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THE ATTENTIONAL BLINK: A STRUCTURAL OR STRATEGIC LIMITATION OF THE ATTENTIONAL SYSTEM?

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INDEX

CHAPTER 4. Multi-target RSVP paradigm: the within trial contingency 49

4.2 Experiment 1 52

ABSTRACT

The Attentional Blink could be considered as a blind spot in perceptual awareness. This phenomenon results in a marked difficulty to identify the second of two sequential targets, that are presented in a close temporal contiguity, when these are embedded in a Rapid Serial Visual Presentation stream of distractors. The critical temporal window duration of this effect (within 200-600 ms after the presentation of the first target) depends on the time needed from the central processing of the first target. It is interesting to underly that when the temporal interval between the targets is equal to, or shorter then, 100 ms, the Attentional Blink disappears, namely the second target is identified without impairment. This effect is known as Lag-1 sparing in the sense that the second target results spared from the Attentional Blink. Crucial to the present research is the aim to investigate the role of the nature of processing carried out on targets in the Lag-1 sparing phenomenon. In a first series of experiments, 0, 1, or 2 digits (and in one case 0, 1, 2 letters) were embedded with equal probability in Rapid Serial Visual Presentation streams of letter distractors (and in one case in streams of digit distractors). In two experiments (i.e., the first and the third) participants were asked to identify the digits in some blocks of trials and to count the digits in others blocks. In one experiment (i.e., the second) the target to identify or counting were letters and the digits were distractors. In one experiment (i.e., the fourth) the counting task was replaced with a digit-sum task. In the last experiment (i.e., the fifth) the counting task was replaced by a counting task of the digits of a given parity sub-class (odd vs. even digits). Lag-1 sparing was always evident when the participants when the task was the explicit identification of the target digits. Lag-1 sparing was evident when participants were required to sum 2 digits or to count digits of a prespecified parity subclass (e.g., count just even digits). The effect was abolished when participants were asked to count the digits independent on their parity subclass. These results suggest that the occurrence of Lag-1 sparing depends on the type of mental representation that have to be generated on the basis of the target and task information. A numbers of researchers have emphatized the role of distractors intervening between successive targets as the primary determinant of the Attentional Blink. These authors argued that this phenomenon is abolished when 3 or more targets are displayed in a condition of contiguity in rapidly presented serial sequences. In a second series of experiments the present investigation delves deeper into the Lag-1 sparing issue. A multi-targets Rapid Serial Visual Presentation paradigm was employed in which 1-, 2-, 3- digit targets were embedded among letter distractors. Across the series of three experiments both, the numbers of presented targets and the temporal lag between them were manipulated. Evidence of an Attentional Blink was found in each

experiment, namely targets that followed the first one in these sequences presented an impairment in the identification task, when the probability of a given target report was condizionalized on a correct response to the preceding targets. These results support and reinforce the notion that some form of capacity limitation in the encoding of targets plays a fundamental role in the elicitation and modulation of the Attentional Blink effect.

ABSTRACT

Il fenomeno Attentional Blink puo' essere considerato un punto debole nella consapevolezza percettiva. Tale effetto si configura come una marcata difficolta' nell'identificazione del secondo, di due stimoli target, quando questi vengono presentati in stretta contiguita' temporale, inseriti all'interno di una serie di stimoli distrattori in un paradigma sperimentale di Presentazione Visiva Seriale Rapida. La finestra temporale critica di questo fenomeno (compresa tra 200-600 ms dopo la presentazione del primo stimolo target) dipende dall'intervallo temporale richiesto al processo di elaborazione del primo stimolo target. E' interessante sottolineare che quando l'intervallo temporale tra i due stimoli target e' uguale, o inferiore, a 100 ms, l'attentional blink scompare, il risultato e' che il secondo stimolo target viene identificato correttamente. Questo effetto e' noto come Lag-1 sparing, da interpretare in questo senso, che il secondo target risulta preservato dall'Attentional Blink. Cruciale per la presente ricerca e' il proposito di investigare il ruolo della natura dell'elaborazione che viene condotta sugli stimoli targets, all'interno del fenomeno Lag-1 sparing. In una prima serie di esperimenti 0, 1, oppure due cifre target (e in un caso 0, 1, 2 lettere) venivano inserite con la medesima probabilita' all'interno di stringhe di Presentazione Visiva Seriale Rapida di lettere impiegate come distrattori (e in un caso all'interno di stringhe di cifre come distrattori). In due esperimenti (rispettivamente, il primo e il terzo) i partecipanti dovevano identificare i numeri in alcuni blocchi di prove e contare il numero di cifre in altri blocchi di prove. In un esperimento (il secondo) gli stimoli targets erano lettere, da identificare o contare, e gli stimoli distrattori erano cifre. In un esperimento (il quarto) il compito di conteggio era sostituito da un compito di somma delle cifre. Nell'ultimo esperimento (il quinto) il comptito di conteggio era sostituito da un compito di conteggio di una data sotto-classe di uguaglianza (cifre pari vs. cifre dispari). Il Lag-1 sparing era sempre presente nelle condizioni in cui ai partecipanti veniva chiesto esplicitamente di identificare le cifre. Il Lag-1 sparing era evidente quando i partecipanti dovevano sommare le due cifre o contare le cifre di una sotto-classe prespecificata (es., contare unicamente le cifre pari). L'effetto era abolito quando i partecipanti dovevano contare le cifre in modo indipendente dalla loro stessa sotto-classe. Tali risultati suggeriscono che la presenza del Lag-1 sparing dipende dalla tipologia di rappresentazione mentale che e' stata generata sulla base delle informazione proveniente dallo stimolo target e dal compito richiesto. Alcuni ricercatori hanno enfatizzato il ruolo dei distrattori, che intervengono tra due stimoli target successivi, come determinante primaria dell'Attentional Blink. Questi autori sostengono che tale fenomeno sia abolito quando 3 o piu' targets sono presentati in condizione di contiguita' all'interno di sequenze di stimoli distrattori presentate rapidamente. In una seconda serie di tre esperimenti la presente investigazione approfondisce in dettaglio la problematica Lag-1 sparing. E' stato impiegato un paradigma di Presentazione Visiva Serial Rapida con 1-, 2-, 3- cifre (stimoli target) inseriti all'interno di una serie di lettere (stimoli distrattori). Attraverso la serie di esperimenti sono stati manipolati sia il numero di stimoli target presentati sia l'intervallo temporale di presentazione di questi ultimi. La presenza di un Attentional Blink e' stata riscontrata in ciascun esperimento, gli stimoli targets che seguivano temporalmente il primo stimolo target, all'interno delle sequenze di stimoli, presentavano un prestazione deficitaria nel compito di identificazione, quando la probabilita' di un dato stimolo target era condizionata ad una corretta identificazione dei precedenti stimoli target. Tali risultati sostengono e rinforzano la nozione secondo cui alcune forme di limitazione a livello delle risorse di codifica degli stimoli target giocano un ruolo fondamentale nell'elicitare e nel modulare l'effetto di Attentional Blink.

CHAPTER 1

INTRODUCTION

THEORETICAL MODELS OF THE ATTENTIONAL BLINK

1.1 *The Attentional Blink phenomenon*

A way to comprehend the architecture of the human cognitive system consists in “overloading” the system itself, the aim is to individuate the capacity limits of all the single components that constitute it (Pashler, 1994). Among all the researches, that pertain to the Cognitive Sciences field, there is a branch that has pointed the spotlight to the attentional phenomenons. Attention is a cognitive mechanism that contributes to select and elaborate important information that is coming from the world through our senses. The ways in which is possible studying these cognitive process are numerous and various, this is due to the main interest of each study. How the attention influences cognitive processing is so charming and sometimes unexpected. In the Experimental Psychology’s ambit a technique that is mainly employed, to show the limits of the human cognitive system, is the dual-task paradigm. To the present purpose the dual-task paradigm that has been employed is the Rapid Serial Visual Presentation (a.k.a., RSVP) in which two target stimuli (T1 and T2), that are embedded among a succession of distractors stimuli, have to be identified. In literature the results that has been obtained clearly suggest that one or more T1 processing stages interfere with T2 processing when the temporal interval between T1 and T2 (a.k.a., stimulus onset asynchrony; SOA) is comprised between 200-600 ms. This phenomenon has been defined as Attentional Blink (a.k.a., AB).

The classical experimental procedure that allows to observe the AB is the RSVP, as it was already mentioned. Usually, the sequence of stimuli is presented in the same spatial position, normally at the centre of the screen. At the beginning of each RSVP presentation there is a fixation point that disappears at the start of each trial. In literature, the most widely temporal inter-stimulus distance is 100 ms, and the time of each stimulus presentation is 100 ms (10 stimuli/second). Although, the temporal duration of each stimulus can vary between 15 to 120 ms and can be followed by a blank display of 20-75 ms (in this way the presentation frequency can reach the 15 stimuli/second). Among all the stimuli that are embedded inside the RSVP there are two target stimuli (T1 and T2). T1 and T2 can be defined on physical features (for example a different color compare to the distractor items), semantic (different alphanumeric category for example digit targets vs. letter distractors or viceversa), or on a combination of both these characteristics. The applications of this paradigm consists in the repetition of a certain number of trials with the same structure. The main systematic experimental manipulation concerns the temporal interval between T1 and T2 presentation (SOA), that is modulated as a function of the number of items interposed between the two target stimuli.

The first time in which this theoretical denomination, namely Attentional Blink, was employed, dates back to the 1992 when Raymond and colleagues has coined the term (Raymond, Shapiro, & Arnell, 1992). This group of authors has formulated the first model of the AB that is known as *Attentional Gate Model* (Raymond, et al., 1992). The procedure that has been utilized was an RSVP of letters, each letter was presented for 15 ms with a temporal interval among the stimuli (*inter-stimulus interval;* ISI) of 75 ms (11.11 stimuli/second). T1 was a white letter among black letters, while T2 was the X letter in black that appeared just in 50% of the trials. In half of the experiment the task was to identified the white letter (T1) and to check if the black X letter (T2) was presented, while in the other half of the experiment the request was to ignore the white letter (T1) and to detect just the black X. The authors obtained a decrement in T2 response accuracy just in the dual-task condition (in which the observers was obliged to respond to both the target (T1 and T2)). In a second experiment the variation was that the letter following T1 (namely T1+1 stimulus) was omitted. In this situation T2 accuracy comes back to a high level and it was independent from the temporal interval between T1 and T2 presentation. Analogously to the temporarily reduction in the perceptive processing in the visual modality following an eye blink, the authors decided to label the phenomenon, observed in their first experiment, as *Attentional Blink.* They hypothesized that the detection was pre-attentive (in absence of a attentional driven selection) depending on one of its features (in this case the color). This occurrence should be the determiner of an attentional episode onset and it implied the opening of a “gate” that is conceived as a regulator of the visual information flow towards the high level processing stages. The authors suggested that the AB effect was the consequence of a prolonged closing of the attentional gate due to the potential interference to T1 processing that the T1+1 stimulus could imply. This “preservative” action however prevented T2 from being processed when this stimulus fell in a critical temporal window that is around 200-600 ms after T1 stimulus presentation. Thus, if the T1+1 stimulus is omitted there will be a reduction in the interference and this will imply a rapid closing and subsequent opening of the attentional gate, on the base of T2 physical features that are task relevant.

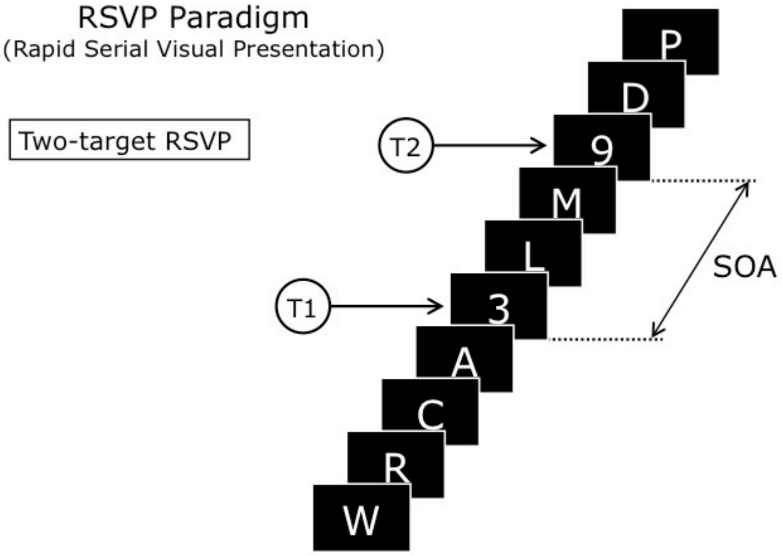

Figure 1. Graphical depiction of a Lag 3 trial (when a severe AB deficit is typically observed) in a standard AB task. In this example participants are required to search for two digits (TARGET 1: T1; TARGET 2: T2) and to report their identiy at the end of each RSVP stream. Typically, both T1 serial position and T1-T2 SOA are varied across trials. Each black frame represents the presentation of a stimulus.

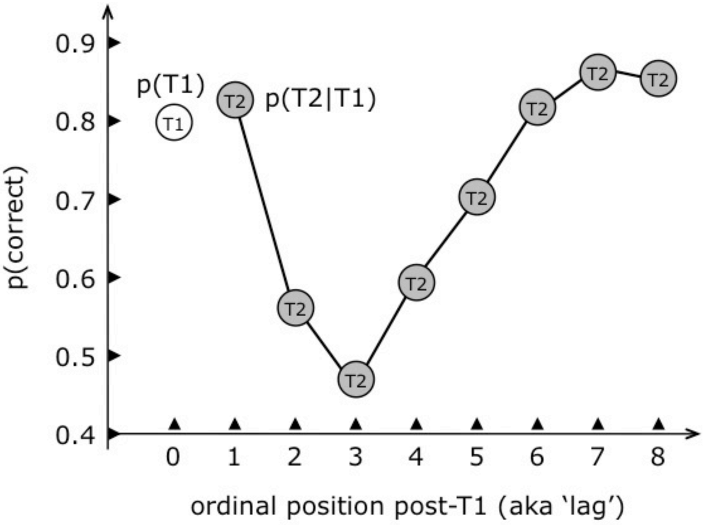

Figure 2. Schematic representations of T1 and T2|T1 (T2 accuracy given T1 correctly reported) proportion of correct responses as a function of T1-T2 lag. The AB corresponds to the severe impairment in T2|T1 performance observed at lags between 1 and 5 relative at lags between 6 and 8. The Lag-1 sparing instead reflects the high T2|T1 proportion of correct responses to T2 at Lag 1.

1.2 *Attentional Blink Bottleneck Models*

One perspective on the AB phenomenon is provided by models postulating that the processing of targets encoded for later report proceeds in two stages: an initial high-capacity identification stage followed by a low-capacity memory-encoding stage. This idea is instantiated in two-stage models like those of Chun and Potter (1995) and Jolicoeur and Dell'Acqua (1998). According to these models, all alphanumeric characters composing an RSVP sequence are processed up to the level of individual character identities at an early stage (Stage 1), but only T1 and T2 are selected for access to a later stage of processing (Stage 2) that consolidates T1 and T2 into durable memory representations that a are stored in visual short-term memory (VSTM). The metaphor of an attentional gate is normally invoked by these models to explain how the system isolates T1 and T2 for further processing. The onset of T1 elicits the opening of the gate, which is held to operate sluggishly (the gate takes some time to close). Given that short-term consolidation is a capacity-limited process, some competition between T1 and T2 ensues such that some of the gain in performance for T2 occurs at a cost to performance for T1 (Potter, Staub, & O'Connor, 2002).

1.2.1 *The Two-Stage Model*

Chun and Potter (Chun & Potter, 1995) created a theoretical model, namely the *Two-Stage Model*, in which, for the first time in the Attentional Blink literature, they hypothesized the existence of two distinct stages in the visual information processing. The first stage (Stage 1) is assumed to be involved in the perceptive processing of all the RSVP stimuli, without the attention investment, till the stimulus identification and the extraction of semantic features (e.g., semantic membership). The stimuli representations, that are generated at this level, activated an attentional response based on the target physical features. This response promoted the target representation consolidation in a more stable and long-lasting form (Stage 2) that could be retrieve subsequently from the VSTM to execute the identification task. The failure in transferring the targets perceptive representation to the Stage 2, in a short temporal interval, more likely implied their loss. Moreover, Stage 2 is assumed as a processing stage exclusively assigned to the representations consolidation of stimuli that are presented in the visual modality. Thus, the AB effect is thought as observable in the circumstance of employing a T1 and T2 visual stimuli. Another key assumption, in agreement with the literature (Broadbent & Broadbent, 1987), is that the Stage 2 is serial. Thus, T2 representation, that is generated at the Stage 1, does not gain the access to Stage 2 until the moment in which the process of T1 consolidation is finished. The critical experimental condition is the one in which T2 is presented at a short SOA after T1 (between 200-600 ms), in fact in this situation T2 access to the Stage 2 is delayed insofar as the consolidation of T1 representation is still underway. This delay in the consolidation of T2 representation could imply its loss due to the decay of T2 perceptive representation (Potter, 1993).

1.2.2 *The Central Interference Theory*

The *Central Interference Theory* (Jolicoeur, 1999) is projected as an important reelaboration and integration of the *Two-Stage Model* (Chun & Potter, 1995), this model is conceived as a more complete theoretical reference framework. Although short-term consolidation is capacity limited, these authors (Jolicoeur & Dell' Acqua, 1998) postulate that several items can be consolidated simultaneously. However, the simultaneous consolidation of several items must begin at the same time, or close to it. It is hypothesized that short-term consolidation operates on the principle of a batch processor. A consolidation batch can contain more than one item. However, once initiated, a batch must be completed before new items can be added to the batch. This would allow two targets to be consolidated simultaneously if they are presented in very close temporal contiguity (i.e., at Lag 1), but not at longer lags, if T1 already triggered a new batch and an ensuing consolidation cycle. At longer lags, processing of T1 initiates a consolidation batch before the processing of T2 prepares T2 consolidation. In this case, T2 arrives too late to enter the consolidation batch containing T1, and so T2 must wait for the consolidation cycle of T1 to finish. During this waiting time, T2 can be lost due to decay or overwriting by items trailing T2 in the RSVP stream. To deeply understand this model is better to take into account one of Jolicoeur's experiments (Jolicoeur, 1999). There was a RSVP of letters at the center of the screen (10 stimuli/sec). In half of the trials there was one of two possible red letters, H or S (T1), among white letters; after a certain SOA was shown one of two possible letters, X or Y (T2). Then, there was another control condition in which T1 was absent. Moreover, there were mixed block of trials in which there was a T1 associated task or a simple speeded response or a binary speeded response between the H and the S letters. The task associated to T2 consisted in a binary choice between the letter X and Y. T2 response was without temporal pressure. The most important result obtained with this paradigm is referred to the comparison between T2 response accuracy in function of the task that was associated to T1: the worst performance to T2 was found in the case of a speeded binary response to T1 (H or S). Interesting is to underlined as one modulation in the AB effect could be achieved even in a task that needed a speeded response to T1. The critical assumption of the Jolicoeur's theory is referred to the necessity of central processing, subsequent to the stimulus identification and previous to the eventual motor response. This central elaboration is fundamental for a set of different operations: the response selection (Pashler, 1994), the short term consolidation (Jolicoeur & Dell'Acqua, 1998), the mental rotation (Van Selst & Jolicoeur, 1994), and the information retrieval from the long term memory (Carrier & Pashler, 1995). In agreement with the idea of a bottleneck in the information processing, this model assumed that the central processing stage should be serial: as a consequence the theory postulate that the operations that involved this kind of resources could not be accomplished in parallel. Thus, whenever one of these operations is in course, others operations that involved the central processing stage had to be postponed. The major difference with the *Two-Stage Model* (Chun & Potter, 1995) is that the *Central Interference Theory* (Jolicoeur, 1999) referred directly to the critical stage that is involved in the AB terming it *short term consolidation* (Jolicoeur & Dell'Acqua, 1998). Moreover, another assumption was that even other operations that are linked to T1 task could determine the postponement of the short term consolidation (STC) of T2 representation. In conclusion, the *Central Interference Theory* assumed that the STC stage was mutual for all the the different sensory modalities, this assumption derived primarily from another study (Arnell & Jolicoeur, 1999) that demonstrated the AB effect in the auditory modality.

Several recent proposal seem to be in line with the general idea that T1 and T2 can be subject to simultaneous consolidation, sometimes at the expenses of information of report order (Akyurek & Hommel, 2005; Hommel & Akyurek, 2005). Furthermore, the notion of substantial overlap in the processing of T1 and T2 within the Lag-1 sparing window has recently provided with the magnetoencephalography (MEG) technique (Kessler et al., 2005a, 2005b) by showing an overlap of the M300 responses elicited by T1 and T2 (the MEG equivalent of the P300 event-related component observed with electrophysiological recordings) as the temporal interval between their onsets was reduced. It is interesting to note that the overlap of M300 peak responses was observed in regions held to be of interest for identification processes (e.g., inferotemporal regions) but not in regions more likely involved in sequencing (e.g., frontoparietal regions).

1.2.3 *The Two-Stage Competition Model*

Potter and collaborators (Potter et al., 2002) proposed a further extension to their previous two-stage model (Chun & Potter, 1995), challenging the hypothesis that the first target gained in any circumstances privileged access to capacity-limited processing resources due to its temporal position. It was already known that at Lag 1, performance on the second target was typically better compare to the that for T1 and that report order of these two target was often reversed (Hommel & Akyurek, 2005), thus the first target may not always be the first item to enter the bottleneck. To test this hypothesis Potter and colleagues (Potter et al., 2002) presented a target word in each of two concurrent RSVP, spatially separated, streams of symbol distractors (one stream above the other) to reduce the temporal lag between the targets without altering stimulus duration. The results demonstrated that when the target were separated by a very brief interval (13-53 ms), T2 reporting was superior to report of T1, a pattern of results opposite to the one that is encountered usually in the AB experiments. The situation changed, at an SOA of 100 ms, performance was comparable for both the targets, and at an SOA of 213 ms, the standard AB for T2 appeared again. The higher level on T2 performance at very short SOAs indicated that T1 is not always the first target that is consolidated before. In the light of this findings, Potter and colleagues (Potter, et al., 2002) postulated the *Two-Stage Competition Model* of visual attention. This approach proposes that targets item compete in Stage 1 to gain access to a capacity-limited Stage 2 of processing. Usually the first target that is identified enters the second stage first. T1 impairment at very short lags (13-53 ms) is explained as it follows. At the moment that T1 is detected, an attentional gate is opened, and the elaboration involved in the preliminary process of identification begins. When T2 appears at a very short SOA after T1, this target item benefits from the fact that the attentional gate has been already opened, thus it accesses faster to the limited pool of attentional processing resources compare to a situation in which a previous target stimulus had not opened the attentional gate. This occurrence implies that T2 identification results more efficient and this target enters the the bottleneck stage before T1. Instead, at the usual RSVP presentation rates (around 100 ms/item), T1 would have already been identified and gained access to Stage 2 before T2 arrival, resulting in a T2 processing deficit.

1.3 *Attentional Blink Control-Based Models*

This group of model assess the AB as an attentional deficit due to issues linked with the control of the attentional input filter. For one theory the filter (Di Lollo, Kawahara, Ghorashi, & Enns, 2005), could be influenced endogenously and exogenously, respectively by top-down control from the central processor, and by bottom-up control from the stimuli presented in the RSVP, when the central processor switches from monitoring the RSVP stream to consolidate the first target stimulus. At the time in which T1 is presented, the central processor (that can execute just a single operation at a time) starts to consolidate this target for subsequent report and the input attentional filter passes under exogenous control. If the stimulus that is placed in position T1 + 1 is a target (T2), there are not issues (because the filter is properly set) and even T2 can gain access to the same attentional episode of T1. This second stimulus will be spared from the AB. If the stimulus T1 + 1 is a distractors a disruption occurs in the configuration of the attentional input filter. Thus, the stimulus placed in position T1 + 2, even if it is a target (T2), will fall in the AB window. In both cases (Lag-1 sparing or AB) there will be a loss of control from the central processor over the attentional input filter.

The second theory of the AB, that is based on a control issue (Olivers & Meeter, 2008), proposed a slightly different explanation of the attentional input filter features. As for Di Lollo and collaborators (2005) the input filter inhibits distractors, that are presented in positions before T1, to prevent them to gain access to the working memory. Moreover, it enhances attentionally T1, and this effect is reflecting even to the stimulus placed in position T1 + 1. If T1 + 1 stimulus is a target (T2), then it gains access to the same attentional episode of T1, namely a Lag-1 sparing effect occurs. If the stimulus in position T1 + 1 is a distractor, it entails a transient suppression, that is produced by the input filter, that implies an AB, because the input filter has to be reset to prevent distractors to gain access to working memory.

1.3.1 *Temporary Loss of Control Theory (TLC)*

This relatively recent theoretical approach proposed a control-based perspective to explain the AB effect (Di Lollo et al., 2005). In one of their experiments the authors implemented two different RSVP typologies. After a sequence of digit stimuli, in one condition, namely the *Uniform*, were shown three consecutive letters stimuli (target stimuli), in another condition, namely the *Varied*, the second letter was substituted with a randomly selected digit. The task was to report the letters identity in both the experimental conditions (three letters in the *Uniform* and two letters in the *Varied*). The behavioral analyses were run on T1 accuracy (the first target letter) and for T2 (for the sake of simplicity the third target letter in the *Uniform* condition and the second target letter in the *Varied* condition). The behavioral analyses showed a decremental effect on T2 identification in the *Varied* condition (a digit stimulus was interposed between the two letters). Unexpectedly, in the *Uniform* condition, in which all the target stimuli shared the same category (three letters), the AB effect was absent. On these findings the authors proposed an AB phenomenon's explanatory model, namely the *Temporary Loss of Control Model*. This theoretical framework assumes that initially the attentional system is configured in the optimal way to elaborate T1, and this configuration was monitored by a central attentional processor. When T1 is presented, the central processor is occupied with its elaboration, in this condition a temporary loss of attentional control occurs, in the maintenance of the optimal attentional configuration in selecting the following stimuli. Thus, the attentional configuration passes under exogenous control due to T1 + 1 stimulus. In the condition in which T1 + 1 stimulus belonged to T1 same category (*Uniform* condition), the initial configuration remained unchanged and T2 could gain access to next processing stage, in this case the filter is tuned properly. Instead, in case of a mismatch between T1 and T1 + 1 category (*Varied* condition), the second stimulus modified the attentional filter configuration and this occurrence excluded T2 (the third stimulus of the triplet) from the subsequent elaboration processes.

1.3.2 *Boost and Bounce Theory (BB)*

This approach does not take into account a capacity limits role in the generation of the AB phenomenon. The model postulated in this theory presents two main stages, one is involved in sensorial processing and the other pertains to the working memory elaboration. Perceptual features of a stimulus (shape, color and orientation) and its high level representations (including semantic and categorical information) are activated during sensorial processing. For the reason that, usually, all the stimuli are presented at the same spatial location in an RSVP stream, each visual item's activation strength (at sensorial processing level) is influenced by those stimuli that appear just before and after it, and this is due to the forward and backward masking. Working Memory (a.k.a., WM) plays a fundamental role in this model. First of all, WM establishes an attentional set (because it maintains task instructions). Second, it stores encoded stimuli's representations, and items that have to be reported and in addition that have been linked to a response. Third, and crucial, WM controls an input filter that enhances the target-like stimuli processing (stimuli that match its setting) and inhibits item that do not match the target set (e.g., distractors). The input filter works in this way: it inhibits the distractors presented before T1, preventing them from gaining access to working memory, and it attentionally enhances the first target, thus this target can gain access to the WM store. Because of its temporal proximity to the first target and for the peculiar dynamics of the enhancement, the T1 + 1 distractor receives a strong attentional *boost* despite the fact that this item is a distractor. The attentional enhancement of T1 + 1 distractor (a stimulus that does not require a subsequent report) triggers a considerable but transient suppression, namely the *bounce*, of successive presented stimuli by the input filter and this action is performed to prevent that the T1 + 1 distractor could gain access to the working memory, the result will be an AB. Instead, if the stimulus in position T1+1 is a target (T2), the attentional enhancement produced by T1 will determine a Lag-1 sparing effect, namely the second target will be spared from the AB.

CHAPTER 2

AN EXCEPTION TO THE RULE: LAG-1 SPARING

2.1 *Lag-1 sparing phenomenon*

Lag-1 sparing is a sub-effect of the AB, in literature this phenomenon has been ascribed to the sluggishness of an attentional gate closure (Chun & Potter, 1995). These authors have postulated that the gate presents some peculiar features: on presentation of the first target (T1) it thought to open rapidly but to close sluggishly, in this way it allows the item next to T1 (T1 + 1, at Lag 1 temporal position), in the RSVP stream, to gain access to the same attentional episode along with T1. When T2 is the next item to T1, both targets are processed together, and the AB does not appear, even T2 results preserved from the AB. This theoretical explanation, namely the attentional gating hypothesis, is a valid explanation in all the studies, in literature, in which there were evidences of Lag-1 sparing's occurrence.

However, in an exhaustive review of the literature, Visser and colleagues (Visser, Bischof, & Di Lollo, 1999) have found a Lag-1 sparing effect in approximately half of the experiments considered and no presence of this effect in the other half. Lag-1 sparing occurs, as it is postulated, when T2 gains access to the same temporal windows as T1. Why does it occur in one half of the experiments but not in the other? Nevertheless, the fact that in some circumstances Lag-1 sparing is absent does exclude an attentional-gating account in order to explain the phenomenon. The starting point in analyzing this effect is to take into account that two successive target stimuli can become part of the same attentional episode just under peculiar conditions. Inside Visser and collaborators' review (1999) there is a fully detailed examination in which the authors have ranged in four classes all the considered studies, based on the type of switches involved: 1) switches in location, 2) switches in modality, 3) switches in task, and 4) switches in category. Thus, the experiments considered were related to the distribution of attention and to rapid changes in the attentional set both in spatial and nonspatial domains.

The first reported results were related to all the experiments that did not present any switches between the targets. Lag-1 sparing was presented all over these studies, and the authors have concluded that this phenomenon occurs in presentation conditions in which two successive target belong to the same category, are presented in the same modality, in the same location, and require the same type of task performance.

The second type of studies were the ones related to changes in the targets' display spatial locations, they were different for T1 and T2. No Lag-1 sparing was found when a switch in targets' relative spatial location was present.

The third type of researches concerns switches in targets category. The majority of the considered studies presented a Lag-1 sparing effect. Just one study, that involved a distractor presentation in a to-be-ignore modality stream, supports the idea for which divided attention may reduce or completely abolish Lag-1 sparing.

The fourth group of experiments concerned situations in which the two targets were presented in different modalities. Unless there are concomitant switches in others dimensions, no AB and then no Lag-1 sparing were found in literature. However, the authors underlined that modalities switches, when implemented in conjunction with other switches, had a strong effect.

A global perspective on the effects of multiple switching is offered inside the review. The authors have highlighted that multidimensional changes lead to a Lag-1 sparing abolition. Visser and colleagues (1999) nevertheless suggested to be cautious considering the intrigues and potentially important results. They avoided to formulate an informed hypothesis.

To summarize the review results: Lag-1 sparing is found when no switches in attentional set were present between the targets or when the switches was unidimensional (in task or category). Moreover, the phenomenon was not found in situations of location switches or in circumstances of switches that involved two or more dimensions.

Could the attentional-gating model still be valid to explain the Lag-1 sparing effect? The pattern of results obtained can be easily explained by the cited model after a revision of it. In the original model the temporal contiguity was the only condition for the target stimuli for entering the same attentional window. Why Lag-1 sparing does not appear in all the considered studies? Given that the temporal inter-target interval was approximately the same in all the listed experiments one should expect Lag-1 sparing in all of them. Thus, the authors added a second criterion, namely a filter that controls access to the attentional window. Following this assumption, two targets can enter the same attentional window when they present similar processing requirements, but not when the elaboration processes are substantially different. The fact that Lag-1 sparing is found to occur in situations of unidimensional switches, excluding spatial switches between the targets, supports the idea by which the input filter can be configured to manage both target, provided that they occupied the same spatial locations and that they presented a difference in just one dimension. The second target must arrive while the attentional gate (opened by T1 presentation) is still open, around 100-200 ms after T1, and it must match the input filter characteristics (even the spatial location). The filter purpose is to select those stimulus target-like attributes for performing the task at hand.

2.2 *Control-based models' interpretation*

In literature to account for Lag-1 sparing there are two control-based models that state this effect to a filtering hypothesis rather then to a resource-depletion one. These alternative accounts where proposed by two different research groups. However, they came to different theoretical ends postulating in one case the *Temporary Loss of Control* theory (Di Lollo et al., 2005) and in the other the *Boost and Bounce* theory (Olivers & Meeter, 2008). The TLC (Di Lollo et al., 2005) approach is based on the assumption of the existence of an attentional input filter that initially, at the start of the RSVP stream, is configured to exclude the leading distractors stimuli and to accept the first target stimulus. Moreover, the authors assumed that the input filter is governed endogenously, at the beginning of the RSVP sequence, in a top-down way from higher brain regions (central processor) to check the stimuli's stream for the targets features. Another critical statement pertain to the fact that, when the first target arrives the central processor starts to elaborate this stimulus and to prepare response plans, and for this reason the input filter remains without the required endogenous control. In this situation, namely the absence of central processor control, the input filter configuration comes under exogenous control by the subsequent stimulus in position T1 + 1, the Lag 1 position. If T1 + 1 stimulus is from the same category as T1, it matches the current input filter configuration and it gains access to further elaboration. Instead, if the item that is placed in T1 + 1 position is a distractors, it implies an exogenous modification of the input filter configuration, which is no more optimally set to the target category and, as a consequence, the stimulus at Lag 2, is not efficiently elaborated even when it is a target category stimulus.

In boost and bounce theory (Olivers & Meeter, 2008) as in the TLC one, no role is assigned to resource depletion in the AB effect. A postulate of the model is that each stimulus is processed, during the sensory elaboration, along both its perceptual features (shape, color, orientation) and its high-level representations (semantic and categorial information). Each stimulus activation is influenced by both the stimuli that appear before and after it, namely the forward and backward masking. In this model working memory is controlling an input filter to enhance the elaboration of stimuli target-like and to inhibit the distractors stimuli, that do not match the target features. The input filter in the first instance inhibits the distractors displayed before T1 to prevent them from accessing to working memory, and in second instance enhances at attentional level T1, this second action gives the possibility to this target to gain access to the working memory store. The stimulus placed in position T1 + 1, for its temporal proximity and the enhancement due to T1, also receive an attentional boost, even if it is a distractor. In this situation the attentional enhancement implies a subsequent transient suppression, namely the bounce, for the reason that the distractor stimulus does not require being reported. Thus, the input filter produces this suppression that involves all the stimuli presented in successive positions, the obtained results is an AB. Lag-1 sparing is explained has it follows, the phenomenon is due to the initial boost, that has been produced by T1, and this sparing effect is extended to Lag 2 and Lag 3, in a situation of contiguous target RSVP stream part (in agreement with Di Lollo and colleagues (2005) and Olivers and collaborators (2007)). Indeed, under this circumstances there are no inhibitory signals produced by the input attentional filter because the T1 + 1 and T1 + 2 stimuli are both target stimuli.

2.3 *The present investigation*

The theoretical interpretations, that have been just introduced, constitute the present research framework. The main interest is addressed to the Lag-1 sparing “behavior” in different experimental conditions.

First, the description of a series of experiments concerning two targets experimental paradigms is proposed to test whether or not the occurrence of Lag-1 sparing depends on the type of mental representation that must be generated on the basis of target and task information. The central experimental manipulation concerns whether a task of reporting the stimuli identity (identification), that is known to involve the short-term consolidation of specific target-identity codes, shows the same pattern, in term of AB and Lag-1 sparing, of another task (counting) involving solely the information about the stimulus class (digit vs. letters). Neither two-stage models nor control-based models would make different predictions, namely both type of models would aspect to observed an AB, as well as a Lag-1 sparing effect, the theoretical reasons will be explained in Chapter 3 introduction.

Second, in a three experiments' series a new methodological procedure, namely the application of the *within trial contingency principle,* will be employed in a context of multi-targets experimental paradigms (up to three targets). Two-stage models and control-based models have demonstrated empirically that is possible to extend the Lag-1 sparing benefit beyond the Lag 1 position. Multi-targets RSVP experimental paradigms (Di Lollo et al., 2005) involving three consecutive targets stimuli (first target - second target - third target, presented in successive positions without intervening distractors), or up to four targets (Olivers, van der Stigchel, & Hulleman, 2007) or even up to six targets (Nieuwenstein & Potter, 2006), supported the notion of a protracted sparing in this particular conditions. Is important to underline that both kind of theoretical approach have demonstrated a protracted sparing.

Dwelling scrupulously upon the mentioned studies, something very interesting appears: the authors did not constrain the proportion in reporting of the last target (the third one, the fourth one or the sixth one) just to trials in which all the previous targets have been correctly reported. Thus, all the obtained results are rather misleading, and the aim of the second series of experiments is to applied this kind of methodological constraint, to the behavioral analyses, and to test again the multi-targets paradigms to replicate the absence of the AB that is predicted from the cited literature.

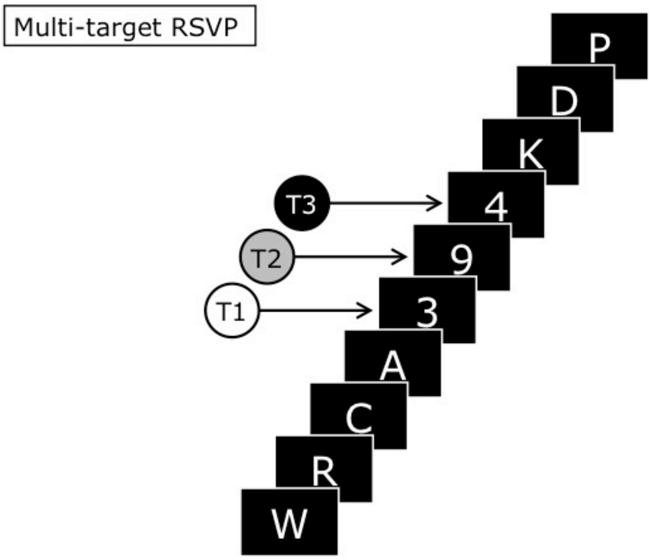

Figure 3. Graphical depiction of a trial in the *Uniform* condition employed by Di Lollo and colleagues (2005).

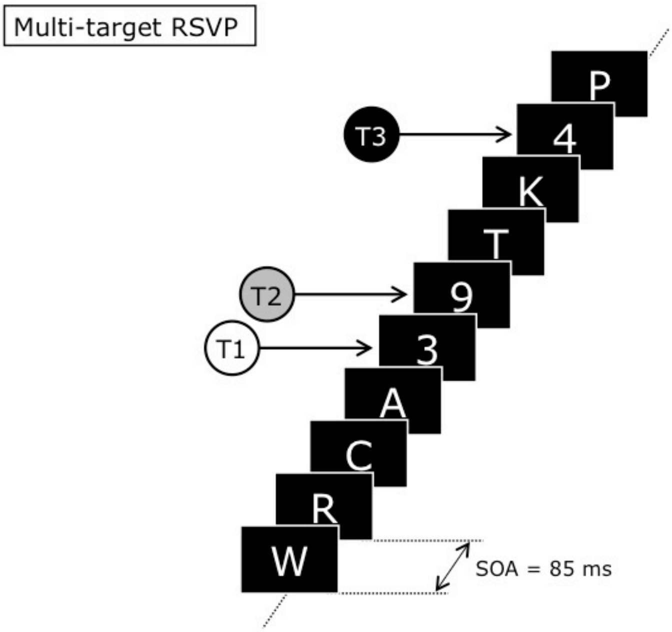

Figure 4. Graphical representation of a trial in the second series of experiments in the present investigation. This is a depiction of a Lag 3 trial, namely the position occupied by T3 compare to T2 position (when a severe AB deficit most likely occurs for T3), in a standard multi-target AB task. Across the series of experiments the targets relative position were orthogonally varied as it is clearly explained in Chapter 4.

CHAPTER 3

IDENTIFICATION VS. COUNTING

3.1 *The Study*

A rapid serial visual presentation (RSVP) was used to investigate the role of the nature of processing carried out on targets in the lag-1 sparing phenomenon. Lag-1 sparing refers to a higher accuracy in the task associated with the 2nd target when the 2 targets are immediately successive in the RSVP stream relative to when there are 1 or 2 intervening items between the targets. In 5 experiments, 0, 1, or 2 digits (and in one case 0, 1, or 2 letters) were embedded with equal probability in RSVP streams of letter distractors (and in one case a stream of digit distractors). In two (i.e., the first and the third) of the experiments, participants identified the digits in some blocks of trials, and the counted the number of presented digits in other experimental blocks. In one experiment (i.e., the second), the alphanumeric class of targets and distractors was reversed (i.e., letters were targets and digits were distractors). In one experiment (i.e., the fourth) the counting task was replaced with a digit-sum task. In the last experiment (i.e., the fifth) the counting task was replaced by a counting task of a given parity sub-class.

The issue at the core of the present investigation is related to the complex interplay between attention control of the input filter mechanisms, on the one hand, and the aspects of processing taking place prior to the capacity-demanding consolidation of the representation selected for further processing on the other.

In the two-stage framework (Chun & Potter, 1995), it is hypothesized that stimuli are processed up to the level of individual identities before consolidation (Jolicoeur, 1998). The logical implication of this hypothesis is that the production of identity codes for T1, T2, and the distractors should take place regardless of whether the task associated with T1 and T2 requires identification. Put in another way, whether identity is the information that must be reported from T1 and T2, the identity codes are generated, likely via the automatic activation of the corresponding identity nodes at the level of conceptual short-term memory (Potter, 1976, 1993). However, Di Lollo and collaborators (2005) have argued that an input filter is tuned to detect the relevant characteristics of target information for filtering purposes. The central operator in this framework sends signals back to earlier processing stages to keep them tuned to the target information that is relevant for the task at hand. The emphasis in this view is on the important role played by early processing of the information that is critical to isolate target from distractor information.

Most experiments working with the AB paradigm have used stimuli for which participants have long-term memory representations (e.g., letters, digits), and it is surprising that the specific role of such representations in the modulation of the AB effect and Lag-1 sparing has so far never been explicitly addressed. It is interesting to note that Raymond (Raymond, 2003) reported two AB experiments in which novel objects were used as stimuli. The stimuli were simple geometric shapes (tridentlike or arrowed patterns), presented using the RSVP technique. The distractors included in each RSVP stream were always tridents, and T1 was distinguished from distractors because it carried a unique feature, a thicker line segment superimposed horizontally on either a trident or an arrowhead. In this way, T1 was defined as an old object when it was a trident (because it was preceded by several distractors with the same "identity" or a new object when it was an arrowhead). In two experiments, Raymond showed the presence of an AB effect only when T1 was a new object and no AB effect when T1 was an old object. Raymond argued that the need to generate a new object file is an important determinant for the occurrence of an AB effect (Kellie & Shapiro, 2004). However, when Raymond observed an AB, Lag-1 sparing was absent. This raises the interesting possibility that the absence of Lag-1 sparing in Raymond's experiments might have resulted from the fact that participants had to process stimuli that were novel. More specifically, one may hypothesized that when the task requires the consolidation of stimulus identities for which there is a unique correspondence in long-term memory (as in the case of to-be reported familiar stimuli such as alphanumeric character, real-world objects, scenes, faces, etc.), the resulting *identification code* (Kawahara, Di Lollo, & Enns, 2001), or *token instantiation* (Chun, 1997), receives re-entrant support from long-term memory, which is likely to prolong a fleeting activation caused by a brief (and masked) stimulus presentation. A reasonable supposition is that this activation prolongation may be the critical element for the integration of two (or more) such codes generated on the basis of sequential stimuli and for their simultaneous short-term consolidation which results in Lag-1 sparing. The present paradigm design was created to test whether the requirements to generate a reportable identity code from visual stimulus (vis-à-vis other forms of codes) had a modulatory role in the

AB and Lag-1 sparing. In the experiments an unpredictable number of digits (ranging from 0 to 2) was embedded in a RSVP stream of letters and instructed the participants either to identify the digits for delayed report, as has been often required in the studies of Lag-1 sparing, or to simply count the digits, followed by a delayed report of the total number of digits rather than of which digits had been presented. This procedure allows to maintain a similar selection cue in all cases (i.e., select digit targets and reject letter distractors) while varying what operation following the initial selection had to be performed on the basis of the selected objects. The assumption underlying this design was that whereas the task to report what digits had been displayed on a given trial could be carried out only via the consolidation of specific digit-identity codes, the counting task relied solely on information about the stimulus class (digits vs. letters), namely the detection of a discontinuity at the alphanumeric level in the flow of visual information. Neither two-stages models nor temporary loss of control (TLC) model would make a differential prediction on the presence (or amount) of Lag-1 sparing in the two tasks. Lag-1 sparing should be observed with counting and identifying in the two-stage framework because the generation of identity codes is not subject to voluntary control. Lag-1 sparing should be observed with counting and identifying in the TLC framework because the information used to filter target from distractor information is the same in both tasks. Therefore, finding a dissociation in term of Lag-1 sparing between the two tasks that were adopted would represent a challenge for both models.

3.2 *Experiment 1*

Experiment 1 was the starting point of the present investigation. Zero, 1, or 2 digits were embedded in RSVP sequences of letters, and the subjects were instructed to identify the digits in half of the blocks of trials and to count the digits in the other half. Target selection had the same basis in both cases, namely, select digits and reject letters.

3.2.1 *Method*

Subjects. A total of 90 university students (52 female, 38 male) from the University of Padova, Padova, Italy, ranging in age from 19 to 33 years, were assigned at random to the five experiments in the present study (*n* = 18 in each experiment). The subjects were paid or received course credit for their participation. All subjects had normal or corrected-to-normal acuity, and none reported a history of prior neurological disorders.

Stimuli. The stimuli were 22 letters of the English alphabet (all except the letters *B*, *I*, *O*, and *Z*) and the digits *2* to *9*. These characters were displayed in light gray (34 cd/m2) on a uniform black background (6 cd/m2) on a cathode ray tube computer screen placed about 70 cm from a subject's eyes. Luminance measurements were performed using a Minolta LS-100 chromameter. All characters fit in a square portion of the screen with a side of 0.95°. The characters were displayed using the RSVP technique. Each character was displayed for 85 ms at the center of the screen and was immediately replaced by the next item (interstimulus interval [ISI] was 0 ms), yielding a presentation rate of approximately 12 item/s. Each RSVP stream of stimuli was generated by randomly selecting letters without replacement from the list of 22 letters. In 2-digit trials, there were 6–9 letters before T1, and T2 could occur at Lags 1, 3, or 7 after T1. There were 1–4 distractors presented starting at Lag 8, ensuring that T2 was always followed by at least 1 distractor. In 1-digit trials, T1 was replaced by a distractor in the RSVP sequence. In 0-digit trials, both T1 and T2 were replaced by distractors.

Procedure. Each trial began with the presentation of a *plus* sign at the center of the screen. The trial started with a spacebar press, which caused the *plus* sign to disappear. After a blank interval of 800 ms, the RSVP stream was displayed. Streams with 0 digits, 1 digit, and 2 digits were equally likely to be presented throughout the experiment. The task was either to count the number of presented digits or to report which digits had been presented. Subjects performed three blocks of 54 trials for each task, and task order was counterbalanced across subjects, with half of the subjects performing the counting task first and the identification task second and the other half performing the tasks in the reverse order. In the identification task, a question was displayed 800 ms after the end of the RSVP stream, inviting subjects to report the digit(s) by pressing the corresponding keys on the numeric keypad of the computer keyboard or *0* if no digit was presented. The instructions mentioned explicitly that the order in which the responses were given in the identification task (when more than one response was made) was not important. In the counting task, a question was displayed 800 ms after the end of the RSVP stream presentation inviting subjects to indicate the number of digits seen in the RSVP sequence by pressing one among the *0*, *1*, or *2* keys of the numeric keypad. In both the identification task and the counting task, responses were made without speed pressure. One block of 18 practice trials preceded the series of three blocks in a given task. In each block of trials, the three levels of the lag manipulation were equiprobable.

3.2.2 *Results*

The proportions of correct responses in 0-digit, 1-digit, and 2-digit trials were analyzed separately using an analysis of variance (ANOVA) in which lag (in 1-digit and 2-digit trials only) and task were treated as within-subject factors. In the identification task, the order in which subjects indicated the identity of T1 and T2 in 2-digit trials was not taken into account.

0-digit condition. The proportion of correct responses in the identification task and in the counting task was the same (i.e., .87). Errors in both tasks were entirely false alarms involving the incorrect indication of the presence of one digit in the RSVP streams, no false alarms due to the incorrect report of two digits ever occurred in this condition.

1-digit condition. The proportions of correct responses were .95 in the identification task and .84 in the counting task. These proportions differed significantly, $F(1, 17) = 18.7$, $MSE = 0.017101$, $p < .001$. It is interesting to note that the analysis revealed that most errors in the counting task were represented by false alarms (i.e., subjects responding *2* incorrectly), whereas false alarms were virtually absent in the identification task (.13 vs. .01), *F*(1, 17) = 35.7, *MSE* = 0.010786, *p* < .001, with a small proportion of misses as remaining errors (i.e., .016). The manipulation of lag (reflecting the absolute position of the digit in the RSVP stream) produced no significant effects in this condition (*F* < 1).

2-digit condition. Consider first the identification task (see Figure 5, top panel). The proportion of correct responses to T1 was affected by the lag manipulation, with a lower proportion of correct responses to T1 at Lag 1 compared with that at the other lags, *F*(2, 34) = 50.1, *MSE* = 0.005302, *p* < .001. When the data at Lag 1 were discarded from the analysis, the proportion of correct responses to T1 at Lag 3 and at Lag 7 did not differ significantly (*F* < 1).

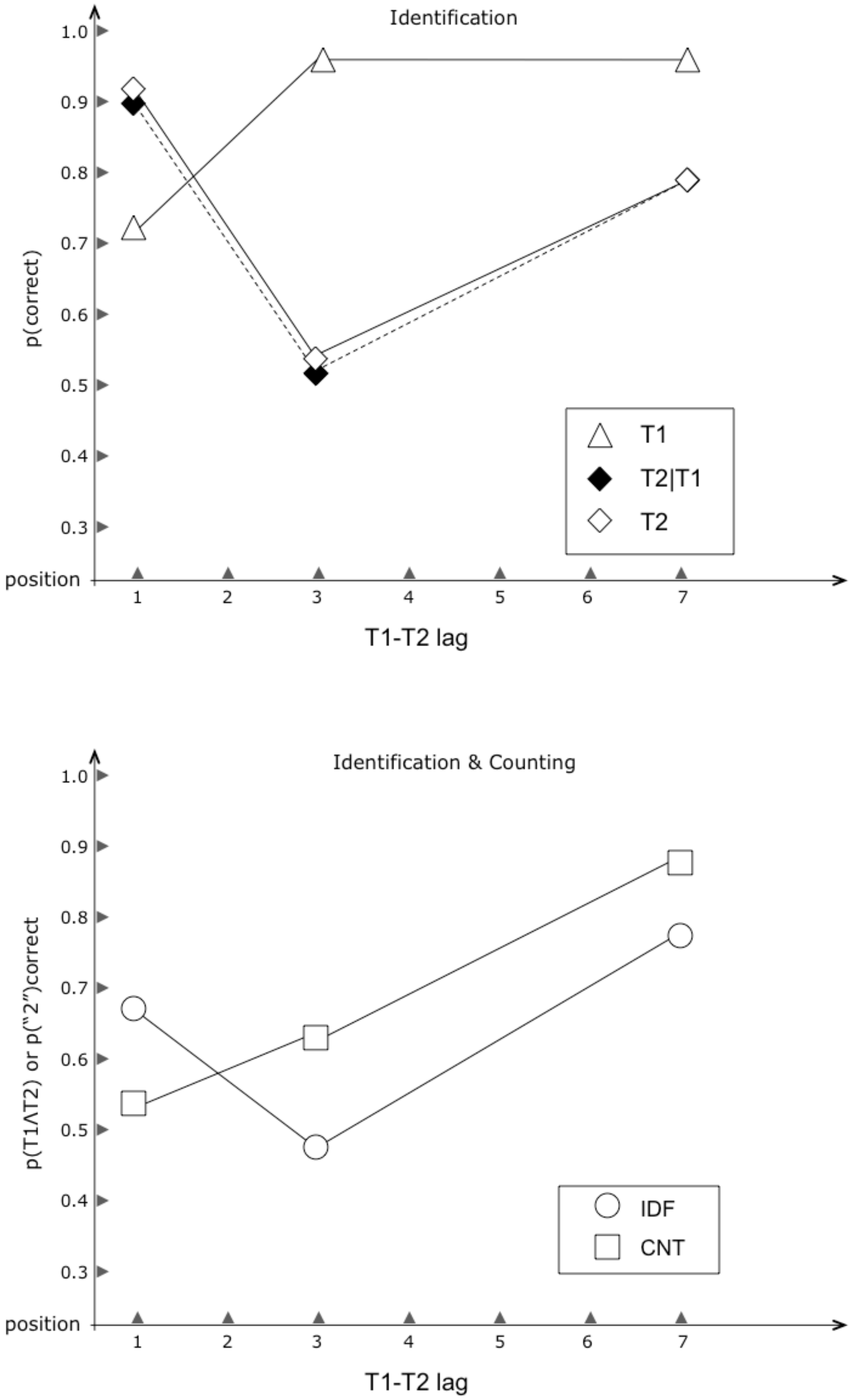

Figure 5. Results in the 2-digit condition of Experiment 1. Top panel: Mean proportion of correct responses in the identification task. Bottom panel: Mean proportion of correct responses in the identification and counting tasks, calculated on the basis of trials in which both T1 and T2 were correctly identified (IDF: identification task), and trials in which a correct '2' response was emitted (CNT: counting task).

The proportion of correct responses to T2 was first analyzed by considering only trials in which T1 was identified correctly. The analysis indicated a marked effect of lag, *F*(2, 34) = 34.4, *MSE* = 0.021848, *p* < .001, that was qualified by the characteristic U-shaped function of the AB effect (see Figure 1, top panel). The difference between the proportion of correct responses to T2 at Lag 1 and the proportion of correct responses to T2 at Lag 3 was significant, *F*(1, 17) = 70.5, *MSE* = 0.020059, *p* < .001, as was the difference between the proportion of correct responses to T2 at Lag 3 and the proportion of correct responses to T2 at Lag 7, *F*(1, 17) = 34.2, MSE = 0.025651, *p* < .001. Another analysis was carried out on the proportion of correct responses to T2 independent of whether T1 was correctly identified on a given trial. The results were similar to those produced by the previous analysis, with a strong effect of lag, *F*(2, 34) = 41.6, *MSE* = 0.018513, *p* < .001, and a U-shaped distribution of the mean proportion of correct responses to T2 across lags (see Figure 5, top panel). The difference between the proportion of correct responses to T2 at Lag 1 and the proportion of correct responses to T2 at Lag 3 was significant, *F*(1, 17) = 54.3, *MSE* = 0.024518, *p* < .001, as was the difference between the proportion of correct responses to T2 at Lag 3 and the proportion of correct responses to T2 at Lag 7, *F*(1, 17) = 33.5, *MSE* = 0.024259, *p* < .001. As can be seen in the top panel of Figure 5, conditionalizing accuracy for T2 on a correct response to T1 made no difference.

For the counting task, the open squares in the bottom panel of Figure 5 show the proportion of correct trials (i.e., when subjects responded *2*) for each lag. These means were submitted to an ANOVA with lag as a within-subject factor, which revealed a significant effect of lag, *F*(2, 34) = 21.3, *MSE* = 0.022513, *p* < .001. In the counting task, it was not possible to determine which target was missed (the first or the second) when subjects responded *1* instead of *2*. A likely supposition was produced about the fact that it was the second target that was missed in the majority of these trials but that sometimes the reverse may have occurred.

There was also a comparison of overall success in the identification task with that in the counting task. To do so, a scoring of overall success was performed in the identification task as the proportion of trials in which T1 and T2 were both identified correctly. The resulting overall accuracy means are also displayed in the bottom panel of Figure 5. An ANOVA was conducted on the means from both tasks treating lag and task as within-subject factors, which revealed a main effect of task, *F*(1, 17) = 4.8, *MSE* = 0.013849, *p* < .05; a main effect of lag, *F*(2, 34) = 19.2, *MSE* = 0.039906, *p* < .001; and a Task X Lag interaction, *F*(2, 34) = 14.1, *MSE* =

0.011492, $p < .001$. Evidence for Lag-1 sparing was clearly present for the identification task but entirely absent for the counting task.

A separate analysis carried out on errors in the identification task revealed a significant effect of lag on the proportion of misses, $F(2, 34) = 37.4$, $MSE = 0.013022$, $p < .001$, but not on the proportion of incorrect responses to T2 ($F < 1$). In the counting task, errors were represented exclusively by cases in which subjects pressed incorrectly *1* (and not *0*, i.e., the alternative response option) after being exposed to 2-digit trials.

3.2.3 *Discussion*

The main goal of Experiment 1 was to compare performance for 2-digit trials across the counting task and the identification task. For the identification task, T1 was identified correctly more frequently than T2 at all lags except at Lag 1, where T2 was identified correctly more frequently than T1 (see Figure 5, top panel). As in previous works, the Lag-1 sparing effect[1] in the T2 accuracy scores was accompanied by a marked drop in accuracy of report for T1, suggesting some competition for limited processing capacity. This competitive trade-off between T1 and T2 makes the analysis of either score alone (T1 or T2) difficult to interpret[2] and, thus, difficult to compare with results from the counting task. For this reason, an assessment was conducted on the overall measure of success in the identification task by computing the proportion of 2-digit trials in which both digits were reported accurately (see Figure 5, bottom panel). Evidence for Lag-1 sparing was still observed in the composite T1–T2 accuracy scores, suggesting an overall advantage at Lag 1 relative to Lag 3, over and above any trade-off between T1 and T2.

In contrast, the results in the counting task provided no evidence for Lag-1 sparing (see Figure 5, bottom panel), and these different patterns of results (Lag-1 sparing for the identification task and the absence of Lag-1 sparing for the counting task) were statistically significant. There was no easy way to determine which digit was missed in 2-digit trials in the

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[1] In Visser, Bischof, and Di Lollo’s (1999) meta-analysis, Lag-1 sparing was said to have occurred in a given AB experiment if the level of performance at Lag 1 exceeded by 5% the lowest level of performance indicated in the AB function (which is usually observed between Lag 2 and Lag 3). In the present study, the criterion for the definition of Lag-1 sparing was more conservative, given that an indication of the quantity of "sparing" was associated with the relative value of probability that the better preformance at Lag 1 compared with that at the other lags was not due to chance.

counting task other than by trying to infer it from the results of the identification task. But, given that the two tasks produce different results (at Lag 1, at least), this approach must be considered with caution. Useful indications come from the analysis of the patterns of errors in 2-digits trials in the two tasks. Errors in the identification task for T2 could be of one of two types, either misses of T2 (i.e., subjects typed in only T1) or incorrect responses to T2 (i.e., subjects typed in two digits, one of which [T2] was incorrect). The distribution of errors in the identification task observed in Experiment 1 was in fact informative of the tendency on the part of subjects actually "not to see" T2 in many 2-digit trials, as witnessed by a proportion of missed T2 that was substantially higher (.07, .46, and .10 from the shortest to the longest lag, respectively) compared with a negligible proportion of incorrect responses to T2 (.01, .02, and .02 from the shortest to the longest lag, respectively). This particular result converges with recent findings by Sergent, Baillet, and Dehaene (2005), who integrated the standard behavioral variable monitored in RSVP designs (i.e., success in reporting target information) with a procedure aimed at estimating the subjective visibility of targets embedded in RSVP streams. The logic in this study was to compare the binary outcome associated with the first type of dependent variable (T2 reported vs. T2 not reported) with a more continuous (on a 100-point scale) estimate of the visibility of T2 in the AB. It is interesting to note that the rate of subjective visibility of T2 and the rate of report were almost perfectly correlated. The rate of visibility was bimodally distributed and, more important, the modes coincided with the extremes of the scale of visibility, suggesting that the AB produced in the majority of cases a dichotomous outcome: T2 was either seen and reported, or T2 was lost radically (as the close-to-nil subjective rating of T2 visibility suggested).

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[2] The T1–T2 trade-off could not be a result of report-order errors because accuracy was scored without regard to order.

3.3 *Experiment 2*

In Experiment 1, the targets were digits, and the task in the counting task was to count how many digits had been presented. The starting point of the second experiment planning concerns the question that updating a mental count for digits could produce a conflict between the state of the mental counter and the numeric value represented by the digits that were counted. Resisting this conflict could be particularly difficult when two digits were presented at short lag, perhaps resulting in the abolition of Lag-1 sparing in the counting task. To rule out this possibility, the alphanumeric class of targets and distractors was reversed in Experiment 2, namely, letters were used as targets and digits as distractors. If the absence of Lag-1 sparing in the counting task was caused by a potential conflict between the identity of the counted targets and the state of the mental counter, then counting letters should eliminate it, and Lag-1 sparing should now be equivalent across the counting task and the identification task.

3.3.1 *Method*

The stimuli and procedure were the same as those used in Experiment 1 except that the targets were letters and the distractors were digits. In the identification task, subjects typed the identity of target letters using the computer keyboard. All other aspects of Experiment 2 were identical to those of Experiment 1.

3.3.2 *Results*

The proportions of correct responses in 0-letter, 1-letter, and 2-letter trials were analyzed separately using an ANOVA in which lag (in 1-letter and 2-letter trials only) and task were treated as within-subject factors. In the identification task, the order in which subjects indicated the identity of T1 and T2 in 2-letter trials was not taken into account.

0-letter condition. The proportions of correct responses were .93 in the identification task and .88 in the counting task. These proportions differed significantly, *F*(1, 17) = 13.3, *MSE* = 0.001517, *p* < .003. Errors in both tasks were entirely due to false alarms in which subjects reported seeing one letter, no false alarms were due to the incorrect report of two letters.

1-letter condition. The proportions of correct responses were .92 in the identification task and .80 in the counting task. These proportions differed significantly, *F*(1, 17) = 65.3, *MSE* = 0.007277, *p* < .001. A tendency analogous to that observed in Experiment 1 was observed in Experiment 2. The analysis revealed that most errors in the counting condition were represented by false alarms (i.e., subjects responded *2* incorrectly), whereas false alarms were virtually absent in the identification condition (.14 for counting vs. .01 for identification), *F*(1, 17) = 33.2, *MSE* = 0.014715, *p* < .001. A close-to-nil proportion of misses constituted the remaining errors. The lag manipulation produced no significant effects in this condition (*F* < 1).

2-letter condition. Consider first the identification task (see Figure 6, top panel). The proportion of correct responses to T1 was affected by the lag manipulation, with a lower proportion of correct responses to T1 at Lag 1 compared with that at the other lags, *F*(2, 34) = 27.9, *MSE* = 0.010527, *p* < .001. When the data at Lag 1 were discarded from the analysis, the proportion of correct responses to T1 at Lag 3 and at Lag 7 did not differ significantly (*F* < 1).

The proportion of correct responses to T2 was first analyzed by considering only trials in which T1 was identified correctly. The analysis indicated a marked effect of lag, *F*(2, 34) = 46.4, *MSE* = 0.024681, *p* < .001, reflected in the classic U-shaped function of the AB effect (see Figure 2, top panel). The difference between the proportion of correct responses to T2 at Lag 1 and the proportion of correct responses to T2 at Lag 3 was significant, *F*(1, 17) = 111.1, *MSE* = 0.017833, *p* < .001. The difference between the proportion of correct responses to T2 at Lag 3 and the proportion of correct responses to T2 at Lag 7 was also significant, *F*(1, 17) = 87.9, *MSE* = 0.018891, *p* < .001. An analogous analysis was carried out on the proportion of correct responses to T2 independent of whether T1 was correctly identified. The results were virtually identical to those produced by scoring T2 accuracy conditionalized on a correct response to T1, with a strong effect of lag, *F*(2, 34) = 68.8, *MSE* = 0.016649, *p* < .001, and a U-shaped distribution of the mean proportion of correct responses to T2 across lags (see Figure 6, top panel). The difference between the proportion of correct responses to T2 at Lag 1 and the proportion of correct responses to T2 at Lag 3 was significant, *F*(1, 17) = 67.8, *MSE* = 0.026115, *p* < .001. The difference between the proportion of correct responses to T2 at Lag 3 and the proportion of correct responses to T2 at Lag 7 was significant, *F*(1, 17) = 79.9, *MSE* = 0.017591,

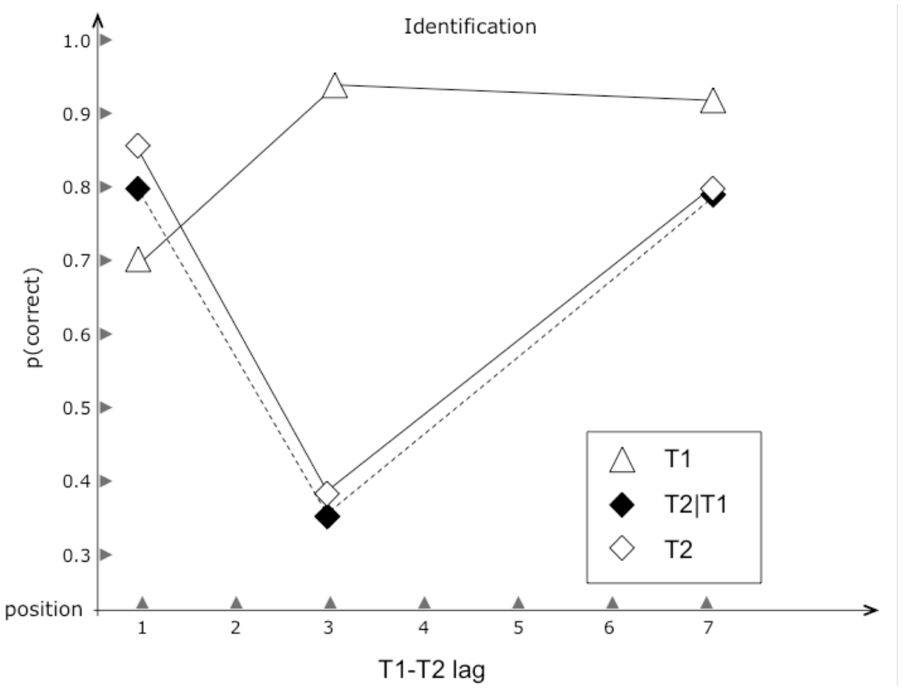
$p < .001$. As usual, results for T2 accuracy differed only negligibly as a function of whether accuracy for T2 was conditional on a correct T1 response.

For the counting task, the open squares in the bottom panel of Figure 6 show the proportion of correct trials (i.e., when subjects responded *2*) for each lag. These means were submitted to an ANOVA with lag as a within-subject factor, which revealed a significant effect of lag, $F(2, 34) = 24.0$, $MSE = 0.022923$, $p < .001$. A direct comparison of overall accuracy in the identification task and accuracy in the counting task was carried out by considering the proportion of trials in which T1 and T2 were both identified correctly in the identification task and trials in which subjects responded *2* correctly in the counting task. An ANOVA on these results revealed a main effect of task, $F(1, 17) = 26.7$, $MSE = 0.014901$, $p < .001$; a main effect of lag, $F(2, 34) = 26.9$, $MSE = 0.038412$, $p < .001$; and a significant Task X Lag interaction, $F(2, 34) = 22.2$, $MSE = 0.008314$, $p < .001$. As in Experiment 1, Lag-1 sparing was found in the identification task and was completely absent in the counting task.

An analysis of the errors in 2-letter trials in the identification task produced analogous results to those found in Experiment 1. Specifically, the larger proportion of errors in the identification task was composed of misses (.10, .49, and .18 from the shortest to the longest lag, respectively) compared with a relatively small proportion of incorrect responses to T2 (.02, .01, and .01 from the shortest to the longest lag, respectively). Separate analyses on errors revealed significant effects of lag on misses, $F(2, 34) = 37.4$, $MSE = 0.013022$, $p < .001$, but not on incorrect responses to T2 ($F < 1$).

3.3.3 *Discussion*

The pattern of results in Experiment 2 was the same as that in Experiment 1. Again, clear-cut evidence for Lag-1 sparing was found when character identities had to be individuated for short-term consolidation (in the identification task) but not when targets were simply counted, which likely does not require consolidating individuated representations. Most important, Experiment 2 rules out the possibility that the absence of Lag-1 sparing in the counting task observed in Experiment 1 was due to conflict between the identities of the counted characters (digits) and the internal (numerical) state of the mental counter.



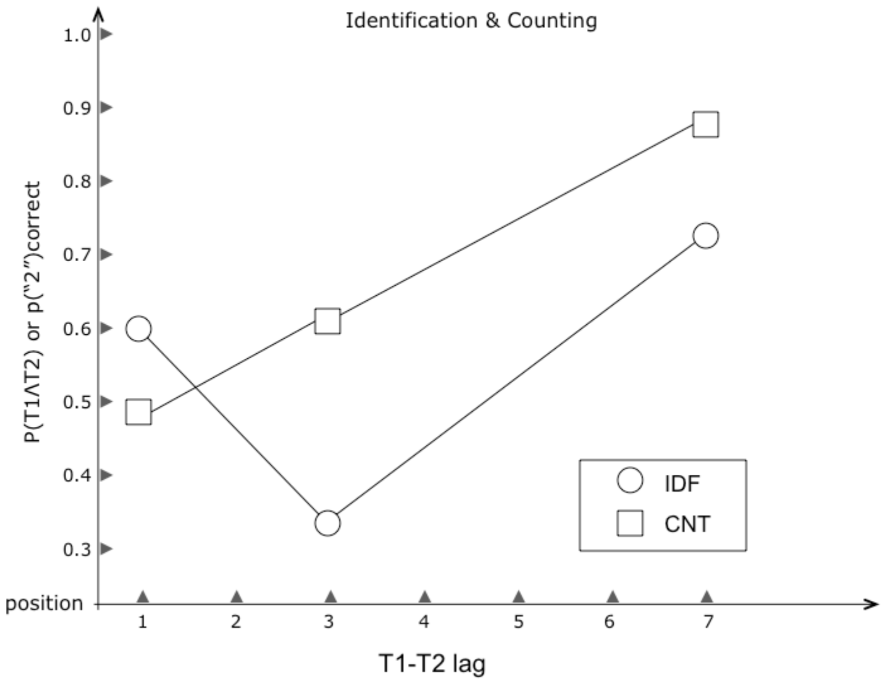


Figure 6. Results in the 2-letter condition of Experiment 2. Top panel: Mean proportion of correct responses in the identification task. Bottom panel: Mean proportion of correct responses in the identification and counting tasks, calculated on the basis of trials in which both T1 and T2 were correctly identified (IDF: identification task), and trials in which a correct '2' response was emitted (CNT: counting task).

3.4 *Experiment 3*

Experiments 1 and 2 clearly demonstrated differences in the patterns of results between the counting task and the identification task. A likely supposition is that such differences arose because of fundamental differences in the processing requirements of the targets in the two tasks. Namely, character identities must be individuated for short-term consolidation in the identification task but not in the counting task. Before this interpretation could be accepted, however, another (perhaps simpler) account must be ruled out. It appears that the counting task was generally easier than the identification task. Perhaps this task difference somehow could account for the modulation of the Lag-1 sparing effect. However, the difference in task difficulty may be more apparent than real, if different probabilities of producing a correct response simply by guessing are taken into account. In the identification task, the probability of guessing correctly the identity of a target was 1/9 in Experiment 1 and 1/22 in Experiment 2. The probability of guessing the correct number of digits in the counting task was much higher than these latter values—that is, 1/3. This difference, per se, might explain why performance appears generally better in the counting task than in the identification task when considering the proportion of correct scores that are not corrected for guessing.

Nonetheless, the idea that the counting task may have been easier than the identification task cannot be dismissed entirely. Counting targets among categorically distinct distractors may simply be easier than identifying the targets to the level of individual character identities because counting requires a less detailed encoding of the targets beyond the initial categorization as either a digit or letter. In Experiment 3, the stimuli were presented behind a camouflage mask that consisted of a scattering of random dots, which were displayed throughout the presentation of a particular RSVP stream. The aim was to degrade the perceptual representation of the stimuli in the RSVP stream (T1, T2, and distractors) so as to render the task more difficult in the presence of the camouflage mask relative to trials in which the stimuli were presented without the mask. Prior research has shown that such a mask can impair accuracy by degrading the information required to perform the task (Bachmann & Allik, 1976; Brehaut, Enns, & Di Lollo, 1999; Enns, 2004; for a review, see Breitmeyer, 1984). The presence of a camouflage mask should impair performance in the AB and, thus, make the task more difficult (Ouimet & Jolicoeur, 2006). Such manipulation would allow to test whether the presence versus absence of Lag-1 sparing could not be accounted for simply on the basis of a vague notion of “task difficulty.”

Figure 7. Example of the stimuli used in Experiment 3. Left: unmasked stimulus. Right: masked stimulus.

3.4.1 *Method*

The stimuli and procedure were the same as those used in Experiment 1, with the following exceptions. On a random half of the trials, a 1.1° square region centered on the RSVP stream was partially filled with a cloud of 200 randomly positioned pixels, as shown in Figure 7. This cloud of pixels was present throughout the RSVP stream. A new cloud was generated at random for each masked trial.

3.4.2 *Results*

The data were analyzed as in Experiment 1 but with the addition of the masking variable. The most important results are shown in Figure 8. As predicted on the basis of the analysis of Ouimet and Jolicoeur (2006), camouflage masking reduced overall accuracy but did not increase or decrease Lag-1 sparing in either task, nor did it affect the overall shape of the AB function (see also Giesbrecht & Di Lollo, 1998).

0-digit condition. The proportions of correct responses in the identification task was the same as that in the counting task (.85 vs. .85, respectively; $F < 1$). Errors in both cases were entirely due to false alarming the presence of one digit in the RSVP streams, no false alarms due to the incorrect detection of two digits when none was presented ever occurred in 0-digit trials.

1-digit condition. The proportions of correct responses were .88 in the identification task and .77 in the counting task. These proportions differed significantly, $F(1, 17) = 19.1$, $MSE = 0.034310$, $p < .001$. As in Experiments 1 and 2, most errors in the counting task were false alarms, but there were very few false alarms in the identification task (.13 vs. .01), $F(1, 17) = 35.7$, $MSE = 0.010786$, $p < .001$. As in the previous experiments, the rate of misses was negligible in this condition (i.e., $M = .01$). The effect of the mask was to decrease the proportion of correct responses relative to the trials without the mask (.80 vs. .85, respectively), $F(1, 17) = 6.5$, $MSE = 0.017823$, $p < .03$. No other factor or interaction between factors produced significant effects in 1-digit trials (all *F*s < 1).

2-digit condition. In the identification task (see Figure 8, top panel), the proportion of correct responses to T1 depended on lag, with a lower proportion of correct responses to T1 at Lag 1 compared with that at the other lags, $F(2, 34) = 46.4$, $MSE = 0.009636$, $p < .001$. When the data at Lag 1 were temporarily excluded from the analysis, the proportion of correct responses to T1 at Lag 3 and at Lag 7 did not differ significantly ($F < 1$). The proportion of correct responses to T1 was lower when the mask was present relative to when the mask was absent (.71 vs. .81, respectively), $F(1, 17) = 14.0$, $MSE = 0.017241$, $p < .002$. The lag and mask factors did not produce interactive effects on the proportion of correct responses to T1 ($F = 1$).

Considering the subset of trials in which T1 was identified correctly, the analysis of the proportion of correct responses to T2 revealed a marked effect of lag, $F(2, 34) = 46.4$, $MSE = 0.024681$, $p < .001$, with an evident reduction of the proportion of correct responses to T2 at

Lag 3 compared with that at the other lags (see Figure 8, top panel). The difference between the proportion of correct responses to T2 at Lag 1 and the proportion of correct responses to T2 at Lag 3 was significant, *F*(1, 17) = 111.1, *MSE* = 0.017833, *p* < .001. The difference between the proportion of correct responses to T2 at Lag 3 and the proportion of correct responses to T2 at Lag 7 was also significant, *F*(1, 17) = 45.3, *MSE* = 0.048870, *p* < .001. The proportion of correct responses to T2 was lower when the mask was present relative to when the mask was absent, *F*(1, 17) = 7.0, *MSE* = 0.020851, *p* < .02. Lag and masking were statistically additive effects (*F* < 1); masking did not increase the degree of Lag-1 sparing.

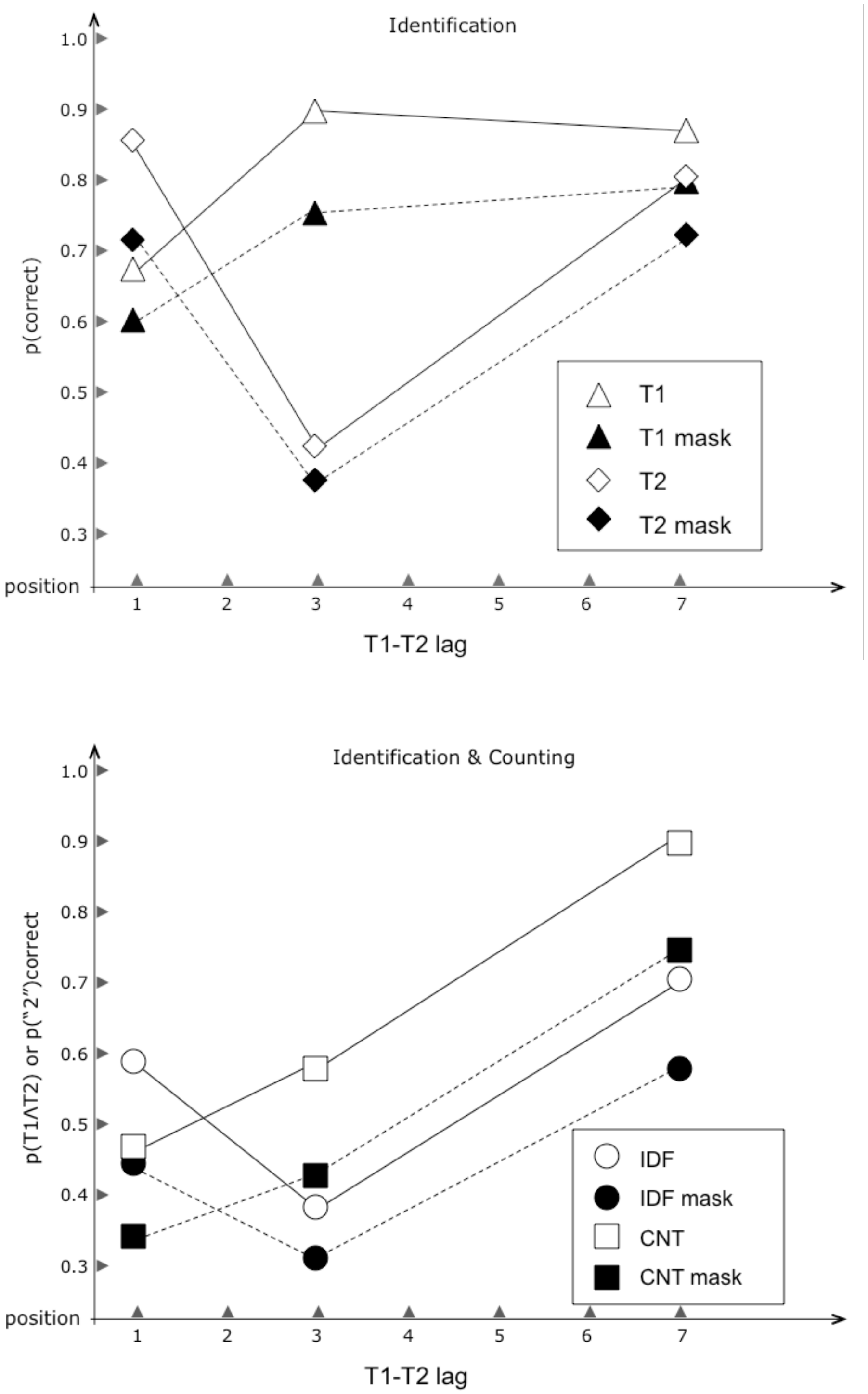


Figure 8. Results in the 2-digit condition of Experiment 3. Top panel: Mean proportion of correct responses in the identification task. The mean proportion of correct responses to T2 is calculated on the basis of trials in which T1 was identified correctly. Bottom panel: Mean proportion of correct responses in the identification and counting tasks, calculated on the basis of trials in which both T1 and T2 were correctly identified (IDF: identification task), and trials in which a correct '2' response was emitted (CNT: counting task).

When 2-digit trials were further analyzed independently of whether T1 was correctly identified, the analysis revealed an effect of lag, *F*(2, 34) = 35.4, *MSE* = 0.017974, *p* < .001, again with a U-shaped pattern of mean proportions of correct responses to T2 across lags. The difference between the proportion of correct responses to T2 at Lag 1 and the proportion of correct responses to T2 at Lag 3 was in fact significant, *F*(1, 17) = 50.3, *MSE* = 0.055001, *p* < .001. The difference between the proportion of correct responses to T2 at Lag 3 and the proportion of correct responses to T2 at Lag 7 was also significant, *F*(1, 17) = 42.9, *MSE* = 0.000005, *p* < .001. In this analysis, however, the mask factor produced effects that were only marginally significant, *F*(1, 17) = 3.3, *MSE* = 0.017974, *p* < .07, and the Mask X Lag interaction did not produce significant effects in this analysis (*F* < 1).

The proportion of trials in which T1 and T2 were both identified correctly in the identification task and the proportion of trials in which subjects responded *2* correctly in the counting task are shown in the bottom panel of Figure 8. Accuracy was better overall in the counting task than in the identification task, *F*(1, 17) = 7.0, *MSE* = 0.045782, *p* < .02. There was also a main effect of lag, *F*(2, 34) = 38.0, *MSE* = 0.052204, *p* < .001; a main effect of mask, *F*(1, 17) = 33.0, *MSE* = 0.021333, *p* < .001; and a significant Task X Lag interaction, *F*(2, 34) = 16.8, *MSE* = 0.028615, *p* < .03. No other factor or interaction approached statistical significance (all *F*s < 1).

3.4.3 *Discussion*

Experiment 3 was designed to rule out explanations of the presence versus absence of Lag-1 sparing across the identification and counting tasks on the basis of the notion that more difficult tasks lead to Lag-1 sparing and easier tasks lead to the abolition of Lag-1 sparing. Any such simplistic attempt at an explanation of the differential Lag-1 sparing effects across tasks can be categorically rejected on the basis of the present results. As can be seen in the bottom panel of Figure 8, overall accuracy in the masked counting condition was essentially the same as in the not-masked identification condition (at Lags 3 and 7), and yet the identification task produced very clear Lag-1 sparing, whereas the counting task did not.

3.5 *Experiment 4*

Experiments 1–3 point to a fundamental difference between encoding specific target identities and counting instances of members of a category in the causes of the Lag-1 sparing phenomenon. An hypothesis is that this difference is taking place at the time targets are encoded rather than when they are later recalled. However, the counting task and the identification task are also quite different in their output requirements. Two distinct target identities have to be retrieved and output for the identification, whereas a single response is required in the counting task. Although it is not immediately obvious how retrieval operations would affect results at Lag 1 differentially from other lags, it is logically possible that the observed differences in Lag-1 sparing across the tasks arose at the time of retrieval from VSTM and motor output of the response(s) rather than at encoding.

Experiment 4 was designed to require similar encoding operations across two tasks but different forms of response. The identification task used in previous experiments remained unchanged. However, rather than asking observers to count presented digits, the requirement in Experiment 4 was to report the sum of all seen digits. As in reporting a count, reporting the sum involves a single response. An allusion is that each of the two digits would need to be identified to the level of individual character identity for subjects to compute the correct sum. Consequently, a supposition is that the identification task and the digit-sum task would be very similar in terms of what information that needed to be encoded but different principally in terms of how the encoded information had to be translated into overt responses. If it was the nature of the encoding operations required for T1 and T2 at the time of their presentation, and not at the time of their retrieval, that was critical for the Lag-1 sparing effect, an equivalent Lag-1 sparing effects should be observed in the identification task and the digit-sum task in the present experiment.

3.5.1 *Method*

The stimuli were the same as those used in Experiments 1–3, with the exception that the digits set was restricted to the digits *2* to *5*. The same masking manipulation used in Experiment 3 was used here. The identification task was the same as in Experiments 1–3. The counting task was replaced by a digit-sum task in which subjects reported the sum of perceived digits, at the end of the trial, without speed pressure. Otherwise, Experiment 4 was the same as the previous experiments.

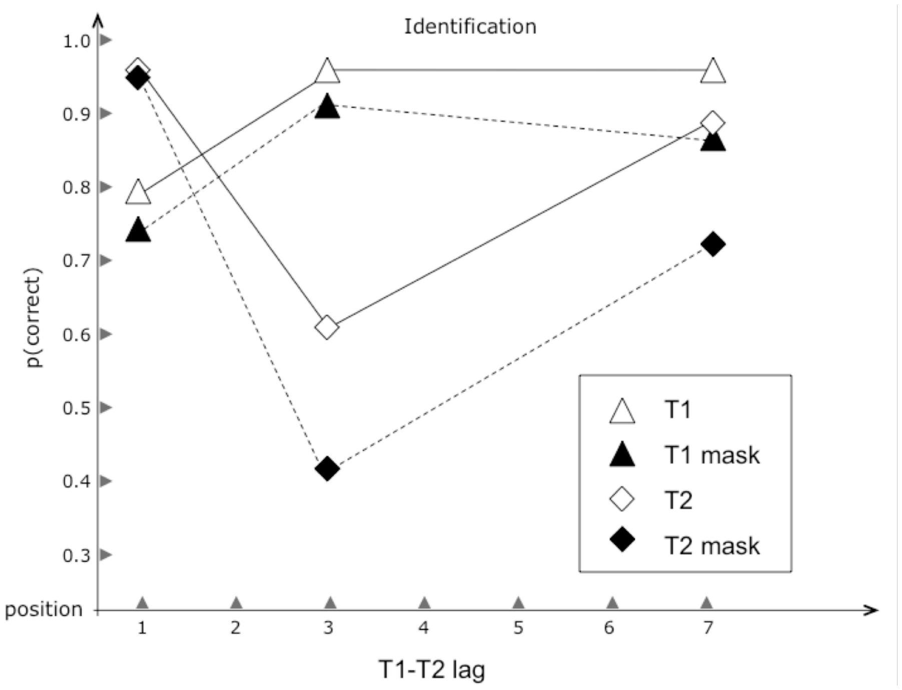
3.5.2 *Results*

0-digit condition. The proportion of correct responses was superior in the digit-sum task compared with the proportion of correct responses in the identification task (.93 vs. .80, respectively), but the effect was statistically marginal, $F(1, 17) = 4.4$, $MSE = 0.088416$, $p < .06$. In the identification task, errors were entirely due to 1-digit false alarms, there were no false alarms due to the incorrect report of two digits when none was presented. It was hard to disentangle whether the digit typed in by a subject at the end of a given trial in the digit-sum task represented a sum of one digit and 0 or the sum of two digits unless the digit *2* was given in response in the digit-sum task. The proportion of such cases was minimal, however ($M = .022$), and consequently inappropriate for a statistical analysis.

1-digit condition. The proportions of correct responses were .93 in the identification task and .84 in the digit-sum task. These proportions differed significantly, $F(1, 17) = 25.2$, $MSE = 0.024517$, $p < .001$. The mask manipulation in this condition did not produce significant effects: The proportion of correct responses was similar when the mask was present and when the mask was absent (.88 vs. .90, respectively), $F < 1$. No other factor or interaction between factors produced significant effects in this condition (all Fs < 1).

2-digit condition. In the identification task (see Figure 9, top panel), the proportion of correct responses to T1 depended on lag, with a lower proportion of correct responses to T1 at Lag 1 compared with those at the other lags, $F(2, 34) = 11.7$, $MSE = 0.026641$, $p < .001$. When the data at Lag 1 were temporary excluded from the analysis, the proportion of correct responses to T1 at Lag 3 and at Lag 7 did not differ significantly (*F* < 1). The proportion of correct responses to T1 was lower when the mask was present relative to when the mask was absent (.84 vs. .90, respectively), *F*(1, 17) = 5.0, *MSE* = 0.014316, *p* < .04. The lag and mask factors did not produce interactive effects on the proportion of correct responses to T1 (*F* < 1).

Considering only trials in which T1 was identified correctly, the analysis of the proportion of correct responses to T2 revealed a marked effect of lag, *F*(2, 34) = 45.4, *MSE* = 0.040080, *p* < .001, with an evident reduction of the proportion of correct responses to T2 at Lag 3 compared to that at the other lags (see Figure 9, top panel). The difference between the proportion of correct responses to T2 at Lag 1 and the proportion of correct responses to T2 at Lag 3 was indeed significant, *F*(1, 17) = 60.1, *MSE* = 0.054235, *p* < .001. The difference between the proportion of correct responses to T2 at Lag 3 and the proportion of correct responses to T2 at Lag 7 was also significant, *F*(1, 17) = 49.7, *MSE* = 0.041448, *p* < .001.



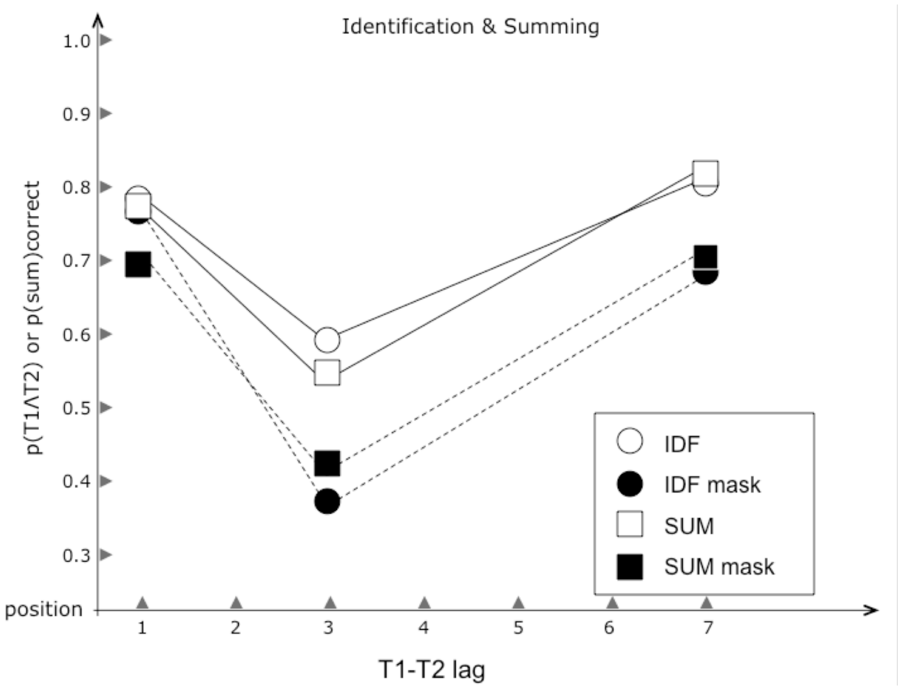


Figure 9. Results in the 2-digit condition of Experiment 4. Top panel: Mean proportion of correct responses in the identification task. The mean proportion of correct responses to T2 is calculated on the basis of trials in which T1 was identified correctly. Bottom panel: Mean proportion of correct responses in the identification and digit-sum tasks, calculated on the basis of trials in which both T1 and T2 were correctly identified (IDF: identification task), and trials in which a correct sum was emitted (SUM: digit-sum task).

The proportion of correct responses to T2 was lower when the mask was present relative to when the mask was absent, *F*(1, 17) = 15.9, *MSE* = 0.006233, *p* < .001, with the masking effect varying across lags, as indicated by a significant Mask X Lag interaction, *F*(2, 34) = 10.9, *MSE* = 0.009221, *p* < 001. An explanation of the apparent discrepancy between the present outcome and that of Experiment 3 in the General Discussion's chapter.

In the identification task, the trend for the masking effects was that of being substantially reduced at Lag 1 compared with the masking effects at other lags. This impression, brought about by visual inspection of the top panel of Figure 5, found statistical support in a separate analysis in which the data at Lag 1 were temporarily excluded from consideration. In the analysis, the interaction between mask and lag was no longer significant (*F* < 1).

An equivalent pattern of results emerged when trials associated with an incorrect response to T1 were included in the data set. There was a main effect of lag, *F*(2, 34) = 49.0, *MSE* = 0.034085, *p* < .001, again with a U-shaped pattern of mean proportions of correct responses to T2 across lags. The difference between the proportion of correct responses to T2 at Lag 1 and the proportion of correct responses to T2 at Lag 3 was in fact significant, *F*(1, 17) = 69.4, *MSE* = 0.044380, *p* < .001. The difference between the proportion of correct responses to T2 at Lag 3 and the proportion of correct responses to T2 at Lag 7 was also significant, *F*(1, 17) = 44.5, *MSE* = 0.039266, *p* < .001. The mask factor produced significant effects, *F*(1, 17) = 26.6, *MSE* = 0.005810, *p* < .001. The Mask X Lag interaction was also significant, *F*(1, 17) = 12.2, *MSE* = 0.009522, *p* < .001. Variations of the masking effects across lags with the unconditional trials were analogous to those observed in the context of the conditional trials, the masking effects were basically absent at Lag 1 compared with masking effects at the other lags. Indeed, as before, when the data at Lag 1 were excluded from consideration, the interaction between mask and lag was no longer significant (*F* < 1).

The proportion of trials in which T1 and T2 were both identified correctly in the identification task and the proportion of trials in which subjects responded correctly in the digit-sum task (see Figure 5, bottom panel) were submitted to an ANOVA that revealed a main effect of lag, *F*(2, 34) = 24.6, *MSE* = 0.078186, *p* < .001, and a main effect of mask, *F*(1, 17) = 16.8, *MSE* = 0.021813, *p* < .001. The Lag X Mask interaction was only marginally significant, *F*(2, 34) = 3.1, *MSE* = 0.027408, *p* < .07. No other factor or interaction reached the significance level in this analysis (all *F*s < 1).

3.5.3 *Discussion*

In contrast with the results of the previous three experiments, Lag-1 sparing was observed in a context in which two sequential digits had to be summed rather than counted. With similar output requirements as in the counting task (a single count), the digit-sum task (a single sum) produced a virtually identical pattern of overall accuracy across lags as found in the identification task. The results suggest that Lag-1 sparing was not caused by differential output requirements across the identification task and counting task in previous experiments but, rather, was due to differences at the time of encoding. The results are discussed in detail in the General Discussion's Chapter.

In Experiment 3, the masking manipulation had effects that were additive with lag for both tasks. In the present experiment, an interaction was observed in which the difference between the not-masked and masked conditions was reduced at Lag 1 relative to what was observed at longer lags. This result, however, appears to be substantially compromised by the likely possibility of a ceiling effect in accuracy results for T2 at Lag 1 in Experiment 4 (as can be seen in the top panel of Figure 9). When performance was lower and not near ceiling, as in Experiment 3, the interaction was not observed. For this reason, and because a modulation of Lag-1 sparing by the mask in the digit-sum task was not observed, only with extreme caution the apparent interaction between masking and lag in the identification task could be interpreted as support for the contribution of task difficulty in the causes of the Lag-1 sparing effect.

3.6 *Experiment 5*

Experiment 5 was designed to test whether the presence and absence of Lag-1 sparing was caused by general processing differences associated with the two tasks (identification vs. counting). In Experiment 5, subjects were asked to count the digits of a given parity subclass. That is, half of the subjects counted the occurrences of even digits, and the other half counted the occurrences of odd digits. As in all other previous experiments, subjects were also required to identify the digits. This choice to restrict the objects of the counting task to a subclass of digits was motivated by the following logic. The hypothesis is that Lag-1 sparing is modulated by the need to process targets up to the level of individual character identities. This is required for the identification task but not for the general counting task. It is required for counting just odd or just even digits, however, because people do not have a highly learned preexisting category of just odd or just even digits. The consequent prediction was that if it was the counting task per se that played a crucial role in determining the absence of Lag-1 sparing in Experiments 1–3, then Lag-1 sparing should also be absent in Experiment 5, because counting was still explicitly required in the present context. If it was, instead, the type of mental representation created to perform the counting task that was crucial for observing Lag-1 sparing with sequential digits, the prediction was radically different: a Lag-1 sparing should be observed in Experiment 5 insofar as counting digits of a given subclass was likely to rely more heavily on information about the digit identities than the counting task carried out on any digit.

3.6.1 *Method*

The stimuli were the same as those used in Experiment 1. In the identification task, subjects typed the identity of target digits using the numeric keypad of a computer keyboard. In the counting task, half of the subjects were instructed to count only the even digits, and the other half were instructed to count only the odd digits. Digit parity and digit number were fully crossed within each block of experimental trials.

3.6.2 *Results*

The proportions of correct responses in 0-digit, 1-digit, and 2-digit trials were analyzed separately using an ANOVA in which lag (in 1-digit and 2-digit trials only) and task were treated as within-subject factors. In the identification task, the order in which subjects indicated the identity of T1 and T2 in 2-letter trials was not taken into account.

0-digit condition. The proportions of correct responses were .89 in the identification task and .88 in the counting task. These proportions did not differ significantly ($F < 1$). Errors in both tasks were entirely due to false alarms in which subjects reported seeing one digit, with no false alarms due to the incorrect report of two digits.

1-digit condition. The proportions of correct responses were .86 in the identification task and .85 in the counting task. No factor or interaction reached statistical significance (all *F*s < 1) in this condition.

2-digit condition. Considering first the identification task (see Figure 10, top panel). The proportion of correct responses to T1 was affected by the lag manipulation, with a lower proportion of correct responses to T1 at Lag 1 compared with that at the other lags, $F(2, 34) = 40.1$, $MSE = 0.004728$, $p < .001$. When the data at Lag 1 were discarded from the analysis, the proportion of correct responses to T1 at Lag 3 and at Lag 7 did not differ significantly ($F < 1$).

When only trials in which T1 was identified correctly were taken into account, the analysis indicated a marked effect of lag, $F(2, 34) = 26.1$, $MSE = 0.022686$, $p < .001$, reflected in the classic U-shaped function of the AB effect (see Figure 10, top panel). The difference between the proportion of correct responses to T2 at Lag 1 and the proportion of correct responses to T2 at Lag 3 was significant, $F(1, 17) = 47.6$, $MSE = 0.020328$, $p < .001$. The difference between the proportion of correct responses to T2 at Lag 3 and the proportion of correct responses to T2 at Lag 7 was also significant, $F(1, 17) = 28.8$, $MSE = 0.027951$, $p < .001$.

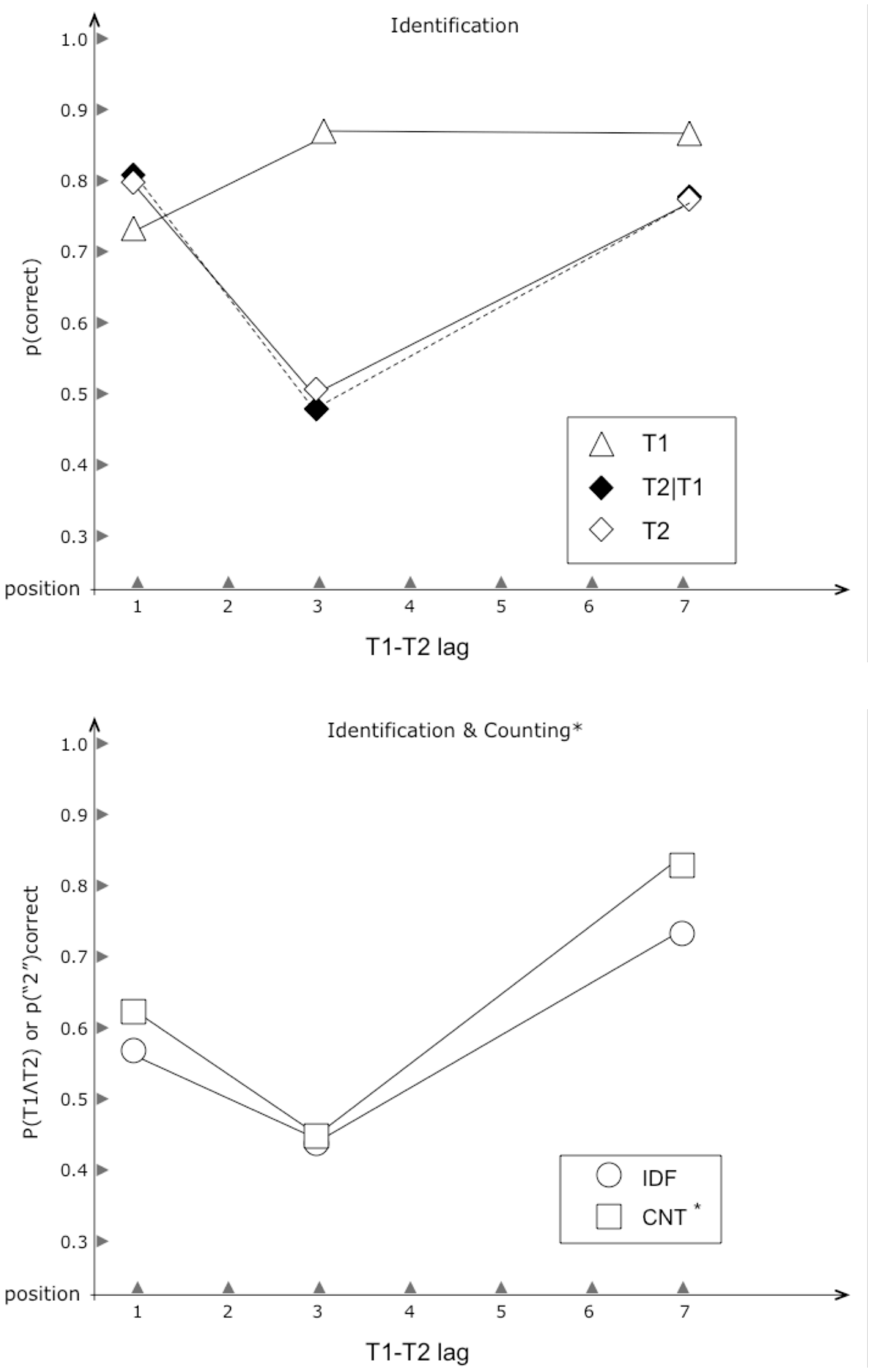


Figure 10. Results in the 2-digit condition of Experiment 5. Top panel: Mean proportion of correct responses in the identification task. Bottom panel: Mean proportion of correct responses in the identification and counting tasks, calculated on the basis of trials in which both T1 and T2 were correctly identified (IDF: identification task), and trials in which a correct '2' response was emitted (CNT: digit-sum task). The asterisk underlines the difference of the counting task in Experiment 5 (that was contingent on digit parity) and the counting task of Experiments 1, 3, and 4, in which digits had to be counted independently of their parity class.

An analogous analysis was carried out on the proportion of correct responses to T2 independent of whether T1 was correctly identified. The results were virtually identical to those produced by scoring T2 accuracy conditionalized on a correct response to T1, with a strong effect of lag, $F(2, 34) = 26.5$, $MSE = 0.017922$, $p < .001$, and a U-shaped distribution of the mean proportion of correct responses to T2 across lags (see Figure 10, top panel). The difference between the proportion of correct responses to T2 at Lag 1 and the proportion of correct responses to T2 at Lag 3 was significant, $F(1, 17) = 52.5$, $MSE = 0.014596$, $p < .001$. The difference between the proportion of correct responses to T2 at Lag 3 and the proportion of correct responses to T2 at Lag 7 was significant, $F(1, 17) = 30.6$, $MSE = 0.021344$, $p < .001$.

For the counting task, the bottom panel of Figure 10 shows the proportion of trials in which subjects responded *2* correctly when two digits of the to-be-monitored parity class were presented. These data were submitted to an ANOVA, which revealed a significant effect of lag, $F(2, 34) = 11.5$, $MSE = 0.053290$, $p < .001$. A direct comparison of overall accuracy in the identification task and accuracy in the counting task was carried out by considering the proportion of trials in which T1 and T2 were both identified correctly in the identification task and trials in which subjects responded *2* correctly in the counting task (see Figure 10, bottom panel). An ANOVA on these data revealed only a main effect of lag, $F(2, 34) = 18.1$, $MSE = 0.048724$, $p < .001$. The effect of task was nonsignificant, $F(1, 17) = 1.7$, $p < .2$, as was the Lag X Task interaction, $F(1, 17) = 1.2$, $p < .3$. When the data from Lag 7 were temporarily excluded from consideration, the effect of lag was significant, $F(1, 17) = 7.0$, $MSE = 0.047443$, $p < .02$; the effects of task and the Task X Lag interaction were not significant (Fs < 1).

3.6.3 *Discussion*

Experiment 5 was designed to deconfound the type of mental representation generated under RSVP conditions and the type of task subjects were required to carry out with the targets once selected from the RSVP sequences. Subjects were instructed to count only digits of a given parity class (only odd or only even), on the assumption that this would have induced the processing of target digits not as simple discontinuities in alphanumeric class (as was hypothesized to occur in Experiments 1–3) but also at the level of individual identities. The results of Experiment 5 were clear-cut. In striking contrast with the results from the counting task in Experiments 1–3, the AB function in the counting task in Experiment 5 was characterized by the clear presence of Lag-1 sparing. In the present study perspective, this makes it extremely unlikely that the counting task per se played any crucial role in suppressing the Lag-1 sparing effect in the counting task of Experiments 1–3. Rather, it must have been the nature of the processing required after potential targets were selected from the RSVP streams that determined whether Lag-1 sparing for T2 occurred or did not occur.

CHAPTER 4

MULTI-TARGET RSVP PARADIGM:
THE WITHIN TRIAL CONTINGENCY

4.1 *The Study*

A number of researchers have emphasized the role of distractors intervening between successive targets as the primary determinant of the attentional blink (AB) phenomenon. They argued that the AB is abolished when 3 or more targets are displayed as temporally contiguous items in rapidly presented serial sequences. In 3 experiments, 1-, 2-, or 3-digit targets were embedded among letter distractors in rapidly presented visual sequences. Across the experiments, both the number of targets and the lag between them were manipulated, producing different proportion of trials in which 3 temporally contiguous targets were presented in the test session. Evidence of an AB affecting the targets that followed the first target in these sequences was found in each experiment when the probability of a given target report was conditionalized on a correct response to the preceding targets, thus reinforcing the notion that some form of capacity limitation in the encoding of targets plays a central role in the elicitation and modulation of the AB effect.

The purpose of the present study was to revisit the issue of protracted sparing in the AB paradigm in light of two considerations. The first consideration concerned the structural organization of the RSVP streams adopted in the Di Lollo and collaborators (Di Lollo et al., 2005) and Olivers and colleagues (Olivers et al., 2007) studies, which were characterized by a particularly compressed temporal distribution of targets embedded in RSVP streams. In these multi-target designs, the lag between successive targets was generally shorter than in standard RSVP designs, given that the targets were always consecutive stimuli, or nearly so (i.e., in most cases, the Lag was always 1). As presently formulated, the TLC (Di Lollo et al., 2005) and BB (Olivers & Meeter, 2008) accounts of the AB do not make any particular commitments to specific structural conditions leading to the protracted sparing. The tenet of such accounts is that independently of variations in (a) the number of targets (with the proviso to keep it below the VSTM capacity limit) embedded in RSVP streams, (b) the overall length of the RSVP stream in which targets are embedded, and (c) the subjects' knowledge about the number of targets displayed in a particular RSVP stream, the protracted sparing should be found whenever there are no distractors discontinuing the presentation of a set of successive targets. However, all such variations have been shown to exert modulatory effects on the AB and Lag-1 sparing phenomena in standard two-target designs. Akyurek and colleagues (Akyurek, Riddell, Toffanin, & Hommel, 2007) have shown variations in reversal errors in report of successive T1 and T2, accompanied by a modulation of the P3 component time-locked to T1 depending on the phenomenological experience subjects had of the rate of presentation of items included in RSVP streams.

MacKay and Juola (MacKay & Juola, 2007) and Martens and Johnson (2005) observed a reduction of the AB when subjects were cued in advance about the lag separating T1 and T2 in an upcoming RSVP stream. In general, these studies suggest that a certain level of uncertainty about the structural properties of the RSVP streams subjects are exposed to may be detrimental in post-T1 targets processing, and on this empirical evidence, we deemed it appropriate to investigate whether introducing uncertainty in a series of multi-target designs could have analogous modulatory effects on the protracted sparing found in prior multi-target designs.

The second consideration concerned the analysis procedure used in these past studies to determine the presence or absence of the protracted sparing. One traditional procedure used in standard two-target designs is to score accuracy for T2 only for trials in which T1 is reported correctly (i.e., T2 correct conditional on a correct T1, or T2|T1). This ensures that the trials contributing to the estimation of the AB are equated in terms of processing load (i.e., T1 was processed correctly) and in terms of memory load (i.e., VSTM load was 1, given the correct report of T1). The present study will refer to the practice of conditionalizing accuracy for T2 on a correct performance to T1 as the within-trial contingency (WTC) principle. When there are only two targets, it appears as though the application of the WTC principle is not critical (Dell'Acqua et al., 2007; Jolicoeur, 1998, 1999). The WTC principle is likely to have more importance in experiments involving more than two targets. The processing load associated with the first two targets (T1 and T2) could have a large impact on the processing of a third target (T3), and differences across trials in which both T1 and T2 are correctly processed versus trials in which T1, T2, or both are missed could be substantial.

A concerns about the studies by Di Lollo (Di Lollo et al., 2005) and Olivers (Olivers et al., 2007) arose from noticing that in the analyses of their results, the WTC principle was not applied in the way it has just been mentioned. Di Lollo and collaborators (2005) scored T3 report treating the probabilities of reporting T1, T2, and T3 as independent probabilities. In this case, one possibility was that a portion of trials in which T3 was reported correctly in triplets of contiguous targets were trials in which T1 was missed, T2 was missed, or even both T1 and T2 were missed, leaving significant processing capacity to encode T3. The same argument applies to Olivers and colleagues' work (2007), in which performance with successive targets was conditionalized on T1 correct responses only[3]. A secondary aim of the present work was to test whether a protracted form of sparing for the last of three consecutive targets (T3) could be replicated following a correct application of the WTC principle by conditionalizing the probability for T3, namely p(T3), on the correct report of both T1 and T2.

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[3] In addition to conditionalizing T*n* (when $n > 1$) report accuracy on the basis of T1 report, Olivers et al. (2007) proposed an elegant algorithm for correcting a given target report for the probability of guessing that was not adopt in any of the present analyses. Note, however, that the application of the WTC principle equates trials in terms of the number of targets correctly reported at the end of each trial. This implies that the probability of guessing a given target across the various conditions that were examined in the present study was equivalent.

4.2 *Experiment 1*

One, two, or three digits were embedded in RSVP sequences of letters at unpredictable and independently varying lags. The participants' task was to report the digits at the end of the trial, without speed pressure. Experiment 1 gave two opportunities. The first, was to monitor the results of a multi-target design in which target report was mutually constrained by a correct response to each target preceding the one monitored in the different conditions implemented in Experiment 1[4], that is, whether the protracted sparing could be found following the correct application of the WTC principle. The second, opportunity was to examine whether the protracted sparing could still be observed, as the TLC and BB accounts would predict, when some form of uncertainty about the number of targets and the lag between them were varied unpredictably from trial to trial.

4.2.1 *Method*

Subjects. A total of 60 university students (31 females and 29 males; age range, 20–33 years) from the University of Padova participated in the following three experiments (20 subjects each). The subjects were paid or received course credit for their participation. All subjects had normal or corrected-to-normal acuity, and none reported a history of neurological disorders.

Stimuli. The stimuli were 22 letters of the English alphabet (all except the letters B, I, O, and Z) and the digits 2–9. These characters were displayed in light gray (34 cd/m2) on a uniform black background (6 cd/m2) on a cathode ray tube computer screen placed at about 70 cm from the subject's eyes. Luminance was measured with a Model LS-100 luminance meter (Konica Minolta, Ramsey, NJ). All characters fit in a square portion of the screen with a side of 0.95°. The RSVP technique was used to display the characters, each of which was displayed for 84 ms at the center of the screen and was immediately replaced by the next item (inter-

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[4] Two prior attempts at constraining target report probability based on the accurate response to preceding targets in a three-target RSVP design have been made by Chun and Potter (1995) and by Shapiro and colleagues (Shapiro, Driver, Ward, & Sorensen, 1997). Though these attempts were somewhat analogous to the present study, it must be noted that Chun and Potter (1995) examined only p(T2|T1) and p(T3|T2) independently. As far as T3 report is concerned, in the present case, p(T3|T1^T2) was considered, which represents a dependent variable that was not computed nor discussed by these authors. Shapiro and collaborators (1997) analyzed their results following the application of the WTC principle but did not vary systematically the lag between successive targets as it was done in the present investigation.

stimulus interval [ISI] = 0 ms). Each RSVP stream of stimuli was generated by randomly selecting letters without replacement from the list of 22 letters. In three-digit trials, the lag between T1 and T2 and the lag between T2 and T3 were manipulated independently and were varied at three possible levels through the interleaving of 0- (Lag = 1), 2- (Lag = 3), or 6- (Lag = 7) letter distractors between T1 and T2 and between T2 and T3. No digit or letter was ever repeated in a given RSVP stream. The number of letters preceding T1 was varied randomly from two to five across trials. In two-digit trials, T3 was replaced with a letter distractor. In one-digit trials, both T2 and T3 were replaced with letter distractors. Each RSVP stream ended with between two and four distractors following the last target.

Procedure. Each trial began with the presentation of a plus sign at the center of the screen. The trial started with a space bar press, which caused the plus sign to disappear. After a fixed blank interval of 800 ms, the RSVP stream was displayed. A question was displayed 800 ms after the end of the RSVP stream, inviting participants to report the digit(s) by pressing the corresponding keys on the numeric keypad of the computer keyboard or “0” if no digit was seen. The instructions mentioned explicitly that the order in which the responses were given (when more than one response was made) was not important. Responses were made without speed pressure. Participants performed seven experimental blocks of 27 trials. One block of 27 practice trials preceded the series of experimental blocks. Streams with one digit, two digits, and three digits were equally likely to be presented within each block of trials.

4.2.2 *Results*

Analysis. The proportion of correct responses to T1 was .72, .90, and .90 at the T1–T2 Lags 1, 3, and 7, respectively. The lower proportion of correct responses to T1 at T1–T2 Lag 1 relative to the other two longer lags resulted in a significant effect of T1–T2 lag, $F(2, 38) = 23.1$, $\eta_p^2 = .549$, $p < .001$. No effect of the T2–T3 lag was detected on T1 report accuracy. A summary of the proportion of correct responses to T2 as a function of the T1–T2 lag and as a function of the T2–T3 lag is graphed in Figure 11. The ANOVA indicated a significant effect of T1–T2 lag, $F(2, 38) = 27.4$, $\eta_p^2 = .590$, $p < .001$; a significant effect of T2–T3 lag, $F(2, 38) = 14.3$, $\eta_p^2 = .430$, $p < .001$; and a significant interaction between these factors, $F(4, 76) = 4.3$,

η_p^2 = .184, p < .005. As is clearly illustrated in Figure 11, the correct responses to T2 were characterized by a classic U-shaped distribution across T1–T2 lags (i.e., an AB effect), with the exception of the condition of the shortest T2–T3 lag, in which the recovery from the AB at the longest T1–T2 lag was only partial relative to the other two T2–T3 lag conditions.

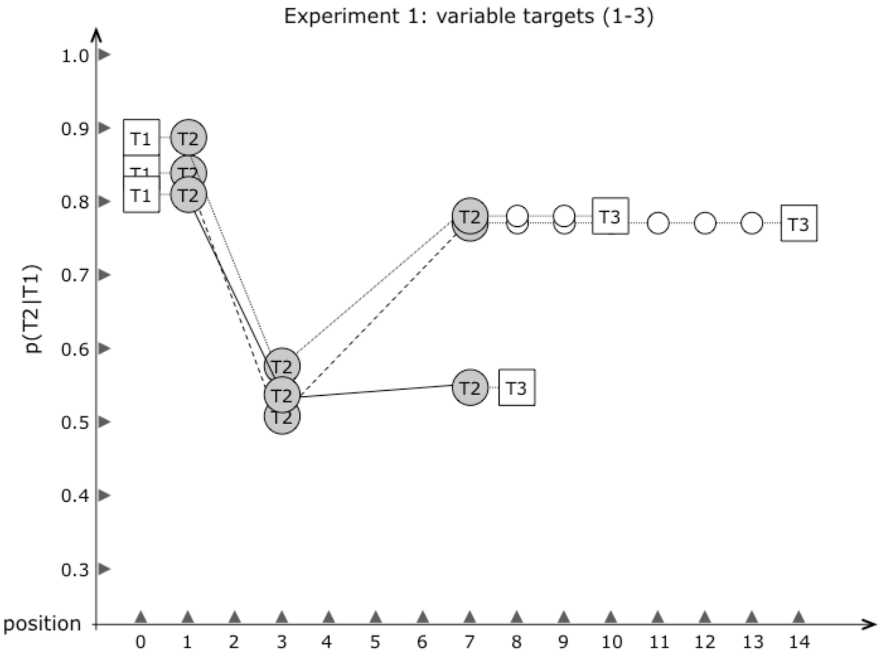

Figure 11. Results of Experiment 1. Grey circular symbols: observed mean proportion of correct responses to T2 (contingent on a correct response to T1). White square symbols: stream positions occupied by T1 and T3 (height in the graph does not represent accuracy) within the RSVP streams generating the displayed T2 report distribution functions. White and smaller circular symbols: letter distractors. In this and all subsequent graphs, values on the x-axis indicate the positions occupied by targets in RSVP streams relative to T1, which is always plotted in position ‘0.’ Note that the number of distractors preceding T1 and following T3, which are not displayed in the graphs, was varied randomly from trial to trial (see text for details).

The proportion of correct responses to T3 as a function of the T1–T2 lag and as a function of the T2–T3 lag is graphed in Figure 12. Overall accuracy for T3 decreased sharply as the lag between T1 and T2 was reduced, *F*(2, 38) = 9.4, η_p^2 = .331, *p* < .001. The lag between T2 and T3 resulted in a typical AB function for T3 accuracy, *F*(2, 38) = 23.5, η_p^2 = .553, *p* < .001. The interaction between these factors was not significant, *F*(4, 76) = 1.7, *p* < .15, indicating that has been observed generally the same AB function of T2–T3 lag for each T1–T2 lag. An additional set of separate analyses was conducted for T3 report accuracy. In one analysis, T3 report accuracy at the shortest T2–T3 lag was compared across T1–T2 lags. As is evident in Figure 12, T3 report accuracy increased as T1–T2 lag was increased, $F(2, 38) = 5.8$, $\eta_p^2 = .235$, $p < .007$. In a second analysis, T3 report accuracy at the longest T2–T3 lag was compared across T1–T2 lags. The analysis revealed a significant effect of T1–T2 lag, $F(2, 38) = 3.3$, $\eta_p^2 = .148$, $p < .05$, arising from the higher T3 report accuracy at the longest T1–T2 lag relative to T3 report accuracy at the other two shorter T1–T2 lags, which did not differ significantly, $F < 1$.

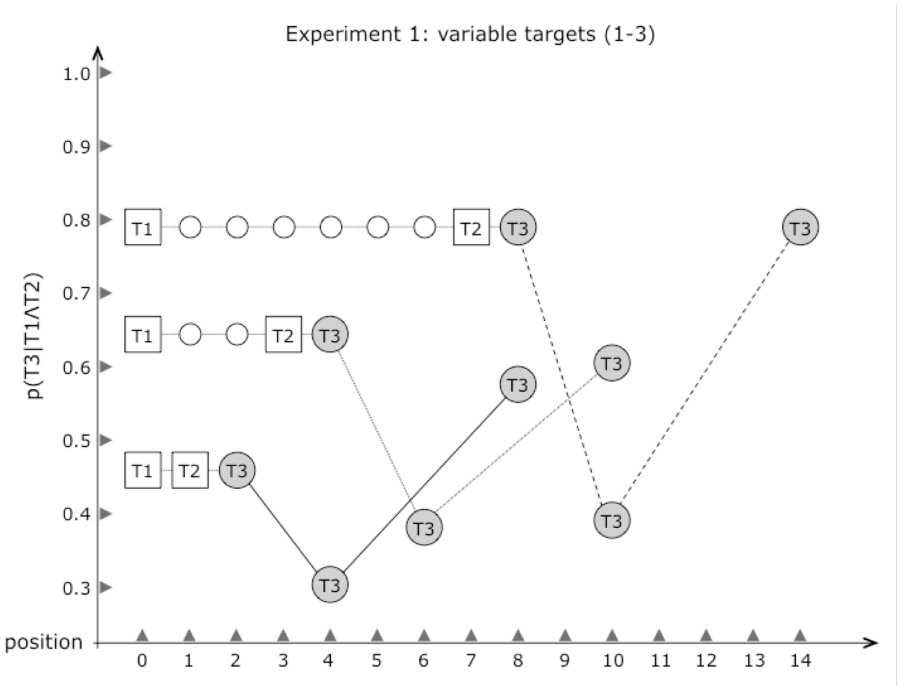

Figure 12. Results of Experiment 1. Grey circular symbols: observed mean proportion of correct responses to T3 (contingent on a correct responseto T1 and a correct response to T2). White square symbols: stream positions occupied by T1 and T2 (height in the graph does not represent accuracy). White and smaller circular symbols: letter distractors.

Protracted sparing and the WTC principle. A comparison on T1 report accuracy and T3 report accuracy (mean proportion correct, represented by "p") was performed when T1, T2, and T3 were contiguous targets. A summary of the results is shown in Figure 13 (leftmost graph).

First, a comparison between p(T1) and p(T3), treating them as independent probabilities, that is, without applying the WTC principle (dotted line). The results of the ANOVA indicated no difference between p(T1) and p(T3), $F < 1$. In two further analyses, there was a comparison between p(T1) with p(T3|T1) and another one between p(T3|T1) with p(T3|T1ˆT2). According to accounts based on the notion of capacity limitations (e.g., Chun & Potter, 2005; Jolicoeur & Dell'Acqua, 1998), considering trials in which only T1 was reported correctly (i.e., disregarding the success in T2 report) or in which both T1 and T2 were reported correctly should produce a differential impact on the AB effect on T3. If the AB for T3 is modulated by the load imposed on mechanisms engaged to consolidate pre-T3 targets, then a larger AB for T3 should be found when trials are conditionalized on just T1 report (T3|T1) compared with accuracy not conditionalized on correct T1, and an even larger AB for T3 should be found when trials are conditionalized on both correct T1 and T2 responses (T3|T1ˆT2). This is because consolidation mechanisms would be taxed to a lesser extent when processing just one pre-T3 target (i.e., just T1) than when processing two pre-T3 targets (i.e., T1 and T2). These results are also summarized in Figure 13 (dashed lines and solid lines). The new ANOVAs showed that p(T3|T1) was significantly worse than p(T1), $F(1, 19) = 4.8$, $\eta_p^2 = .203$, $p < .04$, and p(T3|T1ˆT2) was significantly worse than p(T3|T1), $F(1, 19)= 5.3$, $\eta_p^2 = .219$, $p < .04$.

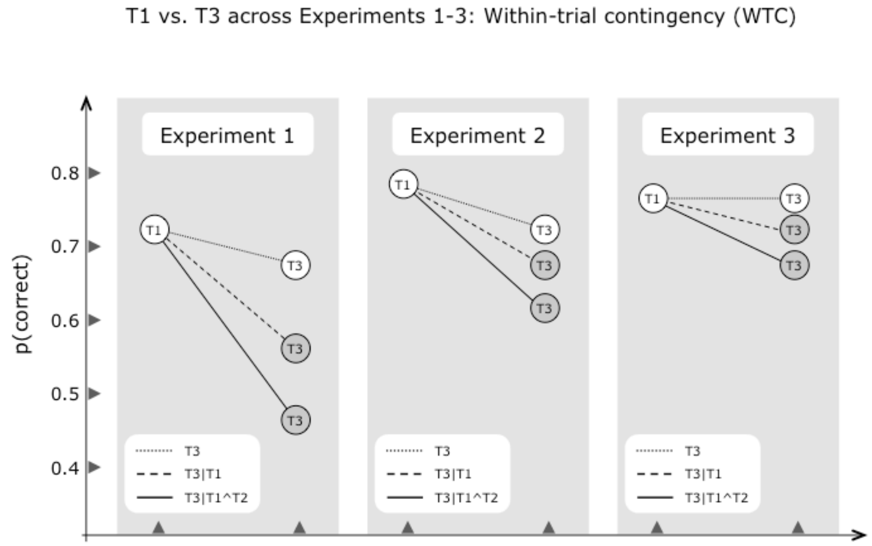

Figure 13. Results of Experiments 1–3. Observed mean proportion of correct responses to T1 and T3 (see labels inside the circles) in 3-digit trials in which the targets were temporally contiguous. The results are shown as a function of the type of algorithm subtended in the application of the WTC principle. Dotted lines: T1–T3 report functions generated by considering trials in which the principle of was not applied (unconditional T3). Dashed lines: T1–T3 report functions generated by considering trials in which the principle of was applied only partially (T3|T1). Solid lines: T1–T3 report functions generated by considering trials in which the principle of was applied in the full version (T3|T1^T2).

4.2.3 *Discussion*

Consider first the results from trials in which T1, T2, and T3 were contiguous targets. Protracted sparing in this condition, namely no significant difference between accuracy for T1 and T3, was observed only when the WTC principle was not applied. In contrast, when the WTC principle was applied, accuracy for T3 was significantly lower than for T1. It should be noted that the AB for T3 increased as a function of the number of pre-T3 targets correctly reported (whether just T1, or both T1 and T2), a result that cannot be explained by either the TLC or the BB account. The two accounts are strongly predicated on protracted sparing of post-T1 targets when a set of targets is not discontinued by distractors. In striking contrast, the results of Experiment 1 raise the possibility that either a reduced level of uncertainty about the temporal or structural distribution of targets in the RSVP streams used in prior multi-target studies (Di Lollo et al., 2005; Olivers et al., 2007) or an incorrect application of the WTC principle may have been responsible for previous reports of protracted sparing.

4.3 *Experiment 2*

The results in Experiment 1 cannot be used to distinguish among the possible causes of the failure to find protracted sparing for T3 when the WTC principle was applied. Although it appears reasonable to suspect that some form of uncertainty on the part of subjects may have contributed to altering the protracted sparing, the results do not make clear whether the uncertainty was generated by variations in the number of targets in the RSVP streams or by the variations of the lags between targets, given that these factors were confounded in Experiment 1.

The aim of Experiment 2 was to isolate one of the factors potentially responsible for the failure to observe the protracted sparing for T3. In this experiment there was a systematic manipulation and control for the impact of variations in the number of targets on protracted sparing predicted by the TLC and BB models. Experiment 2 included two conditions. One condition, *one/two/three targets*, was a replication of Experiment 1, in which the number of targets in the RSVP streams was varied unpredictably. The other condition, *always three targets,* contained only trials with three targets. This manipulation was performed with a within-subjects design, which allowed to determine whether the always-three-targets condition would replicate the protracted sparing for T3 found in prior work (e.g., Di Lollo et al., 2005; Kawahara et al., 2006; Olivers et al., 2007), while also allowing to clarify whether the patterns of results from the one/two/three-targets condition would replicate those found in Experiment 1.

4.3.1 *Method*

The stimuli and the algorithm for the generation of the RSVP streams were identical to those used in Experiment 1. Subjects performed seven experimental blocks of 27 trials in which they were informed through written instructions that the number of target digits varied unpredictably in the RSVP streams. In each of these one/two/three-targets blocks, streams with one digit, two digits, or three digits were equally likely to be presented. A question was displayed 800 ms after the end of the RSVP stream, inviting subjects to report the digit or digits they saw by pressing the corresponding keys on the numeric keypad of the computer keyboard or “0” if no digit was seen. In the always-three-targets condition, subjects also performed seven experimental blocks of 27 trials in which they were informed through written instructions that each RSVP stream always contained three digits. A question was displayed 800 ms after the end of the RSVP stream, inviting subjects to report the digits by pressing the corresponding keys on the numeric keypad of the computer keyboard. Participants in these trial blocks were instructed always to enter three digits as responses and to guess if necessary. The instructions mentioned explicitly that the order in which the responses were given was not important. Responses were made without speed pressure. One block of 27 practice trials preceded each series of experimental blocks in a given condition. The order in which the two series of trial blocks (one/two/three targets vs. always three targets) were performed was counterbalanced across subjects.

4.3.2 *Results*

Analysis. In a first set of analyses, the results from trials with three digits were examined using an ANOVA model that considered one/two/three-targets versus always-three-targets blocks as a within-subjects variable. The ANOVA on the proportion of correct responses to T1 revealed a main effect of the T1–T2 lag, $F(2, 38) = 24.2$, $\eta_p^2 = .560$, $p < .001$, which was the reflection of the lower T1 report accuracy at the shortest T1–T2 lag (.79) relative to the other two longer lags (.89 and .89, at T1–T2 Lags 3 and 7, respectively). No other main effect or interaction was significant in this analysis (all *F*s < 1), and in particular there was no interaction with type of block.

The proportion of correct responses to T2 is shown in Figure 14 as a function of the T1–T2 lag and as a function of the T2–T3 lag. The ANOVA carried out on the proportion of correct responses to T2 revealed a main effect of the T1–T2 lag, $F(2, 38) = 52.5$, $\eta_p^2 = .734$, $p < .001$; a main effect of the T2–T3 lag, $F(2, 38) = 46.0$, $\eta_p^2 = .708$, $p < .001$; and a significant interaction between these two factors, $F(4, 76) < 10.1$, $\eta_p^2 = .348$, $p < .001$. The source of the interaction is evident in Figure 14, in which a pattern of results closely resembling the results obtained in Experiment 1 can be observed. The classic U-shaped AB pattern was evident in all conditions. However, whereas the recovery from the AB was full for T2 followed by T3 presented at T2–T3 Lags 3 and 7, the recovery from the AB was only partial for T2 when the T2–T3 lag was 1. The analysis indicated a main effect of target number, $F(1, 19) = 34.2$, $\eta_p^2 = .643$, $p < .001$, reflecting an overall higher proportion of correct responses to T2 in the always-three-targets condition (.77) relative to the one/two/three-targets condition (.67). No other interaction was significant in this analysis (all $Fs < 1$).

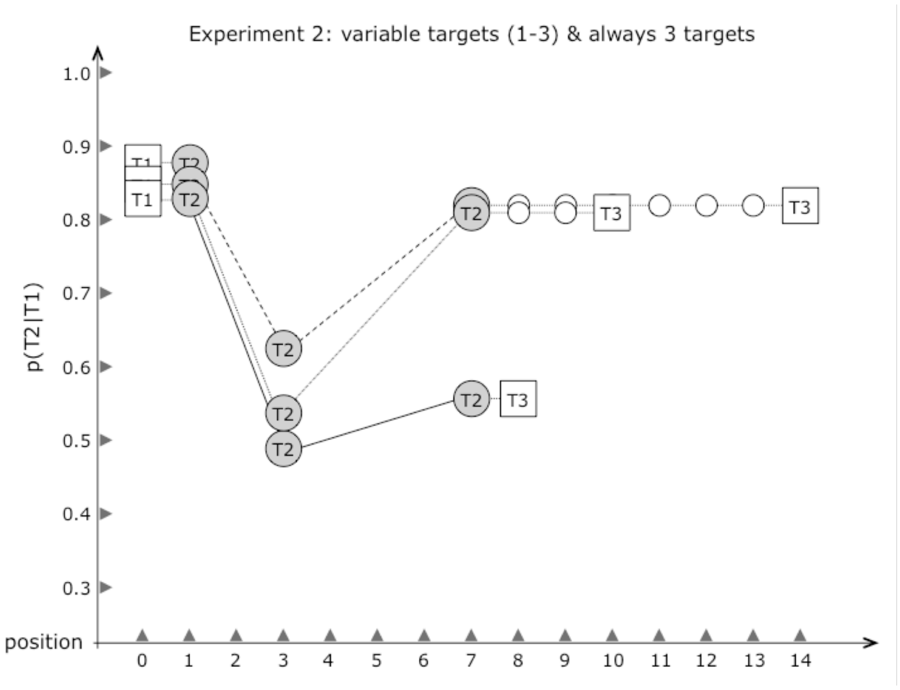

Figure 14. Results of Experiment 2. Grey circular symbols: observed mean proportion of correct responses to T2 (contingent on a correct response to T1). The results have been produced by collapsing data from the condition in which the target number was variable (1-3) and the condition in which the number of target was fixed (always 3). White square symbols: stream positions occupied by T1 and T3 (height in the graph does not represent accuracy). White and smaller circular symbols: letter distractors.

The mean proportion of correct responses to T3 for trials with a correct report of both T1 and T2 is shown in Figures 15 and 16 for each combination of T1–T2 and T2–T3 lags. Figure 15 shows the results from one/two/three-targets blocks, and Figure 16 shows the results from always-three-targets blocks. The ANOVA revealed a main effect of T1–T2 lag, $F(2, 38) = 4.4$, $\eta_p^2 = .189$, $p < .02$; a main effect of the T2–T3 lag, $F(2, 38) = 40.0$, $\eta_p^2 = .678$, $p < .001$; and a significant interaction between these two factors, $F(4, 76) = 4.0$, $\eta_p^2 = .175$, $p < .005$. Accuracy for T3 was higher on average (.70) in always-three-targets blocks than in one/two/three-targets blocks (.52), *F*(1, 19) = 43.8, η_p^2 = .697, *p* < .001. No other factor or interaction was significant in this analysis (all *Fs* < 1).

Additional analyses were conducted on T3 report accuracy. In one analysis, T3 accuracy at the shortest T2–T3 lag was compared across T1–T2 lags. As is evident in both Figures 11 and 12, T3 report accuracy at T2–T3 lag 1 increased as T1–T2 lag increased, *F*(2, 38) = 7.4, η_p^2 = .281, *p* < .002. In a second analysis, T3 report accuracy at the longest T2–T3 lag was compared across T1–T2 lags. The analysis indicated that the effect of T1–T2 lag on T3 report was not significant (*F* < 1).

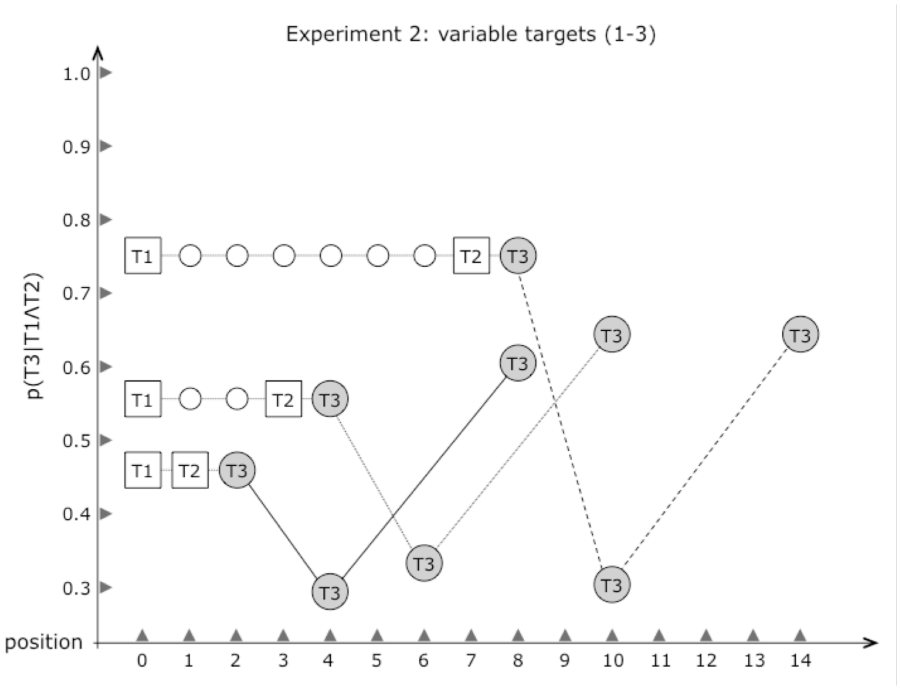

Fig. 15

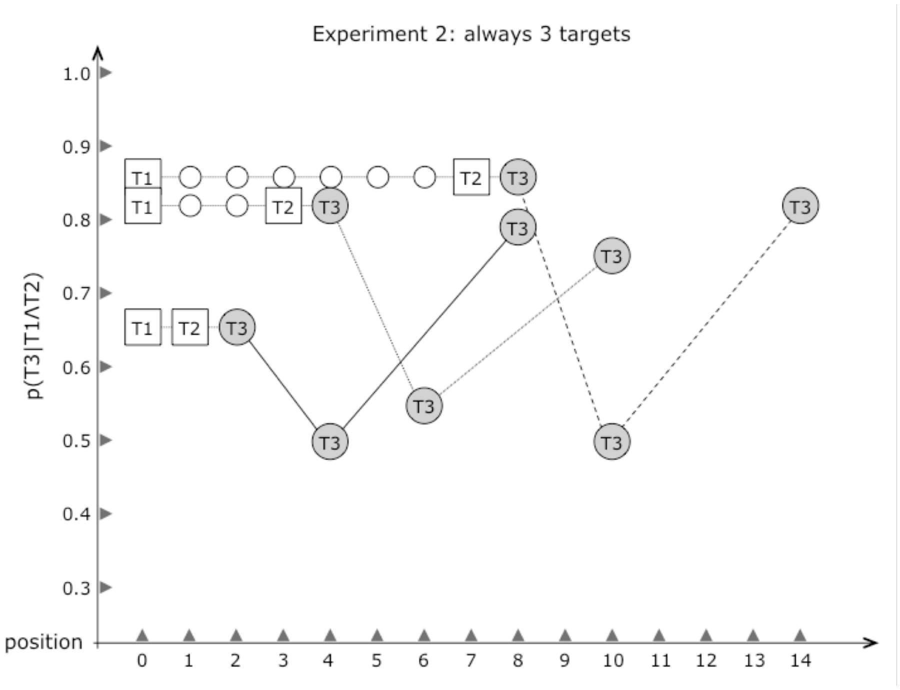

Figure 15 and 16. Results of Experiment 2 (*variable targets, top graph, vs. always 3 targets, bottom graph,* conditions). Grey circular symbols: observed mean proportion of correct responses to T3 (contingent on a correct response to T1 and a correct response to T2). White square symbols: stream positions occupied by T1 and T2 (height in the graph does not represent accuracy). White and smaller circular symbols: letter distractors.

Protracted sparing and the WTC principle. As in Experiment 1, T1 report accuracy and T3 report accuracy were compared when T1, T2, and T3 were contiguous targets. A summary of the results is shown in Figure 13 (center panel). The ANOVA comparing accuracy for T1 and T3 when the WTC principle was not applied revealed a nonsignificant difference, $F(1, 19) = 2.0$, $\eta_p^2 = .106$, $p < .15$; that is, there was a (statistical) protracted sparing for T3 (dotted line), although clearly the mean suggests a lower accuracy for T3. In two separate analyses, a comparison was performed between p(T1) with p(T3|T1) and p(T3|T1) with p(T3|T1ˆT2) using a design identical to that used in Experiment 1. These results are also summarized in Figure 13 (dashed lines and solid lines). The new ANOVAs showed that p(T3|T1) was significantly worse than p(T1), $F(1, 19) = 8.1$, $\eta_p^2 = .298$, $p < .02$), and that p(T3|T1ˆT2) was significantly worse than p(T3|T1), $F(1, 19) = 14.8$, $\eta_p^2 = .439$, $p < .01$.

4.3.3 *Discussion*

As in Experiment 1, the most important findings were those when T1, T2, and T3 were contiguous targets (without intervening distractors). Following the application of the WTC principle, both in the condition of uncertainty about the number of targets (one/ two/three-target blocks) and in the condition in which participants were consistently presented with three targets (always-three- targets blocks), there was a marked difference in the probability of a correct response, p(T1) and p(T3), with p(T3) significantly worse than p(T1) in both types of blocks, the more so as the number of pre-T3 targets reported correctly was included in the conditional probability calculation. Although p(T1) was numerically greater than p(T3) even when p(T3) was not conditionalized on correct pre-T3 targets, the difference was not statistically significant, replicating previous failures to find a deficit in p(T3) when the WTC principle was not applied.

4.4 *Experiment 3*

One tentative conclusion that may be derived from the results of Experiment 2 is that the protracted sparing may be sensitive to unpredictable variations in the number of targets, as it was not found following a correct application of the WTC principle. In Experiment 3, all trials contained three digits. Unlike the procedure in Experiment 2, however, there was a manipulation on temporal distribution of targets embedded in the RSVP streams. In the *variable-lags* condition, the lags between target pairs were varied as in the three-digit trials of Experiments 1 and 2. In the *contiguous-targets* condition, the three targets were presented without any intervening distractors, reproducing exactly the conditions of prior multi-target designs in which forms of protracted sparing were observed (e.g., Di Lollo et al., 2005; Olivers et al., 2007).

In addition, the design of Experiment 3 allowed to test encoding-capacity limitation versus simple memory load, which was not possible to perform in Experiments 1 and 2; these earlier experiments had too few three-target trials due to the inclusion of one-target and two-target trials. Recall that when T1, T2, and T3 were consecutive targets and targets report was scored following the application of the WTC principle, T1 report was consistently superior to T3 report. One account of these results is that targets competed for capacity-limited encoding mechanisms. However, another possibility is that such performance decrements reflected effects of memory load due to the need to maintain representations of earlier targets in memory at the time of presentation of later targets (e.g., Jolicoeur & Dell'Acqua, 1998; Logan, 1978). Indeed, Jolicoeur and Dell'Acqua (1998) found evidence consistent with the view that memory load effects due to maintenance of representations in memory, though smaller than load effects at encoding, were effective in modulating reaction times to an auditory stimulus presented after the to-be-encoded visual information. According to Jolicoeur and Dell'Acqua (1998), one way to differentiate between encoding effects and maintenance effects is to show an interaction of load and lag; this argument is based on the theory that effects at long lags, presumably after encoding is complete, reflect mainly maintenance costs, whereas effects at short lags reflect mainly encoding costs.

The aim to differentiate between encoding and maintenance costs in Experiment 3 was reached by examining lag effects relative to the presentation of T1 and by contrasting results from trials in which T1 was correctly reported with trials in which T1 was missed. The key empirical question was whether T3 report accuracy would be affected to a different extent by the success or failure to report T1 at a short T1–T2 lag compared with a long T1–T2 lag. If T3 report were only affected by variations in memory load induced by maintaining one target versus two targets (i.e., just T2, or T1 and T2), a null effect of the T1–T2 lag would be expected under these conditions.

4.4.1 *Method*

The stimuli and the algorithm for the generation of the RSVP streams were identical to those used in Experiment 1 and Experiment 2, except where noted in the following. All trials contained three targets. There were seven experimental blocks of 27 variable-lags trials in which the number of letter distractors separating the three target digits varied unpredictably in the RSVP streams. There were also seven experimental blocks of 27 contiguous-targets trials in which the three targets in each RSVP were always presented contiguously, and participants were informed of this arrangement prior to testing through written instructions. A question was displayed 800 ms after the end of the RSVP stream, inviting subjects to report the digits by pressing the corresponding keys on the numeric keypad of the computer keyboard; trials were conducted without speed pressure. Subjects were instructed always to enter three digits as responses and to guess if necessary. The instructions mentioned explicitly that the order in which the responses were given was not important. One block of 27 practice trials preceded each series of experimental blocks in a given condition. The order in which the two sets of blocks were performed was counterbalanced across subjects.

4.4.2 *Results*

Analysis. A first set of separate ANOVAs concentrated on the proportion of correct responses to each target in the variable-lags condition. In these analyses, T1–T2 lag and the T2–T3 lag were considered as within-subject factors. The ANOVA on the proportion of correct responses to T1 revealed a main effect of the T1–T2 lag, $F(2, 38) = 11.2$, $\eta_p^2 = .372$, $p < .001$, which reflected the lower T1 report accuracy at the shortest T1–T2 lag (.78) relative to the other two longer lags (.88 and .87, at T1–T2 Lags 3 and 7, respectively). No other main effect or interaction was significant in this analysis (all *Fs* < 1).

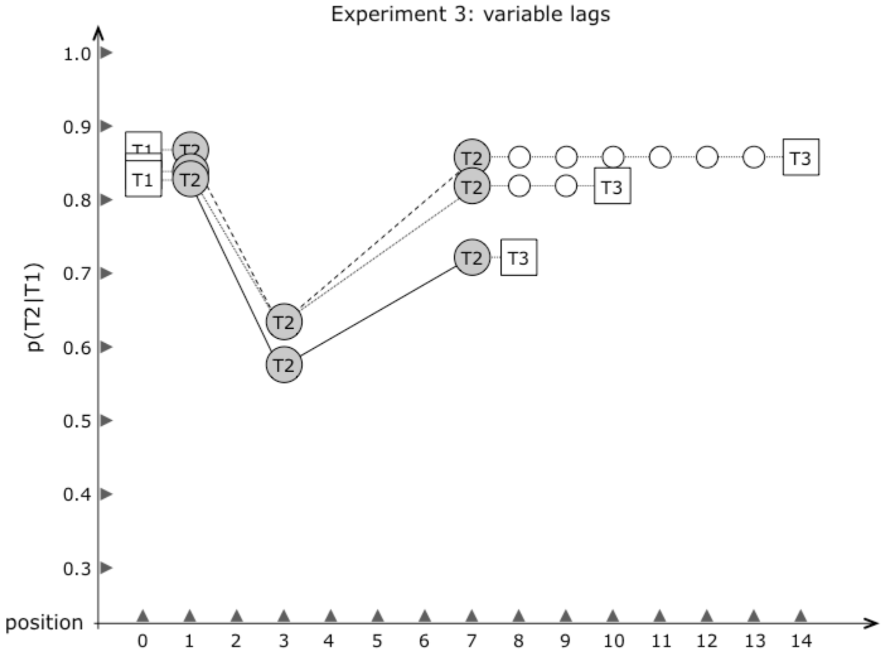

Figure 17. Results of Experiment 3 (variable lags condition). Grey circular symbols: observed mean proportion of correct responses to T2 (contingent on a correct response to T1). White square symbols: stream positions occupied by T1 and T3 (height in the graph does not represent accuracy). White and smaller circular symbols: letter distractors.

The proportion of correct responses to T2 is shown in Figure 17 as a function of the T1–T2 lag and as a function of the T2–T3 lag. The ANOVA carried out on the proportion of correct responses to T2 revealed a main effect of T1–T2 lag, *F*(2, 38) = 59.4, η_p^2 = .758, *p* < .001); a main effect of the T2–T3 lag, *F*(2, 38) = 5.3, η_p^2 = .219, *p* < .01; and a significant interaction between these two factors, *F*(4, 76) = 2.7, η_p^2 = .125, *p* < .04. The source of the interaction is evident in Figure 17 in which a pattern of results closely resembling the results obtained in Experiments 1 and 2 can be observed. Again, whereas the recovery from the AB was full for T2 followed by T3 presented at T2–T3 Lags 3 and 7, the recovery from the AB was only partial for T2 when the T2–T3 lag was 1.

The proportion of correct responses to T3 in the variable-lags condition (light gray circles) and in the contiguous-targets condition (dark gray circle) is shown in Figure 18. A comparison was run on the proportion of correct responses to T3 in the variable-lags condition with the proportion of correct responses to T3 in the contiguous- targets condition, after isolating trials in the variable-lags condition in which the both T1–T2 lag and the T2–T3 lag were both equal to 1 (i.e., when T1, T2, and T3 were contiguous). As can be seen in Figure 18, there was no difference between these two proportions ($F < 1$).

For results from the variable-lags blocks, the ANOVA of T3 report accuracy revealed a main effect of T1–T2 lag, $F(2, 38) = 9.9$, $\eta_p^2 = .342$, $p < .001$; a main effect of the T2–T3 lag, $F(2, 38) = 34.0$, $\eta_p^2 = .642$, $p < .001$; and a significant interaction between these two factors, $F(4, 76) = 2.5$, $\eta_p^2 = .117$, $p < .05$. T3 report accuracy at the shortest T2–T3 lag was compared across T1–T2 lags. As is evident in Figure 18, T3 report accuracy in- creased as T1–T2 lag was increased, $F(2, 38) = 8.0$, $\eta_p^2 = .296$, $p < .002$. T3 report accuracy at the longest T2–T3 lag did not differ across T1–T2 lags ($F < 1$).

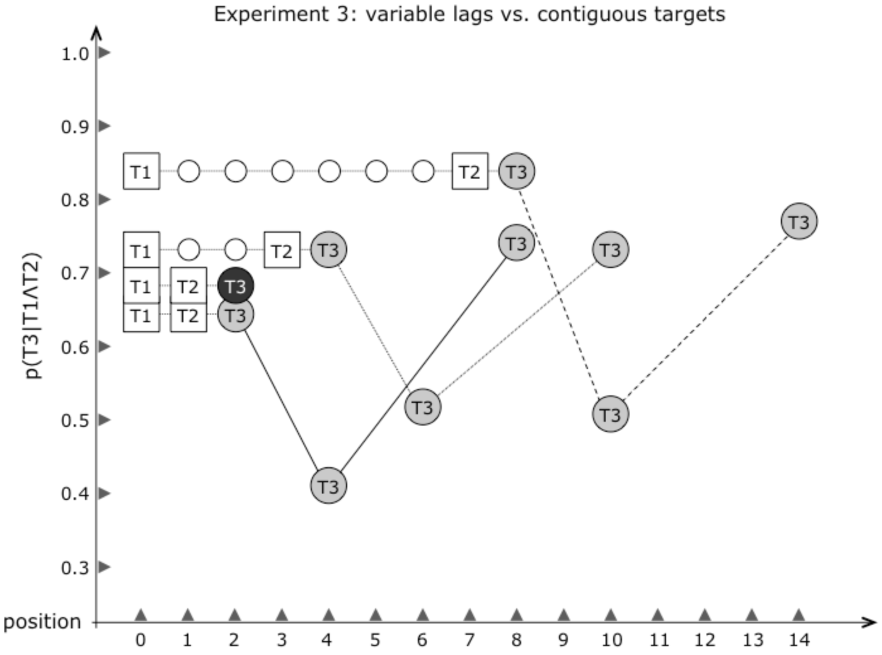

Figure 18. Results of Experiment 3. Grey circular symbols: observed mean proportion of correct responses to T3 (contingent on a correct response to T1 and a correct response to T2). The circular symbol in darker grey represents the mean proportion of correct responses to T3 in the *contiguous targets* condition. White square symbols: stream positions occupied by T1 and T2 (height in the graph does not represent accuracy). White and smaller circular symbols: letter distractors.

Testing effects of memory load versus encoding-capacity limitation. An ANOVA was conducted on T3 report accuracy including only trials in which T2 was correctly reported and considering T1 report accuracy (correct vs. incorrect) and T1–T2 lag as within-subject factors. The analysis was conducted on the data collapsed across T2–T3 lag levels and temporarily excluded from consideration the data at the intermediate T1–T2 lag. The data from 1 subject had to be eliminated to avoid empty cells. A summary of the results is shown in Figure 19. The ANOVA revealed a main effect of T1 accuracy, $F(1, 18) = 48.0$, $\eta_p^2 = .727$, $p < .001$, reflecting a generally higher T3 report accuracy when T1 was missed relative to when T1 was correctly reported, and a significant interaction between T1 accuracy and T1–T2 lag, $F(1, 18) = 5.5$, $\eta_p^2 = .232$, $p < .04$. The interaction reflected a larger effect difference in T3 accuracy for T1 report success versus failure at short T1–T2 lag than at long T1–T2 lag.

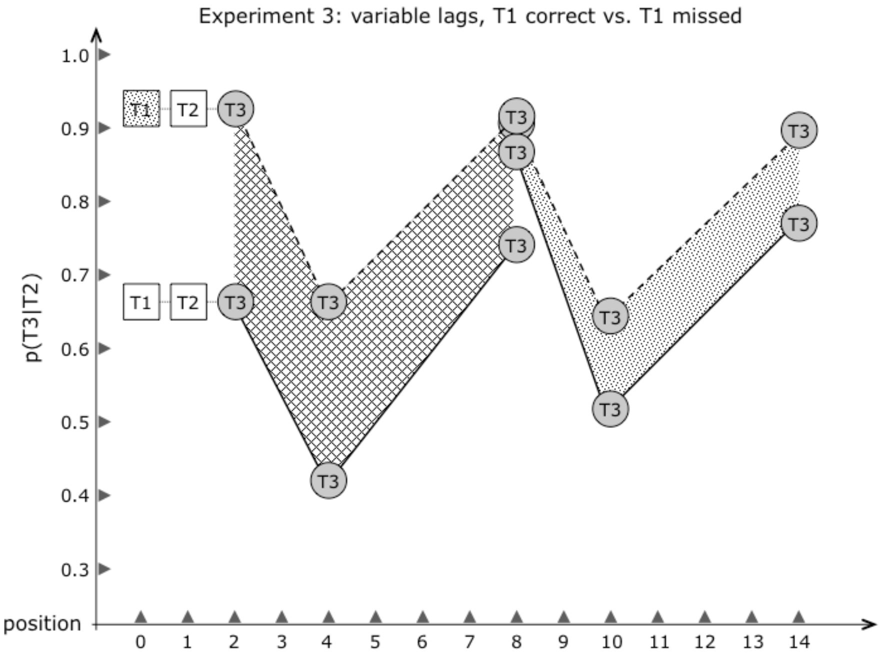

Figure 19. Results of Experiment 3. Grey circular symbols: observed mean proportion of correct responses to T3 (contingent on a correct response to T2). The results are plotted as a function of T1 response accuracy. Dashed lines: T3 report functions generated by considering trials in which T1 had been missed. Solid lines: T3 report functions generated by considering trials in which T1 had been reported correctly. The shaded areas included between dashed and solid lines is a graphical representation of the impact of missing or reporting T1 correctly on T3 report accuracy as a function of the T2–T3 lag. Note that the rightmost T3 functions differ from the leftmost T3 functions in terms of number of distractors intervening between T1 and T2 (i.e., left functions: T1–T2 lag = 1; right functions: T1–T2 lag = 7; see also the text). The results in the T1–T2 lag = 3 condition have been omitted to avoid crowding of the present graph with results that were not considered strictly relevant. The incorrect response to T1 is indicated by the blurred background filling the square symbols indicating the position of T1 within the RSVP stream. White square symbols: stream positions occupied by T1 and T2 (height in the graph does not represent accuracy).

Protracted sparing and WTC principle. As in Experiments 1 and 2, a comparison between T1 report accuracy and T3 report accuracy was performed when T1, T2, and T3 were contiguous targets. A summary of the results is reported in Figure 13 (rightmost panel). The ANOVA comparing p(T1) and p(T3) when the WTC principle was not applied showed a null difference between these two probabilities ($F < 1$), that is, an apparent protracted sparing for T3 (Figure 13 dotted line). In two separate analyses, there was a comparison p(T1) with p(T3|T1) and p(T3|T1) with p(T3|T1ˆT2) using a design identical to that used in Experiments 1 and 2. These results are also summarized in Figure 13 (dashed lines and solid lines, respectively). The new ANOVAs showed that p(T3|T1) was significantly worse than p(T1), $F(1, 19) = 4.5$, $\eta_p^2 = .205$, $p < .05$, and that p(T3|T1^T2) was significantly worse than p(T3|T1), $F(1, 19) = 11.3$, $\eta_p^2 = .374$, $p < .01$.

To ascertain whether the order in which subjects performed the different contiguous-targets and variable-lags conditions of Experiment 3 had any effects in modulating the probability to report T1 and T3, an ANOVA has been conducted on the data filtered according to the WTC principle that considered target (T1 vs. T3) and condition order (contiguous-targets condition first vs. variable-lags condition first) as within-subject factors. The ANOVA revealed a main effect of target, $F(1, 18) = 12.5$, $\eta_p^2 = .410$, $p < .003$, and a trend of subjects to perform generally worse in contiguous-targets blocks if they started with variable-lags blocks, $F(1, 18) = 3.3$, $\eta_p^2 = .154$, $p < .09$, rather than vice versa. The interaction between condition order and target, however, was not significant ($F < 1$).

Combined analysis of p(T1) vs. p(T3) across Experiments 1–3. An ANOVA has been conducted considering Experiment (1 vs. 2 vs. 3) as a between-subject factor and target (T1 vs. T3) and WTC principle (applied vs. not applied) as within-subjects factors. The ANOVA revealed a main effect of the WTC principle, $F(1, 57) = 39.5$, $\eta_p^2 = .409$, $p < .001$, indicating a lower general level of target report accuracy when the WTC principle was applied (.67) relative to when the WTC principle was not applied (.74) and a main effect of target (T1 vs. T3, .76 vs. .65), $F(1, 57) = 13.6$, $\eta_p^2 = .192$, $p < .001$. The WTC principle factor interacted significantly with experiment, $F(2, 57) = 3.4$, $\eta_p^2 = .107$, $p = .04$, and with target, $F(1, 57) = 39.4$, $\eta_p^2 = .409$, $p < .001$. There was also a significant three-way interaction among experiment, WTC principle, and target, $F(1, 57) = 3.4$, $\eta_p^2 = .107$, $p < .04$. Figure 13 suggests that a potential source of this interaction was the reduction in the impact of the WTC principle in Experiment 3 with respect to Experiment 1 and Experiment 2. An ANOVA in which data from Experiment 3 was temporarily excluded again showed a main effect of the application of the WTC principle, $F(1, 38) = 25.9$, $\eta_p^2 = .406$, $p < .001$, and a main effect of target (T1 vs. T3, .76 vs. .62), $F(1, 38) = 10.8$, $\eta_p^2 = .222$, $p < .003$. The WTC principle interacted with target, $F(1, 38) = 25.9$, $\eta_p^2 = .406$, $p < .001$. There was, however, no main effect of experiment ($F < 1$) and no three-way interaction among the factors considered in the analysis, $F(1, 38) = 2.7$, $p > .2$. A further separate analysis was conducted on contiguous trials without the application of the WTC principle, with experiment (between-subject) and target (within-subject) as factors. The analysis detected no significant effects for these factors or interaction (highest $F = 2$, lowest $p = .12$).

4.4.3 *Discussion*

There were three key findings in Experiment 3. The first, was that T3 report accuracy in trials in which the three targets were always temporally contiguous did not differ from T3 report accuracy in trials in which the T1–T2 lag and the T2–T3 lag were varied unpredictably and were both equal to 1. In other words, in terms of T3 report accuracy, it made no difference whether subjects were expecting contiguous targets or not under conditions in which the three targets were contiguous. In Experiment 2, the uncertainty about the number of targets had been ruled out as having a crucial role in the failure to replicate the protracted sparing involving T3 documented in prior studies; the present findings strongly suggest that uncertainty about the temporal distribution of targets in the RSVP streams cannot be a potential factor responsible for such failure.

The second crucial finding, was related to the role of VSTM load in modulating T3 report accuracy in an analysis contingent on the correct report of T2 comparing trials in which T1 was missed with trials in which T1 was correctly reported. T3 report accuracy was indeed lower when T1 was reported correctly, but most important, this effect was larger at short T1–T3 lags than at long T1–T3 lags, suggesting that at least part of the effect was a reflection of encoding-capacity limitations rather than of memory maintenance costs (Jolicoeur & Dell'Acqua, 1998).

The third finding, emerged from the combined analysis of Experiments 1–3 considering the impact of the application of the WTC principle in the comparison between p(T1) and p(T3). The analysis revealed a reduced impact of the WTC principle when three targets were invariably presented in the RSVP streams relative to the impact observed in Experiments 1 and 2, and this suggests that a reduced level of uncertainty on the part of subjects about the structural properties of the RSVP streams may actually have had a beneficial effect on T3 report accuracy in these circumstances. The analysis, however, also indicated a residual AB on T3 when the WTC principle was applied, both partially and in full form. This finding is all the more important if one considers that Experiment 3 was designed to replicate closely the conditions described by Di Lollo and colleagues (2005) and Olivers and collaborators (2007).

CHAPTER 5

GENERAL DISCUSSION

5.1 *Identification vs. Counting*

First of all, the general discussion will deal with the results coming from the Identification vs. Counting series of experiments. The series of experiments has produced new findings concerning the nature of Lag-1 sparing that are largely unexpected, based on extant accounts of the AB, in general, and of Lag-1 sparing, in particular.

The targets in Experiment 1 were digits presented among letters. In different trials, 0, 1, or 2 digits were presented, and the task was to identify them and report their identity at the end of the trial without speed pressure or to count how many digits had been presented and to report this count at the end of the trial, also without speed pressure. A clear Lag-1 sparing effect was observed in the identification task in the combined probability of reporting both T1 and T2 correctly. In contrast, there was no Lag-1 sparing in the counting task (for trials with 2 digits), as shown in the bottom panel of Figure 5.

The theoretical hypothesis on the observed absence of Lag-1 sparing, found in Experiment 1 in the counting task, might have resulted from interference between the need to count digits and the meaning of the counted objects. Experiment 2 ruled out this possibility by requiring observers to count letters presented among digits. Again, Lag-1 sparing was found in the identification task but not in the counting task (see Figure 6, bottom panel).

Experiment 3 tested the hypothesis that Lag-1 sparing with identification but not with counting could be in some way correlated with the overall difficulty of the two tasks (possibly easier in the counting task than in the identification task). In Experiment 3, the aim was to lower overall accuracy, thereby increasing overall task difficulty, by presenting the RSVP sequences through a cloud of random dots (a camouflage mask) in half of the trials. As expected, accuracy was lower when the stimuli (T1, T2, and the distractors) were degraded by the camouflage mask. However, the masking effect was additive with lag and did not modulate the size of the AB effect or the size of the Lag-1 sparing effect in either task. In addition to corroborating the analysis of Ouimet and Jolicoeur (2006), these results are important because they rule out any explanation of the modulation of the Lag-1 sparing effect by appeal to differences in overall task difficulty across the counting and identification tasks.

Experiment 4 was designed to test whether the difference in output requirements between the identification task and the counting task may have played any modulatory role on the Lag-1 sparing effect. In Experiment 4, the counting task was replaced with a digit-sum task. Subjects also performed the identification task in different trial blocks. Clear evidence of Lag-1 sparing effect was observed in the identification task as well as in the digit-sum task. These findings rule out output factors (e.g., memory load for two response codes in identification vs. one response code for counting and summing) among the possible modulatory causes of the Lag-1 sparing effect. However, the results are consistent with the view that computing the sum of two digits requires knowing precisely which two digits had been presented. That is, the digit-sum task requires the individuation of the two digits, just as in the identification task.

In Experiment 5, two aspects have been tested more directly: the nature of the codes generated for each target and the interplay between the mechanisms hypothesized to generate such codes with the attentional filter responsible for selecting T1 and T2 from the distractors in a given RSVP stream. Instead of performing a general counting operation based on an alphanumeric distinction between targets and distractors, the task was to count digits of only a given parity subclass (i.e., count only odd or only even digits). In other blocks of trials, subjects also performed the digit-identification task. Lag-1 sparing was found in both tasks. Thus, counting any digit (e.g., Experiment 1) abolished Lag-1 sparing, but counting only odd digits or only even digits restored Lag-1 sparing. Clearly, it was not the difference in task (identification vs. counting) that was most critical in controlling whether Lag-1 sparing was present or absent. Rather, it was the nature of the representations of the targets that appears to be critical. Counting just odd or just even digits, we believe, required the generation of individual digit identities, just as in the identification task. Lag-1 sparing was found consistently when individual character identities were required by the task, and it was abolished when the task could be performed on the basis of less specific category-level information.

5.1.1 *Structural limitation or control-based approach?*

The present results represent a challenge for both theoretical frameworks examined in the introduction, namely, those based on a two-stage architecture of processing targets under RSVP conditions, such as the central interference theory of Jolicoeur and Dell'Acqua (1998), and the TLC account of Di Lollo e collaborators (2005) or Olivers and colleagues (2007)'s theory. Recently published results (i.e., Kawahara et al., 2005) have already highlighted the difficulty of providing a unified account of all aspects of the AB paradigm, including the Lag-1 sparing effect, the likely related Lag-*N* sparing effect (Di Lollo et al., 2005; Olivers et al., 2007), and results showing that the time taken to process T1 at central stages modulates the AB (e.g., Crebolder, Jolicoeur, & McIlwaine, 2002; Jolicoeur, 1999b; Ouimet & Jolicoeur, 2006). The present findings follow along the same lines by showing that the cited AB models and interpretations lack a set of valid principles to incorporate modulations of Lag-1 sparing effect that are due to the likely different nature of the mental operations subserving counting and identifying (i.e., the tasks used in the present series of designs).

The TLC account puts strong emphasis on the notion of endogenous and exogenous control over the selection criteria implemented at early stages of processing used to separate targets from distractors. Both the occurrence of Lag-1 sparing and the absence of Lag-1 sparing are explained by the principle that Lag-1 sparing occurs only when T2 fits the input configuration set up for T1. Lag-1 sparing is found when the two targets belong to the same (alphanumeric) category but not when they differ from one another in two or more dimensions that are important for target selection (Di Lollo et al., 2005; Visser et al., 1999). Presenting a distractor following T1, in this view, causes an exogenous reconfiguration of selection filters that makes the processing of T2 less efficient than when T2 immediately follows T1. When T2 is presented immediately after T1, the same input filters that were applied to T1 can be applied to T2, and this is thought to result in very efficient processing of T2 and in Lag-1 sparing (relative to performance when one intervening distractor is present between T1 and T2). The present results cannot be explained adequately by the TLC hypothesis, because Lag-1 sparing was present in the identification task and absent in the counting tasks when the selection rules required for T1 and T2 were identical. The TLC hypothesis predicts that Lag-1 sparing should have been observed in both tasks, given that nothing in the presentation sequence would cause an exogenous or endogenous reconfiguration of input filters. It is obvious that the mere similarity of processing operations used on T1 and T2 and/or the state of input filters at the time of the presentation of T1 and T2 are insufficient to explain the present results. Clearly, what happens after selection has a critical role to play in Lag-1 sparing, and exactly how this is to be understood in the context of the notion of input filters is, as of yet, not clear. The absence of Lag-1 sparing in the counting task thus appears to be a troublesome exception for the model proposed by Di Lollo and colleagues (2005).

On the other hand, perhaps a more elaborated version of accounts based on the TLC type of logic cannot be disregarded entirely. Experiments 1–3, for instance, consistently showed that the absence of Lag-1 sparing was accompanied by better performance at longer lags in the counting condition compared with the identification condition, regardless of whether masking by camouflage was used to data-limit the flow of information coming from the RSVP stream. This was reflected in a significant effect of task across these experiments in which the counting task was globally easier than the identification task, when counting did not involve items of a specific parity class (as it did in Experiment 5). This apparent difference in overall task difficulty suggests the possible applicability of an account of Lag-1 sparing proposed by Olivers and Nieuwenhuis (2005; see also Olivers et al., 2007). In this account, Lag-1 sparing and the AB are a consequence of observers overinvesting resources in T1, which leads to the spilling of resources onto the next item in the stream. This overshoot of resources not only accounts for Lag-1 sparing, it also entails that task difficulty may affect Lag-1 sparing. More specifically, it might be that observers allocated fewer resources to T1 in the easier counting task than in the more difficult identification task. Control for target selection was thus relaxed in the counting task, with the consequent reduction of the chances of resources spilling over onto the item next to T1, causing the absence of Lag-1 sparing. The proposal that Lag-1 sparing may be sensitive to effort and/or perceived difficulty on the part of the observers could seemingly provide an alternative account of the results, even though it might be suboptimal to explain why Lag-1 sparing was reinstated when observers were required to count digits on the basis of parity class (Experiment 5). Other results, which must be mentioned for the sake of completeness, are admittedly handled more naturally by the TLC account compared with other types of AB accounts, including the central interference theory. Consider, for instance, the results of Kawahara and collaborators (2006), Olivers and coauthors (2007), and Nieuwenstein, Chun, van der Lubbe, and Hooge (2005) showing that the report of a second or third target presented during the AB is surprisingly good when the target is precued by either another target or by a distractor matching the attentional set used to filter targets from distractors. These findings are clearly at odds with the notion that following the encoding of a batch, encoding of further information suffers from a refractory phase that lasts until the batch is transferred to VSTM. Nieuwenstein and Potter (2006), in particular, showed that observers can report up to four items from an RSVP sequence of six items without any sign of an AB.

However, the present results make it mandatory to consider the specific nature of the post-selection processing of targets required by various tasks to provide a complete understanding of the AB phenomenon both in the present study and in previous studies (Chun & Potter, 1995; Crebolder et al., 2002; Dell'Acqua & Jolicoeur, 2000; Dell'Acqua, Jolicoeur, Pesciarelli, Job, & Palomba, 2003; Dell'Acqua, Sessa, Jolicoeur, & Robitaille, 2006; Dell'Acqua, Turatto, & Jolicoeur, 2001; Jolicoeur, 1998, 1999a, 1999b, 1999c; Jolicoeur & Dell'Acqua, 2000; Jolicoeur, Dell'Acqua, & Crebolder, 2000; Jolicoeur, Dell'Acqua, & Crebolder, 2001; Jolicoeur, Sessa, Dell'Acqua, & Robitaille, 2006a, 2006b; Vogel & Luck, 2003; Vogel, Luck, & Shapiro, 1998). The difference in the post-selection processing of targets may explain why Lag-1 sparing was observed in the identification task but not in the general counting task. According to the central interference theory, short-term consolidation takes a considerable time, and the duration of consolidation sometimes depends on the amount of to-be-consolidated information (Jolicoeur & Dell'Acqua, 1998; but see Vogel, Woodman, & Luck, 2006, for a different proposal). If T1 and T2 are presented at very short SOA (e.g., at Lag 1), there will be a high probability that T1 and T2 could enter the same short-term consolidation batch and, thus, be consolidated simultaneously. This would lead to the occurrence of Lag-1 sparing in standard identification tasks. Consider next the case of the absence of Lag-1 sparing in the counting task of Experiments 1–3. In these experiments, the selection cue for the targets was the same for T1 and T2 and presumably required achieving a classification of each stimulus to the level of the character class (digit vs. letter). Following this classification, when finding a target, the observer would retrieve the current state of a mental counter and update the counter value. Presumably, the value of the target count is maintained in a store in short-term memory, and it is likely that each of the steps involving operations in short-term memory is capacity demanding (Logie & Baddeley, 1987). Akyurek, Hommel, and Jolicoeur (2007), for example, demonstrated that scanning the contents of VSTM is an operation that increases the size of the AB. The present results in the counting tasks provide further converging evidence that accessing and updating a mental count is capacity demanding and may cause an AB. For letters and digits, merely categorizing T1 as a target is likely to take less time than deciding exactly which character had been presented (Brawn & Snowden, 2000; Hick, 1952; Jolicoeur, Gluck, & Kosslyn, 1984; Kawahara et al., 2001). In this vein, one may attribute the modulations of Lag-1 sparing to the notion that post-selection capacity-demanding operations would be initiated sooner in the counting task than in the identification task. The consequence would be that the probability of T2 to be included in the T1 consolidation batch would be higher when consolidation initiates later (with identification) than when consolidation is more prompt (with classification).

5.1.2 *The AB with Identification and Categorization*

The hypothesis that counting in the present designs would depend largely on an initial categorization of each character as either a letter or a digit, followed by further processing associated with updating a mental counter. Despite the apparent simplicity of these operations, performance in the counting task was lower than in the identification task at Lag 1, and the counting task also had a higher false alarm rate in 1-digit (or 1-letter) trials. At longer lags, however, performance was higher in the counting task than in the identification task. What these results show is that the observed performance likely reflects a complex interplay between mechanisms leading to the categorization and selection of items in the RSVP streams and the further processing required to perform the task associated with selected stimuli.

These results lend themselves to a direct comparison with results obtained in different empirical contexts. Grill-Spector and Kanwisher (2005) compared subjects' ability to detect single objects in grayscale photographs with their ability to categorize the objects and identify them for a delayed report. They also manipulated the exposure duration of the photographs using values that ranged from a few tenths of a millisecond to 200 ms. In three experiments, the results were unequivocal. Whether the level of accuracy following the presentation of masked objects (Experiments 1 and 2) or the reaction times to the same unmasked objects (Experiment 3) were monitored, performance in identification was always worse than both categorization and detection at all levels of exposure duration of the photographs. The authors concluded that detection and categorization are similar under many aspects and both different from identification, which likely engages either different functional and neural mechanisms or the same set of mechanisms for a substantially longer time (e.g., Grill-Spector, 2003).

Results of Evans and Treisman (2005) also suggest that something qualitatively different distinguishes the categorization of objects into a small number of categories from identification. They showed RSVP sequences of natural scenes including objects of different semantic categories to their subjects. Two objects of one or two prespecified categories were embedded in each sequence, and subjects had to make an immediate buttonpress on determining that an object belonged to a target category (categorization), followed by a delayed identification response made by typing the object name with no speed pressure at the end of the trial. The manipulation of interest was the temporal interval separating the first from the second object in each sequence. It is interesting to note that whereas a robust AB was found for the identification of two successive objects, no AB was found for their categorization, implying that the categorization of an object as a member of a prespecified category was “attention free” (for a similar conclusion, see also Bonnel, Stein, & Bertucci, 1992).

On the basis of these empirical premises, one may wonder why the AB has been found with counting at all in the present experiments. If counting task was based on categorization, and if categorization is attention free as suggested by Evans and Treisman (2005), then we should have observed either no AB or a much reduced AB compared with the identification task. The discrepancy between the present results and those of Evans and Treisman (2005) should be attributed to factors that are not related to counting per se but that owe instead to something peculiar in the visual structure of letters and digits that made them different from the stimuli used in other investigations involving categorization. Levin, Takarae, Miner, and Keil (2001) have shown that searching for an animal among distracting artifacts (or vice versa) was as efficient when the search target was displayed tachistoscopically in a canonical format as when the target was cut in parts and the parts were randomly scattered around fixation. Analogous examples involve the use of faces as stimuli. It has been shown repeatedly that categorizing an inverted face as a face is an immediate operation, whereas identifying an inverted face is much more difficult (e.g., Rousselet, Mace, & Fabre-Thorpe, 2003). These results suggest that categorization (and detection) may be attention free only when it can be performed on the basis of rudimentary, and possibly unique, features. Very efficient categorization may only be possible when the spatial relations between features and/or parts of an object are not necessary to distinguish objects of different categories. It is possible that the real-world objects used by Evans and Treisman (2005), and by Grill-Spector and Kanwisher (2005) could be categorized on the basis of simple features (see also Kawahara et al., 2001) or individual parts.

The case appears to be different for the alphanumeric characters used in the Identification vs. Counting study of the present investigation. Letters and digits are composed by combining very similar low-level shape features. Although one can argue that the features are not entirely identical, and that extensive learning can allow subjects to use these differences, it is plausibly that with the present stimuli and levels of practice, that letters and digits were categorized primarily via an initial activation of the identity of each character. The visual similarity between letters and digits has recently been the object of empirical scrutiny in a study carried out by Maki, Bussard, Lopez, and Digby (2003). These authors scored letters, digits, mathematical symbols, and false font characters on two conceptual dimensions (familiarity, meaningfulness), as well as on a number of visual dimensions (feature density, feature dissimilarity, pixel density, pixel dissimilarity), and showed that letters and digits were similar under all the aspects scored, and both were dissimilar from symbols (on feature dissimilarity, pixel density, and dissimilarity) and false fonts (on familiarity and meaningfulness). It was on the basis of this type of analysis that is supposed that the initial categorization of characters as either letter or digit would require the activation of a representation corresponding to the identity of the character, and that following this activation of the character “type,” the category membership of the stimulus could be determined. Following this categorization, either a mental updating of a counter (in the counting task) or something akin to the individuation of a “token” for the identification task (Kanwisher, 1987), which is referred to as the individuation of a particular character identity, would precede the short-term consolidation of that individuated identity (in the identification task).

5.1.3 *The Absence of Lag-1 Sparing due to Repetition Blindness?*

In foregoing sections, there is the allusion to the notion that a key difference between the tasks that produced Lag-1 sparing and those that abolished Lag-1 sparing was the need to associate specific character identities with the targets. Kanwisher (1987) referred to this operation as *tokenization* or *token instantiation* (see also Chun, 1997). Token instantiation can be said to be necessary when instances of a certain stimulus category have to be consolidated into VSTM, usually for the explicit report of the identity of such instances within seconds after their presentation. Token instantiation, in this optic, corresponds to binding information about the semantic identity of a stimulus with information about the spatiotemporal characteristics of the context in which the stimulus was physically displayed. Phenomena like repetition blindness suggest that, whereas information about the stimulus category are promptly and automatically activated on presentation of a stimulus with virtually no impediment, instantiating a token corresponding with the visual information may result in significant interference if two identical instances of a stimulus category are presented in close temporal succession.

AB effects and repetition blindness effects have been shown to be functionally dissociable in tasks requiring the identification of target stimuli. Chun (1997) presented target letters embedded in RSVP streams of different types of distractors. On a proportion of trials, the letters could be different, whereas in other trials the letters were the same. The critical result was produced by varying the nature of the distractors composing the RSVP sequence: When the distractors were visually and categorically dissimilar from the target letters (i.e., symbols such as =, *%*, or *?*), the AB effect disappeared when the targets were distinct letters, but a clear repetition blindness effect was still observed at the shortest lags when the targets were identical letters. The repetition blindness effect, specifically, brought about a linear decrease in report accuracy as lag was decreased.

Could the generic counting task induce a form of repetition blindness because of the repetition of a stimulus category? One might imagine that such an effect could come about because the general counting task might shift the functionally relevant level of categorization from specific digit identities to the category level (digits vs. letters). Perhaps repetition blindness would appear as a function of the repetition of the functionally relevant level of representation in the task, in this case stimulus alphanumeric class. If so, perhaps the absence of Lag-1 sparing in the general counting task would be due to the repetition of this task-defined functionally relevant level of processing. Note that this level of processing would be what many experts would characterize as semantic in nature. The hypothesis, however, of repetition blindness mediated by semantic processing of repeated stimuli is not uncontroversial.

One indication that repetition blindness does not seem to reflect the repetition of categorical information comes from a repetition blindness study conducted by Kanwisher and Potter (1990) using words as stimuli. To test whether repetition blindness could affect information about words' meaning, and not simply their orthographic representations, these authors presented either identical words or different words with the same meaning (i.e., synonyms) embedded in apparently well-structured sentences. These authors found no evidence of repetition blindness for word meanings, whereas (not surprisingly) a robust repetition blindness effect was found for identical words. On the basis of these results, Kanwisher and Potter (1990) concluded that repetition blindness was unlikely to exert effects beyond the lexical (repeated) codes. However, one could argue that Kanwisher and Potter's results do not test the hypothesis that is entertained in the first series of experiments in the present work. In Kanwisher and Potter's experiment, the task was not to categorize the words but, rather, to report individual words. This would mean that the functionally relevant level of representation in the task was not the category level (or the level at which meaning repeated) but, rather, at the level of individual lexical (or phonological; see Bavelier & Potter, 1992) entry, which could explain why they did not observe category-level repetition blindness.

A similar objection applies to a study that has instead reported results that may be raised to support the opposite argument. MacKay and Miller (1994) had proficient bilingual subjects read sentences in which target words in English and Spanish were preceded by within- and across-language identical, semantically related, or different pre-target words. The results were clear in indicating that a semantic version of repetition blindness for semantically similar words occurred even across languages, suggesting that a semantic level of analysis of the word stimuli was probably involved in the effect found. Further work will be required to clarify the possible role of category-level repetition blindness in the present first Study's results.

5.2 *Multi-target RSVP paradigm: the within trial contingency*

Secondly, the general discussion will deal with the results obtained in the second Study (i.e, “Multi-target RSVP paradigm: the within trial contingency” in Chapter 4).

Across the series of experiments, the level of uncertainty was manipulated along two dimensions, the target–target lag and the number of targets, and analyzed the most critical results (i.e., those from trials with three contiguous targets, with and without the application of the WTC principle). When T3 accuracy was not conditionalized on correct report of T1 and T2, p(T3) was not significantly different from p(T1). As can be seen in Figure 13, this can been found in all three experiments, thereby replicating a key pattern of results reported by Di Lollo and coauthors (2005) and Olivers and colleagues (2007). In each of the present experiments, however, p(T3), when scored in accordance with the WTC principle, always reflected an AB; that is, p(T3) report was consistently worse than p(T1). A crucial finding was related to whether only T1 was taken into account for conditionalizing T3 report (T3|T1) or whether both T1 and T2 were taken into account (T3|T1ˆT2). When both pre-T3 targets were taken into account, T3 report suffered from an AB that was more pronounced relative to the condition in which only T1 was taken into account.

This pattern of results was conceptually replicated in all three experiments, albeit with quantitative variations that are informative vis-à-vis the relative weight of participants’ knowledge about the structural properties of the RSVP streams in processing multiple targets. The results of Experiment 3, in particular, when compared with the results of Experiments 1 and 2, provide a suggestion that reducing the level of uncertainty allowed a more efficient processing of contiguous sequential targets, a finding that is consistent with prior work suggesting that subjects’ advance knowledge about the structural or temporal organization of RSVP paradigms often results in beneficial effects on post-T1 targets processing. Despite the quantitative variations mentioned, however, it is clear that the present findings represent a serious challenge for both the TLC and BB models, as presently formulated, under several aspects. First, neither of these models at present reflects the possibility that when targets are immediately successive items embedded in RSVP streams, post-T1 targets processing may be influenced by a subjectively controlled dynamic adjustment of the accessibility of VSTM by multiple targets. That was made manifest across Experiments 1–3 through the systematic manipulation of a subset of temporal or structural parameters (i.e., the number of targets and the target–target lag) used in the generation of the RSVP streams. Second and also important, although for different reasons, it is hard to see how the TLC and BB accounts could explain the residual AB effect on T3 found in Experiment 3, that is, under conditions that replicated exactly the general structure of the paradigms used in studies showing the protracted sparing. According to the TLC account, p(T1) and p(T3) should be equivalent because no loss of control over attentional selection mechanisms and no reset in favor of distracting information are hypothesized to occur in the absence of distractors. With no intervening distractors, equivalent results would be predicted by the BB account, according to which successful access to VSTM by multiple targets is granted by an uninterrupted sequence of target-locked boosts of activation. On the other hand, these findings highlight the importance of the application of the WTC principle in the examination of results in multi-target RSVP designs and provide direct support for a tenet of capacity limitation accounts: a decrease in correct report of T3 should be expected as capacity is devoted to encoding other targets, and this decrease should be larger when there are more competing targets, as was found again in the present second Study (e.g., Jolicoeur & Dell'Acqua, 1998).

A comment is in order concerning a further empirical case apparently against capacity limitations as the prime cause of the AB effect that was reported by Nieuwenstein and Potter (2006). The experiment in that study, that is directly comparable to the present experiments, is their Experiment 2, in which monochromatic targets could be selected on the basis of their alphanumeric class (and not color, as used in other experiments reported by Nieuwenstein and Potter, 2006). Subjects were exposed to sequences of six letters, and the task was either to report as many of them at the end of *whole-report* trials or to start encoding the letters in the RSVP stream after detecting a specific letter that was shown to subjects prior to the beginning of each *partial-report* trial. A whole-report superiority effect was observed for targets occupying a given position in the RSVP steam relative to the same target in the partial-report condition, when the probability of reporting a given target was estimated according to the WTC principle. It must be noted that the whole-report versus partial-report comparison is confounded with a task switch, which is known to exacerbate, under particular conditions, the AB effect (Enns, Visser, Kawahara, & Di Lollo, 2001; Peterson & Juola, 2000; Potter et al. 1998; Visser et al., 1999). Contrary to the whole-report condition, in which participants had simply to identify and encode as many letters as possible from each RSVP stream (no task switch), in the partial-report condition, participants had first to detect the cued letter (i.e., T1) and then start to identify and encode as many letters as possible among those trailing T1 (task switch). Therefore, one possible explanation for the worse performance in partial report relative to whole report is that the switch from an attentional set that had been adjusted to *detect* T1 to an attentional set that had been adjusted to *identify* the letters immediately following T1 could have reduced accuracy in the partial-report condition relative to the whole-report condition. A task switch was implicated in none of the present experiments.

5.2.1 *Capacity Limitations framework*

The second series of experiments' findings seem to be more easily accounted for by capacity limitations models on the basis of two explanatory principles. One principle, is that the processing of targets encoded for later report proceeds in two stages: an initial high-capacity identification stage followed by a lower capacity memory-encoding stage. This idea is instantiated in the two-stage model of Chun and Potter (1995) and the central interference theory proposed by Jolicoeur (1998). According to this type of model, all alphanumeric characters composing a RSVP sequence are processed up to the level of individual character identities (Dux & Coltheart, 2005) at an early stage (Stage 1) but only T1 and T2 are selected for access to a later stage of processing (Stage 2) that consolidates T1 and T2 into durable memory representations that are stored in VSTM (see Duncan, 1980). The metaphor of an attentional gate is normally invoked in these models to explain how the system isolates T1 and T2 for further processing. The identification or categorization of T1 causes the gate to open, and this is hypothesized to be a rapid sequence of events; in contrast, the closing of the gate is hypothesized to be more sluggish (Shih, 2000, 2008). If T2 immediately follows T1, T2 is selected for processing in Stage 2 before the gate can close, and T1 and T2 are processed in Stage 2 at the same time. Jolicoeur and Dell'Acqua (1998) referred to this encoding process as *short-term consolidation*. Given that short-term consolidation is a capacity-limited process, some competition between T1 and T2 ensues, such that some of the gain in performance for T2 occurs at a cost to performance for T1. The second principle, is instantiated in the model proposed by Jolicoeur and Dell'Acqua (1998), which incorporates basically the same assumptions concerning the different stages implicated in target consolidation, with the important addition that the time devoted to target consolidation increases as the quantity of information to be encoded into VSTM increases. The principle suggests that, all else being equal, the short-term consolidation of two alphanumeric characters takes longer than the short-term consolidation of a single alphanumeric character (see also Jolicoeur, 1999; Jolicoeur, Tombu, Oriet, & Stevanovski, 2002; Ouimet & Jolicoeur, 2006).

The two principles outlined are sufficient to explain the present findings. An AB is triggered every time a stimulus that needs to be consolidated in VSTM is encountered. The AB is manifest unless a target (T2) trailing the one critical for the AB generation (i.e., T1) is presented within 100 –120 ms of T1. In that case, T1 and the trailing target, T2, are integrated into a single postperceptual processing batch that undergoes consolidation, with the consequent (sometimes partial) sparing of T2. This explains the two consecutive U-shaped AB effects characterizing the performance of T2 and the performance of T3 in a context of manipulation of both the T1–T2 lag and the T2–T3 lag in three-digit trials. Consolidating a batch consisting of two integrated targets (e.g., T1 and T2) takes longer than consolidating a batch consisting of a single target. Manipulating the probability that T1 and T2 would be integrated into a single to-be-consolidated batch should have a modulatory consequence for T3 report performance. A similar prediction would be made on the basis of the overall amount of attention resources required for the processing of T1 in three-target trials. With the increase of the T1–T2 lag, the probability that T1 and T2 would enter the same consolidation batch decreases. Conversely, following an increment in attention resources needed for T1 processing, less attention resources should be left for processing post-T1 targets, especially when targets are temporally contiguous. This, on the one hand, explains why in three-digit trials on which T3 was the item immediately following T2, T3 report accuracy improved as the T1–T2 lag was increased. On the other hand, the prediction that increasing the attention demands for T1 processing would alter the availability of resources for T3 processing in three-target trials has just been empirically confirmed by Dux, Asplund, and Marois (2009) and by Dux and Harris (2007). These studies showed that in a design closely resembling that used by Di Lollo and coauthors (2005), T3 report was consistently suppressed relative to T1 report when T1 was associated with a marked color difference with respect to distractors and when T1 was rotated by 90° with respect to distractors. A particularly marked color difference associated with an abrupt onset, as well as the recognition of an object displayed in a noncanonical position, had already been shown to demand more attention with respect to less salient changes marking a difference between targets and distractors or canonically positioned objects (e.g., Maki & Mebane, 2006; Serences, Shomstein, Leber, Golay, Egeth and Yantis, 2005; Van Selst & Jolicoeur, 1994).

Finally, in the third experiment (i.e, in the second Study), accuracy of report for T3 was examined depending on whether T1 was reported correctly or incorrectly. At long T1–T2 lags, a U-shaped decrement in T3 report dependent upon a correct report of both T1 and T2 was found, and these effects were larger than when T2 was correctly reported but T1 was missed. The subsequent assumption was that such divergence could constitute evidence of differential VSTM load, reflected in T3 report, in the two types of trials. When the lag between T1 and T2 was decreased, as predicted by capacity models, the VSTM load effect on T3 report increased in magnitude. As suggested previously, decreasing the lag between T1 and T2 increases the probability that consolidation mechanisms will be busy with T1 at the time of presentation of T3. The ensuing costs in terms of consolidation time, which are assumed to be diminished if T1 is missed and not subjected to short-term consolidation, add to VSTM load costs, supporting further the arguments for a central role of capacity limitations of short-term consolidation in the AB phenomenon (Jolicoeur & Dell'Acqua, 1998). The results and analyses suggest that the explicit exclusion of encoding-capacity limitations embodied in the TLC and BB models prevent these models from providing a complete account of important aspects of the AB phenomenon.

5.3 *Concluding remarks*

In conclusion, from a general point of view, that considers the overall results of both the series of experiments, the AB and the Lag-1 sparing are configured as two hot topics, in the cognitive sciences, that are still under debate. Capacity limitations and control-based frameworks are still trying to validate a general model that could account for all the AB and Lag-1 sparing facets. Further investigation are needed to comprehend in detail this attentional phenomenon that has been demonstrated in a wide range of experimental conditions. Moreover, it is important do not forget that, looking at the AB literature, this processing deficit seems to have a multifactorial origin. For example attentional selection, working memory encoding, episodic registration, response selection, and distractors inhibition are some of these factors and all of them have to be taken into account. However, the present results seem to argue for a situation in which the former processes rely on a common capacity limitation in attentional resources and this constraint is the main cognitive cause of the AB. Although the literature is far from having settle on a integral and convincing explanation of this phenomenon, the perspective that this apparent cognitive limitation may reflect even an attentional control is matter of debate. Further studies are needed to understand how this fundamental temporal deficit influences human visual awareness.

BIBLIOGRAPHY

Akyurek, E. G., & Hommel, B. (2005). Target integration and the attentional blink. *Acta Psychologica 119*(3), 305-314.

Akyurek, E. G., Hommel, B., & Jolicoeur, P. (2007). Direct evidence for a role of working memory in the attentional blink. *Memory & Cognition, 35*(4), 621-627.

Akyurek, E. G., Riddell, P. M., Toffanin, P., & Hommel, B. (2007). Adaptive control of event integration: evidence from event-related potentials. *Psychophysiology, 44*(3), 383-391.

Arnell, K. M., & Jolicoeur, P. (1999). The attentional blink across stimulus modalities: Evidence for central processing limitations. *Journal of Experimental Psychology: Human Perception and Performance, 25*(3), 630-648.

Bachmann, T., & Allik, J. (1976). Integration and interruption in the masking of form by form. *Perception, 5,* 79-97.

Bavalier, D., & Potter, M. C. (1992). Visual and phonological codes in repetition blindness. *Journal of Experimental Psychology: Human Perception and Performance, 18,* 134-147.

Bonnel, A. -M., Stein, J. -F., & Bertucci, P. (1992). Does attention modulate the perception of luminance changes? *Quarterly Journal of Experimental Psychology: Human Experimental Psychology, 44*(A), 601-626.

Brawn, P. T., & Snowden, R. J. (2000). Attention to overlapping objects: Detection and discrimination of luminance changes. *Journal of Experimental Psychology: Human Perception and Performance, 26,* 342-358.

Brehaut, J. C., Enns, J. T., & Di Lollo, V. (1999). Visual masking plays two roles in the attentional blink. *Perception and Psychophysics, 61,* 1436-1448.

Breitmeyer, B. G., (1984). *Visual masking: An integrative approach*. New York: Oxford University Press.

Broadbent, D. E., & Broadbent, M. H. (1987). From detection to identification: response to multiple targets in rapid serial visual presentation. *Perception & Psychophysics, 42*(2), 105-113.

Carrier, L. M., & Pashler, H. (1995). Attentional limits in memory retrieval. *Journal of Experimental Psychology: Learning Memory and Cognition, 21*(5), 1339-1348.

Chun, M. M. (1997). Types and tokens in visual processing: a double dissociation between the attentional blink and repetition blindness. *Journal of Experimental Psychology: Human Perception and Performance, 23*(3), 738-755.

Chun, M. M., & Potter, M. C. (1995). A two-stage model for multiple target detection in rapid serial visual presentation. *Journal of Experimental Psychology: Human Perception and Performance, 21*(1), 109-127.

Crebolder, J. M., Jolicoeur, P., & McIlwaine, J. D. (2002). Loci of signal probability effects and of the attentional blink bottleneck. *Journal of Experimental Psychology: Human Perception and Performance, 28,* 695-716.

Dell'Acqua, R., & Jolicoeur, P. (2000). Visual encoding of patterns is subject to dual-task interference. *Memory & Cognition, 28,* 184-191.

Dell'Acqua, R., Turatto, M., & Jolicoeur, P. (2001). Cross-modal attentional deficits in processing tactile stimulation. *Perception & Psychophysics, 63*, 777-789.

Dell'Acqua, R., Jolicoeur, P., Pesciarelli, F., Job, R., Palomba, D. (2003). Electrophysiological evidence of visual encoding deficits in a cross-modal attentional blink paradigm. *Psychophysiology, 40,* 629-639.

Dell'Acqua, R., Pascali, A., Jolicoeur, P., & Sessa, P. (2003). Four-dot masking produces the attentional blink. *Vision Research, 43,* 1907-1913.

Dell'Acqua, R., Sessa, P., Jolicoeur, P., & Robitaille, N. (2006). Spatial attention freezes during the attentional blink. *Psychophysiology, 43,* 394-400.

Dell'Acqua, R., Jolicoeur, P., Pascali, A., & Pluchino, P. (2007). Short-term consolidation of individual identities leads to lag-1 sparing. *Journal of Experimental Psychology: Human Perception and Performance, 33,* 593-609.

Dell'Acqua, R., Jolicoeur, P., Luria, R., & Pluchino, P. (2009). Reevaluating encoding-capacity limitations as a cause of the attentional blink. *Journal of Experimental Psychology: Human Perception and Performance, 35,* 338-351.

Di Lollo, V., Kawahara, J., Ghorashi, S. M. S., & Enns, J. T. (2005). The attentional blink: Resource depletion or temporary loss of control? *Psychological Research, 69*(3), 191-200.

Duncan, J., (1980). The demonstration of capacity limits. *Cognitive Psychology, 12,* 75-96.

Dux, P. E., Asplund, C. L., & Marois, R. (2009). Both exogenous and endogenous target salience manipulations support resource depletion accounts of the attentional blink: A reply to Olivers et al. *Psychonomic Bulletin & Review, 16*(1), 219-224.

Dux, P. E., & Coltheart, V. (2005). The meaning of the mask matters: Evidence of conceptual interference in the attentional blink. *Psychological Science, 16,* 775-779.

Dux, P. E., & Harris, I. M. (2007). Viewpoint costs occur during consolidation: Evidence from the attentional blink. *Cognition, 104*, 47-58.

Enns, J. T. (2004). Object substitution and its relation to others forms of visual masking. *Vision Research, 44,* 1321-1331.

Enns, J. T., Visser, T. A., Kawahara, J., & Di Lollo, V. (2001). Visual masking and task-switching in the attentional blink. In K. L. Shapiro (Ed.), *The Limits of attention* (pp. 65-81). New York: Oxford University Press.

Evans, K. K., & Treisman, A. (2005). Perception of objects in natural scenes: It is really attention free? *Journal of Experimental Psychology: Human Perception and Performance, 31,* 1476-1492.

Giesbrecht, B. L., & Di Lollo, V. (1998). Beyond the attentional blink: Visual masking by object substitution. *Journal of Experimental Psychology: Human Perception and Performance, 24,* 1454-1466.

Grill-Spector, K. (2003). The functional organization of the ventral visual pathway and its relationship with object recognition. In N. Kanwisher & J. Duncan (Eds), *Functionalneuroimaging of visual cognition: Attention and performance XX* (pp. 169-193). London: Oxford University Press.

Grill-Spector, K., & Kanwisher, N. (2005). Visual recognition: As soon as you know it is there, you know what it is. *Psychological Science, 16,* 152-160.

Hick, W. E. (1952). On the rate gain of information. *Quarterly Journal of Experimental Psychology, 4,* 11-26.

Hommel, B., & Akyurek, E. G. (2005). Lag-1 sparing in the attentional blink: benefits and costs of integrating two events into a single episode. *Quarterly Journal of Experimental Psychology, 58A*, 1415-1433.

Jolicoeur, P. (1998). Modulation of the attentional blink by on-line response selection: Evidence from speeded and unspeeded Task$_1$ decisions. *Memory & Cognition, 26*(5), 1014-1032.

Jolicoeur, P. (1999a). Concurrent response-selection demands modulate the attentional blink. *Journal of Experimental Psychology: Human Perception and Performance, 25*(4), 1097-1113.

Jolicoeur, P. (1999b). Dual-task interference and visual encoding. *Journal of Experimental Psychology: Human Perception and Performance, 25,* 596-616.

Jolicoeur, P. (1999c). Restricted attentional capacity between sensory modalities. *Psychonomic Bulletin & Review, 6,* 87-92.

Jolicoeur, P., & Dell' Acqua, R. (1998). The demonstration of short-term consolidation. *Cognitive Psychology, 36*(2), 138-202.

Jolicoeur, P., Dell'Acqua, R. (2000). Selective influence of second target exposure duration and Task$_1$ load effects in the attentional blink phenomenon. *Psychonomic Bulletin & Review, 7,* 472-479.

Jolicoeur, P., Dell'Acqua, R., & Crebolder, J. (2000). Multitasking performance deficits: Forging some links between the attentional blink and the psychological refractory period. In S. Monsell & J. Driver (Eds.), *Control of cognitive processes: Attention and Performance XVIII* (pp. 309-330). Cambridge, MA: MIT Press.

Jolicoeur, P., Dell'Acqua, R., & Crebolder, J. (2001). The attentional blink bottleneck. In K. L. Shapiro (Ed.), *The limits of attention* (pp. 82-89). New York: Oxford University Press.

Jolicoeur, P., Gluck, M. A., & Kosslyn, S. M. (1984). Pictures and names: Making the connection. *Cognitive Psychology, 16,* 243-275.

Jolicoeur, P., Sessa, P., Dell'Acqua, R., & Robitaille, N. (2006a). Attentional control and capture in the attentional blink paradigm: Evidence from human electrophysiology. *European Journal of Cognitive Psychology, 18,* 560-578.

Jolicoeur, P., Sessa, P., Dell'Acqua, R., & Robitaille, N. (2006b). On the control of visual spatial attention: Evidence from human electrophysiology. *Psychological Research, 70,* 414-424.

Jolicoeur, P., Tombu, M., Oriet, C., & Stevanovsky, B. (2002). From perception to action: Making the connection. In W. Prinz & B. Hommel (Eds.) *Common mechanisms in perception and action: Attention and performance XIX* (pp. 558-586). Oxford, England: Oxford University Press.

Kanwisher, N. G. (1987). Repetition blindness: Type recognition without token individuation. *Cognition, 27,* 117-143.

Kawahara, J., Di Lollo, V., & Enns, J. T. (2001). Attentional requirements is visual detection and identification: evidence from the attentional blink. *Journal of Experimental Psychology: Human Perception and Performance, 27*(4), 969-984.

Kawahara, J., Enns, J. T., & Di Lollo, V. (2006). The attentional blink is not a unitary phenomenon. *Psychological Research, 70*(6), 405-413.

Kawahara, J., Kumada, T., & Di Lollo, V. (2006). The attentional blink is governed by a temporary loss of control. *Psychonomic Bulletin & Review, 13,* 886-890.

Kellie, F. J., & Shapiro, K. L. (2004). Object file continuity predicts attentional blink magnitude. *Perception & Psychophysics, 66*(4), 692-712.

Kessler, K., Schmitz, F., Gross, J., Hommel, B., Shapiro, K., & Schnitzler, A. (2005a). Cortical mechanisms of attention in time: neural correlates of the Lag-1-sparing phenomenon. *European Journal of Neuroscience, 21*, 2563-2574.

Kessler, K., Schmitz, F., Gross, J., Hommel, B., Shapiro, K., & Schnitzler, A. (2005b). Target consolidation under high temporal processing demands as revealed by MEG. *Neuroimage, 26*, 1030-1041.

Levin, D. T., Takarae, Y., Miner, A. G., & Keil, F. (2001). Efficient visual search by category: Specifying the features that mark the difference between artifacts and animals in preattentive vision. *Perception & Psychophysics, 63,* 676-697.

Logan, G. D., (1978). Attention in character-classification tasks: Evidence for the automaticity of component stages. *Journal of Experimental Psychology: General, 69,* 32-63.

Logie, R. H., & Baddeley, A. D. (1987). Cognitive processes in counting. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 13,* 310-326.

MacKay, A., & Juola, J. F. (2007). Are spatial and temporal attention independent? *Perception & Psychophysics, 69*(6), 972-979.

MacKay, D. G., & Miller, M. D. (1994). Semantic blindness: Repeated concepts are difficult to encode and recall under time pressure. *Psychological Science, 5,* 52-55.

Maki, W. S., Bussard, G., Lopez, K., & Digby, B. (2003). Sources of interference in the attentional blink: Target-distractors similarity revisited. *Perception & Psychophysics, 65,* 188-201.

Maki, W. S., & Mebane, M. W. (2006). Attentional capture triggers an attentional blink. *Psychonomic Bulletin Review, 13,* 125-131.

Martens, S., & Johnson, A. (2005). Timing attention: Cueing target onset interval attenuates the attentional blink. *Memory & Cognition, 33,* 234-240.

Nieuwenstein, M. R., Chun, M. M., van der Lubbe, R. H., & Hooge, I. T. (2005). Delayed attentional engagement in the attentional blink. *Journal of Experimental Psychology: Human Perception and Performance, 31*(6), 1463-1475.

Nieuwenstein, M. R., & Potter, M. C. (2006). Temporal limits of selection and memory encoding: A comparison of whole versus partial report in rapid serial visual presentation. *Psychological Science, 17*(6), 471-475.

Olivers, C. N. L. (2007). The time course of attention: It is better than we thought. *Current Directions in Psychological Sciences, 16,* 11-15.

Olivers, C. N. L., & Meeter, M. (2008). A boost and bounce theory of temporal attention. *Psychological Review, 115*(4), 836-863.

Olivers, C. N. L., & Nieuwenhuis, S. (2005). The benefical effect of concurrent task-irrilevant mental activity on temporal attention. *Psychological Science, 16,* 265-269.

Olivers, C. N. L., van der Stigchel, S., & Hulleman, J. (2007). Spreading the sparing: against a limited-capacity account of the attentional blink. *Psychological Research, 71*(2), 126-139.

Ouimet, C., & Jolicoeur, P. (2006). Beyond Task_1 difficulty: The duration of T1 encoding modulates the attentional blink. *Visual Cognition, 15,* 290-304.

Pashler, H. (1994). Dual-task interference in simple tasks: data and theory. *Psychological Bulletin, 116*(2), 220-244.

Peterson, M. S., & Juola, J. F. (2000). Evidence for distinct attentional bottlenecks in attention switching and attentional blink tasks. *Journal of General Psychology, 127,* 6-26.

Potter, M. C. (1976). Short-term conceptual memory for pictures. *Journal of Experimental Psychology: Human Learning and Memory, 2*(5), 509-522.

Potter, M. C. (1993). Very short-term conceptual memory. *Memory & Cognition, 21*(2), 156-161.

Potter, M. C., Chun, M. M., Banks, B. S., & Muckenhoupt, M. (1998). Two attentional deficits in serial target search: The attentional blink and an amodal task-switch deficit. *Journal of Experimental Psychology: Memory, and Cognition, 24,* 979-992.

Potter, M. C., Dell'Acqua, R., Pesciarelli, F., Job, R., Peressotti, F., & O'Connor, D. (2005). Bidirectional semantic priming in the attentional blink. *Psychonomic Bulletin & Review, 12,* 460-465.

Potter, M. C., Staub, A., & O'Connor, D. H. (2002). The time course of competition for attention: attention is initially labile. *Journal of Experimental Psychology: Human Perception and Performance, 28*(5), 1149-1162.

Raymond, J. E. (2003). New objects, not new features, trigger the attentional blink. *Psychological Science, 14*(1), 54-59.

Raymond, J. E., Shapiro, K. L., & Arnell, K. M. (1992). Temporary suppression of visual processing in an RSVP task: an attentional blink? *Journal of Experimental Psychology: Human Perception and Performance, 18*(3), 849-860.

Rousselet, G. A., Mace, M. J-M., & Fabre-Thorpe, M. (2003). Is it an animal? Is it a human face? Fast processing in upright and inverted natural scenes. *Journal of Vision, 3,* 440-465.

Serences, J. T., Shomstein, S., Leber, A. B., Golay, X., Egeth, H. E., & Yantis, S. (2005). Coordination of voluntary and stimulus-driven attentional control in human cortex. *Psychological Science, 16,* 114-122.

Sergent, C., Baillet, S., & Dehaene, S. (2005). Timing of the brain events underlying access to consciousness during the attentional blink. *Nature Neuroscience, 8,* 1391-1400.

Shapiro, K., Driver, J., Ward, R., & Sorensen, R. E. (1997). Priming from the attentional blink: A failure to extract visual tokens but not visual types. *Psychological Science, 8*(2), 95-100.

Shapiro, K., Raymond, J. E., & Arnell, K. M. (1994). Attention to visual pattern information produces the attentional blink in rapid serial visual presentation. *Journal of Experimental Psychology: Human Perception and Performance, 20,* 357-371.

Shin, S. (2000). Recall of two visual targets embedded in RSVP streams of distractors depends on their temporal and spatial relationship. *Perception & Psychophysics, 62,* 1348-1355.

Shin, S. (2008). The attention cascade model and the attentional blink. *Cognitive Psychology, 56,* 210-236.

Van Selst, M., & Jolicoeur, P. (1994). Can mental rotation occur before the dual-task bottleneck? *Journal of Experimental Psychology: Human Perception and Performance, 20*(4), 905-921.

Visser, T. A. W., Bischof, W. F., & Di Lollo, V. (1999). Attentional switching in spatial and nonspatial domains: Evidence from the attentional blink. *Psychological Bulletin, 125,* 458-469.

Visser, T. A. W., Zuvic, S. M., Bischof, W. F., & Di Lollo, V. (1999). The attentional blink with targets in different spatial locations. *Psychonomic Bulletin & Review, 6,* 432-436.

Vogel, E. K., & Luck, S. J. (2003). Delayed working memory consolidation during the attentional blink. *Psychonomic Bulletin & Review, 9,* 739-743.

Vogel, E. K., Luck, S. J., & Shapiro, K. L. (1998). Electrophysiological evidence for a postperceptual locus of suppression during the attentional blink. *Journal of Experimental Psychology: Human Perception and Performance, 24,* 1656-1674.

Vogel, E. K., Woodman, G. F., & Luck, S. J. (2006). The time course of consolidation in visual working memory. *Journal of Experimental Psychology: Human Perception and Performance,32*(6),1436-1451.