252   429.66674   414.66574   430.06493   425.04249
   468.32967   473.29152   420.53397   410.26715   420.09144   411.17426

blktype  ( 2 )
soa  ( 6 )
nlet  ( 3 )
   461.74189   488.03199
   478.49025   466.28571
   432.68646   426.65848
   407.85268   406.75000
   425.55320   410.69903
   406.71987   408.25781
   487.68326   478.18359
   440.14464   446.34040
   459.18348   400.15000
   420.12388   409.20759
```

```
   442.94382   417.18604
   431.01280   419.07217
   477.65264   459.00670
   466.07143   480.51161
   409.82775   431.24018
   433.11830   387.41600
   422.18452   417.99836
   408.66810   413.68043

blktype   ( 2 )
   DF        SS                MS
    1      9342.237763        9342.237763
   15      202448.640467        13496.576031
F(1,15) = 0.692193    p <= 0.418468

soa   ( 6 )
   DF        SS                MS
    5      349201.343136        69840.268627
   75      444334.273367        5924.456978
F(5,75) = 11.788468    p <= 0.000000     ****

blktype   ( 2 )
soa   ( 6 )
   DF        SS                MS
    5      10250.941399        2050.188280
   75      307004.248614        4093.389982
F(5,75) = 0.500853    p <= 0.774668

nlet   ( 3 )
   DF        SS                MS
    2      1363.731811        681.865905
   30      133434.270259        4447.809009
F(2,30) = 0.153304    p <= 0.858537

blktype   ( 2 )
nlet   ( 3 )
   DF        SS                MS
    2      8146.339415        4073.169708
   30      107002.255348        3566.741845
F(2,30) = 1.141986    p <= 0.332671

soa   ( 6 )
nlet   ( 3 )
   DF        SS                MS
   10      31526.256237        3152.625624
  150      470744.011138        3138.293408
F(10,150) = 1.004567    p <= 0.442268

blktype   ( 2 )
soa   ( 6 )
nlet   ( 3 )
   DF        SS                MS
   10      42544.522645        4254.452265
  150      750020.911916        5000.139413
F(10,150) = 0.850867    p <= 0.580667

--------------------- END -----------------
```

Experiment 1: Mean proportions correct for the tone task (task 2)

```
model is
-->  sj  ( 16 )
     blktype  ( 2 )
     soa  ( 6 )
     rem_ny  ( 2 )
     nlet  ( 3 )

KEY:
      soa       (1) = 300 (2) = 400 (3) = 500 (4) = 600 (5) = 800 (6) = 1000
      blktype   (1) = Control (2) = Select
      rem_ny    (1) = ignore (2) = encode
      nlet      (1) = 1 (2) = 2 (3) = 3

blktype  ( 2 )
     0.97796     0.97635

soa  ( 6 )
     0.98079     0.97429     0.97621     0.97476     0.98176     0.97512

blktype  ( 2 )
soa  ( 6 )
     0.97971     0.98186
     0.97134     0.97724
     0.97560     0.97681
     0.97576     0.97377
     0.98676     0.97677
     0.97859     0.97165

rem_ny  ( 2 )
     0.97638     0.97793

blktype  ( 2 )
rem_ny  ( 2 )
     0.97576     0.97700
     0.98016     0.97570

soa  ( 6 )
rem_ny  ( 2 )
     0.98332     0.97272     0.97728     0.96912     0.97742     0.97843
     0.97826     0.97587     0.97514     0.98040     0.98610     0.97181

blktype  ( 2 )
soa  ( 6 )
rem_ny  ( 2 )
     0.98778     0.97885
     0.96621     0.97923
     0.98039     0.97417
     0.96187     0.97638
     0.98438     0.97046
     0.97396     0.98291
     0.97164     0.98487
     0.97648     0.97526
     0.97082     0.97946
     0.98965     0.97115
     0.98914     0.98307
```

```
     0.98322     0.96040

nlet   ( 3 )
     0.97555     0.97977     0.97614

blktype   ( 2 )
nlet   ( 3 )
     0.97821     0.97289
     0.98309     0.97646
     0.97258     0.97970

soa   ( 6 )
nlet   ( 3 )
     0.98343     0.97410     0.96102     0.97424     0.98340     0.97711
     0.98579     0.97168     0.98307     0.98730     0.98148     0.96932
     0.97315     0.97711     0.98453     0.96274     0.98040     0.97893

blktype   ( 2 )
soa   ( 6 )
nlet   ( 3 )
     0.98828     0.97857
     0.97219     0.97600
     0.96360     0.95843
     0.98208     0.96641
     0.98828     0.97852
     0.97483     0.97938
     0.99219     0.97938
     0.96875     0.97461
     0.98524     0.98090
     0.98230     0.99230
     0.99152     0.97145
     0.97852     0.96013
     0.95867     0.98763
     0.97309     0.98112
     0.97796     0.99110
     0.96289     0.96259
     0.98047     0.98034
     0.98242     0.97545

rem_ny   ( 2 )
nlet   ( 3 )
     0.97364     0.97745
     0.97863     0.98091
     0.97686     0.97542

blktype   ( 2 )
rem_ny   ( 2 )
nlet   ( 3 )
     0.97659     0.97070
     0.97983     0.97507
     0.97913     0.97814
     0.98704     0.97479
     0.97157     0.98216
     0.97360     0.97725

soa   ( 6 )
rem_ny   ( 2 )
```

```
nlet  ( 3 )
     0.98499     0.96828     0.95843     0.97422     0.98047     0.97548
     0.98186     0.97991     0.96360     0.97427     0.98633     0.97873
     0.98438     0.96745     0.98524     0.98393     0.97731     0.97349
     0.98720     0.97591     0.98090     0.99067     0.98566     0.96515
     0.98058     0.98242     0.98816     0.94922     0.97448     0.98633
     0.96571     0.97179     0.98090     0.97626     0.98633     0.97154

blktype   ( 2 )
soa   ( 6 )
rem_ny   ( 2 )
nlet  ( 3 )
     0.99219     0.97780
     0.96894     0.96763
     0.96094     0.95592
     0.97656     0.97188
     0.98438     0.97656
     0.97656     0.97439
     0.98438     0.97935
     0.97545     0.98438
     0.96627     0.96094
     0.98760     0.96094
     0.99219     0.98047
     0.97309     0.98438
     0.99219     0.97656
     0.94531     0.98958
     0.99306     0.97743
     0.97154     0.99632
     1.00000     0.95461
     0.97266     0.97433
     0.99219     0.98220
     0.99219     0.95964
     0.97743     0.98438
     0.99306     0.98828
     0.98303     0.98828
     0.98438     0.94593
     0.97896     0.98220
     0.98438     0.98047
     0.98717     0.98915
     0.93750     0.96094
     0.96875     0.98021
     0.97266     1.00000
     0.93837     0.99306
     0.96181     0.98177
     0.96875     0.99306
     0.98828     0.96424
     0.99219     0.98047
     0.99219     0.95089

blktype   ( 2 )
   DF        SS                MS
    1      0.000745          0.000745
   15      0.181066          0.012071
F(1,15) = 0.061750    p <= 0.807121

soa   ( 6 )
   DF        SS                MS
```

```
    5      0.010246          0.002049
   75      0.214369          0.002858
F(5,75) = 0.716944    p <= 0.612685

blktype   ( 2 )
soa   ( 6 )
   DF        SS                MS
    5      0.008505          0.001701
   75      0.223031          0.002974
F(5,75) = 0.572034    p <= 0.721171

rem_ny   ( 2 )
   DF        SS                MS
    1      0.000691          0.000691
   15      0.056620          0.003775
F(1,15) = 0.182948    p <= 0.674929

blktype   ( 2 )
rem_ny   ( 2 )
   DF        SS                MS
    1      0.002332          0.002332
   15      0.056431          0.003762
F(1,15) = 0.619945    p <= 0.443332

soa   ( 6 )
rem_ny   ( 2 )
   DF        SS                MS
    5      0.013065          0.002613
   75      0.243621          0.003248
F(5,75) = 0.804425    p <= 0.550078

blktype   ( 2 )
soa   ( 6 )
rem_ny   ( 2 )
   DF        SS                MS
    5      0.034561          0.006912
   75      0.220694          0.002943
F(5,75) = 2.348994    p <= 0.048953        ****

nlet   ( 3 )
   DF        SS                MS
    2      0.004019          0.002009
   30      0.152434          0.005081
F(2,30) = 0.395452    p <= 0.676834

blktype   ( 2 )
nlet   ( 3 )
   DF        SS                MS
    2      0.011056          0.005528
   30      0.091434          0.003048
F(2,30) = 1.813828    p <= 0.180455

soa   ( 6 )
nlet   ( 3 )
   DF        SS                MS
   10      0.047887          0.004789
  150      0.411646          0.002744
```

```
F(10,150) = 1.744954   p <= 0.075695

blktype  ( 2 )
soa  ( 6 )
nlet  ( 3 )
   DF        SS              MS
   10      0.022578         0.002258
  150      0.382440         0.002550
F(10,150) = 0.885570   p <= 0.548214

rem_ny  ( 2 )
nlet  ( 3 )
   DF        SS              MS
    2      0.001400         0.000700
   30      0.044569         0.001486
F(2,30) = 0.471299   p <= 0.628734

blktype  ( 2 )
rem_ny  ( 2 )
nlet  ( 3 )
   DF        SS              MS
    2      0.001907         0.000954
   30      0.081307         0.002710
F(2,30) = 0.351857   p <= 0.706245

soa  ( 6 )
rem_ny  ( 2 )
nlet  ( 3 )
   DF        SS              MS
   10      0.016474         0.001647
  150      0.567792         0.003785
F(10,150) = 0.435218   p <= 0.927308

blktype  ( 2 )
soa  ( 6 )
rem_ny  ( 2 )
nlet  ( 3 )
   DF        SS              MS
   10      0.055517         0.005552
  150      0.379743         0.002532
F(10,150) = 2.192936   p <= 0.021071    ****

--------------------- END ----------------
```

Experiment 1: Mean proportions correct for the encode task (task 1)

```
model is
-->    sj     (16)
       blktype(2)
       soa    (6)
       nlet   (3)

KEY:
       soa       (1) = 300 (2) = 400 (3) = 500 (4) = 600 (5) = 800 (6) = 1000
       blktype   (1) = Control (2) = Select
       rem_ny    (1) = ignore (2) = encode
       nlet      (1) = 1 (2) = 2 (3) = 3

blktype(2)
       0.9138      0.9256

soa(6)
       0.8802      0.957       0.9064      0.9197      0.9112      0.9424

blktype(2)
soa    (6)
       0.8494      0.911
       0.9485      0.9655
       0.9099      0.903
       0.9044      0.9351
       0.9446      0.8779
       0.9263      0.9586

nlet   (3)
       0.9115      0.9243      0.9227

blktype(2)
nlet   (3)
       0.8796      0.9434
       0.9121      0.9364
       0.9498      0.8957

soa    (6)
nlet   (3)
       0.8752      0.9635      0.7937      0.9312      0.9436      0.9425
       0.9242      0.9505      0.9417      0.88        0.8953      0.965
       0.8411      0.9369      0.9839      0.9479      0.8958      0.9308

blktype(2)
soa    (6)
nlet   (3)
       0.7623      0.9861
       0.9849      0.982
       0.7757      0.8121
       0.8683      0.9941
       0.9875      0.8978
       0.8991      0.986
       0.9228      0.9255
       0.9147      0.9864
       0.9688      0.9145
       0.8715      0.8886
```

```
     0.8656     0.925
     0.9294     0.9785
     0.863      0.8193
     0.9458     0.928
     0.9856     0.9822
     0.9733     0.9225
     0.9807     0.8109
     0.9503     0.9112

blktype     (2)
     DF     SS     MS
     1      1.846 1.846
     15     87.29 5.81
"F(1,15)"   =      0.317213     p     <=     0.581609

soa   (6)
     DF     SS     MS
     5      3567.163917 713.432783
     75     36573.06529 487.640871
"F(5,75)"   =      1.463029     p     <=     0.212049

blktype(2)
soa   (6)
     DF     SS     MS
     5      2350.021468 470.004294
     75     29346.04524 391.280603
"F(5,75)"   =      1.201195     p     <=     0.316916

nlet  (3)
     DF     SS     MS
     2      187.991688  93.995844
     30     6771.804939 225.726831
"F(2,30)"   =      0.416414     p     <=     0.66316

blktype(2)
nlet  (3)
     DF     SS     MS
     2      3457.594638 1728.797319
     30     10326.33299 344.2111
"F(2,30)"   =      5.022491     p     <=     0.01314      ****

soa   (6)
nlet  (3)
     DF     SS     MS
     10     9037.489504 903.74895
     150    102874.4398 685.829598
"F(10,150)" =      1.317746     p     <=     0.225764

blktype(2)
soa   (6)
nlet  (3)
     DF     SS     MS
     10     4672.061531 467.206153
     150    77472.42286 516.482819
"F(10,150)" =      0.904592     p     <=     0.53066

--------------------   END   ----------------
```

Experiment 2: Mean response times for the letter task (task 1)

```
model is
-->  sj  ( 10 )
     vollh  ( 2 )
     soa  ( 5 )

KEY:
vollh   (1) = quiet (2) = loud
soa     (1) = 50 (2) = 111 (3) = 245 (4) = 542 (5) = 1200


vollh  ( 2 )
   574.55888   580.01037

soa  ( 5 )
   539.13322   543.51686   565.64117   590.61494   647.51695

vollh  ( 2 )
soa  ( 5 )
   535.44042   542.82602
   538.70365   548.33006
   564.83792   566.44443
   589.95368   591.27619
   643.85873   651.17516

vollh  ( 2 )
   DF       SS                MS
    1     742.968553        742.968553
    9     8199.327613        911.036401
F(1,9) = 0.815520   p <= 0.390023

soa  ( 5 )
   DF       SS                MS
    4     156832.756387        39208.189097
   36     788995.835219        21916.550978
F(4,36) = 1.788976   p <= 0.152445

vollh  ( 2 )
soa  ( 5 )
   DF       SS                MS
    4     282.405266        70.601316
   36     23459.918741        651.664409
F(4,36) = 0.108340   p <= 0.978846

-------------------- END ----------------
```

Experiment 2: Mean proportions correct for the tone task (task 2)

```
model is
-->  sj  ( 10 )
     vollh  ( 2 )
     soa  ( 5 )

KEY:
vollh   (1) = quiet (2) = loud
soa     (1) = 50 (2) = 111 (3) = 245 (4) = 542 (5) = 1200

vollh   ( 2 )
     0.89009     0.91769

soa   ( 5 )
     0.91736     0.90731     0.90743     0.90201     0.88535

vollh   ( 2 )
soa   ( 5 )
     0.90674     0.92799
     0.88796     0.92666
     0.89062     0.92424
     0.87615     0.92787
     0.88899     0.88171

vollh   ( 2 )
   DF        SS               MS
    1      0.019049         0.019049
    9      0.119090         0.013232
F(1,9) = 1.439550    p <= 0.260842

soa   ( 5 )
   DF        SS               MS
    4      0.011058         0.002765
   36      0.090570         0.002516
F(4,36) = 1.098866    p <= 0.372001

vollh   ( 2 )
soa   ( 5 )
   DF        SS               MS
    4      0.009991         0.002498
   36      0.082506         0.002292
F(4,36) = 1.089851    p <= 0.376198

--------------------- END ----------------
```

Experiment 2: Mean proportions correct for the letter task (task 1)

```
model is
-->  sj  ( 10 )
     vollh  ( 2 )
     soa  ( 5 )

KEY:
vollh  (1) = quiet (2) = loud
soa    (1) = 50 (2) = 111 (3) = 245 (4) = 542 (5) = 1200

vollh  ( 2 )
     0.97072     0.96787

soa  ( 5 )
     0.96350     0.96392     0.97307     0.97377     0.97221

vollh  ( 2 )
soa  ( 5 )
     0.96915     0.95784
     0.96841     0.95942
     0.96869     0.97745
     0.97076     0.97678
     0.97659     0.96784

vollh  ( 2 )
   DF       SS               MS
    1     0.000203         0.000203
    9     0.003358         0.000373
F(1,9) = 0.545003   p <= 0.479174

soa  ( 5 )
   DF       SS               MS
    4     0.002107         0.000527
   36     0.027803         0.000772
F(4,36) = 0.682080   p <= 0.608952

vollh  ( 2 )
soa  ( 5 )
   DF       SS               MS
    4     0.001789         0.000447
   36     0.014439         0.000401
F(4,36) = 1.115030   p <= 0.364576

--------------------- END ----------------
```

Experiment 3: Mean response times for the tone task (task 2)

```
model is
-->  sj   ( 22 )
     soa   ( 5 )
     nlet   ( 2 )
     rem_ny   ( 2 )
     vollh   ( 2 )

KEY:
     soa      (1) = 200 (2) = 261 (3) = 395 (4) = 692 (5) = 1350
     nlet     (1) = 1 (2) = 3
     rem_ny   (1) = ignore (2) = encode

soa   ( 5 )
   875.02581   837.73571   775.35773   728.84804   634.38262

nlet   ( 2 )
   722.89974   817.64023

soa   ( 5 )
nlet   ( 2 )
   801.48977   757.66359   717.85592   703.50426   633.98515
   948.56184   917.80782   832.85954   754.19183   634.78009

rem_ny   ( 2 )
   687.25529   853.28468

soa   ( 5 )
rem_ny   ( 2 )
   770.91466   740.53466   672.77280   654.96309   597.09123
   979.13696   934.93675   877.94267   802.73300   671.67401

nlet   ( 2 )
rem_ny   ( 2 )
   691.64678   682.86380
   754.15270   952.41665

soa   ( 5 )
nlet   ( 2 )
rem_ny   ( 2 )
   758.36975   728.05882   681.05824   682.70770   608.03938
   783.45956   753.01050   664.48736   627.21848   586.14308
   844.60979   787.26837   754.65360   724.30083   659.93092
  1113.66412  1082.60514  1001.23173   881.16518   683.41711

vollh   ( 2 )
   819.65325   720.88671

soa   ( 5 )
vollh   ( 2 )
   936.31309   893.77748   811.45918   786.87206   669.84445
   813.73852   781.69393   739.25629   670.82403   598.92079

      123          112       72                 126                 73 ms

nlet   ( 2 )
```

```
vollh   ( 2 )
   771.87014   867.43637
   673.92934   767.84408

soa   ( 5 )
nlet   ( 2 )
vollh   ( 2 )
   868.33245   812.74219   754.53748   764.41346   659.32509
  1004.29373   974.81277   868.38088   809.33066   680.36381
   734.64709   702.58499   681.17437   642.59506   608.64521
   892.82996   860.80288   797.33821   699.05300   589.19637

rem_ny   ( 2 )
vollh   ( 2 )
   746.23582   893.07069
   628.27476   813.49867

soa   ( 5 )
rem_ny   ( 2 )
vollh   ( 2 )
   854.87871   817.74077   709.42274   716.07221   633.06466
  1017.74747   969.81419   913.49562   857.67191   706.62425
   686.95060   663.32855   636.12287   593.85397   561.11780
   940.52645   900.05931   842.38972   747.79409   636.72378

nlet   ( 2 )
rem_ny   ( 2 )
vollh   ( 2 )
   748.92135   743.55028
   794.81892   991.32245
   634.37220   622.17731
   713.48648   913.51086

soa   ( 5 )
nlet   ( 2 )
rem_ny   ( 2 )
vollh   ( 2 )
   852.07961   797.13664   722.50106   742.56474   630.32470
   857.67780   838.34490   696.34442   689.57968   635.80461
   884.58528   828.34775   786.57390   786.26219   688.32548
  1150.90965  1111.28063  1040.41733   929.08163   724.92301
   664.65988   658.98099   639.61543   622.85065   585.75406
   709.24132   667.67610   632.63030   564.85728   536.48154
   804.63430   746.18898   722.73331   662.33946   631.53636
  1076.41860  1053.92965   962.04612   833.24873   641.91120

soa   ( 5 )
   DF        SS                    MS
    4      6288909.997566          1572227.499392
   84      2704411.055389          32195.369707
F(4,84) = 48.833963    p <= 0.000000     ****

nlet   ( 2 )
   DF        SS                    MS
    1      1974667.153044          1974667.153044
   21      1292543.255946          61549.678855
F(1,21) = 32.082493    p <= 0.000013     ****
```

```
soa   ( 5 )
nlet   ( 2 )
   DF          SS                    MS
    4      800503.653977          200125.913494
   84      1744435.593786          20767.090402
F(4,84) = 9.636685    p <= 0.000002     ****

rem_ny   ( 2 )
   DF          SS                    MS
    1      6064466.941889          6064466.941889
   21      2640696.167295          125747.436538
F(1,21) = 48.227360    p <= 0.000001     ****

soa   ( 5 )
rem_ny   ( 2 )
   DF          SS                    MS
    4      563777.239776          140944.309944
   84      1291868.470607          15379.386555
F(4,84) = 9.164495    p <= 0.000003     ****

nlet   ( 2 )
rem_ny   ( 2 )
   DF          SS                    MS
    1      2357763.776863          2357763.776863
   21      1359596.031851          64742.668183
F(1,21) = 36.417464    p <= 0.000005     ****

soa   ( 5 )
nlet   ( 2 )
rem_ny   ( 2 )
   DF          SS                    MS
    4      381541.882031          95385.470508
   84      1119879.032254          13331.893241
F(4,84) = 7.154683    p <= 0.000052     ****

vollh   ( 2 )
   DF          SS                    MS
    1      2146062.384493          2146062.384493
   21      4431604.925689          211028.805985
F(1,21) = 10.169523    p <= 0.004415     ****

soa   ( 5 )
vollh   ( 2 )
   DF          SS                    MS
    4      111041.406298          27760.351575
   84      1227734.851821          14615.891093
F(4,84) = 1.899327    p <= 0.118109

nlet   ( 2 )
vollh   ( 2 )
   DF          SS                    MS
    1      150.008399          150.008399
   21      250391.494152          11923.404483
F(1,21) = 0.012581    p <= 0.911758

soa   ( 5 )
```

```
nlet   ( 2 )
vollh   ( 2 )
   DF        SS                 MS
    4     25001.032676         6250.258169
   84     1034495.889589         12315.427257
F(4,84) = 0.507515   p <= 0.730313

rem_ny   ( 2 )
vollh   ( 2 )
   DF        SS                 MS
    1     81054.534139         81054.534139
   21     173906.501849         8281.261993
F(1,21) = 9.787703   p <= 0.005078    ****

soa   ( 5 )
rem_ny   ( 2 )
vollh   ( 2 )
   DF        SS                 MS
    4     90060.683944         22515.170986
   84     948952.720707         11297.056199
F(4,84) = 1.993012   p <= 0.102979

nlet   ( 2 )
rem_ny   ( 2 )
vollh   ( 2 )
   DF        SS                 MS
    1     1471.419049         1471.419049
   21     173731.805828         8272.943135
F(1,21) = 0.177859   p <= 0.677505

soa   ( 5 )
nlet   ( 2 )
rem_ny   ( 2 )
vollh   ( 2 )
   DF        SS                 MS
    4     19029.201220         4757.300305
   84     781234.821887         9300.414546
F(4,84) = 0.511515   p <= 0.727406

--------------------- END -----------------
```

Experiment 3: Mean response times for the tone task (ENCODE trials)

```
model is
-->  sj   ( 22 )
     soa   ( 5 )
     nlet   ( 2 )
     vollh   ( 2 )

KEY:
     soa      (1) = 200 (2) = 261 (3) = 395 (4) = 692 (5) = 1350
     nlet     (1) = 1 (2) = 3
     rem_ny   (1) = ignore (2) = encode

soa   ( 5 )
   979.13696   934.93675   877.94267   802.73300   671.67401

nlet   ( 2 )
   754.15270   952.41665

soa   ( 5 )
nlet   ( 2 )
   844.60979   787.26837   754.65360   724.30083   659.93092
  1113.66412  1082.60514  1001.23173   881.16518   683.41711

vollh   ( 2 )
   893.07069   813.49867

soa   ( 5 )
vollh   ( 2 )
  1017.74747   969.81419   913.49562   857.67191   706.62425
   940.52645   900.05931   842.38972   747.79409   636.72378

nlet   ( 2 )
vollh   ( 2 )
   794.81892   991.32245
   713.48648   913.51086

soa   ( 5 )
nlet   ( 2 )
vollh   ( 2 )
   884.58528   828.34775   786.57390   786.26219   688.32548
  1150.90965  1111.28063  1040.41733   929.08163   724.92301
   804.63430   746.18898   722.73331   662.33946   631.53636
  1076.41860  1053.92965   962.04612   833.24873   641.91120

soa   ( 5 )
   DF        SS                 MS
    4     5161356.548979         1290339.137245
   84     2233120.331913         26584.765856
F(4,84) = 48.536788    p <= 0.000000     ****

nlet   ( 2 )
   DF        SS                 MS
    1     4323945.449175         4323945.449175
   21     2248690.242479         107080.487737
F(1,21) = 40.380330    p <= 0.000003     ****
```

```
soa   ( 5 )
nlet   ( 2 )
   DF        SS                 MS
    4     1078657.041841        269664.260460
   84     1813372.740453         21587.770720
F(4,84) = 12.491529    p <= 0.000000     ****

vollh   ( 2 )
   DF        SS                 MS
    1     696487.617841        696487.617841
   21     1744044.861483        83049.755309
F(1,21) = 8.386390    p <= 0.008644     ****

soa   ( 5 )
vollh   ( 2 )
   DF        SS                 MS
    4     26082.295391         6520.573848
   84     1107558.205108        13185.216727
F(4,84) = 0.494537    p <= 0.739749

nlet   ( 2 )
vollh   ( 2 )
   DF        SS                 MS
    1     340.899701         340.899701
   21     200757.021698         9559.858176
F(1,21) = 0.035659    p <= 0.852033

soa   ( 5 )
nlet   ( 2 )
vollh   ( 2 )
   DF        SS                 MS
    4     12490.841246         3122.710312
   84     1049493.332310        12493.968242
F(4,84) = 0.249937    p <= 0.908946

--------------------- END -----------------
```

Experiment 3: Mean response times for the tone task (IGNORE trials)

```
model is
-->  sj   ( 22 )
     soa   ( 5 )
     nlet   ( 2 )
     vollh   ( 2 )

KEY:
     soa      (1)  = 200  (2)  = 261  (3)  = 395  (4)  = 692  (5)  = 1350
     nlet     (1)  = 1  (2)  = 3
     rem_ny   (1)  = ignore  (2)  = encode

soa   ( 5 )
   770.91466    740.53466    672.77280    654.96309    597.09123

nlet   ( 2 )
   691.64678    682.86380

soa   ( 5 )
nlet   ( 2 )
   758.36975    728.05882    681.05824    682.70770    608.03938
   783.45956    753.01050    664.48736    627.21848    586.14308

vollh   ( 2 )
   746.23582    628.27476

soa   ( 5 )
vollh   ( 2 )
   854.87871    817.74077    709.42274    716.07221    633.06466
   686.95060    663.32855    636.12287    593.85397    561.11780

nlet   ( 2 )
vollh   ( 2 )
   748.92135    743.55028
   634.37220    622.17731

soa   ( 5 )
nlet   ( 2 )
vollh   ( 2 )
   852.07961    797.13664    722.50106    742.56474    630.32470
   857.67780    838.34490    696.34442    689.57968    635.80461
   664.65988    658.98099    639.61543    622.85065    585.75406
   709.24132    667.67610    632.63030    564.85728    536.48154

soa   ( 5 )
   DF        SS                 MS
    4     1691330.688363          422832.672091
   84     1763159.194083          20989.990406
F(4,84) = 20.144491    p <= 0.000000     ****

nlet   ( 2 )
   DF        SS                 MS
    1     8485.480732         8485.480732
   21     403449.045317         19211.859301
F(1,21) = 0.441679    p <= 0.513545
```

```
soa   ( 5 )
nlet   ( 2 )
   DF        SS                 MS
    4     103388.494167        25847.123542
   84     1050941.885587        12511.212924
F(4,84) = 2.065917    p <= 0.092514

vollh   ( 2 )
   DF        SS                 MS
    1     1530629.300792        1530629.300792
   21     2861466.566054        136260.312669
F(1,21) = 11.233126    p <= 0.003022    ****

soa   ( 5 )
vollh   ( 2 )
   DF        SS                 MS
    4     175019.794851        43754.948713
   84     1069129.367420        12727.730565
F(4,84) = 3.437765    p <= 0.011858    ****

nlet   ( 2 )
vollh   ( 2 )
   DF        SS                 MS
    1     1280.527746        1280.527746
   21     223366.278281        10636.489442
F(1,21) = 0.120390    p <= 0.732065

soa   ( 5 )
nlet   ( 2 )
vollh   ( 2 )
   DF        SS                 MS
    4     31539.392650        7884.848162
   84     766237.379166        9121.873561
F(4,84) = 0.864389    p <= 0.488871

-------------------- END ----------------
```

Experiment 3: Mean proportions correct for the tone task (task 2)

```
model is
-->  sj  ( 22 )
     soa  ( 5 )
     nlet  ( 2 )
     rem_ny  ( 2 )
     vollh  ( 2 )

KEY:
     soa     (1) = 200 (2) = 261 (3) = 395 (4) = 692 (5) = 1350
     nlet    (1) = 1 (2) = 3
     rem_ny  (1) = ignore (2) = encode
     vollh   (1) = quiet  (2) = loud

soa  ( 5 )
     0.97347     0.97047     0.97760     0.98196     0.98336

nlet  ( 2 )
     0.97730     0.97745

soa  ( 5 )
nlet  ( 2 )
     0.97434     0.97176     0.97844     0.98054     0.98139
     0.97261     0.96918     0.97676     0.98339     0.98533

rem_ny  ( 2 )
     0.97720     0.97755

soa  ( 5 )
rem_ny  ( 2 )
     0.97217     0.97107     0.97478     0.98459     0.98337
     0.97478     0.96987     0.98042     0.97934     0.98335

nlet  ( 2 )
rem_ny  ( 2 )
     0.97224     0.98216
     0.98236     0.97275

soa  ( 5 )
nlet  ( 2 )
rem_ny  ( 2 )
     0.96607     0.96901     0.97090     0.97503     0.98017
     0.97827     0.97314     0.97865     0.99415     0.98657
     0.98261     0.97452     0.98598     0.98605     0.98261
     0.96694     0.96522     0.97486     0.97262     0.98409

vollh  ( 2 )
     0.97343     0.98131

soa  ( 5 )
vollh  ( 2 )
     0.96977     0.96522     0.97441     0.97650     0.98127
     0.97718     0.97572     0.98079     0.98743     0.98545

nlet  ( 2 )
vollh  ( 2 )
```

```
     0.97475     0.97212
     0.97985     0.98278

soa   ( 5 )
nlet   ( 2 )
vollh   ( 2 )
     0.97710     0.96901     0.97242     0.97676     0.97844
     0.96243     0.96143     0.97641     0.97624     0.98409
     0.97158     0.97452     0.98447     0.98433     0.98433
     0.98278     0.97693     0.97710     0.99053     0.98657

rem_ny   ( 2 )
vollh   ( 2 )
     0.97278     0.97408
     0.98161     0.98102

soa   ( 5 )
rem_ny   ( 2 )
vollh   ( 2 )
     0.97052     0.96556     0.97056     0.97693     0.98034
     0.96901     0.96488     0.97827     0.97607     0.98220
     0.97382     0.97658     0.97899     0.99225     0.98640
     0.98054     0.97486     0.98258     0.98261     0.98450

nlet   ( 2 )
rem_ny   ( 2 )
vollh   ( 2 )
     0.96665     0.97891
     0.98284     0.96533
     0.97782     0.98540
     0.98187     0.98017

soa   ( 5 )
nlet   ( 2 )
rem_ny   ( 2 )
vollh   ( 2 )
     0.96935     0.96556     0.96453     0.96178     0.97204
     0.97169     0.96556     0.97658     0.99208     0.98864
     0.98485     0.97245     0.98030     0.99174     0.98485
     0.95317     0.95730     0.97624     0.96040     0.97955
     0.96279     0.97245     0.97727     0.98829     0.98829
     0.98485     0.98072     0.98072     0.99621     0.98450
     0.98037     0.97658     0.99167     0.98037     0.98037
     0.98072     0.97314     0.97348     0.98485     0.98864

soa   ( 5 )
   DF        SS                MS
    4     0.021085          0.005271
   84     0.211330          0.002516
F(4,84) = 2.095238   p <= 0.088601

nlet   ( 2 )
   DF        SS                MS
    1     0.000005          0.000005
   21     0.037479          0.001785
F(1,21) = 0.003004   p <= 0.956807
```

```
soa   ( 5 )
nlet   ( 2 )
   DF         SS                 MS
    4       0.001585           0.000396
   84       0.144714           0.001723
F(4,84)  = 0.229963    p <= 0.920850

rem_ny    ( 2 )
   DF         SS                 MS
    1       0.000028           0.000028
   21       0.039050           0.001860
F(1,21)  = 0.014979    p <= 0.903755

soa   ( 5 )
rem_ny    ( 2 )
   DF         SS                 MS
    4       0.002951           0.000738
   84       0.160900           0.001915
F(4,84)  = 0.385209    p <= 0.818656

nlet   ( 2 )
rem_ny    ( 2 )
   DF         SS                 MS
    1       0.020972           0.020972
   21       0.041853           0.001993
F(1,21)  = 10.522725    p <= 0.003886     ****

soa   ( 5 )
nlet   ( 2 )
rem_ny    ( 2 )
   DF         SS                 MS
    4       0.005388           0.001347
   84       0.107390           0.001278
F(4,84)  = 1.053613    p <= 0.384707

vollh   ( 2 )
   DF         SS                 MS
    1       0.013665           0.013665
   21       0.046671           0.002222
F(1,21)  = 6.148513    p <= 0.021712     ****

soa   ( 5 )
vollh   ( 2 )
   DF         SS                 MS
    4       0.001424           0.000356
   84       0.156223           0.001860
F(4,84)  = 0.191379    p <= 0.942285

nlet   ( 2 )
vollh   ( 2 )
   DF         SS                 MS
    1       0.001700           0.001700
   21       0.037325           0.001777
F(1,21)  = 0.956648    p <= 0.339167

soa   ( 5 )
nlet   ( 2 )
```

```
vollh   ( 2 )
   DF        SS                MS
    4      0.008804          0.002201
   84      0.157480          0.001875
F(4,84)  = 1.174024    p <= 0.328170

rem_ny   ( 2 )
vollh   ( 2 )
   DF        SS                MS
    1      0.000197          0.000197
   21      0.034943          0.001664
F(1,21)  = 0.118279    p <= 0.734329

soa   ( 5 )
rem_ny   ( 2 )
vollh   ( 2 )
   DF        SS                MS
    4      0.001753          0.000438
   84      0.131452          0.001565
F(4,84)  = 0.280059    p <= 0.890128

nlet   ( 2 )
rem_ny   ( 2 )
vollh   ( 2 )
   DF        SS                MS
    1      0.005766          0.005766
   21      0.056406          0.002686
F(1,21)  = 2.146611    p <= 0.157697

soa   ( 5 )
nlet   ( 2 )
rem_ny   ( 2 )
vollh   ( 2 )
   DF        SS                MS
    4      0.007250          0.001813
   84      0.141091          0.001680
F(4,84)  = 1.079160    p <= 0.372088

-------------------- END ----------------
```

Experiment 3: Mean proportions correct for the tone task (ENCODE trials)

```
model is
-->  sj   ( 22 )
     soa   ( 5 )
     nlet   ( 2 )
     vollh   ( 2 )

KEY:
     soa      (1) = 200 (2) = 261 (3) = 395 (4) = 692 (5) = 1350
     nlet     (1) = 1 (2) = 3
     rem_ny   (1) = ignore (2) = encode

soa   ( 5 )
     0.97254     0.96970     0.97822     0.98011     0.98201

nlet   ( 2 )
     0.98106     0.97197

soa   ( 5 )
nlet   ( 2 )
     0.97917     0.97348     0.98485     0.98674     0.98106
     0.96591     0.96591     0.97159     0.97348     0.98295

vollh   ( 2 )
     0.97348     0.97955

soa   ( 5 )
vollh   ( 2 )
     0.96780     0.96402     0.97538     0.97727     0.98295
     0.97727     0.97538     0.98106     0.98295     0.98106

nlet   ( 2 )
vollh   ( 2 )
     0.98182     0.96515
     0.98030     0.97879

soa   ( 5 )
nlet   ( 2 )
vollh   ( 2 )
     0.98485     0.96970     0.97727     0.99242     0.98485
     0.95076     0.95833     0.97348     0.96212     0.98106
     0.97348     0.97727     0.99242     0.98106     0.97727
     0.98106     0.97348     0.96970     0.98485     0.98485

soa   ( 5 )
   DF        SS               MS
    4     0.009533         0.002383
   84     0.180050         0.002143
F(4,84) = 1.111851    p <= 0.356435

nlet   ( 2 )
   DF        SS               MS
    1     0.009091         0.009091
   21     0.044381         0.002113
F(1,21) = 4.301560    p <= 0.050565
```

```
soa   ( 5 )
nlet   ( 2 )
   DF        SS                MS
    4      0.003851          0.000963
   84      0.116288          0.001384
F(4,84) = 0.695434   p <= 0.597201

vollh   ( 2 )
   DF        SS                MS
    1      0.004040          0.004040
   21      0.050821          0.002420
F(1,21) = 1.669568   p <= 0.210355

soa   ( 5 )
vollh   ( 2 )
   DF        SS                MS
    4      0.002273          0.000568
   84      0.144255          0.001717
F(4,84) = 0.330853   p <= 0.856502

nlet   ( 2 )
vollh   ( 2 )
   DF        SS                MS
    1      0.006313          0.006313
   21      0.069381          0.003304
F(1,21) = 1.910825   p <= 0.181398

soa   ( 5 )
nlet   ( 2 )
vollh   ( 2 )
   DF        SS                MS
    4      0.012626          0.003157
   84      0.147790          0.001759
F(4,84) = 1.794107   p <= 0.137631

--------------------- END ----------------
```

Experiment 3: Mean proportions correct for the tone task (IGNORE trials)

```
model is
-->  sj  ( 22 )
     soa  ( 5 )
     nlet  ( 2 )
     vollh  ( 2 )

KEY:
     soa     (1) = 200 (2) = 261 (3) = 395 (4) = 692 (5) = 1350
     nlet    (1) = 1 (2) = 3
     rem_ny  (1) = ignore (2) = encode

soa  ( 5 )
     0.97159     0.97064     0.97348     0.98390     0.97917

nlet  ( 2 )
     0.97008     0.98144

soa  ( 5 )
nlet  ( 2 )
     0.96591     0.96780     0.96780     0.97348     0.97538
     0.97727     0.97348     0.97917     0.99432     0.98295

vollh  ( 2 )
     0.97083     0.98068

soa  ( 5 )
vollh  ( 2 )
     0.96970     0.96591     0.96780     0.97727     0.97348
     0.97348     0.97538     0.97917     0.99053     0.98485

nlet  ( 2 )
vollh  ( 2 )
     0.96288     0.97879
     0.97727     0.98409

soa  ( 5 )
nlet  ( 2 )
vollh  ( 2 )
     0.96591     0.96591     0.95833     0.96212     0.96212
     0.97348     0.96591     0.97727     0.99242     0.98485
     0.96591     0.96970     0.97727     0.98485     0.98864
     0.98106     0.98106     0.98106     0.99621     0.98106

soa  ( 5 )
   DF        SS              MS
    4     0.011143        0.002786
   84     0.172885        0.002058
F(4,84) = 1.353472   p <= 0.257097

nlet  ( 2 )
   DF        SS              MS
    1     0.014205        0.014205
   21     0.034406        0.001638
F(1,21) = 8.669729   p <= 0.007743    ****
```

```
soa   ( 5 )
nlet   ( 2 )
   DF         SS                MS
    4      0.002999          0.000750
   84      0.153251          0.001824
F(4,84) = 0.410919   p <= 0.800315

vollh   ( 2 )
   DF         SS                MS
    1      0.010669          0.010669
   21      0.035164          0.001674
F(1,21) = 6.371683   p <= 0.019717      ****

soa   ( 5 )
vollh   ( 2 )
   DF         SS                MS
    4      0.001168          0.000292
   84      0.157860          0.001879
F(4,84) = 0.155371   p <= 0.960072

nlet   ( 2 )
vollh   ( 2 )
   DF         SS                MS
    1      0.002273          0.002273
   21      0.017172          0.000818
F(1,21) = 2.779449   p <= 0.110327

soa   ( 5 )
nlet   ( 2 )
vollh   ( 2 )
   DF         SS                MS
    4      0.007039          0.001760
   84      0.157544          0.001876
F(4,84) = 0.938292   p <= 0.445943

--------------------- END -----------------
```

Experiment 3: Mean proportions correct for the encode task (task 1)

```
model is
-->  sj  ( 22 )
     soa  ( 5 )
     nlet  ( 2 )
     vollh  ( 2 )

KEY:
     soa     (1) = 200 (2) = 261 (3) = 395 (4) = 692 (5) = 1350
     nlet    (1) = 1 (2) = 3
     rem_ny  (1) = ignore (2) = encode

soa  ( 5 )
     0.95960      0.95640      0.96752      0.96490      0.96581

nlet  ( 2 )
     0.98362      0.94208

soa  ( 5 )
nlet  ( 2 )
     0.98189      0.98168      0.99001      0.97672      0.98778
     0.93732      0.93111      0.94502      0.95308      0.94385

vollh  ( 2 )
     0.96298      0.96271

soa  ( 5 )
vollh  ( 2 )
     0.96526      0.95191      0.97066      0.96506      0.96201
     0.95395      0.96089      0.96437      0.96474      0.96962

nlet  ( 2 )
vollh  ( 2 )
     0.98280      0.94316
     0.98444      0.94099

soa  ( 5 )
nlet  ( 2 )
vollh  ( 2 )
     0.98788      0.97851      0.98795      0.97617      0.98347
     0.94264      0.92530      0.95337      0.95395      0.94055
     0.97590      0.98485      0.99208      0.97727      0.99208
     0.93200      0.93693      0.93666      0.95220      0.94715

soa  ( 5 )
   DF        SS              MS
    4     0.007650        0.001913
   84     0.115340        0.001373
F(4,84) = 1.392877    p <= 0.243444

nlet  ( 2 )
   DF        SS              MS
    1     0.189806        0.189806
   21     0.301399        0.014352
F(1,21) = 13.224750   p <= 0.001544     ****
```

```
soa   ( 5 )
nlet   ( 2 )
   DF         SS                MS
    4      0.009426          0.002357
   84      0.128263          0.001527
F(4,84)  = 1.543302    p <= 0.197142

vollh   ( 2 )
   DF         SS                MS
    1      0.000008          0.000008
   21      0.028017          0.001334
F(1,21)  = 0.005862    p <= 0.939694

soa   ( 5 )
vollh   ( 2 )
   DF         SS                MS
    4      0.006727          0.001682
   84      0.165128          0.001966
F(4,84)  = 0.855480    p <= 0.494237

nlet   ( 2 )
vollh   ( 2 )
   DF         SS                MS
    1      0.000400          0.000400
   21      0.029828          0.001420
F(1,21)  = 0.281281    p <= 0.601427

soa   ( 5 )
nlet   ( 2 )
vollh   ( 2 )
   DF         SS                MS
    4      0.002221          0.000555
   84      0.085089          0.001013
F(4,84)  = 0.548197    p <= 0.700821

--------------------- END -----------------
```

Experiment 4: Mean response times for the tone task (task 2)

```
model is
-->  sj   ( 15 )
     soa   ( 5 )
     tone_eh   ( 2 )

KEY:
     soa        (1) = 50 (2) = 111 (3) = 245 (4) = 542 (5) = 1200
     tone_eh    (1) = easy  (2) = hard

soa   ( 5 )
   720.08552   614.74412   540.26933   533.74925   462.94563

tone_eh   ( 2 )
   521.61900   627.09854

soa   ( 5 )
tone_eh   ( 2 )
   702.92466   560.37482   485.61569   469.10054   390.07931
   737.24638   669.11343   594.92297   598.39795   535.81195

soa   ( 5 )
   DF       SS                MS
    4     1142741.208348        285685.302087
   56     275396.830436       4917.800543
F(4,56) = 58.092088    p <= 0.000000    ****

tone_eh   ( 2 )
   DF       SS                MS
    1     417222.433230       417222.433230
   14     108684.116318       7763.151166
F(1,14) = 53.743953    p <= 0.000004    ****

soa   ( 5 )
tone_eh   ( 2 )
   DF       SS                MS
    4     54572.347426       13643.086856
   56     81036.083048       1447.072912
F(4,56) = 9.428058   p <= 0.000007    ****

--------------------- END ----------------
```

Experiment 4: Mean response times for the letter task (task 1)

```
model is
-->  sj  ( 15 )
     soa  ( 5 )
     tone_eh  ( 2 )

KEY:
     soa        (1) = 50 (2) = 111 (3) = 245 (4) = 542 (5) = 1200
     tone_eh    (1) = easy  (2) = hard

soa  ( 5 )
   536.23969   537.37486   552.08504   572.22748   571.70616

tone_eh  ( 2 )
   556.27319   551.58010

soa  ( 5 )
tone_eh  ( 2 )
   545.93483   537.00868   551.45487   563.47255   583.49503
   526.54455   537.74105   552.71521   580.98242   559.91729

soa  ( 5 )
   DF       SS                MS
    4     37236.398784         9309.099696
   56     76224.464752         1361.151156
F(4,56) = 6.839137   p <= 0.000148    ****

tone_eh  ( 2 )
   DF       SS                MS
    1     825.939992         825.939992
   14     12474.454615        891.032472
F(1,14) = 0.926947   p <= 0.351993

soa  ( 5 )
tone_eh  ( 2 )
   DF       SS                MS
    4     8478.655594         2119.663899
   56     37236.836396        664.943507
F(4,56) = 3.187735   p <= 0.019832    ****

--------------------- END -----------------
```

Experiment 4: Mean proportions correct for the tone task (task 2)

```
model is
-->  sj   ( 15 )
     soa   ( 5 )
     tone_eh   ( 2 )

KEY:
     soa        (1) = 50 (2) = 111 (3) = 245 (4) = 542 (5) = 1200
     tone_eh    (1) = easy  (2) = hard

soa   ( 5 )
     0.92130     0.91365     0.92708     0.92153     0.92164

tone_eh   ( 2 )
     0.92749     0.91459

soa   ( 5 )
tone_eh   ( 2 )
     0.93487     0.91545     0.94048     0.92822     0.91844
     0.90774     0.91185     0.91368     0.91484     0.92484

soa   ( 5 )
   DF       SS              MS
    4     0.002753        0.000688
   56     0.240727        0.004299
F(4,56) = 0.160095   p <= 0.957583

tone_eh   ( 2 )
   DF       SS              MS
    1     0.006242        0.006242
   14     0.183870        0.013134
F(1,14) = 0.475273   p <= 0.501839

soa   ( 5 )
tone_eh   ( 2 )
   DF       SS              MS
    4     0.006409        0.001602
   56     0.296811        0.005300
F(4,56) = 0.302296   p <= 0.875217

--------------------- END -----------------
```

Experiment 4: Mean proportions correct for the letter task (task 1)

```
model is
-->  sj   ( 15 )
     soa   ( 5 )
     tone_eh   ( 2 )

KEY:
     soa        (1) = 50 (2) = 111 (3) = 245 (4) = 542 (5) = 1200
     tone_eh    (1) = easy  (2) = hard

soa   ( 5 )
     0.95513     0.96924     0.97487     0.97245     0.97807

tone_eh   ( 2 )
     0.96856     0.97135

soa   ( 5 )
tone_eh   ( 2 )
     0.94895     0.96779     0.97712     0.97203     0.97690
     0.96131     0.97070     0.97263     0.97287     0.97925

soa   ( 5 )
   DF        SS                MS
    4      0.009499          0.002375
   56      0.025183          0.000450
F(4,56) = 5.280902   p <= 0.001112     ****

tone_eh   ( 2 )
   DF        SS                MS
    1      0.000294          0.000294
   14      0.003424          0.000245
F(1,14) = 1.200421   p <= 0.291728

soa   ( 5 )
tone_eh   ( 2 )
   DF        SS                MS
    4      0.001115          0.000279
   56      0.018447          0.000329
F(4,56) = 0.846317   p <= 0.501868

--------------------- END -----------------
```

Experiment 5: Mean response times for the tone task (task 2)

```
model is
-->  sj   ( 14 )
     soa   ( 5 )
     rem_ny  ( 2 )
     tone_eh   ( 2 )

KEY:
     soa      (1) = 200 (2) = 261 (3) = 395 (4) = 692 (5) = 1350
     rem_ny   (1) = ignore (2) = encode
     tone_eh  (1) = easy (2) = hard

soa   ( 5 )
   745.37084   722.23574   697.35879   630.26308   576.07784

rem_ny   ( 2 )
   590.21307   758.30944

soa   ( 5 )
rem_ny   ( 2 )
   635.76247   611.20897   609.61089   570.21973   524.26330
   854.97921   833.26250   785.10669   690.30642   627.89238

tone_eh   ( 2 )
   579.34440   769.17811

soa   ( 5 )
tone_eh   ( 2 )
   664.21193   636.24904   591.02626   522.64542   482.58935
   826.52975   808.22243   803.69131   737.88073   669.56633

rem_ny   ( 2 )
tone_eh   ( 2 )
   494.14136   664.54744
   686.28478   852.07144

soa   ( 5 )
rem_ny   ( 2 )
tone_eh   ( 2 )
   555.72286   517.19928   494.79024   458.98599   444.00844
   772.70100   755.29880   687.26228   586.30486   521.17026
   715.80208   705.21865   724.43153   681.45348   604.51816
   937.25742   911.22620   882.95109   794.30797   734.61450

soa   ( 5 )
   DF        SS                  MS
    4      1090176.786667         272544.196667
   52      970702.515646        18667.356070
F(4,52) = 14.600043    p <= 0.000000     ****

rem_ny   ( 2 )
   DF        SS                  MS
    1      1977947.206272         1977947.206272
   13      782281.155293        60175.473484
F(1,13) = 32.869658    p <= 0.000069     ****
```

```
soa   ( 5 )
rem_ny   ( 2 )
   DF        SS                MS
    4     168565.328630        42141.332157
   52     756129.042770        14540.943130
F(4,52) = 2.898115    p <= 0.030649     ****

tone_eh   ( 2 )
   DF        SS                MS
    1     2522578.473216        2522578.473216
   13     1331322.295888        102409.407376
F(1,13) = 24.632292    p <= 0.000259     ****

soa   ( 5 )
tone_eh   ( 2 )
   DF        SS                MS
    4     31511.020173        7877.755043
   52     250382.882038        4815.055424
F(4,52) = 1.636067    p <= 0.179170

rem_ny   ( 2 )
tone_eh   ( 2 )
   DF        SS                MS
    1     373.433511        373.433511
   13     118324.399995        9101.876923
F(1,13) = 0.041028    p <= 0.842619

soa   ( 5 )
rem_ny   ( 2 )
tone_eh   ( 2 )
   DF        SS                MS
    4     17875.539245        4468.884811
   52     332997.145119        6403.791252
F(4,52) = 0.697850    p <= 0.596914

-------------------- END ----------------
```

Experiment 5: Mean response times for the tone task (ENCODE trials)

```
model is
-->  sj   ( 14 )
     soa   ( 5 )
     tone_eh   ( 2 )

KEY:
     soa      (1) = 200 (2) = 261 (3) = 395 (4) = 692 (5) = 1350
     rem_ny   (1) = ignore (2) = encode
     tone_eh  (1) = easy (2) = hard

soa   ( 5 )
   854.97921   833.26250   785.10669   690.30642   627.89238

tone_eh   ( 2 )
   664.54744   852.07144

soa   ( 5 )
tone_eh   ( 2 )
   772.70100   755.29880   687.26228   586.30486   521.17026
   937.25742   911.22620   882.95109   794.30797   734.61450

soa   ( 5 )
   DF        SS                 MS
    4     1044795.327748        261198.831937
   52     1175719.123139        22609.983137
F(4,52) = 11.552367    p <= 0.000001    ****

tone_eh   ( 2 )
   DF        SS                 MS
    1     1230783.685024        1230783.685024
   13     474927.622194       36532.894015
F(1,13) = 33.689740    p <= 0.000061    ****

soa   ( 5 )
tone_eh   ( 2 )
   DF        SS                 MS
    4     18786.398774        4696.599693
   52     289952.479786         5576.009227
F(4,52) = 0.842287    p <= 0.504767

--------------------- END -----------------
```

Experiment 5: Mean response times for the tone task (IGNORE trials)

```
model is
-->  sj   ( 14 )
     soa   ( 5 )
     tone_eh   ( 2 )

KEY:
     soa     (1) = 200 (2) = 261 (3) = 395 (4) = 692 (5) = 1350
     rem_ny  (1) = ignore (2) = encode
     tone_eh (1) = easy (2) = hard

soa  ( 5 )
   635.76247   611.20897   609.61089   570.21973   524.26330

tone_eh   ( 2 )
   494.14136   686.28478

soa  ( 5 )
tone_eh   ( 2 )
   555.72286   517.19928   494.79024   458.98599   444.00844
   715.80208   705.21865   724.43153   681.45348   604.51816

soa  ( 5 )
   DF       SS                MS
    4     213946.787549         53486.696887
   52     551112.435278         10598.316063
F(4,52) = 5.046717   p <= 0.001636    ****

tone_eh   ( 2 )
   DF       SS                MS
    1     1292168.221702        1292168.221702
   13     974719.073689         74978.390284
F(1,13) = 17.233875   p <= 0.001138    ****

soa  ( 5 )
tone_eh   ( 2 )
   DF       SS                MS
    4     30600.160644        7650.040161
   52     293427.547371        5642.837449
F(4,52) = 1.355708   p <= 0.262048

-------------------- END ----------------
```

Experiment 5: Mean proportions correct for the tone task (task 2)

```
model is
-->  sj   ( 14 )
     soa   ( 5 )
     rem_ny   ( 2 )
     tone_eh   ( 2 )

KEY:
     soa     (1) = 200 (2) = 261 (3) = 395 (4) = 692 (5) = 1350
     rem_ny  (1) = ignore (2) = encode
     tone_eh (1) = easy (2) = hard

soa   ( 5 )
     0.91592      0.91890      0.92113      0.91369      0.92411

rem_ny   ( 2 )
     0.95238      0.88512

soa   ( 5 )
rem_ny   ( 2 )
     0.95982      0.95238      0.95536      0.93452      0.95982
     0.87202      0.88542      0.88690      0.89286      0.88839

tone_eh   ( 2 )
     0.92619      0.91131

soa   ( 5 )
tone_eh   ( 2 )
     0.93452      0.92560      0.92857      0.91667      0.92560
     0.89732      0.91220      0.91369      0.91071      0.92262

rem_ny   ( 2 )
tone_eh   ( 2 )
     0.95952      0.89286
     0.94524      0.87738

soa   ( 5 )
rem_ny   ( 2 )
tone_eh   ( 2 )
     0.97619      0.96131      0.97024      0.93452      0.95536
     0.89286      0.88988      0.88690      0.89881      0.89583
     0.94345      0.94345      0.94048      0.93452      0.96429
     0.85119      0.88095      0.88690      0.88690      0.88095

soa   ( 5 )
   DF         SS                MS
    4      0.003807           0.000952
   52      0.113728           0.002187
F(4,52)  = 0.435173    p <= 0.782580

rem_ny   ( 2 )
   DF         SS                MS
    1      0.316691           0.316691
   13      2.059871           0.158452
F(1,13)  = 1.998662    p <= 0.180936
```

```
soa   ( 5 )
rem_ny   ( 2 )
   DF        SS                 MS
    4      0.015340          0.003835
   52      0.168862          0.003247
F(4,52) = 1.180948    p <= 0.330059

tone_eh   ( 2 )
   DF        SS                 MS
    1      0.015501          0.015501
   13      0.044048          0.003388
F(1,13) = 4.574867    p <= 0.052000

soa   ( 5 )
tone_eh   ( 2 )
   DF        SS                 MS
    4      0.010107          0.002527
   52      0.090067          0.001732
F(4,52) = 1.458756    p <= 0.228145

rem_ny   ( 2 )
tone_eh   ( 2 )
   DF        SS                 MS
    1      0.000025          0.000025
   13      0.020288          0.001561
F(1,13) = 0.015890    p <= 0.901617

soa   ( 5 )
rem_ny   ( 2 )
tone_eh   ( 2 )
   DF        SS                 MS
    4      0.006114          0.001528
   52      0.110727          0.002129
F(4,52) = 0.717770    p <= 0.583641

--------------------- END -----------------
```

Experiment 5: Mean proportions correct for the tone task (ENCODE trials)

```
model is
-->  sj   ( 14 )
     soa   ( 5 )
     tone_eh   ( 2 )

KEY:
     soa     (1) = 200 (2) = 261 (3) = 395 (4) = 692 (5) = 1350
     tone_eh (1) = easy (2) = hard

soa   ( 5 )
     0.87202     0.88542     0.88690     0.89286     0.88839

tone_eh   ( 2 )
     0.89286     0.87738

soa   ( 5 )
tone_eh   ( 2 )
     0.89286     0.88988     0.88690     0.89881     0.89583
     0.85119     0.88095     0.88690     0.88690     0.88095

soa   ( 5 )
   DF        SS               MS
    4      0.006870         0.001718
   52      0.206324         0.003968
F(4,52) = 0.432865    p <= 0.784239

tone_eh   ( 2 )
   DF        SS               MS
    1      0.008383         0.008383
   13      0.046478         0.003575
F(1,13) = 2.344692    p <= 0.149676

soa   ( 5 )
tone_eh   ( 2 )
   DF        SS               MS
    4      0.006870         0.001718
   52      0.115352         0.002218
F(4,52) = 0.774238    p <= 0.546964

--------------------- END -----------------
```

Experiment 5: Mean proportions correct for the tone task (IGNORE trials)

```
model is
-->  sj   ( 14 )
     soa   ( 5 )
     tone_eh   ( 2 )

KEY:
     soa     (1) = 200 (2) = 261 (3) = 395 (4) = 692 (5) = 1350
     tone_eh (1) = easy (2) = hard

soa   ( 5 )
     0.95982     0.95238     0.95536     0.93452     0.95982

tone_eh   ( 2 )
     0.95952     0.94524

soa   ( 5 )
tone_eh   ( 2 )
     0.97619     0.96131     0.97024     0.93452     0.95536
     0.94345     0.94345     0.94048     0.93452     0.96429

soa   ( 5 )
   DF        SS               MS
    4     0.012277         0.003069
   52     0.076265         0.001467
F(4,52) = 2.092672   p <= 0.095025

tone_eh   ( 2 )
   DF        SS               MS
    1     0.007143         0.007143
   13     0.017857         0.001374
F(1,13) = 5.200010   p <= 0.040093     ****

soa   ( 5 )
tone_eh   ( 2 )
   DF        SS               MS
    4     0.009350         0.002338
   52     0.085441         0.001643
F(4,52) = 1.422635   p <= 0.239541

-------------------- END ----------------
```

Experiment 5: Mean proportions correct for the encode task (task 1)

```
model is
--> sj  ( 14 )
    soa  ( 5 )
    tone_eh  ( 2 )
KEY:
    soa     (1) = 200 (2) = 261 (3) = 395 (4) = 692 (5) = 1350
    tone_eh (1) = easy (2) = hard


soa  ( 5 )
    0.92704     0.93335     0.93628     0.93486     0.93005

tone_eh  ( 2 )
    0.93599     0.92865

soa  ( 5 )
tone_eh  ( 2 )
    0.93339     0.93615     0.93452     0.94134     0.93452
    0.92069     0.93054     0.93804     0.92838     0.92558

soa  ( 5 )
   DF       SS              MS
    4     0.001574        0.000394
   52     0.040330        0.000776
F(4,52) = 0.507438   p <= 0.730434

tone_eh  ( 2 )
   DF       SS              MS
    1     0.001885        0.001885
   13     0.005793        0.000446
F(1,13) = 4.231204   p <= 0.060331

soa  ( 5 )
tone_eh  ( 2 )
   DF       SS              MS
    4     0.001285        0.000321
   52     0.028464        0.000547
F(4,52) = 0.586931   p <= 0.673523

-------------------- END ----------------
```

Experiment 6: Mean response times for the tone task (task 2)

```
model is
-->  sj   ( 10 )
     soa   ( 5 )
     nlet   ( 2 )
     rem_ny   ( 2 )
     vollh   ( 2 )

KEY:
     soa       (1) = 50 (2) = 111 (3) = 245 (4) = 542 (5) = 1200
     nlet      (1) = 1 (2) = 3
     rem_ny    (1) = ignore   (2) = encode
     vollh     (1) = quiet    (2) = loud

soa   ( 5 )
   681.04350   654.15780   623.16363   563.61361   543.00517

nlet   ( 2 )
   593.34642   632.64706

soa   ( 5 )
nlet   ( 2 )
   666.36468   642.26260   591.99398   534.94708   531.16379
   695.72231   666.05301   654.33328   592.28014   554.84655

rem_ny   ( 2 )
   559.55821   666.43528

soa   ( 5 )
rem_ny   ( 2 )
   610.20206   594.26477   556.46780   517.63907   519.21732
   751.88493   714.05084   689.85945   609.58815   566.79301

nlet   ( 2 )
rem_ny   ( 2 )
   559.55103   559.56538
   627.14182   705.72874

soa   ( 5 )
nlet   ( 2 )
rem_ny   ( 2 )
   615.64019   591.85591   560.49015   518.96790   510.80101
   604.76394   596.67364   552.44545   516.31023   527.63364
   717.08917   692.66929   623.49780   550.92625   551.52657
   786.68069   735.43238   756.22110   668.25006   582.05946

vollh   ( 2 )
   648.31855   577.67493

soa   ( 5 )
vollh   ( 2 )
   717.76510   692.19984   657.32113   596.47225   577.83443
   644.32189   616.11577   589.00613   530.75497   508.17590

nlet   ( 2 )
vollh   ( 2 )
```

```
   630.99139   665.64570
   555.70145   599.64841

soa   ( 5 )
nlet   ( 2 )
vollh   ( 2 )
   709.21269   681.79823   626.21280   567.49021   570.24303
   726.31751   702.60145   688.42945   625.45428   585.42583
   623.51667   602.72697   557.77515   502.40394   492.08455
   665.12712   629.50457   620.23711   559.10600   524.26726

rem_ny   ( 2 )
vollh   ( 2 )
   592.30842   704.32868
   526.80799   628.54188

soa   ( 5 )
rem_ny   ( 2 )
vollh   ( 2 )
   649.66163   615.63212   590.79197   560.50909   544.94730
   785.86857   768.76756   723.85028   632.43541   610.72157
   570.74250   572.89742   522.14364   474.76904   493.48735
   717.90129   659.33411   655.86863   586.74090   522.86446

nlet   ( 2 )
rem_ny   ( 2 )
vollh   ( 2 )
   593.66561   590.95123
   668.31718   740.34018
   525.43645   528.17953
   585.96645   671.11730

soa   ( 5 )
nlet   ( 2 )
rem_ny   ( 2 )
vollh   ( 2 )
   664.16977   610.38667   599.37348   552.30278   542.09535
   635.15348   620.87758   582.21045   568.71540   547.79924
   754.25561   753.20980   653.05212   582.67765   598.39071
   817.48153   784.32532   794.64844   682.19316   623.05242
   567.11061   573.32515   521.60682   485.63303   479.50667
   574.37439   572.46970   522.68045   463.90505   507.46803
   679.92273   632.12879   593.94348   519.17485   504.66242
   755.87985   686.53944   717.79377   654.30695   541.06649

soa   ( 5 )
   DF        SS                  MS
    4     1101237.903576         275309.475894
   36     683763.525451        18993.431263
F(4,36) = 14.494984    p <= 0.000000     ****

nlet   ( 2 )
   DF        SS                  MS
    1     154453.981001        154453.981001
    9     161381.937593        17931.326399
F(1,9) = 8.613639    p <= 0.016624     ****
```

```
soa  ( 5 )
nlet  ( 2 )
   DF        SS                MS
    4     28785.942812        7196.485703
   36     127514.243115        3542.062309
F(4,36) = 2.031722   p <= 0.110605

rem_ny  ( 2 )
   DF        SS                MS
    1     1142270.820294        1142270.820294
    9     287225.108397       31913.900933
F(1,9) = 35.792266   p <= 0.000207    ****

soa  ( 5 )
rem_ny  ( 2 )
   DF        SS                MS
    4     116412.140484       29103.035121
   36     174012.165754       4833.671271
F(4,36) = 6.020897   p <= 0.000814    ****

nlet  ( 2 )
rem_ny  ( 2 )
   DF        SS                MS
    1     154341.240360       154341.240360
    9     121246.180818       13471.797869
F(1,9) = 11.456618   p <= 0.008066    ****

soa  ( 5 )
nlet  ( 2 )
rem_ny  ( 2 )
   DF        SS                MS
    4     57227.736936       14306.934234
   36     129014.592939       3583.738693
F(4,36) = 3.992181   p <= 0.008812    ****

vollh  ( 2 )
   DF        SS                MS
    1     499052.048156       499052.048156
    9     224831.110443       24981.234494
F(1,9) = 19.977077   p <= 0.001556    ****

soa  ( 5 )
vollh  ( 2 )
   DF        SS                MS
    4     1361.958837        340.489709
   36     170316.413844       4731.011496
F(4,36) = 0.071970   p <= 0.990161

nlet  ( 2 )
vollh  ( 2 )
   DF        SS                MS
    1     2158.832086        2158.832086
    9     34531.290799        3836.810089
F(1,9) = 0.562663   p <= 0.472342

soa  ( 5 )
nlet  ( 2 )
```

```
vollh  ( 2 )
   DF        SS                 MS
    4     2475.513958         618.878490
   36     95749.835463         2659.717652
F(4,36) = 0.232686   p <= 0.918159

rem_ny  ( 2 )
vollh  ( 2 )
   DF        SS                 MS
    1     2645.234310         2645.234310
    9     17917.312346         1990.812483
F(1,9) = 1.328721   p <= 0.278729

soa  ( 5 )
rem_ny  ( 2 )
vollh  ( 2 )
   DF        SS                 MS
    4     34842.315284         8710.578821
   36     69189.999812         1921.944439
F(4,36) = 4.532170   p <= 0.004556    ****

nlet  ( 2 )
rem_ny  ( 2 )
vollh  ( 2 )
   DF        SS                 MS
    1     367.718466         367.718466
    9     28191.931036         3132.436782
F(1,9) = 0.117391   p <= 0.739748

soa  ( 5 )
nlet  ( 2 )
rem_ny  ( 2 )
vollh  ( 2 )
   DF        SS                 MS
    4     10382.319008         2595.579752
   36     228399.170455         6344.421402
F(4,36) = 0.409112   p <= 0.800857

--------------------- END ----------------
```

Experiment 6: Mean response times for the tone task (ENCODE trials)

```
model is
-->  sj  ( 10 )
     soa  ( 5 )
     nlet  ( 2 )
     vollh  ( 2 )

KEY:
     soa       (1) = 50 (2) = 111 (3) = 245 (4) = 542 (5) = 1200
     nlet      (1) = 1 (2) = 3
     vollh     (1) = quiet   (2) = loud

soa  ( 5 )
   751.88493   714.05084   689.85945   609.58815   566.79301

nlet  ( 2 )
   627.14182   705.72874

soa  ( 5 )
nlet  ( 2 )
   717.08917   692.66929   623.49780   550.92625   551.52657
   786.68069   735.43238   756.22110   668.25006   582.05946

vollh  ( 2 )
   704.32868   628.54188

soa  ( 5 )
vollh  ( 2 )
   785.86857   768.76756   723.85028   632.43541   610.72157
   717.90129   659.33411   655.86863   586.74090   522.86446

nlet  ( 2 )
vollh  ( 2 )
   668.31718   740.34018
   585.96645   671.11730

soa  ( 5 )
nlet  ( 2 )
vollh  ( 2 )
   754.25561   753.20980   653.05212   582.67765   598.39071
   817.48153   784.32532   794.64844   682.19316   623.05242
   679.92273   632.12879   593.94348   519.17485   504.66242
   755.87985   686.53944   717.79377   654.30695   541.06649

soa  ( 5 )
   DF       SS                MS
    4     931110.127898        232777.531974
   36     646399.327518        17955.536875
F(4,36) = 12.964109   p <= 0.000001    ****

nlet  ( 2 )
   DF       SS                MS
    1     308795.211071        308795.211071
    9     260749.127819        28972.125313
F(1,9) = 10.658355   p <= 0.009765    ****
```

```
soa   ( 5 )
nlet   ( 2 )
   DF        SS                  MS
    4      81047.479886          20261.869972
   36      183982.652600          5110.629239
F(4,36) = 3.964653    p <= 0.009118      ****

vollh   ( 2 )
   DF        SS                  MS
    1      287181.953773          287181.953773
    9      162684.057184          18076.006354
F(1,9) = 15.887467    p <= 0.003177      ****

soa   ( 5 )
vollh   ( 2 )
   DF        SS                  MS
    4      23054.007032          5763.501758
   36      154356.081139          4287.668921
F(4,36) = 1.344204    p <= 0.272547

nlet   ( 2 )
vollh   ( 2 )
   DF        SS                  MS
    1      2154.253627          2154.253627
    9      46334.882928          5148.320325
F(1,9) = 0.418438    p <= 0.533865

soa   ( 5 )
nlet   ( 2 )
vollh   ( 2 )
   DF        SS                  MS
    4      3910.977612          977.744403
   36      216728.728685          6020.242463
F(4,36) = 0.162409    p <= 0.955995

-------------------- END ----------------
```

Experiment 6: Mean response times for the tone task (IGNORE trials)

```
model is
-->  sj  ( 10 )
     soa  ( 5 )
     nlet  ( 2 )
     vollh  ( 2 )

KEY:
     soa       (1) = 50 (2) = 111 (3) = 245 (4) = 542 (5) = 1200
     nlet      (1) = 1 (2) = 3
     vollh     (1) = quiet   (2) = loud

soa  ( 5 )
   610.20206   594.26477   556.46780   517.63907   519.21732

nlet  ( 2 )
   559.55103   559.56538

soa  ( 5 )
nlet  ( 2 )
   615.64019   591.85591   560.49015   518.96790   510.80101
   604.76394   596.67364   552.44545   516.31023   527.63364

vollh  ( 2 )
   592.30842   526.80799

soa  ( 5 )
vollh  ( 2 )
   649.66163   615.63212   590.79197   560.50909   544.94730
   570.74250   572.89742   522.14364   474.76904   493.48735

nlet  ( 2 )
vollh  ( 2 )
   593.66561   590.95123
   525.43645   528.17953

soa  ( 5 )
nlet  ( 2 )
vollh  ( 2 )
   664.16977   610.38667   599.37348   552.30278   542.09535
   635.15348   620.87758   582.21045   568.71540   547.79924
   567.11061   573.32515   521.60682   485.63303   479.50667
   574.37439   572.46970   522.68045   463.90505   507.46803

soa  ( 5 )
   DF       SS                MS
    4     286539.916163        71634.979041
   36     211376.363687        5871.565658
F(4,36) = 12.200320    p <= 0.000002     ****

nlet  ( 2 )
   DF       SS                MS
    1     0.010290         0.010290
    9     21878.990592         2430.998955
F(1,9) = 0.000004    p <= 0.998403
```

```
soa   ( 5 )
nlet   ( 2 )
   DF        SS                MS
    4     4966.199862        1241.549966
   36     72546.183454        2015.171763
F(4,36) = 0.616101   p <= 0.653850

vollh   ( 2 )
   DF        SS                MS
    1     214515.328692        214515.328692
    9     80064.365605        8896.040623
F(1,9) = 24.113573   p <= 0.000835    ****

soa   ( 5 )
vollh   ( 2 )
   DF        SS                MS
    4     13150.267089        3287.566772
   36     85150.332517        2365.287014
F(4,36) = 1.389923   p <= 0.256944

nlet   ( 2 )
vollh   ( 2 )
   DF        SS                MS
    1     372.296924        372.296924
    9     16388.338907        1820.926545
F(1,9) = 0.204455   p <= 0.661850

soa   ( 5 )
nlet   ( 2 )
vollh   ( 2 )
   DF        SS                MS
    4     8946.855355        2236.713839
   36     107420.277233        2983.896590
F(4,36) = 0.749595   p <= 0.564806

--------------------- END -----------------
```

Experiment 6: Mean proportions correct for the tone task (task 2)

```
model is
-->  sj   ( 10 )
     soa   ( 5 )
     nlet   ( 2 )
     rem_ny   ( 2 )
     vollh   ( 2 )

KEY:
     soa       (1) = 50 (2) = 111 (3) = 245 (4) = 542 (5) = 1200
     nlet      (1) = 1 (2) = 3
     rem_ny    (1) = ignore   (2) = encode
     vollh     (1) = quiet    (2) = loud

soa   ( 5 )
     0.96979     0.96771     0.97083     0.96563     0.96146

nlet   ( 2 )
     0.96917     0.96500

soa   ( 5 )
nlet   ( 2 )
     0.96875     0.97292     0.97083     0.97083     0.96250
     0.97083     0.96250     0.97083     0.96042     0.96042

rem_ny   ( 2 )
     0.96750     0.96667

soa   ( 5 )
rem_ny   ( 2 )
     0.96458     0.96875     0.97500     0.97292     0.95625
     0.97500     0.96667     0.96667     0.95833     0.96667

nlet   ( 2 )
rem_ny   ( 2 )
     0.97167     0.96333
     0.96667     0.96667

soa   ( 5 )
nlet   ( 2 )
rem_ny   ( 2 )
     0.96667     0.98750     0.98333     0.96667     0.95417
     0.96250     0.95000     0.96667     0.97917     0.95833
     0.97083     0.95833     0.95833     0.97500     0.97083
     0.97917     0.97500     0.97500     0.94167     0.96250

vollh   ( 2 )
     0.95792     0.97625

soa   ( 5 )
vollh   ( 2 )
     0.96667     0.96042     0.95625     0.96458     0.94167
     0.97292     0.97500     0.98542     0.96667     0.98125

nlet   ( 2 )
vollh   ( 2 )
```

```
     0.95583     0.96000
     0.98250     0.97000

soa  ( 5 )
nlet  ( 2 )
vollh  ( 2 )
     0.96250     0.96250     0.95417     0.96250     0.93750
     0.97083     0.95833     0.95833     0.96667     0.94583
     0.97500     0.98333     0.98750     0.97917     0.98750
     0.97083     0.96667     0.98333     0.95417     0.97500

rem_ny  ( 2 )
vollh  ( 2 )
     0.95583     0.96000
     0.97917     0.97333

soa  ( 5 )
rem_ny  ( 2 )
vollh  ( 2 )
     0.95417     0.96667     0.95417     0.97083     0.93333
     0.97917     0.95417     0.95833     0.95833     0.95000
     0.97500     0.97083     0.99583     0.97500     0.97917
     0.97083     0.97917     0.97500     0.95833     0.98333

nlet  ( 2 )
rem_ny  ( 2 )
vollh  ( 2 )
     0.95500     0.95667
     0.95667     0.96333
     0.98833     0.97000
     0.97667     0.97000

soa  ( 5 )
nlet  ( 2 )
rem_ny  ( 2 )
vollh  ( 2 )
     0.95000     0.97500     0.96667     0.95833     0.92500
     0.95833     0.95833     0.94167     0.98333     0.94167
     0.97500     0.95000     0.94167     0.96667     0.95000
     0.98333     0.95833     0.97500     0.95000     0.95000
     0.98333     1.00000     1.00000     0.97500     0.98333
     0.96667     0.94167     0.99167     0.97500     0.97500
     0.96667     0.96667     0.97500     0.98333     0.99167
     0.97500     0.99167     0.97500     0.93333     0.97500

soa  ( 5 )
   DF        SS               MS
    4     0.004444         0.001111
   36     0.137569         0.003821
F(4,36) = 0.290764   p <= 0.882043

nlet  ( 2 )
   DF        SS               MS
    1     0.001736         0.001736
    9     0.012500         0.001389
F(1,9) = 1.249995   p <= 0.292507
```

```
soa   ( 5 )
nlet   ( 2 )
   DF          SS                 MS
    4      0.002778           0.000694
   36      0.125347           0.003482
F(4,36) = 0.199445    p <= 0.937014

rem_ny   ( 2 )
   DF          SS                 MS
    1      0.000069           0.000069
    9      0.028055           0.003117
F(1,9) = 0.022276   p <= 0.884645

soa   ( 5 )
rem_ny   ( 2 )
   DF          SS                 MS
    4      0.010000           0.002500
   36      0.052153           0.001449
F(4,36) = 1.725708    p <= 0.165702

nlet   ( 2 )
rem_ny   ( 2 )
   DF          SS                 MS
    1      0.001736           0.001736
    9      0.040278           0.004475
F(1,9) = 0.387928   p <= 0.548845

soa   ( 5 )
nlet   ( 2 )
rem_ny   ( 2 )
   DF          SS                 MS
    4      0.030556           0.007639
   36      0.135764           0.003771
F(4,36) = 2.025574    p <= 0.111508

vollh   ( 2 )
   DF          SS                 MS
    1      0.033611           0.033611
    9      0.059097           0.006566
F(1,9) = 5.118683   p <= 0.049976     ****

soa   ( 5 )
vollh   ( 2 )
   DF          SS                 MS
    4      0.019861           0.004965
   36      0.140903           0.003914
F(4,36) = 1.268604    p <= 0.300277

nlet   ( 2 )
vollh   ( 2 )
   DF          SS                 MS
    1      0.006944           0.006944
    9      0.028819           0.003202
F(1,9) = 2.168676   p <= 0.174936

soa   ( 5 )
nlet   ( 2 )
```

```
vollh   ( 2 )
   DF        SS                 MS
    4      0.001389          0.000347
   36      0.077430          0.002151
F(4,36) = 0.161435    p <= 0.956462

rem_ny   ( 2 )
vollh   ( 2 )
   DF        SS                 MS
    1      0.002500          0.002500
    9      0.020764          0.002307
F(1,9) = 1.083609    p <= 0.325047

soa   ( 5 )
rem_ny   ( 2 )
vollh   ( 2 )
   DF        SS                 MS
    4      0.007917          0.001979
   36      0.072986          0.002027
F(4,36) = 0.976209    p <= 0.432623

nlet   ( 2 )
rem_ny   ( 2 )
vollh   ( 2 )
   DF        SS                 MS
    1      0.000278          0.000278
    9      0.018819          0.002091
F(1,9) = 0.132841    p <= 0.723921

soa   ( 5 )
nlet   ( 2 )
rem_ny   ( 2 )
vollh   ( 2 )
   DF        SS                 MS
    4      0.008056          0.002014
   36      0.097847          0.002718
F(4,36) = 0.740950    p <= 0.570347

--------------------- END -----------------
```

Experiment 6: Mean proportions correct for the encode task (task 1)

```
model is
-->  sj  ( 10 )
     soa  ( 5 )
     nlet  ( 2 )
     vollh  ( 2 )

KEY:
     soa       (1) = 50 (2) = 111 (3) = 245 (4) = 542 (5) = 1200
     nlet      (1) = 1 (2) = 3
     vollh     (1) = quiet   (2) = loud

soa  ( 5 )
     0.95521     0.95104     0.96042     0.95312     0.96250

nlet  ( 2 )
     0.99583     0.91708

soa  ( 5 )
nlet  ( 2 )
     0.99583     0.99792     0.99375     0.99167     1.00000
     0.91458     0.90417     0.92708     0.91458     0.92500

vollh  ( 2 )
     0.95958     0.95333

soa  ( 5 )
vollh  ( 2 )
     0.96458     0.94375     0.96250     0.96042     0.96667
     0.94583     0.95833     0.95833     0.94583     0.95833

nlet  ( 2 )
vollh  ( 2 )
     0.99583     0.92333
     0.99583     0.91083

soa  ( 5 )
nlet  ( 2 )
vollh  ( 2 )
     0.99583     0.99583     0.99583     0.99167     1.00000
     0.93333     0.89167     0.92917     0.92917     0.93333
     0.99583     1.00000     0.99167     0.99167     1.00000
     0.89583     0.91667     0.92500     0.90000     0.91667

soa  ( 5 )
   DF        SS                MS
    4     0.003767          0.000942
   36     0.043976          0.001222
F(4,36) = 0.771032    p <= 0.551215

nlet  ( 2 )
   DF        SS                MS
    1     0.310078          0.310078
    9     0.139661          0.015518
F(1,9) = 19.981953    p <= 0.001554     ****
```

```
soa   ( 5 )
nlet   ( 2 )
   DF        SS                MS
    4      0.003941         0.000985
   36      0.052830         0.001467
F(4,36) = 0.671384   p <= 0.616121

vollh   ( 2 )
   DF        SS                MS
    1      0.001953         0.001953
    9      0.014800         0.001644
F(1,9) = 1.187686   p <= 0.304115

soa   ( 5 )
vollh   ( 2 )
   DF        SS                MS
    4      0.006684         0.001671
   36      0.062934         0.001748
F(4,36) = 0.955865   p <= 0.443422

nlet   ( 2 )
vollh   ( 2 )
   DF        SS                MS
    1      0.001953         0.001953
    9      0.018967         0.002107
F(1,9) = 0.926786   p <= 0.360850

soa   ( 5 )
nlet   ( 2 )
vollh   ( 2 )
   DF        SS                MS
    4      0.005469         0.001367
   36      0.049566         0.001377
F(4,36) = 0.992996   p <= 0.423873

--------------------- END -----------------
```

Experiment 6: Mean proportions correct for the tone task (ENCODE trials)

```
model is
-->  sj   ( 10 )
     soa   ( 5 )
     nlet   ( 2 )
     vollh   ( 2 )

KEY:
     soa       (1) = 50 (2) = 111 (3) = 245 (4) = 542 (5) = 1200
     nlet      (1) = 1 (2) = 3
     vollh     (1) = quiet   (2) = loud

soa   ( 5 )
     0.97500     0.96837     0.96629     0.95792     0.96549

nlet   ( 2 )
     0.96671     0.96652

soa   ( 5 )
nlet   ( 2 )
     0.97083     0.96174     0.95795     0.97417     0.96886
     0.97917     0.97500     0.97462     0.94167     0.96212

vollh   ( 2 )
     0.95921     0.97402

soa   ( 5 )
vollh   ( 2 )
     0.97917     0.95379     0.95795     0.95750     0.94765
     0.97083     0.98295     0.97462     0.95833     0.98333

nlet   ( 2 )
vollh   ( 2 )
     0.95539     0.96303
     0.97803     0.97000

soa   ( 5 )
nlet   ( 2 )
vollh   ( 2 )
     0.97500     0.94924     0.94167     0.96500     0.94606
     0.98333     0.95833     0.97424     0.95000     0.94924
     0.96667     0.97424     0.97424     0.98333     0.99167
     0.97500     0.99167     0.97500     0.93333     0.97500

soa   ( 5 )
   DF       SS              MS
    4     0.006017        0.001504
   36     0.066208        0.001839
F(4,36) = 0.817913    p <= 0.522254

nlet   ( 2 )
   DF       SS              MS
    1     0.000002        0.000002
    9     0.035382        0.003931
F(1,9) = 0.000493    p <= 0.982762
```

```
soa   ( 5 )
nlet   ( 2 )
   DF        SS                 MS
    4     0.016245          0.004061
   36     0.112327          0.003120
F(4,36) = 1.301606   p <= 0.287869

vollh   ( 2 )
   DF        SS                 MS
    1     0.010956          0.010956
    9     0.039907          0.004434
F(1,9) = 2.470927   p <= 0.150419

soa   ( 5 )
vollh   ( 2 )
   DF        SS                 MS
    4     0.013762          0.003440
   36     0.108284          0.003008
F(4,36) = 1.143792   p <= 0.351682

nlet   ( 2 )
vollh   ( 2 )
   DF        SS                 MS
    1     0.003068          0.003068
    9     0.039010          0.004334
F(1,9) = 0.707826   p <= 0.421957

soa   ( 5 )
nlet   ( 2 )
vollh   ( 2 )
   DF        SS                 MS
    4     0.003684          0.000921
   36     0.069709          0.001936
F(4,36) = 0.475629   p <= 0.753313

--------------------- END -----------------
```

Experiment 6: Mean proportions correct for the tone task (IGNORE trials)

```
model is
-->  sj   ( 6 )
     soa   ( 5 )
     nlet   ( 2 )
     vollh   ( 2 )

KEY:
     soa       (1) = 50 (2) = 111 (3) = 245 (4) = 542 (5) = 1200
     nlet      (1) = 1 (2) = 3
     vollh     (1) = quiet    (2) = loud

soa   ( 5 )
     0.97058     0.97816     0.97816     0.97715     0.95006

nlet   ( 2 )
     0.97480     0.96684

soa   ( 5 )
nlet   ( 2 )
     0.96338     0.97778     0.99306     0.97652     0.96326
     0.97778     0.97854     0.96326     0.97778     0.93687

vollh   ( 2 )
     0.95328     0.98836

soa   ( 5 )
vollh   ( 2 )
     0.94811     0.96326     0.95631     0.97715     0.92159
     0.99306     0.99306     1.00000     0.97715     0.97854

nlet   ( 2 )
vollh   ( 2 )
     0.95263     0.95394
     0.99697     0.97975

soa   ( 5 )
nlet   ( 2 )
vollh   ( 2 )
     0.92677     0.95556     0.98611     0.96818     0.92652
     0.96944     0.97096     0.92652     0.98611     0.91667
     1.00000     1.00000     1.00000     0.98485     1.00000
     0.98611     0.98611     1.00000     0.96944     0.95707

soa   ( 5 )
   DF        SS               MS
    4     0.013886         0.003471
   20     0.076478         0.003824
F(4,20) = 0.907839    p <= 0.478275

nlet   ( 2 )
   DF        SS               MS
    1     0.001898         0.001898
    5     0.012152         0.002430
F(1,5) = 0.781031    p <= 0.417289
```

```
soa   ( 5 )
nlet   ( 2 )
   DF        SS                MS
    4      0.008864          0.002216
   20      0.035344          0.001767
F(4,20) = 1.253907    p <= 0.320649

vollh   ( 2 )
   DF        SS                MS
    1      0.036909          0.036909
    5      0.019226          0.003845
F(1,5) = 9.598725    p <= 0.026909     ****

soa   ( 5 )
vollh   ( 2 )
   DF        SS                MS
    4      0.011448          0.002862
   20      0.054058          0.002703
F(4,20) = 1.058879    p <= 0.402474

nlet   ( 2 )
vollh   ( 2 )
   DF        SS                MS
    1      0.002577          0.002577
    5      0.007425          0.001485
F(1,5) = 1.735256    p <= 0.244875

soa   ( 5 )
nlet   ( 2 )
vollh   ( 2 )
   DF        SS                MS
    4      0.012146          0.003036
   20      0.045354          0.002268
F(4,20) = 1.338992    p <= 0.290122

---------------------- END -----------------
```

Appendix B

Overview

Experiment 1 examined whether the decision to encode or ignore a stimulus based on colour required a capacity limited cognitive mechanism. In this experiment performance on blocks of trials where an online decision to encode or ignore was required was compared to performance on blocks of trials where no online decision to encode or ignore was required. The results revealed no additional interference on blocks where an online decision was required and thus it may be concluded that the decision to encode or ignore based on colour does not require a capacity limited cognitive mechanism.

Experiments 2 through 6 employ the locus of cognitive slack logic as a means of assessing the nature of the capacity limited cognitive mechanism involved in the encoding task. In Experiment 2 a tone loudness manipulation was employed in task 2 of a PRP paradigm experiment to confirm that the manipulation affected a relatively early stage of processing. As expected, a significant PRP effect was observed, however more importantly, the tone loudness manipulation produced a highly significant underadditive interaction with decreasing SOA, indicating both that the tone task was susceptible to interference and that the tone loudness manipulation affected a stage before the PRP bottleneck. In Experiment 3 the same tone loudness manipulation was employed in task 2 of an encoding paradigm experiment. In this experiment the tone loudness manipulation produced additive effects of SOA in the absence of an effect of SOA on task 1 accuracy. The results from Experiment 3 imply that the dual-task interference observed in the encoding paradigm is the result of a processing bottleneck with a locus at or before the locus of the tone loudness manipulation. Further, because the same tone loudness manipulation that produced underadditivity in a PRP paradigm experiment (Experiment 2) produced additivity in an encoding paradigm experiment (Experiment 3) it may be reasoned that the so-called PRP bottleneck and the bottleneck encountered in the encoding paradigm are distinct. Experiments 4 and 5 replicated Experiment 2 and 3 using a tone localization difficulty manipulation in task 2. The results from Experiments 4 and 5 mirror those of Experiments 2 and 3; an underadditive interaction between the tone localization difficulty manipulation and decreasing SOA was observed in the PRP paradigm experiment (Experiment 4) while additive effects between the tone localization difficulty manipulation and SOA in the absence of an effect of SOA on task 1 were instead observed in the encoding paradigm experiment (Experiment 5). Experiment 6 replicated Experiment 3 using shorter SOAs and additive effects of the task 2 difficulty manipulation and SOA in the absence of an effect of SOA on task 1 accuracy were again found. The results from Experiments 4, 5, and 6 thus lend additional weight to the conclusion that the interference observed in the encoding paradigm results from a processing bottleneck that is distinct from the PRP bottleneck.