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The number of expected targets modulates access to working memory: a new unified account of lag-1 sparing and distractor intrusions

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Abstract

In rapid serial visual presentation (RSVP) tasks, failures of attentional selectivity are frequently observed when a single target is followed by a potentially reportable distractor (distractor intrusions). However, in tasks with two targets, accuracy for both targets is typically high when they are presented in immediate succession (lag-1 sparing). To account for this apparent contradiction, we tested whether expectations about the number of targets affects the number of items encoded in working memory (WM). Coloured target digits were embedded among grey letters and digits. The first target was followed either by a grey digit, or a second target (another coloured digit). To manipulate expectations, the ratio of one-target and two-targets trials (75%-25% or vice versa) was varied between blocks. Participants were much more likely to report seeing two targets when two targets were expected. Analogous results were obtained in an additional experiment where two successive coloured digits appeared on all trials, and participants were instructed to either report both or only the first digit. ERP markers of attentional allocation (N2pc) and WM storage processes (CDA) were larger when two targets were expected, regardless of the actual number of targets. These results show that the number of expected targets modulates the activation of sensory representations during attentional episodes, which affects the probability that they are subsequently encoded in WM. These findings suggest that a single mechanism can account both for lag-1 sparing and distractor intrusions in RSVP tasks. They also provide new evidence for strategic top-down control over WM encoding.
Keywords: distractor intrusions, lag-1 sparing, RSVP, temporal selection, working memory

Public Significance Statement

When targets and distractors are presented in rapid succession at the same location, temporal attention plays an important role in whether observers can correctly report these targets. Our results suggest that expectations about the number of targets play an important role in modulating temporal attention. They show that expecting more targets increases the amount of information that can gain access to working memory.

Our subjective present feels continuous and complete, flowing smoothly and in rich detail from one moment to the next. However, this experience is an illusion, extrapolated from incomplete perceptual information. In reality, our conscious minds are severely limited in the amount of data they can sample and process simultaneously and successively. These limitations can have benign consequences, such as enjoying films comprised of static images, but can also have detrimental results, like when drivers fail to detect brief but potentially important events on the road.

While the temporal limitations in perception are often invisible to introspection, they can be revealed and explored using controlled lab experiments. To this end, researchers have often used rapid serial visual presentation (RSVP) tasks, where one or more targets are embedded among streams of distractors that appear consecutively and in rapid succession at the same location. Such tasks have shown that goal-directed selective attention is a key mechanism for target detection in dynamic environments. When the target object is known in advance, attention can be rapidly deployed towards items with target-matching features. This mechanism allows us to ignore irrelevant information, focus on a smaller and more manageable amount of potentially relevant information, and detect targets successfully even when they appear for as little as 20 ms (Potter et al., 2014).

Among the many insights obtained with the RSVP paradigm, two findings from tasks where RSVP streams contain two successive target objects (T1 and T2) have attracted particular interest among attention researchers. In such tasks, the temporal lag between T1 and T2 plays a crucial role in determining whether both targets will be encoded in working memory (WM) and subsequently reported. The attentional blink refers to the highly robust finding that T2 is usually identified when it is separated from T1 by more than 600 ms, but is often missed when it appears between 200 and 500 ms after the first target. The similarly robust lag-1 sparing effect demonstrates that when the two targets are presented in immediate succession (i.e., when T2 appears at lag-1), accuracy in reporting both remains high, although they are often reported in the wrong order (order reversals, Hommel & Akyürek, 2005). The question why targets presented at lag-1 appear to be exempt from the attentional blink has not yet been decisively answered. Some have argued that the attentional blink reflects a temporary T1-induced disruption of an input filter that selects target-matching sensory input, and that lag-1 sparing occurs when this filter is still active (Di Lollo et al., 2005; Taatgen et al, 2009; see also: Visser, 2015). Others suggest that lag-1 sparing occurs when successive targets are processed within the same attentional episode–a brief period of amplified sensory processing that is triggered by T1 and also benefits the processing of items that appear in close temporal proximity (Olivers & Meeter, 2008; Vul et al., 2008; 2009; Wyble et al., 2009; 2011; Zivony & Eimer, 2020).

In addition to the attentional blink and lag-1 sparing, there is a third highly reliable observation in RSVP tasks that has received much less attention. In single-target RSVP streams report accuracy strongly depends on the nature of the distractor that immediately follows the target. Accuracy is high (about 80-90%), when this post-target distractor does not match the response category of the target (e.g., when a digit target is followed by a letter), but drops precipitously (to 40-50%; e.g., Zivony & Eimer, 2021a) when this both items come from the same category (e.g., a digit target followed by a digit distractor). In the latter case, observers will often erroneously report the identity of the post-target distractor instead of the target (e.g., Botella et al., 2001; Goodbourn et al., 2016; Ludowici, & Holcombe, 2021; Vul et al., 2008).

These distractor intrusion errors could be the result of two different processes. On the one hand, participants may encode both the target and the post-target distractor into WM, but sometimes perceive and the distractor as having appeared first, and therefore report it. In this case, distractor intrusion errors would be conceptually equivalent to the order reversals that are frequently observed during lag-1 sparing. Alternatively, competitive interactions between the target and the post-target distractor may result in only the distractor being encoded, while the target is excluded from entering WM. If this was the case, distractor intrusions and lag-1 sparing would reflect substantially different outcomes. These two possibilities are not mutually exclusive. In a previous study (Zivony & Eimer, 2020), we found that the target and the post-target distractor were sometimes both encoded, but that on a large number of trials, only one of these items entered WM, resulting in intrusion errors when this item was the distractor.

These findings present a conundrum that raises important questions about attentional selectivity in the time domain. Task performance is usually inversely related to task difficulty, yet searching for two targets (lag-1 sparing tasks) instead of just one (distractor intrusions tasks) makes it more likely that the first target is correctly reported, and increases the likelihood that this target is encoded in WM. The purpose of the current study was to account for this counterintuitive difference between distractor intrusions and lag-1 sparing tasks, in order to obtain new insights into the control and temporal limitations of attentional object selection and WM encoding processes in RSVP tasks.

There are two obvious differences between distractor intrusions and lag-1 sparing tasks. First, the first target is either followed by a second target (lag-1 sparing) or by a non-target item (distractor intrusion). Second, observers either have to detect and report two targets (lag-1 sparing) or only a single target (distractor intrusions). Either of these factors could affect the attentional processing and subsequent WM encoding of target objects in these two types of tasks. The nature of the item that follows T1 (T2 or distractor) may be important because targets, unlike distractors, match the currently active task set, resulting in a facilitation of early perceptual processing that is mediated by feature-based attention (Zhang & Luck, 2008). By attracting attention, T2 may effectively act as a retro-cue for T1 (Griffin & Nobre, 2003; Souza & Oberauer, 2016), increasing the probability that T1 is encoded in WM. Although T1 performance in lag-1 sparing tasks is typically lower when T1 (e.g., a digit) is followed by T2 (another digit) rather than by a distractor (a letter; e.g., Olivers et al., 2007), this may be due to the costs of perceptual competition between two successive digits exceeding any potential benefits of retro-cueing. These costs are also present in distractor intrusion tasks when the post-target item matches the target category. However, because targets are defined by an additional attribute (e.g., colour) that is absent for post-target distractors, these distractors cannot act as retro-cues, and this could result in a further reduction of T1 accuracy in these tasks relative to lag-1 sparing tasks. We refer to this possibility as the retro-cue hypothesis.

The number of to-be-reported targets (one versus two) could be important because target-related expectations may modulate the attentional processing and encoding of items in RSVPs. It is generally acknowledged that expectations about the probability of task-relevant features, objects, and events can affect visual selectivity (e.g., Feldman & Friston, 2010; Summerfield & de Lange, 2014). It is therefore plausible to assume that expectations about the number of target objects (quantity expectations) may have similar effects, although this possibility has not yet been investigated systematically. In distractor intrusion tasks, participants expect to find and report only a single target. This may reduce the number of items that are encoded in WM relative to lag-1 sparing tasks, where two targets are presented on every trial. If quantity expectations affect WM encoding, the probability that both T1 and the post-target distractor should be encoded will be lower in distractor intrusion tasks, resulting in reduced T1 accuracy. This expectation-related gating of WM access may be strategic and adaptive in restricting the number of WM representations to those that are likely to be task-relevant. We refer to this possibility as the quantity expectation hypothesis. In contrast to the retro-cue hypothesis, which postulates that differences between distractor intrusion and lag-1 sparing tasks will only affect T1 accuracy, the quantity expectation hypothesis assumes that expecting two instead of a single target should increase the likelihood of being encoded in WM for both T1 and the post-target distractor.

Because distractor intrusions and lag-1 sparing have typically been investigated separately, these alternative possibilities have not yet been tested. One previous study has explored the effects of quantity expectations on target detection in RSVP streams (Visser, 2015). In this study, participants searched for one or two digits (T1 and T2) among letters. When present, T2 appeared at lag-1, and this was the case in either 33% or 67% of trials in any given block. T2 accuracy was substantially reduced in blocks where participants expected a single target relative to two targets. This result is compatible with the quantity expectation hypothesis, and Visser (2015) suggested that expecting two targets extends the temporal window during which items are selectively processed. However, since this study did not measure distractor intrusions (post-target distractors were always letters), and focused exclusively on T2 accuracy during lag-1 sparing and not on T1 reports, it did not address the performance differences between distractor intrusion and lag-1 sparing tasks. Accordingly, it could not attest to the potential role of the post-T1 item (retro-cue hypothesis) or of quantity expectations in producing these differences.

To investigate these questions directly, we used an RSVP task where participants searched for coloured digits among grey letters and digits. In Experiments 1 and 2, two lateral RSVP streams were presented, and trials with a single target and trials with two targets were intermixed (see Figure 1A and 1B). The target(s) were presented with equal probability and unpredictably either in the left or right RSVP stream. The first target digit (T1) was followed by either a second coloured target digit (T2; two-targets trials) or by a grey digit (post-T1 distractor, PTD; single target trials). This procedure combined the critical features of lag-1 sparing and distractor intrusion tasks. Two-targets trials were identical to trials where lag-1 sparing is typically observed in attentional blink experiments. In single-target trials, the PTD always shared the response dimension with the target, as in standard distractor intrusion tasks.

At the end of each trial, two response screens were shown (Figure 1C). Participants had to first report the identity of the first coloured digit, and then the identity of the second coloured digit (if present). They also had the option to report having seen only a single target. The critical manipulation concerned the frequency of one-target and two-targets trials in a given experimental block. Expect 1 blocks contained 75% single-target and 25% two-targets trials, and these probabilities were reversed in Expect 2 blocks (Figure 1D). The target quantity expectations induced in this way were proportional rather than absolute, in contrast to standard lag-1 sparing and distractor intrusion tasks where the number of targets on each trial (two or one) is fixed and therefore certain. This issue is revisited in Experiment 3.

According to the retro-cue hypothesis, the probability that the first coloured digit (T1) will be correctly reported is modulated by whether the post-target item can act as an attentional retro-cue. Because targets were defined by colour, T1 performance should therefore be better on two-targets trials where T1 is immediately followed by another coloured digit (T2) than on single-target trials where it is followed by a grey digit (PTD). This performance benefit for two-targets trials should be present regardless of the expected number of targets. In contrast, according to the quantity expectations hypothesis, T1 accuracy should be higher in Expect 2 as compared to Expect 1 blocks, irrespective of whether the target is followed by a second target or by a distractor. Furthermore, the probability of reporting the post-T1 item should also be higher in Expect 2 blocks, and this should be the case both for T2 reports in two-targets blocks trials and for reports of the PTD in single-target trials.

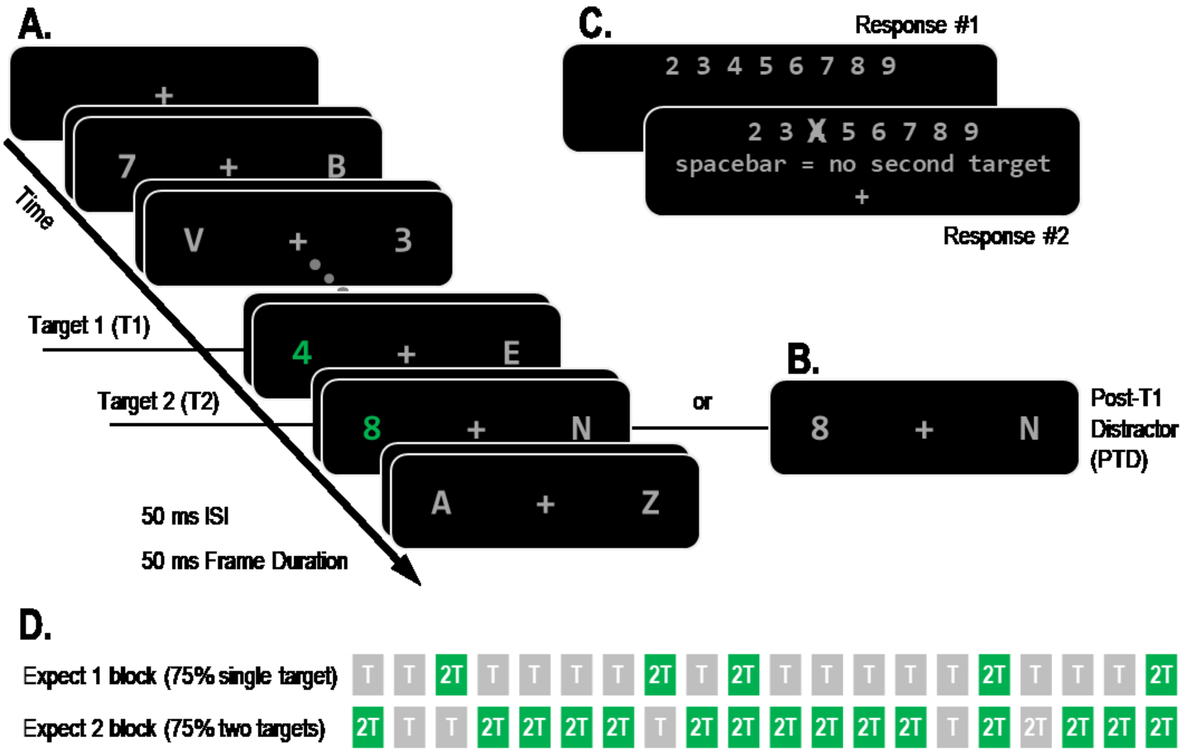

Figure 1. Illustration of the stimulus sequence in Experiments 1-2. Participants had to report the coloured digits (green, orange or blue) in one of two RSVP streams. The first target appeared at positions 5 to 8 within a stream and was followed by three additional frames. At the same location as the target, the immediately following frame contained either a second coloured target digit (A) or a grey distractor digit (B). Participants could either select two digits or press the spacebar on the second response screen to report seeing a single target (C). The ratio of single-target to two-targets trials was 3:1 on expect one-target blocks and 1:3 on expect two-targets blocks (D). The boxes illustrate a random sequence of trials in different blocks. Grey boxes reflect single-target trials and the green boxes reflect two-targets trials.

Experiment 1

Method

Sample Size Selection

The goal of Experiment 1 was to test the effect of the expected number of targets (and the actual number of targets) on accuracy in an RSVP task, and specifically on the likelihood to report T1 in either the first or second response. Since this was the first time that these effects are tested in a within-subject design, we could not estimate the relevant effect sizes and therefore could not use a power analysis to justify our sample size. We therefore treat all the analyses in Experiment 1 as exploratory. The results of this first experiment were used to determine the appropriate sample size for the other two experiments of this study. Importantly, this included Experiment 2, which was a direct replication of Experiment 1. Based on our previous studies with this paradigm (Zivony & Eimer, 2020, 2021a), we used a sample size of N=14 for Experiment 1, which turned out to provide sufficient power to detect the critical effects (see Sample Size Selection in Experiment 2).

Participants

Participants were 14 (8 women) volunteers (*M*age = 27.14, *SD* = 6.89) who participated for a payment of £8. All reported normal or corrected-to-normal visual acuity and normal colour vision. All methods used in this experiment, and subsequent experiments, were approved by the institution's departmental ethical guidelines committee at Birkbeck, University of London.

Apparatus

Stimuli were presented on a 24-inch BenQ monitor (100 Hz; 1920 × 1080 screen resolution) attached to a SilverStone PC, with participant viewing distance at approximately 80 cm. Manual responses were registered via a standard computer keyboard.

Stimuli and design

The sequence of events is illustrated in Figure 1A. Each trial began with the presentation of a fixation display (a grey 0.75°× 0.75° "+" sign at the center of the screen). After 500 ms, two lateral RSVP streams including 8 to 11 frames appeared along with the fixation cross. Frames consisted of two alphanumeric characters (1° in height) appearing at a center-to-center distance of 3.5° to the left and right of fixation. Each frame appeared for 50 ms, followed by an ISI of 50 ms. Distractor in the RSVP streams were grey (CIE colour coordinates: 0.309/.332, luminance 46.6 cd/m^2). Target colour was randomly selected in each trial from a set of three colours: blue (CIE colour coordinates: 0.167/.123), green (.306/.615), or orange (.568/.401). All colours were equiluminant (46.6-47.3 cd/m^2).

On each trial, a coloured target digit (T1) was presented unpredictably in one of the two RSVP streams on the left or right side. T1 was always followed by another digit in the same stream. This post-target digit was either a second target (T2) in the same colour as T1 (Figure 1A) or a grey distractor item (PTD); see Figure 1A and 1B). Digits (including the target and post-target digit distractor) were drawn without replacement from a set of eight digits (2, 3, 4, 5, 6, 7, 8 and 9). Letters in each stream were randomly selected without replacement from a 24-letter set (all English alphabet letters, excluding I and O). T1 appeared with equal probability and unpredictably in the 5th, 6th, 7th, or 8th frame, either in the left or right RSVP stream. This target frame contained one digit and one letter. The frame immediately preceding the target frame always included two letters (to prevent any pre-target intrusion errors). All other pre-target frames were equally likely to contain two letters, or one digit and one letter (with digit and letter location randomly selected for each frame). The T1 frame was always followed by three additional frames. The immediately following frame always contained a digit at the same location as T1 (T2 or PTD) and a letter. The two final frames on each trial always included two letters.

Participants' task was to report the numerical value(s) of the coloured digit(s) in the RSVP stream without time pressure at the end of each trial. They were instructed that when reporting two targets, they should try to report them in the right order. On each trial, two response screens were presented, following the RSVP stream. The first response screen contained all eight possible digits in a row, 4° above fixation, with a center-to-center distance between each digit of 1.6° (Figure 1C). Participants chose a target digit by pressing the corresponding keyboard button. Once the first response choice was registered, the chosen digit was crossed out, and the prompt "spacebar = no second target" appeared 2.5° above fixation. At this point, participants could either choose a second target from the remaining seven digits on the response screen, or press the space bar to indicate that they detected only a single target. Following this second response, a blank screen appeared for 500 ms, after which a new trial began.

The critical manipulation concerned the frequency of single-target and two-targets trials in any given block. In Expect 1 blocks, T1 was followed by a post-target distractor (PTD) on 75% of the trials, and by T2 on 25% of the trials. In Expect 2 blocks, T1 was followed by T2 on 75% of the trials and by PTD on 25% of the trials. Participants were told that single-target or two-targets trials would be more frequent in a given block, but were not informed about the exact proportion of these two types of trials. In all blocks, single-target and two-targets trials were presented in random order.

The experiment consisted of 30 practice trials and 600 experimental trials, divided into twelve 50-trial blocks. Participants were allowed to take self-paced breaks between blocks. Seven of the participants completed six Expect 1 blocks prior to six Expect 2 blocks, and this order was reversed for the other 7 participants. All participants completed 20 practice trials before the first half of the experiment and another 10 practice trials before the second half. They could repeat the practice blocks if they wished. The relative frequency of single-target and two-targets trials for the next phase of the experiment was specified verbally by the experimenter ("mostly one target" or "mostly two targets") before each of the two practice sessions. The experimenter remained in the testing room during practice until participants reported seeing the less frequent number of targets at least once (i.e., one target in Expect 2 blocks and two targets in Expect 1 blocks).

Participants were informed that target digits were equally likely to appear in the left or right RSVP stream, and that task-irrelevant digits would appear prior to the target. This ensured that attentional allocation processes would be guided by the selection feature (colour), rather than by alphanumerical category (i.e., attending to the first digit in the stream).

Results

To test the retro-cue hypothesis, we examined how the identity of the post-T1 item (T2 or PTD) affected T1 accuracy. As can be seen from Figure 2 (left panel), T1 accuracy was not superior on trials where T1 was followed by T2 (red squares) relative to trials where it was followed by PTD (red circles). In fact, T1 accuracy was lower on two-targets than single-target trials. This difference was significant in Expect 1 blocks, $M = 47.2\%$ vs. $M = 61.2\%$, $F(1,13) = 36.98$, $p < .001$, $\eta_p^2 = .74$, but not in Expect 2 blocks, $M = 66.8\%$ vs. $M = 70.0\%$, $F(1,13) = 3.04$, $p = .11$, $\eta_p^2 = .19$.

Importantly, T1 accuracy was higher in Expect 2 as compared to Expect 1 blocks, $M = 68.4\%$ vs. $M = 54.2\%$, $F(1,13) = 29.89$, $p < .001$, $\eta_p^2 = .70$. This quantity expectation effect was reliably present both for two-targets as well as for single-target trials ($p < .001$ and $p = .002$, respectively; Figure 2, left panel). Similarly, expecting two targets also increased the frequency of post-T1 item reports, $M = 82.7\%$ vs. $M = 63.5\%$, $F(1,13) = 25.72$, $p < .001$, $\eta_p^2 = .66$ (Figure 2, middle panel). This was the case both for reports of T2 on two-targets trials (grey squares; $p = .003$) and for PTD reports on single-target trials (grey circles; $p < .001$).

Finally, we examined whether quantity expectations also increased the frequency of guesses, by examining trials where participants reported a digit other than T1, T2, or PTD (Figure 2, right panel). This was indeed the case, with more guesses in Expect 2 relative to Expect 1 blocks, $M = 17.6\%$ vs. $M = 8.1\%$, $F(1,13) = 11.66$, $p = .005$, $\eta_p^2 = .47$. This effect emerged both on single-target and two-targets trials ($p < .001$ and $p = .02$). The full distribution of different types of reports measured for first and second responses is presented in Table 1. The overall frequencies of T1 and post-T1 reports (averaged across one-target and two-targets trials) are shown in Table 2.

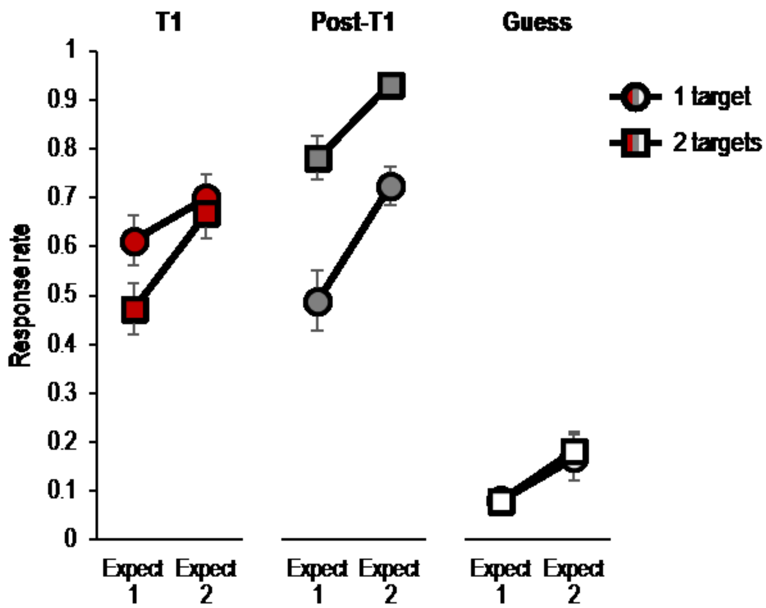

Figure 2. T1 accuracy, post-T1 reports (T2 or PTD), and guesses (i.e., reports of digits other than T1, T2, or PTD) in Experiment 1, as a function of the actual and expected number of targets (Expect 1 vs. Expect 2). In Expect 1 blocks, 75% of trials included single-target RSVPs and 25% of trials included two-targets RSVPs. These ratios were reversed for Expect 2 blocks. The frequency for all reports was combined across both responses.

Table 1*. Frequency of first and second response choice combinations in Experiment 1, for trials with a single target (upper) and two targets (lower), as function of whether participants expected one target (left) or expected two targets (right).*

	EXPECT ONE TARGET					EXPECT TWO TARGETS				
SINGLE TARGET	2nd T1	2nd Intrusion	2nd Guess	No 2nd response	Total	2nd T1	2nd Intrusion	2nd Guess	No 2nd response	Total
1st T1	-	0.07	0.01	0.45	**0.53**	-	0.27	0.03	0.20	**0.50**
1st Intrusion	0.07	-	0.02	0.32	**0.41**	0.19	-	0.07	0.17	**0.43**
1st Guess	0.01	0.01	0.00	0.04	**0.06**	0.01	0.02	0.02	0.02	**0.07**
Total	**0.08**	**0.08**	**0.02**	**0.81**	**1.00**	**0.20**	**0.30**	**0.11**	**0.39**	**1.00**
TWO TARGETS	2nd T1	2nd T2	2nd Guess	No 2nd response	Total	2nd T1	2nd T2	2nd Guess	No 2nd response	Total
1st T1	-	0.16	0.00	0.18	**0.34**	-	0.32	0.01	0.03	**0.36**
1st T2	0.13	-	0.02	0.46	**0.61**	0.30	-	0.10	0.17	**0.57**
1st Guess	0.01	0.02	0.00	0.03	**0.05**	0.01	0.04	0.01	0.01	**0.07**
Total	**0.13**	**0.17**	**0.03**	**0.66**	**1.00**	**0.31**	**0.36**	**0.12**	**0.21**	**1.00**

Note. Marginal totals may not sum to 1.00 as values are rounded to two decimals.

Table 2 *Frequency of T1 and Post-T1 reports on the first and second response in Experiments 1-3.*

CONDITION	T1			POST-T1		
	1st response	**2nd response**	**Total**	**1st response**	**2nd response**	**Total**
Experiment 1						
Expect 1	0.44	0.11	**0.55**	0.51	0.13	**0.54**
Expect 2	0.43	0.25	**0.68**	0.50	0.33	**0.83**
Experiment 2						
Expect 1	0.47	0.15	**0.62**	0.51	0.20	**0.71**
Expect 2	0.49	0.31	**0.80**	0.48	0.41	**0.89**
Experiment 3						
Search 1	0.33	0.27	**0.60**	0.57	0.28	**0.85**
Search 2	0.44	0.37	**0.81**	0.50	0.43	**0.93**

Note. The results were combined across one-target and two-targets trials in Experiments 1-2 (giving both types of trials equal weight in the calculation of average percentages), and across single-stream and two-stream blocks in Experiment 3.

Discussion

Experiment 1 produced two clear results that provide new insights into the factors that are responsible for the different patterns of performance observed in lag-1 sparing and distractor intrusion experiments. First, comparing T1 accuracy on trials where T1 was followed by another coloured target (T2) and on trials where it was followed by a grey post-target distractor (PTD) showed the exact opposite of what the retro-cue hypothesis predicts. Instead of improving T1 performance, the presence of a coloured post-target digit (T2) actually resulted in a general decrease in T1 report accuracy relative to trials with a grey post-target digit. This difference was reliable in Expect 1 but not in Expect 2 blocks. This observation demonstrates that when presented immediately after T1, the second target does not act as a retro-cue that facilitates T1 processing. Instead, the presence of T2 appears to impair the detection of the first target, presumably due to competitive interactions that decrease the strength of the target's sensory representation (Chun, 1997; Dell'Acqua et al., 2012; Potter et al., 2002). While the PTD was always grey, T2 shared T1's colour. This could have resulted in stronger backward masking of T1 by T2 than by the PTD. Thus, the retro-cue hypothesis clearly cannot account for the superior T1 accuracy observed in lag-1 sparing relative to distractor intrusion studies.

In contrast, and critically, the other factor manipulated in Experiment 1 (quantity expectations) had a strong effect on performance, in the predicted direction. Reports of either T1 and the post-T1 item (T2 or PTD) were more frequent in blocks where participants expected two targets relative to blocks where they expected a single target (see Table 2). Importantly, this was the case not only for two-targets trials, but also for trials where only a single target was presented. These findings provide initial evidence that the expected number of targets (one versus two) modulates attentional mechanisms involved in gating access to WM, by increasing or decreasing the probability that two successive items are encoded on any given trial, irrespective of whether the post-T1 item is a target or a distractor.

However, and importantly, this conclusion has to remain tentative. Given the design of Experiment 1, it is entirely possible that these quantity expectation effects on the frequency of T1 and post-T1 reports are unrelated to WM access, but instead can be fully accounted for by differences in response bias. When told to expect mostly single-target trials, participants might have been reluctant to report two different targets, even if they had in fact perceived and encoded both T1 and the post-T1 item. Thus, in Expect 1 blocks, there may have been a strong bias to report the presence of a single target by choosing the space bar option for the second response screen. In Expect 2 blocks, participants may instead have preferred to guess the identity of a second target rather than reporting a single target, even when only a single item was perceived. The frequency of guesses was indeed significantly higher in Expect 2 blocks, indicative of a more liberal response bias. If the willingness to report a single versus two targets was biased as a result of quantity expectations, this could explain why the frequency of both T1 and post-T1 reports was lower in Expect 1 as compared to Expect 2 blocks.

Thus, the critical question is whether the quantity expectation effects observed in Experiment 1 are entirely the result of response bias, or are at least in part reflect the number of items encoded in WM. To answer this question, Experiment 2 used the same procedures as the first experiment, but also measured event-related potential (ERP) markers of attentional object selection (N2pc component) and WM storage (CDA component). As these ERP markers are recorded on-line during visual processing, and prior to response selection, they are unaffected by any differences in response bias, and can therefore provide more direct and objective insights into links between quantity expectations and WM encoding in RSVP tasks.

Experiment 2

To determine whether target quantity expectations have an effect on the number of items that are encoded in WM, Experiment 2 replicated the procedures of Experiment 1, but additionally measured ERP components elicited following the presentation of the target frame. Specifically, we focused on the contralateral delayed activity (CDA), which is an established electrophysiological index of WM storage (see Luria et al., 2016, for review). The CDA is elicited during the delay period of lateralised WM tasks, and reflects an enhanced negativity at posterior electrodes contralateral to the side of to-be-memorized visual items that typically starts around 350 ms after the onset of a memory display. Importantly, because CDA amplitudes increase with the number of memorized items (e.g., Vogel & Machizawa, 2004), the CDA provides an objective measure of how many items are encoded and maintained in WM during a retention interval prior to any subsequent report. While CDA components are typically obtained in match-to-sample WM tasks, they can also be used to assess the WM encoding of one or more items in lateralised RSVP streams. In Experiment 2, we compared CDA amplitudes in Expect 1 and Expect 2 blocks independently of the actual number of targets (one or two) presented in any given trial. If quantity expectations modulate how many items are encoded from RSVP streams, CDA amplitudes should be larger in Expect 2 as compared to Expect 1 blocks. In contrast, if the quantity expectation effects found in Experiment 1 were exclusively the result of response bias, and entirely unrelated to WM encoding, no such CDA amplitude differences between Expect 2 and Expect 1 blocks should be observed.

If quantity expectations affect how many items from the RSVP stream gain access to WM, the question arises which mechanisms may be responsible for such a link between quantity expectations and WM encoding. In our previous work (Zivony & Eimer, 2021a), we have proposed a framework specifying the key components that determine WM encoding in RSVP tasks (as illustrated in Figure 3). The first component is the general assumption that competitive interactions between T1 and the post-T1 item reduce the activation of their sensory representations over time. A second and critical component in this framework is the attentional episode (e.g., Wyble et al., 2009; 2011), the period of exponentially increased activation of sensory representations that is triggered once a target-defining selection feature (e.g., a colour, as in Experiment 1) is detected at a specific location. A third component is a hypothetical activation threshold that determines whether a specific sensory representation is sufficiently activated to gain access to WM. Expectations about the number of targets likely to be encountered in an RSVP stream could affect the timing of the attentional episode, the degree to which processing is amplified during this period, or the threshold for encoding items in WM. As shown in Figure 3, each of these mechanisms would change the probability that the target and the post-target item are encoded.

In RSVP tasks where observers expect a single target (Figure 3A), inhibitory interactions between target and post-target distractor representations can result in the activation level of one of these representations remaining below the encoding threshold, resulting in distractor intrusion errors when the target representation is insufficiently activated. Expecting two instead of just a single target may result in attentional episodes being triggered more rapidly. As a result, the processing of both T1 and the post-T1 item is more strongly amplified during the episode, thereby and increasing the likelihood that both items will cross the encoding threshold (early-onset hypothesis; Figure 3B). Another possibility is that expecting two targets does not affect the onset of the attentional episode, but instead increases the processing amplification during this episode. This will again result in a stronger activation of both representations, and in increased chance that they will be encoded (increased-amplification hypothesis; Figure 3C). Finally, expecting two rather than one target may not modulate the attentional episode at all, but instead lower the activation threshold required for a representation to be encoded, thus again increasing the probability that two items will gain access to WM (encoding-threshold hypothesis; Figure 3D).

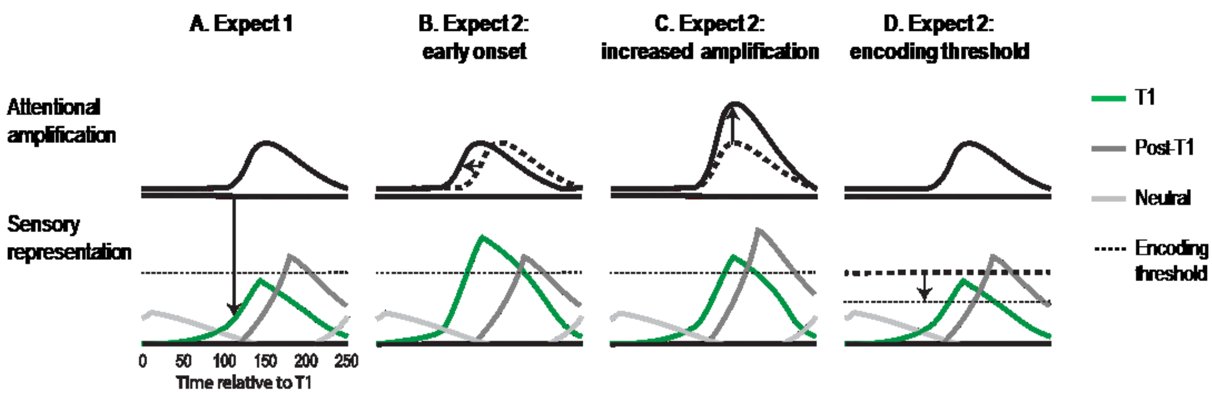

Figure 3. Illustration of the three mechanisms that could mediate the link between quantity expectations and the probability that T1 (green line) and the post-T1 item (dark grey line) will be encoded in WM. The strength of sensory representations accumulates over time but is reduced by perceptual competition from temporally adjacent items. The attentional episode (upper row) exponentially increases the strength of these representations. When participants expect a single target (A), the sensory representation of T1 often falls below the activation threshold required for encoding (thin dotted line), resulting in distractor intrusion errors. Expecting two targets may result in (B) an earlier onset of the attentional episode; (C) increased amplification during this episode; or (D) a lower encoding threshold. In all three cases, this increases the likelihood that both T1 and the post-T1 items will be sufficiently activated to be encoded in WM.

A second goal of Experiment 2 was to distinguish between these three possible mechanisms on the basis of another lateralised ERP component measured during the period following the target frame. Here, we focused on the N2pc component, which is an established ERP marker of the allocation of attention to visual objects with task-relevant features (e.g., Eimer, 1996; Woodman & Luck, 1999). The onset latency of the N2pc can be used to index the speed with which an attentional episode is triggered (Zivony & Eimer, 2021a; see also Foster et al., 2020). We have previously shown that this speed is not constant, but varies across trials. Importantly, an earlier onset of an episode (as indicated by a shorter-latency N2pc) in single-target RSVP streams is associated with more accurate T1 reports and fewer intrusion errors (Zivony & Eimer, 2021a), and with a higher probability that both T1 and the post-T1 distractor are encoded in WM (Zivony & Eimer, 2020). If expecting two rather than a single target results in attentional episodes being triggered earlier (Figure 3B), N2pc components elicited by the target frame should be triggered more rapidly in Expect 2 as compared to Expect 1 blocks. In contrast, if quantity expectations modulate the amount of amplification during an attentional episode (Figure 3C), N2pc onset latencies should not differ between these two types of blocks, but N2pc amplitudes should be larger in Expect 2 blocks. Finally, if these expectations only operate at the level of encoding thresholds without modulating attentional episodes (Figure 3D), any increase in the number of encoded items in Expect 2 blocks (as reflected by larger CDA amplitudes) should not be accompanied by earlier N2pc onsets or larger N2pc amplitudes in these blocks relative to Expect 1 blocks.

Experiment 2

Method

Sample size selection

One goal of Experiment 2 was to replicate the quantity expectation effects on performance observed in Experiment 1, and in particular the quantity expectation effect on T1 accuracy. A power analysis based on the associated effect size found in Experiment 1 (η_p^2 = .70) indicated that 14 participants provide sufficient power to reliably detect this effect. The other main goal of Experiment 2 was to test whether quantity expectations affect CDA amplitudes. As Experiment 1 showed that quantity expectations had an effect on the reported number of target items (one or two), we based our sample size selection on our previous experiment (Zivony & Eimer, 2020, Experiment 4) that measured CDA amplitude differences between trials with single-item and two-item responses, using a similar RSVP paradigm. The mean difference between these two types of trials (*M* = -0.53 μV vs. *M* = -1.04 μV) resulted in an effect size of η_p^2 = .42. Based on these data, we conducted the power analysis with G*Power (Faul et al., 2013), using an alpha of .05, and power of .80. The power analysis revealed that the minimum sample size required to obtain a reliable effect on CDA amplitudes was 14 participants.

Participants

Overall, 18 volunteers participated in the experiment for £25. All reported normal or corrected-to-normal visual acuity and normal colour vision. Four participants were excluded from all analysis because of excessive eye movement and eye blinks that resulted in rejection of more than 35% of their EEG data. The mean age of the remaining 14 participants (8 women) was 28.2 years (*SD* = 6.51).

Apparatus, stimuli, design, and analysis of behavioural data.

The apparatus, stimuli and design were identical to Experiment 1, except for the following changes. To enable the measurement of CDA components during the retention phase and prior to response selection and execution, the first response screen that followed the RSVP streams was preceded by a fixation display that was presented for 500 ms. Behavioural data were analysed in the same way as in Experiment 1.

EEG Recordings

EEG was DC-recorded from 27 scalp electrodes, mounted on an elastic cap at sites Fpz, F7, F8, F3, F4, Fz, FC5, FC6, T7, T8, C3, C4, Cz, CP5, CP6, P9, P10, P7, P8, P3, P4, Pz, PO7, PO8, PO9, PO10, and Oz. A 500-Hz sampling rate with a 40 Hz low-pass filter was applied. The horizontal electrooculogram (HEOG) was calculated offline as the voltage difference between electrodes lateral to the external canthi of the left and right eye, and was used to measure horizontal eye movements. Channels were referenced online to a left-earlobe electrode, and re-referenced offline to an average of both earlobes. No other filters were applied after EEG acquisition. Due to the COVID-19 pandemic, we adopted a protocol that reduced the contact time between experimenter and participant in the experiment room. Therefore, electrode impedance in all electrodes was kept <10 kO (instead of <5 kO, which is standard in our lab). Given this change, the criterion for detecting horizontal eye movements was defined as activity in trials where the voltage difference between the two HEOG channels exceeded ±40 µV (instead of ±30 µV, which is standard in our lab). Trials with horizontal eye movements, eye blinks (exceeding ±60 µV at Fpz), and muscle movement artefacts (exceeding ±80 µV at all other channels) were removed as artefacts.

EEG Analyses

N2pc and CDA components were computed on the basis of averaging EEG epochs starting 100 ms prior to the onset of the target frame and ending 800 ms after frame onset. The average loss of epochs due to artefacts prior to averaging was 16.0% (*SD* = 10.4%). All ERPs were averaged relative to a 100 ms pre-stimulus baseline. Averaged ERP waveforms were computed separately for trials with a target in the left or right RSVP stream, in order to compare ERPs at electrodes PO7/PO8 contralateral and ipsilateral to the location of the target.

The main analyses compared N2pc and CDA components recorded in Expect 1 and Expect 2 blocks, which differed in the number of targets presented on the majority of trials (one or two). Since our goal was no assess the effects of quantity expectations on these components, independently of the actual number of targets presented on any given trial, all averaged waveforms were based on 75 randomly selected trials that contained the expected number of targets (e.g., single-target trials in Expect 1 blocks) and on all 75 trials that contained the unexpected number of targets (e.g., two-targets trials in Expect 1 blocks). ERPs for single-target and two-targets trials were collapsed and then averaged, separately for Expect 1 and Expect 2 blocks.[1]

In line with our previous study (Zivony & Eimer, 2020), the analysis window for CDA mean amplitudes was 400-800 ms after target frame onset. While shorter than the CDA window used in some other studies, this window prevents any overlap of the CDA time window with the preceding N2pc component, while minimizing data loss due to artefact rejection. CDA amplitude was defined as the mean amplitude of difference waveforms computed by subtracting ERPs at PO7/8 ipsilateral to the target from contralateral ERPs. Because CDAs are reflected by negative amplitude values (i.e., contralateral negativities) in these difference waves, one-tailed t-tests against zero were used to assess the presence of CDA components in Expect 1 and Expect 2 blocks.

N2pc mean amplitudes were based on ipsilateral-contralateral difference waveforms in the 200–300 ms time window after the onset of the target frame (e.g., Kiss et al., 2008; Zivony & Eimer, 2020; 2021a). As in our previous studies, N2pc onset latencies were calculated on the basis of contralateral-ipsilateral difference waveforms, following an application of a 10Hz low pass filter. We employed the jackknife procedure described by Miller et al. (1998), with the N2pc onset criterion defined as the point where the difference waveform reached 50% of the

[1] For each averaged waveform, the number of single-target and two-targets trials was equal prior to artefact rejection (75:75), but not necessarily after artefact rejection. For example, if eye movement artefacts were more common on two-targets trials, these trials would contribute less to the averaged ERP than single-target trials. To ensure that this did not skew any of the results, all N2pc and CDA analyses were repeated by first computing separate ERPs for single-target and two-targets trials, and then averaging these two ERPs, so that both types of trials contributed equally to the resulting N2pc and CDA waveforms. There were no differences between the results of these additional analysis and the results reported below.

average N2pc peak amplitude (averaged across trials with correct responses and distractor intrusion trials, and measured within a 150-300 ms post-target interval). A relative onset criterion was used to avoid any distortions due to N2pc amplitude differences (Zivony & Eimer, 2021a; see also Grubert & Eimer, 2015; Grubert et al., 2011, for similar procedures). In statistical analyses of N2pc onset latency differences, *F* scores were corrected according to the formula provided by Ulrich and Miller (2001). Analogous to Zivony and Eimer (2020; 2021a), we also compared N2pc amplitudes and onset latencies between trials where participants first reported T1 and trials where they first reported the post-T1 item. For this analysis that focused exclusively on the N2pc, shorter epochs were used (from 100 ms before to 500 ms after frame target onset). The average loss of epochs due to artefacts prior to averaging was 6.5% (SD = 6.8%).

To ensure that small eye movements that were undetected by artefact rejection did not create any systematic differences between Expect 1 trials and Expect 2 blocks, we analyzed HEOG data obtained after artefact rejection in the N2pc time range (200-300 ms) and CDA time range (400-800 ms). For each participant and condition, we computed the averaged amplitude difference between HEOG electrodes ipsilateral versus contralateral to side of the target, such that positive values reflect a residual average tendency for an eye gaze deviation towards the target. Average HEOG differences during the N2pc time window were 0.87 µV for Expect 1 blocks and 0.72 µV for Expect 2 blocks. For the CDA time window, the respective values were 1.67 µV and 1.42 µV (reflecting an average eye gaze deviation of less than 0.1° for both trial types, Lins et al., 1993). Critically, HEOG deviations in Expect 1 and Expect 2 blocks did not differ significantly in the N2pc time period, $t(13) = 1.03$, $p = .33$, $d = 0.08$, or the CDA time period, $t(13) = 1.39$, $p = .19$, $d = 0.12$.

Statistical analysis of null results

Evaluation of the different hypotheses tested in this experiment includes the interpretation of null results, in particular for the N2pc component. Since the absence of a significant effect does not itself constitute evidence for the null hypothesis, statistical tests with non-significant results for N2pc onset latencies and mean amplitudes were supplemented, when possible, with a corresponding calculation of a Bayes Factor in favour of the null hypothesis (BF_{01}). All tests were conducted using JASP (0.9.2). Bayes Factors associated with a two-way interaction were calculated by dividing two Bayes Factors: (*i*) the Bayes Factor associated with the full model (including the interaction and both main effects), and (*ii*) the Bayes Factor associated with the model that includes only the two main effects (Wagenmakers et al., 2018). Bayes Factors associated with a main effect in a two-way design were isolated by dividing the model with both main effects and the model with the irrelevant main effect. Since Ulrich and Miller's (2001) correction for jackknifed N2pc onset latency data only applies to frequentist statistics, we applied the adjustment described by Smulders (2010) to retrieve an estimate of individual N2pc onset latencies from jackknifed ERPs, and used these data for the Bayesian analysis. Following Dienes and Mclatchie (2018), we consider a BF10 to provide evidence for the null hypothesis if it smaller than 0.33 (i.e., BF01 > 3). Since we had no a-priori expectations regarding these effects, we used default priors for all of these tests ($r_A = 0.5$).

Results

Behavioral results

The behavioral results fully replicated those of Experiment 1[2]. The full response distribution is reported in Table 3, and the total number of T1 and post-T2 reports are shown in Table 2. Expecting two targets as compared to a single target increased the frequency of T1 reports [Figure 4, left panel, M = 80.0% vs. M = 61.7%, $F(1,13) = 28.73$, $p < .001$, $\eta_p^2 = .69$], T2 reports [Figure 4, middle panel, grey squares, M = 95.5% vs. M = 84.2%, $F(1,13) = 11.13$, $p = .005$, $\eta_p^2 = .46$], and post-T1 distractors [Figure 4, middle panel, grey circles, M = 82.3% vs. M = 58.8%, $F(1,13) = 34.60$, $p < .005$, $\eta_p^2 = .73$].. Guesses (reports of a digit other than T1, T2, or PTD; Figure 4, right panel) were also more frequent in Expect 2 relative to Expect 1 blocks, M = 10.2% vs. M = 4.1%, $F(1,13) = 9.02$, $p = .01$, $\eta_p^2 = .41$. These effects were all reliably present both on single-target and two-targets trials (all ps < .02).

[2] The combined sample from Experiments 1 and 2 allowed us to examine whether quantity expectations effects are modulated by the order of block presentation (Expect 1 first vs. Expect 2 first). For this analysis, we collapsed the data across single-target and two-targets trials. Block order modulated quantity expectation effects on T1 accuracy, $F(1,26) = 5.98$, $p = .022$, $\eta_p^2 = .19$. These effects were larger for participants that started with Expect 1 blocks, M = 79.4% vs. M = 58.3% for Expect 2 as compared to Expect 1 blocks, than for participants who completed Expect 2 blocks first, M = 69.0% vs. M = 57.6%, but was significant in both cases ($p < .001$ and $p = .004$, respectively). Block order did not modulate quantity expectation effects on post-T1 reports or on guesses, both ps > .05.

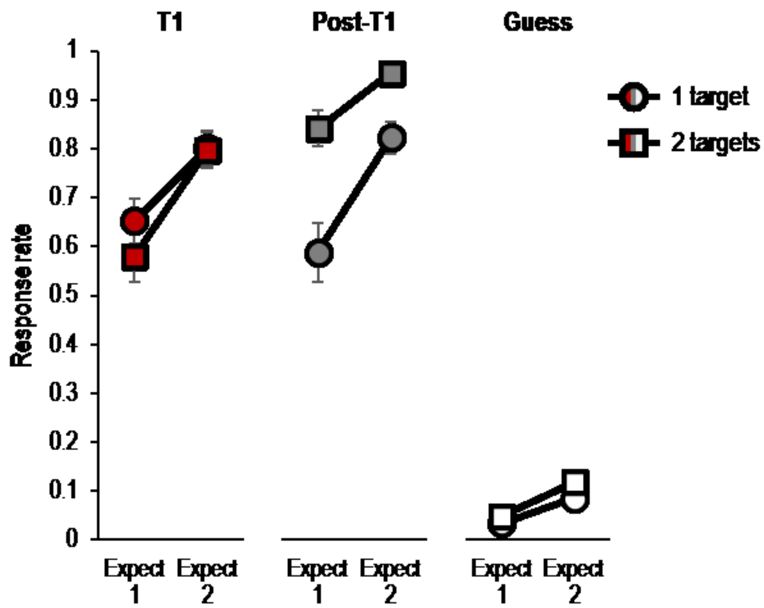

Figure 4. T1 accuracy, post-T1 reports (T2 or PTD), and guesses (i.e., reports of digits other than T1 or the post-T1 item) in Experiment 2, as a function of the actual and expected number of targets (Expect 1 vs. Expect 2). In Expect 1 blocks, 75% of trials included single-target RSVPs and 25% of trials included two-targets RSVPs. These ratios were reversed for Expect 2 blocks. The frequency for all reports was combined across both responses.

Table 3. *Frequency of first and second response choice combinations in Experiment 2, for trials with a single target (upper) and two targets (lower), as function of whether participants expected one target (left) or expected two targets (right).*

	EXPECT ONE TARGET					EXPECT TWO TARGETS				
SINGLE TARGET	**2nd T1**	**2nd Intrusion**	**2nd Guess**	**No 2nd response**	**Total**	**2nd T1**	**2nd Intrusion**	**2nd Guess**	**No 2nd response**	**Total**
1st T1	-	0.15	0.01	0.39	**0.54**	-	0.37	0.03	0.13	**0.53**
1st Intrusion	0.11	-	0.01	0.32	**0.44**	0.26	-	0.03	0.15	**0.44**
1st Guess	0.00	0.00	0.00	0.01	**0.02**	0.01	0.01	0.00	0.00	**0.03**
Total	**0.11**	**0.15**	**0.01**	**0.73**	**1.00**	**0.27**	**0.38**	**0.06**	**0.29**	**1.00**
TWO TARGETS	**2nd T1**	**2nd T2**	**2nd Guess**	**No 2nd response**	**Total**	**2nd T1**	**2nd T2**	**2nd Guess**	**No 2nd response**	**Total**
1st T1	-	0.25	0.01	0.14	**0.40**	-	0.42	0.02	0.01	**0.45**
1st T2	0.18	-	0.02	0.38	**0.58**	0.34	-	0.06	0.11	**0.51**
1st Guess	0.00	0.01	0.00	0.01	**0.02**	0.01	0.03	0.00	0.00	**0.04**
Total	**0.19**	**0.26**	**0.03**	**0.53**	**1.00**	**0.35**	**0.45**	**0.08**	**0.13**	**1.00**

Note. Marginal totals may not sum to 1.00 as values are rounded to two decimals.

Electrophysiology

Quantity expectation effects on N2pc and CDA components. Figure 5A shows ERP waveforms triggered in the 800 ms interval after target frame onset at electrodes PO7 and PO8 contralateral and ipsilateral to this frame, separately for Expect 1 and Expect 2 blocks. The corresponding difference waves obtained by subtracting ipsilateral from contralateral ERPs are shown in Figure 5B. Clear N2pc components were followed by clear CDA components on both types of trials. Notably, the amplitudes of both components were larger in Expect 2 as compared to Expect 1 blocks.

N2pc mean amplitudes measured in the 200-300 ms post-target time window were significantly different from zero both in Expect 2 and in Expect 1 blocks, both *p*s < .001. Critically, mean N2pc amplitudes were significantly larger in Expect 2 blocks, M = -2.91 µV vs. M = -2.40 µV, $t(13) = 2.63$, $p = .022$, $d = 0.70$. In contrast, N2pc onset latencies did not differ reliably between Expect 2 and Expect 1 blocks, M = 187.1 ms vs. M = 190.7 ms, $F_{adjusted} < 1$, $BF_{01} = 3.23$. CDA mean amplitudes measured in the 400–800 ms post-target time window were significantly different from zero in Expect 2 blocks and also in Expect 1 blocks, $p = .004$ and $p < .001$, respectively. Crucially, CDA amplitudes were significantly larger in Expect 2 blocks relative to Expect 1 blocks, M = -1.99 µV vs. M = -1.56 µV, $t(13) = 2.88$, $p = .014$, $d = 0.77$.

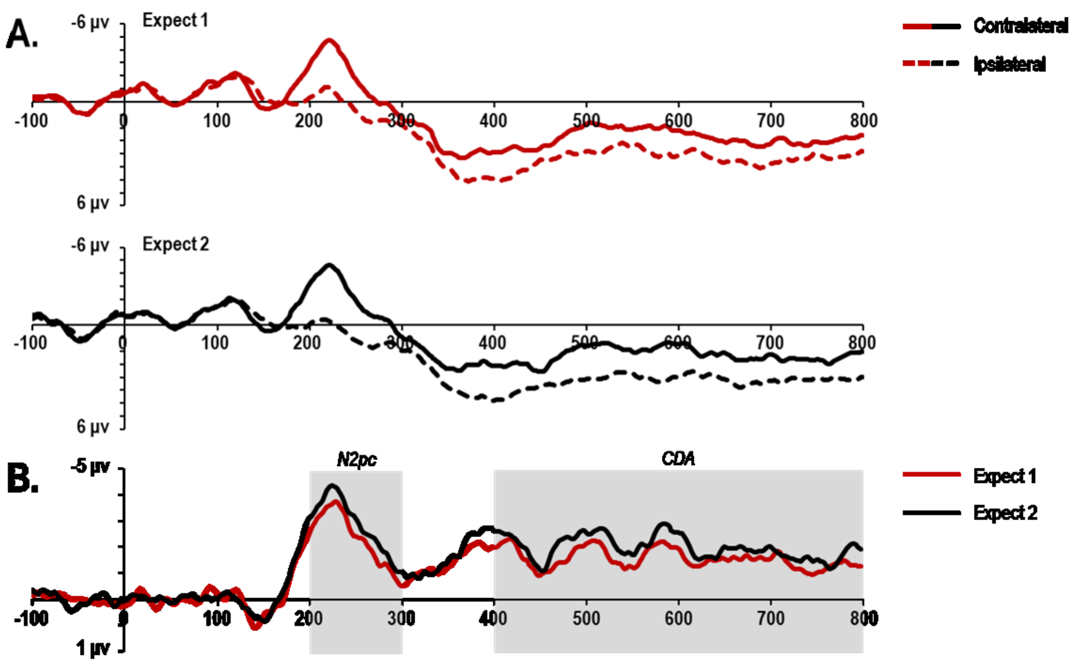

Figure 5. Grand-average event-related potentials (ERPs) waveforms on electrodes PO7/PO8 elicited in Experiment 2 by target frames, shown separately for Expect 1 blocks (red lines) and Expect 2 blocks (black lines). A: Waveforms recorded at electrodes contralateral and ipsilateral to the target. B: Difference waveforms obtained by subtracting ipsilateral from contralateral ERPs. The N2pc time window (200-300 ms) and CDA time window (400-800 ms) are marked in grey.

N2pc components on trials where T1 or the post-T1 item was first reported. Figure 6A shows ERP waveforms obtained in the 500 ms interval after target frame onset at PO7/8 contralateral and ipsilateral to the target frame, separately for trials where the first reported item was T1 or the post-T1 digit. The corresponding difference waves obtained by subtracting ipsilateral from contralateral ERPs are shown in Figure 6B. These ERPs were collapsed across Expect 1 and Expect 2 blocks, and also across single-target trials (where the post-T1 item was a distractor; PTD) and two-targets trials (where the post-T1 item was T2). However, N2pc onset latencies and N2pc mean amplitudes measured in the 200-300 ms time window after target frame onset were computed separately for these two types of trials. As can be seen in Figure 6, N2pc components emerged earlier on trials when the first reported item was T1 relative to trials where the item following T1 was reported first. An ANOVA of N2pc onset latencies with the factors first report (T1, post-T1 item) and trial type (single-target, two-targets) revealed a main effect of first report, reflecting an earlier N2pc onset on trials where participants reported T1 first relative to trials where participants reported the post-T1 item, $M = 185.7$ ms vs. $M = 191.3$ ms, $F_{adjusted}(13) = 10.51$, $p = .006$. There was no main effect of trial type, $F_{adjusted} < 1$, $BF_{01} = 3.60$, and, critically, no interaction between the two factors, $F_{adjusted} < 1$, $BF_{01} = 2.79$, demonstrating that the N2pc delay for trials where the post-T1 item was reported first was present regardless of whether this item was a PTD (intrusion error) or T2 (order reversal). In contrast, N2pc mean amplitudes did not differ significantly between trials with T1 and post-T1 first reports, $M = -2.69$ µV vs. $M = -2.75$ µV, $F < 1$, $BF_{01} = 3.33$, and there was also no main effect of trial type and no interaction between both factors, both Fs < 1 ($BF_{01} = 3.55$ and $BF_{01} = 2.83$, respectively).

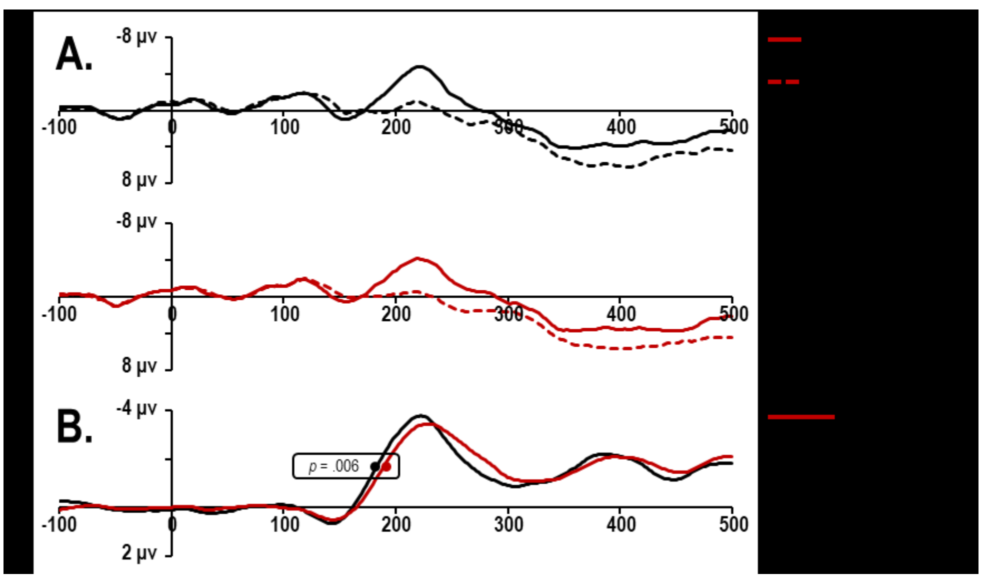

Figure 6. Grand-average event-related potentials (ERPs) waveforms on electrodes PO7/PO8 elicited in Experiment 2 by target frames, shown separately for trials where participants reported either T1 (black lines) or the post-T1 item on their first response (red lines). A) Waveforms recorded at electrodes contralateral and ipsilateral to the target. B) N2pc difference waveforms obtained by subtracting ipsilateral from contralateral ERPs. N2pc onset latencies are indicated by dots. In line with the N2pc onset analyses, a 10 Hz low-pass filter was applied to these waveforms.

Discussion

The results of Experiment 2 provide further support for the hypothesis that quantity expectations affect WM encoding. The behavioural results fully replicated those of Experiment 1. An increase in the expected number of target (from one to two) resulted in higher T1 accuracy, more post-T1 reports, but also in more guesses. As these differences could in principle be exclusively the result of a more liberal response bias in Expect 2 blocks, the CDA results obtained in Experiment 2 are critical. There was a clear effect of quantity expectations on CDA amplitudes, which were significantly larger in Expect 2 relative to Expect 1 blocks. As the CDA is an objective on-line marker of WM encoding that is unaffected by any difference in response bias between these two types of blocks, these results suggest that the behavioural effects of quantity expectations observed in Experiments 1 and 2 do not solely reflect a response bias in favour of reporting the expected number of targets. Instead, the behavioural results reflect, at least in part, the result of a systematic difference in the number of items that gain access to WM in Expect 2 as compared to Expect 1 blocks.

As these CDA results demonstrate the existence of a link between quantity expectations and WM encoding, the question is which of the three mechanisms outlined earlier (see Figure 3) may be responsible for this link. The N2pc results observed in Experiment 2 provide some important clues. First, we found evidence against the hypothesis that expecting two targets as compared to a single target was associated with an earlier emergence of N2pc components. The absence of any N2pc onset latency difference between Expect 1 and Expect 2 blocks, which was also substantiated by the corresponding Bayes Factor, indicates that attentional episodes were not triggered more rapidly in blocks where two targets were expected, as postulated by the early-onset hypothesis (Figure 3B). The lack of an N2pc onset difference between Expect 1 and Expect

2 blocks contrasts with the presence of a small yet reliable N2pc latency differences between trials where T1 versus the post-T1 item was first reported. This result is in line with our previous finding that N2pc components emerge earlier on trials with correct T1 reports relative to trials with distractor intrusion errors (Zivony & Eimer, 2020; 2021a), and that there was considerable variation in the speed of attentional episodes in Experiment 2. Yet, this variability was unrelated to quantity expectations, thus leading to the conclusion that the early-onset hypothesis cannot explain the link between these expectations and WM encoding. This conclusion is further supported by the observation that the probability that T1 was reported first was not affected by quantity expectations in either Experiment 1 or 2 (see Table 2). Across both experiments, these probabilities were 46.0% in Expect 2 and 45.2% in Expect 1 blocks, respectively, $F < 1$ (BF_{01} = 4.45). If attentional episodes had been triggered more rapidly in Expect 2 blocks, this should have been reflected by a substantial increase in the frequency of these reports (Hilkenmeier et al., 2012; Zivony & Eimer, 2021a).

In contrast to the absence of N2pc onset differences between Expect 1 and Expect 2 blocks, there were clear differences in amplitudes, with N2pc components being larger when two targets were expected. This is in line with the increased-amplification hypothesis, which postulates that quantity expectations modulate the degree of processing amplification during an attentional episode (Figure 3C). The presence of expectation-related N2pc amplitude differences in Experiment 2 is not necessarily inconsistent with the encoding-threshold hypothesis (Figure 3D), as a lower threshold in Expect 2 blocks could have contributed to the increase in the number of items encoded in these blocks. It does however suggest that encoding thresholds are not the only factor responsible for quantity expectation effects on WM encoding, but that modulations of sensory processing during attentional episodes are also involved. These modulations increase the strength of sensory representations of T1 and the post-T1 item in an indiscriminate fashion (Zivony & Eimer, 2021a), which can explain why quantity expectation effects increase the probability of post-T1 reports both for T2 on two-targets trials and for the PTD on single-target trials.

Experiment 3

The first two experiments suggest that quantity expectations affect WM encoding in an RSVP task. However, the task settings in these experiments differed in several aspects from the typical tasks that have previously been used to study lag-1 sparing and distractor intrusion effects. The goal of Experiment 3 was to test whether analogous effects can also be observed under conditions that are more similar to these earlier studies. Moreover, although the reliable effect of quantity expectations on CDA amplitudes of Experiment 2 suggest that response bias cannot fully account for performance differences between these two types of blocks, the size of this effect was relatively small. For this reason, Experiment 3 was designed to obtain converging behavioural evidence from a task that better controls for response bias.

In Experiments 1 and 2, participants were informed about the likelihood of single-target and two-targets trials, but remained uncertain about whether one of two targets would be presented on any given trial. In contrast, the number of targets is always fixed and therefore certain in standard distractor intrusion tasks (one target) and lag-1 sparing tasks (two targets). The fact that participants had the choice to report either one or two targets on any given trial also differs from standard attentional blink tasks where participants always have to provide two separate reports for T1 and T2 (e.g., Hommel & Akyürek, 2005; Potter et al., 2002; Goodbourn et al., 2016). As discussed above, this is likely to differentially affect response bias in Expect 1 and Expect 2 blocks and can heavily skew the behavioural estimates of the magnitude of quantity expectation effects. In the first two experiments, target items appeared unpredictably in one of two lateral RSVP streams, while a single central RSVP stream presented at fixation was used in most (but not all) previous distractor intrusion and lag-1 sparing experiments. Spatial certainty is a key factor in determining the ability to detect and report of masked targets (e.g., Enns & Di Lollo, 1997), and this may explain why Visser (2015), who used a single RSVP stream, found quantity expectation effects on T2 reports, but not on T1 reports. It is thus important to determine whether expectations about the number of targets affect WM encoding similarly in single-stream and dual-stream RSVP tasks. Finally, the colour of the post-T1 item differed on single-target and two-targets trials, and Expect 1 versus Expect 2 blocks differed in the relative number of these two types of trials. This might have resulted in explicit or implicit statistical learning about the probability of target colour repetitions in RSVP streams, which could have differentially affected performance in Expect 1 and Expect 2 blocks, independently of any quantity expectation effects.

Experiment 3 was designed to address all of these issues. Stimulus parameters and task instructions were changed relative to the first two experiments, to make them more similar to those used in typical lag-1 sparing and distractor intrusion studies. Each trial contained two successively presented coloured digits, to eliminate any colour differences between one-target and two-targets trials. The presence of two coloured items on all trials also required a change in task instructions. Participants were now instructed to report either the first coloured digit or both coloured digits (Search 1 and Search 2 tasks). These two tasks were presented in successive blocks, with task order counterbalanced across participants. Thus, and in contrast to Experiments 1 and 2, there was now certainty about the number of targets (one or two) in any given block, as in typical distractor intrusion and lag-1 sparing tasks. To eliminate any differential response bias induced in these two tasks from affecting performance, the option to provide only a single target report was removed. On each trial, participants now had to provide two successive reports. In the Search 1 task, they were told to provide two guesses about the target's identity, to maximize their performance. Therefore, participants in the Search 1 task should have no motivation to report only one of the two coloured digits when they perceived both of them. Finally, the Search 1 and Search 2 tasks were either performed with a single central RSVP stream or two lateral streams, to test whether any effects of quantity expectations on target reports differed as a function of the number of RSVP streams. No EEG was recorded in Experiment 3.

The critical question was whether searching for two as compared to just a single target would increase the number of items encoded in WM, as reflected by performance measures. Analogous to Experiments 1 and 2, this should again be reflected in a larger percentage of T1 and post-T1 items being reported in the Search 2 task relative to the Search 1 task. In addition, if fewer items are encoded under Search 1 instructions, this should specifically affect the second response. Relative to the Search 2 task, these responses should contain a larger number of random guesses (i.e., neither T1 nor PTD reports).

Because participants completed the Search 1 task prior to the Search 2 task, or vice versa, it is possible that strategic carry-over effects will influence performance in the second half of Experiment 3 (unlike in Experiments 1 and 2, where no such carry-over effects were present, see footnote 2). Specifically, participants who start with the Search 2 task might learn that searching for two items is strategically beneficial as it maximizes accuracy, and therefore adopt the same strategy in the Search 1 task, even when they are explicitly told to search for a single target. In contrast, participants who start with the Search 1 task should switch strategies from single-target to two-targets search in the second half of the experiment. Clear evidence for such a differential carry-over effect was indeed found (see below), and we therefore exclusively focus on performance in the first half of Experiment 1, with task (Search 1 or Search 2) as a between-participant factor.

Method

Sample size selection. As all trials in Experiment 3 included two coloured digits, we based our sample size calculation on two-targets trials in Experiments 1 and 2 and examined the effect of quantity expectations (Expect 1 versus Expect 2 blocks) on T1 accuracy, M = 51.63%, SD = 20.1% vs. M = 73.33%, SD = 17.64%. However, since the order in which the two tasks were presented was expected to substantially modulate quantity expectation effects, analyses were restricted to performance in the first half of Experiment 3, and focused on comparing reports between the group of participants who performed the Search 1 task first and participants who started with Search 2. Because this is a between-participants comparison, we treated the data from Expect 1 and Expect 2 blocks in Experiments 1 and 2 that were used for sample size estimation as if it came from two different groups, and calculated the between-subject effect size, d = 1.10. Based on these data, we calculated the sample size required to observe a significant effect using G*Power (Faul et al., 2013), with an alpha of .05 and power of .80. The minimum sample size was 22 (11 starting with Search 1 and 11 with Search 2).

Participants

Participants were 22 (14 women) volunteers (Mage = 26.59, SD = 6.19) who participated for a payment of £5. All reported normal or corrected-to-normal visual acuity and normal colour vision.

Apparatus, stimuli and design

The apparatus, stimuli and design were identical to Experiment 1 except for the following changes. The first target was always followed by another coloured digit of the same colour. Participants completed 320 experimental trials divided to 8 blocks of 40 trials each. At the beginning of this experiment, participants were told that there would be two coloured digits on each trial. However, unlike in Experiments 1 and 2 (where each block contained a mix of single-target and two-targets trials), the experimenter did not check that participants could differentiate between the two digits by the end of the practice session. In four successive blocks, the task was to search for the "*first coloured digit"* (Search 1 task). Nevertheless, participants provided two unique guesses on each trial and were asked to use these responses in order to maximize their accuracy, while aiming to report the target on the first response. Thus, unlike Experiments 1 and 2, participants could not press the spacebar to indicate that they only saw one target. In the other four successive blocks, the task was to search for "*two coloured digits*" (Search 2 task). Here, participants were asked to report the targets in their order of presentation if possible. The instruction to search for the first coloured digit or two coloured digits was repeated after every block. The full instructions given to participants are included in the Supplementary File. The task was switched after 4 blocks and the task-order (Search 1 first vs. Search 2 first) was counterbalanced between subjects. Participants searched for the target or targets in either two RSVP streams (Figure 7A) or a single RSVP stream (Figure 7B). The number of streams changed every block, and the number of streams on the first block was counterbalanced between subjects.

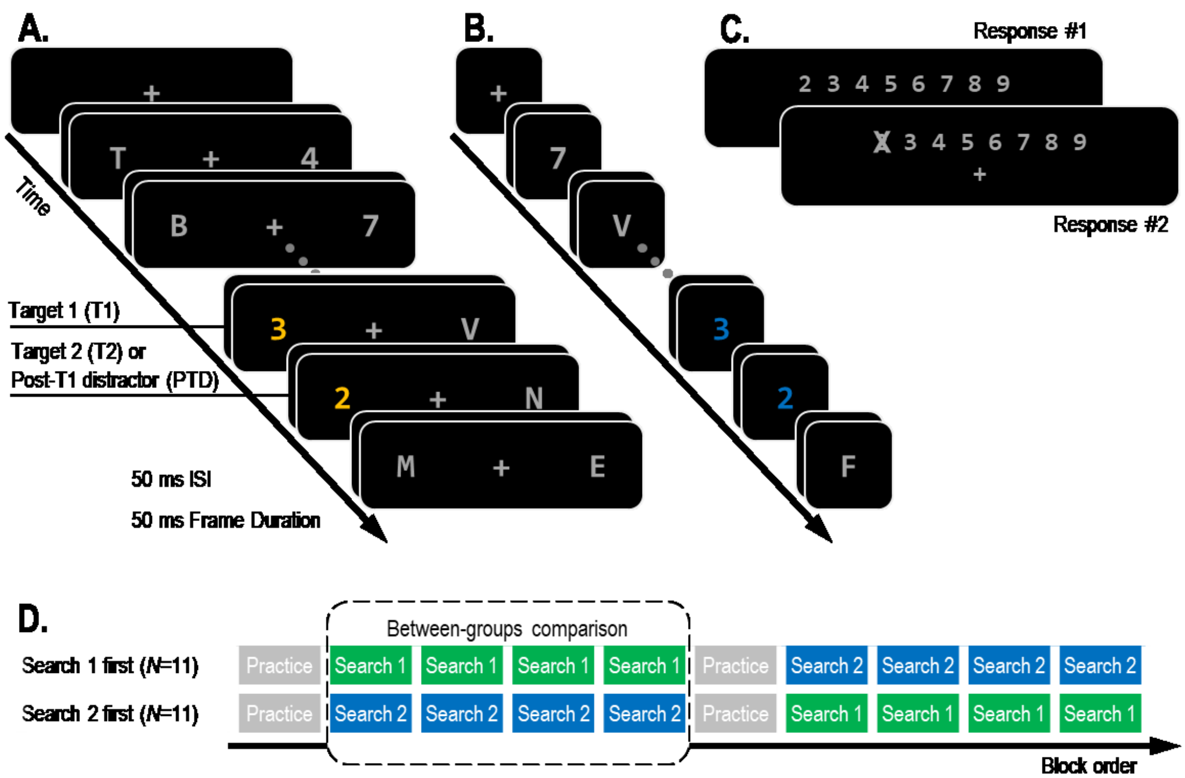

Figure 7. Illustration of the stimulus sequence in Experiments 3. Participants had to report the identity of either the first coloured digit (Search 1 task) or both coloured digits (Search 2 task) digits that appeared in either two RSVP streams (A) or a single RSVP stream (B). Participants always provided two successive reports in both tasks (C). In the example shown here, the first response was "2", which was crossed out in the second response screen. (D) Half of the participants completed four blocks of the Search 1 task, followed by four blocks of the Search 2 task. This order was switched for the rest of the participants. The main analysis was a between-groups comparison of performance in the two tasks during the first half of the experiment.

Results

Preliminary analysis conducted across both halves of the experiment revealed that as expected, the order of task presentation (Search 1 first vs. Search 2 first) substantially modulated target quantity expectation effects. These effects emerged only for participants that started with the Search 1 task, and not for participants who completed the Search 2 task first. The analysis of the data set for both experimental halves, including the effect of block order, is presented in full in the Supplementary File. This effect of block order is likely the result of both unspecific practice effects (resulting in better performance in the second half of the experiment) and a transfer of task strategies learned in the first part of the experiment to the second part (see above). To exclude such practice and transfer effects, we eliminated data obtained in the second half of the experiment from all analyses, and only retained the results from the first half, with task (Search 1 versus Search 2) as a between-participants variable.

T1 accuracy (Figure 8, left panel) was higher for participants who searched for two targets than for those who searched for a single target, M = 80.4% vs M = 60.3%, $F(1,20) = 6.15$, p = .02, $\eta_p^2 = .24$. Searching for two targets also increased the likelihood that the post-T1 item was reported (Figure 8, middle panel), although this effect did not reach statistical significance, M = 89.7% vs M = 81.0%, $F(1,20) = 4.03$, $p = .058$, $\eta_p^2 = .17$. In marked contrast to the effects of quantity expectations on guesses in Experiments 1 and 2, the frequency of reporting items other than T1, T2, or PTD was much lower for participants who searched for two targets relative to those who searched for a single target (Figure 8, right panel), M = 25.0% vs. M = 50.9%, $F(1,13)$ = 11.66, $p = .005$, $\eta_p^2 = .47$. The full distribution of all combinations of first and second response choices is presented in Table 4. This table shows that reports of items other than T1, T2, and the PTD (guesses) were not only more frequent for participants in the Search 1 task, but occurred much more often for their second response choice (44.5% as compared to only 20.5% for participants in the Search 1 task; $t(20) = 2.60$, $p = .017$, $d = 1.11$). In contrast, the frequency of guesses on the first response did not differ between participants in the Search 1 and Search 2 tasks (9.5% versus 6.5%; t <1).

Figure 8 also shows that presenting a single as compared to two RSVP streams increased T1 accuracy, M = 76.9% vs. M = 63.9%, $F(1,20) = 40.30$, $p < .001$, $\eta_p^2 = .67$, reduced the number of guesses, $M = 32.0\%$ vs. $M = 43.9\%$, $F(1,20) = 7.78$, $p = .011$, $\eta_p^2 = .28$, but had no effect on T2 accuracy, $M = 85.5\%$ vs. $M = 85.2\%$, $F < 1$. However, the number of RSVP streams did not modulate any of the effects of task instructions (Search 1 versus Search 2) on T1 reports, post-T1 reports, and guesses, all *p*s > .20.

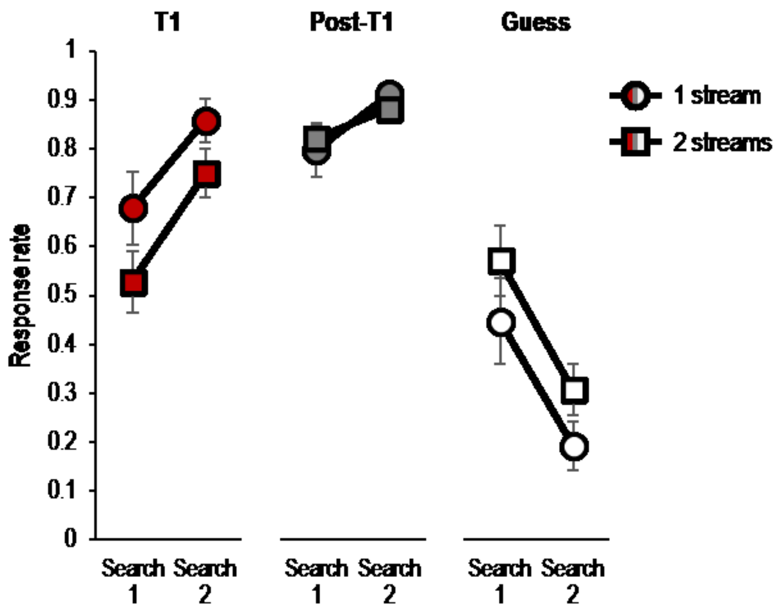

Figure 8. T1 accuracy, post-T1 reports (i.e., either T2 or PTD), and guesses (i.e., reports of digits other than T1, T2, or PTD) in the first half of Experiment 3, shown separately for single-stream and two-stream blocks, and separately for participants in the Search 1 and Search 2 tasks.

Table 4. *Frequency of first and second response choice combinations in the first half of Experiment 3, for participants in the Search 1 and Search 2 tasks (upper and lower panels), shown separately for blocks with a single RSVP stream (left) or two RSVP streams (right).*

	SINGLESTREAM				TWO STREAMS			
SEARCH 1	**2nd T1**	**2nd Intrusion**	**2nd Guess**	**Total**	**2nd T1**	**2nd Intrusion**	**2nd Guess**	**Total**
1st T1	-	0.28	0.11	**0.40**	-	0.20	0.07	**0.27**
1st Intrusion	0.27	-	0.25	**0.52**	0.24	-	0.38	**0.62**
1st Guess	0.01	0.04	0.03	**0.09**	0.02	0.05	0.03	**0.10**
Total	**0.28**	**0.32**	**0.40**	**1.00**	**0.26**	**0.24**	**0.49**	**1.00**
SEARCH 2	**2nd T1**	**2nd T2**	**2nd Guess**	**Total**	**2nd T1**	**2nd T2**	**2nd Guess**	**Total**
1st T1	-	0.46	0.04	**0.49**	-	0.34	0.04	**0.38**
1st T2	0.35	-	0.11	**0.45**	0.35	-	0.19	**0.54**
1st Guess	0.02	0.02	0.02	**0.05**	0.02	0.04	0.02	**0.08**
Total	**0.36**	**0.48**	**0.16**	**1.00**	**0.37**	**0.38**	**0.25**	**1.00**

Note. Marginal totals may not sum to 1.00 as values are rounded to two decimals.

Discussion

In Experiment 3, participants either had to report only the first of two coloured targets (Search 1) or both of these targets (Search 2), and provided two successive response choices on each trial. Participants who performed the Search 2 task reported T1 more frequently than those who performed the Search 1 task, and also provided more reports of the post-T1 item (although this difference was only marginally significant). This pattern of results suggests that analogous to the effects of probabilistic quantity expectations in Experiments 1 or 2, the explicit instruction to report two rather than a single target increased the number of items encoded in WM. Importantly, and in contrast to Experiments 1 and 2, guesses (reports other than T1, T2, or PTD) were much more frequent for participants who searched for a single target[3]. For these

[3] It is noteworthy that the overall guess rate in Experiment 3 was also markedly higher than in the two previous experiments (M = 37.9% vs. M = 9%). This is unsurprising, as participants had to provide two different target reports on each trial, and no longer had the option to report having perceived a single target.

participants, the vast majority of guesses were recorded for the second response (see Table 4). The fact that these guesses were more frequent for participants in the Search 1 as compared to the Search 2 task is critical, as guesses on the second response can be interpreted as a clear indication that only a single item (either T1 or the post-T1 item) was encoded. If this interpretation is correct, the pattern of guess responses in Experiment 3 provides additional evidence that the instruction to report two targets versus a single target increases the probability that two items will be encoded. These task instructions specifically increase the likelihood that T1 will be encoded (from 60% in Search 1 to 80% in Search 2), presumably because T1 is more susceptible to competitive interactions with the post-T1 item than vice versa, and therefore profits more from task-dependent strategic modulations of WM access.

Perhaps unsurprisingly, task performance was generally better in blocks with a single central RSVP stream relative to blocks with two lateral streams, with higher T1 accuracy and lower guess rates for single-stream blocks. As target location was certain in single-stream blocks, this is compatible with the notion that focused spatial attention enhances early perceptual processing (Luck et al., 1997) and therefore results in faster target detection and consequently in earlier attentional episodes (Foster et al., 2020; Zivony & Eimer, 2021a, Experiment 3; see also: Ludowici & Holcombe, 2021). It is also notable that only T1 reports but not reports of the post-T1 item showed benefits in single-stream blocks. This suggests that T1 is more susceptible to an encoding failure than the post-T1 item under conditions of spatial uncertainty. Importantly, quantity expectation effects were not modulated by the number of streams, suggesting that they are not dependent on focused spatial attention.

Robust quantity expectation effects on WM encoding emerged in Experiment 3 even though the post-T1 item was always a coloured digit. This rules out the possibility that these effects are related to any explicit or implicit statistical learning about the number or probability of target-matching features in any given trial. Overall, the results of Experiment 3 showed that explicit task instructions about the number of to-be-reported targets in RSVP streams affect the number of items encoded, analogous to the single-target and two-targets probabilities manipulated in Experiments 1 and 2. These findings indicate that such quantity expectation effects are not limited to a specific set of task settings, but are also present under conditions that are similar to standard lag-1 sparing and distractor intrusion experiments.

General Discussion

The current study was motivated by a theoretical conundrum. When presented with two consecutive targets in an RSVP stream, observers usually encode and report both of them (lag-1 sparing; e.g., Hommel & Akyürek, 2005). In contrast, when searching for a single target, they often erroneously report the post-target distractor (distractor intrusions) and fail to encode the preceding target entirely (Zivony & Eimer, 2020). Both phenomena are highly robust and have been demonstrated in many studies. Yet it remains puzzling why performance should be better in a putatively harder two-targets report task than when observers have to find and report only a single target. Because lag-1 sparing and distractor intrusions have never been directly compared, this puzzle has remained unresolved.

In this study, participants searched for coloured digits in RSVP streams. In Experiments 1 and 2, the critical manipulation concerned the actual and the expected number of targets (one versus two). In both experiments, target quantity expectations had strong effects on perceptual reports: the probabilities that the first target (T1) and the item that immediately followed this target were reported were both higher when participants expected two as compared to just a single target.

Importantly, this was the case not only on two-targets trials, but also on single-target trials where T1 was followed by a grey nontarget digit (post-target distractor; PTD). Analogous results were obtained in Experiment 3 where quantity expectations were manipulated differently. Instead of varying the ratio of one-target versus two-targets trials in a given block, all RSVP streams contained two successive coloured digits, and participants had to report either only the first or both of them. Because participants had the option to provide only a single target report in Experiments 1 and 2, the effects of quantity expectations on perceptual reports observed in these experiments could in principle exclusively reflect a more liberal response bias in Expect 2 blocks. However, analogous effects were found in Experiment 3 where this option was removed, and two perceptual reports were required on all trials. This suggests that response bias alone cannot account for these findings. More direct electrophysiological support for this conclusion was provided in Experiment 2, where CDA components were found to be reliably larger in Expect 2 as compared to Expect 1 blocks. As CDA amplitudes are an established marker for the number of items encoded in WM (Vogel & Machizawa, 2004) that is unaffected by response bias, this result shows that quantity expectations modulate access to WM, prior to response selection and execution. The probability that both T1 and the post-T1 item are encoded and subsequently reported increases when two instead of just one target are expected.

These results offer new insights into the mechanisms that are responsible for lag-1 sparing and distractor intrusions in RSVP tasks. At a more general level, they also provide novel evidence for the strategic top-down control of WM encoding. With respect to the conundrum that motivated this research, our findings can explain the puzzling discrepancy in performance between lag-1 sparing and distractor intrusion tasks. One critical difference between these two tasks is that observers know that they have to report two targets in lag-1 sparing experiments but only a single target in studies investigating distractor intrusions. Our results demonstrate that these target quantity expectations affect the number of items encoded in WM. This increases the probability that the first target will be encoded and subsequently reported in lag-1 sparing relative to distractor intrusion experiments, resulting in better T1 performance, in spite of the fact that two-targets report tasks are more demanding. Importantly, such target quantity expectations do not only modulate the likelihood that T1 gains access to WM, but also affect the encoding of the item that immediately follows T1 (T2 on two-targets trials or PTD on single-targets trials). The observation that quantity expectations affect T2 performance confirms previous observations. Visser (2015) found higher T2 accuracy in blocks where observers expected two targets relative to blocks where a single target was expected, and suggested that this was due to temporal variability in the duration of the attentional window triggered by T1. If this window was extended when two targets are expected, this should selectively facilitate the processing of T2 and increase the probability that T2 is encoded. While Visser (2015) did not investigate distractor intrusions, this explanation could also account for our observation that expecting two targets also increased the likelihood of post-target intrusions (i.e., reports of the PTD) on one-target trials. However, the observation from Experiment 2 that N2pc components following T1 were larger in Expect 2 as compared to Expect 1 blocks suggests an alternative explanation. As discussed earlier, this N2pc amplitude difference indicates that the amount of attentional amplification during the attentional window was modulated by quantity expectations, resulting in larger activations of sensory representations of the T1 and post-T1 item in Expect 2 blocks, and increasing the likelihood that either of these items would cross the encoding threshold. In contrast to Visser (2015), we also observed clear quantity expectation effects on T1 reports, which is in line with this increased amplification account. The fact that both T2 and PTD reports were more frequent in Expect 2 blocks suggests that this amplification is indiscriminate, and enhances the activation states of the post-T1 item regardless of whether or not it matches the target-defining attribute (colour; see also Zivony & Eimer, 2021a). This conclusion that both lag-1 sparing and distractor intrusions are the result of indiscriminate amplification during attentional episodes challenges previous accounts of lag-1 sparing (Di Lollo et al., 2005; Taatgen et al., 2009). These authors assume that sparing is the result of a target-selective attentional filter that remains active for a short period prior to the attentional blink and enables target-nontarget discrimination within a brief period.

The fact that quantity expectations affect WM encoding in RSVP streams regardless of whether these streams contain just a single or two target items, as shown by our results, also implies that lag-1 sparing and distractor intrusions are essentially two expressions of the same mechanism, even though they appear to represent opposite effects (one reflects a performance benefit whereas the other reflects an error). This is conceptually important, because it opens up the possibility of developing a unified account of these two phenomena, thus integrating research on the attentional blink and on distractor intrusions, which has so far been pursued largely independently (see also Zivony & Eimer, 2021b, for an outline of such an integrative model).

At a more general level, our findings also demonstrate that strategic factors related to target quantity expectations affect WM encoding mechanisms, and specifically the number of items that gain access to WM. WM capacity is a limited resource, and top-down control over WM access is obviously important, as it can prevent irrelevant information from competing with the active maintenance of task-relevant objects and events. The role of cognitive control processes for WM encoding has typically been investigated in matching-to sample tasks where static memory sample displays with target and distractor objects are followed after a retention period by a test display. For example, Vogel, McCollough, & Machizawa (2005) have shown that there are substantial individual differences in the ability to selectively restrict WM access to feature-defined target objects by excluding distractors. CDA components recorded during the retention period revealed that individuals with high WM capacity were more effective in filtering out distractors than low-capacity individuals. This suggests that WM performance may not be a function of overall WM capacity, but primarily reflects the ability to selectively prevent distractor information from being encoded. However, it is less clear whether and to what degree WM access can also be strategically modulated. Flexible-resource models of WM (e.g., Husain & Bays, 2008) assume an inverse relationship between how many representations are maintained in WM and their quality/precision, and suggest that the number of items encoded can be voluntarily adjusted in line with the precision required by a specific WM task. This assumption was challenged by Zhang & Luck (2011), who manipulated the precision of stored colour representations required for accurate WM performance. They found no evidence for a quality/quantity trade-off, even when participants were given incentives to increase the number of stored WM representations. This finding suggests strict limitations in the ability to strategically regulate how many items are selected for access to WM (but see Bengson & Luck, 2015). In contrast, the precision with which items are represented in WM appears to be subject to strategic adjustment, but only when overall WM load is low (Machizawa et al., 2012).

These previous studies investigated the top-down control of selectivity during WM encoding with a single static memory sample displays containing multiple items. The temporal demands on attentional control are clearly different in RSVP tasks, as single items are presented in rapid succession, and attentional control mechanisms have to select the right object at the right moment in time. Our results show that under these circumstances, WM encoding is still sensitive to top-down expectations about the number of to-be-reported targets, indicating that access to WM can be adjusted strategically in dynamic environments. However, the level at which this type of top-down control operates still needs to be fully determined. The N2pc results observed in Experiment 2 provide initial evidence that the effects of quantity expectations on WM encoding are mediated by differences in activation levels during the attentional episode. These differences may not be a direct result of target quantity expectations, but could be due to a more general difference in the anticipated difficulty associated with single-target versus two-targets report tasks. When observers expect or know that two targets will have to be detected and reported, generic attentional preparation may be higher than when a single-target report is expected, resulting in stronger attentional facilitation which then indirectly increases the probability that two successive items are encoded. The current results do not rule out that other and more directly expectation-related strategic adjustments (such as lowering encoding thresholds and/or extending the attentional window) may also contribute to the behavioural effects observed in the present study, and this will need to be investigated more systematically in future work. For example, the role of expectation-induced changes to encoding thresholds can be tested by manipulating quantity expectations in tasks where T1 and T2 are not only presented in immediate succession but also with longer lags. According to the increased amplification hypothesis, expectation effects are limited to stimuli presented within the same attentional episode, and such effects should therefore not be observed when T1 and T2 are separated by intervals that exceed the duration of this episode. In contrast, if quantity expectations result in more sustained changes to encoding thresholds, expectation effects should not be restricted to lag 1 but should also be found at longer lags, during the entire attentional blink period and possibly even beyond.

In summary, the current study demonstrated that expectations related to the number of target items present in RSVP streams have clear and systematic effects on the number of items encoded in WM. These findings reconcile apparently contradictory observations from lag-1 sparing and distractor intrusion studies, and also provide new evidence for strategic top-down control over WM encoding in RSVP tasks.

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