Is all sparing created equal? Comparing lag-1 sparing and extended sparing in temporal object perception.

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Abstract

When two targets (T1, T2) are presented amongst a rapid stream of distractors, T2 accuracy is impaired if the targets are separated by at least one distractor (attentional blink). However, this impairment largely disappears if the targets follow one another directly (lag-1 sparing), and in fact, as many as four or five consecutive targets may be identified quite accurately under these conditions (extended sparing). Although all current models propose a common mechanism for both lag-1 and extended sparing, this hypothesis has yet to be tested. To this end, we examined the effect of various types of attentional switches, known to impact lag-1 sparing, on extended sparing, in order to determine whether they would have a similar effect. Results suggested substantial parallels between the two types of sparing. We discuss these results in terms of a unified account of sparing in temporal object perception.

When observers are asked to identify two targets from amongst a stream of distractors, they typically identify the first target (T1) quite accurately, but are often much poorer at identifying the second target (T2), at inter-target intervals (lags) of less than about half-a-second. This second-target deficit has come to be known as the attentional blink (AB), and has been studied extensively for the past twenty years due to the insights that it gives into mechanisms underlying awareness (e.g., Broadbent, 1987; Chun & Potter, 1995; Raymond, Shapiro, & Arnell, 1992; Jolicoeur & Dell'Acqua, 1998; Di Lollo, Kawahara, & Enns, 2005; see Dux & Marois , 2009 for a review).

Conventional explanations of the AB have often been couched in terms of competition amongst visual inputs for limited resources. Specifically, T1 processing is assumed to occupy capacity-limited processing resources that are also required for T2. As a result when T2 is presented soon after T1, these resources are unavailable, leaving T2 vulnerable to decay or visual masking (cf. Chun & Potter, 1995; Giesbrecht & Di Lollo, 1998; Jolicoeur & Dell'Acqua, 1998; Visser, 2007). Such accounts are consistent with research showing that T2 must generally be backward masked for the AB to occur (Giesbrecht & Di Lollo, 1998; Brehaut, Enns, & Di Lollo, 2000), demonstrations that AB magnitude varies with T1 processing time (Visser, 2007ab; Visser & Ohan, 2007), and evidence that placing varying priority on T1 identification modulates AB magnitude (Dux, Asplund, & Marois, 2008, 2009; Dell'Acqua, Jolicoeur, Luria, & Pluchino, 2009).

However, while "bottleneck" models neatly explain why T2 performance should increase with temporal lag between targets, they cannot explain the surprising finding that T2 performance is often greatly increased when it follows T1 directly in time, compared to when targets are separated by at least one distractor. That is, in many studies T2 accuracy is relatively high at a lag 1, where T2 performance should be worst according to bottleneck models, because T2 is presented at maximal temporal proximity to T1. This phenomenon, known as "lag-1 sparing" (e.g., Potter, Chun, Banks, & Muckenhoupt, 1998; Visser, Bischof, & Di Lollo, 1999; Visser, Zuvic, Bischof, & Di Lollo, 1999), has been found in at least half of published studies. Moreover, it suggests that the mechanisms underlying target processing may be fundamentally different for consecutive targets compared to those separated by one or more distractors.

Why does lag-1 sparing occur in some studies, but not others? Visser et al. (1999) suggested that this difference was likely to be due to the presence or absence of attentional switches. In a review of published AB studies to that time, they found robust lag-1 sparing arose when T1 and T2 were drawn from the same category of stimuli, required the same task, and were presented in the same spatial location. However, in the reviewed studies, sparing was invariably absent when stimuli were presented in different spatial locations or required a switch in both stimulus class and type of task (or modality). On the basis of this analysis, Visser et al. (1999) suggested that lag-1 sparing occurs when two criteria are met. First, T2 has to be presented in close temporal contiguity to T1 in order to enter an attentional gate spawned by the initial target. Second, T2 has to match an "input filter" that is set-up, based on task instructions, to pass items that share target characteristics to high-level processing. If T2 does not share sufficient characteristics with T1, it cannot pass the filter set for the initial target and sparing cannot occur.

Although this theoretical framework has been widely used (see below), the conditions that yield sparing have proven to be more variable than initially conceived. For example, since the publication of Visser et al.'s review, several studies have demonstrated that sparing can occur when targets are presented in different spatial locations (e.g., Jefferies, Ghorashi, Kawahara, & Di Lollo, 2007; Jefferies & Di Lollo, 2009; Kawahara & Yamada, 2006; Lunau & Olivers, 2010; Shih, 2000; Williams, Visser, Cunnington, & Mattingley, 2008). However, this only happens when experimental conditions, such as the simultaneous presentation of dual rapid serial visual presentation (RSVP) streams (Kawahara & Yamada, 2006; Jefferies & Di Lollo, 2009; Jefferies et al., 2007, 2010), spur participants to adopt a more diffuse focus of attention that encompasses both possible target locations. Under conventional conditions with a single central RSVP containing T1 and a peripheral T2, attention is tightly focused on the T1 location, and thus sparing does not occur.

Interestingly, a number of studies have also demonstrated that sparing can extend beyond lag 1. For example, Di Lollo, Kawahara, Ghorashi, & Enns (2005) presented observers with three consecutive targets (Uniform condition), or two targets separated by a single distractor (Varied condition). They found that identification of all targets in the Uniform condition was quite accurate, and in particular, the final item in the Uniform condition was identified far more accurately than the item at the same temporal location in the Varied condition. In other words, whereas an AB was shown for the third item in the Varied condition, sparing was obtained for this item in the Uniform condition. Later work by Olivers, van der Stigchel, & Hulleman (2007) expanded and replicated this work, showing that four or five consecutive targets appeared to suffer little significant downturn in performance.

To our knowledge, all current theories propose identical mechanisms to account for both extended sparing and conventional lag-1 sparing. For example, as in Visser et al. (1999), Di Lollo et al.'s temporary loss of control model proposes that observers establish an input filter (see also Ghorashi, Zuvic, Visser, & Di Lollo, 2003; Visser, Bischof, & Di Lollo, 2004) designed to pass inputs with target-like characteristics onto high-level resources and exclude those that do not share these attributes. Importantly, the same resources required for identifying a visual stimulus are also required to maintain the filter. Thus, when T1 is being processed, the filter is vulnerable to being exogenously reset by an incompatible distractor. On the other hand, as long as items continue to be targets, the input filter will continue to be compatible with target characteristics, and targets will continue to gain immediate access to high-level resources (subject to capacity limits of short-term memory), thereby avoiding the AB.

Other theories make similar predictions. The "boost-and-bounce" theory of Olivers and Meeter (2008) suggests that presentation of a target leads to an attentional "boost" for subsequent targets and an inhibitory "bounce" for non-targets. Because the boost is tied to the appearance of a target stimulus, not only will T2 benefit from the appearance of T1, leading to lag-1 sparing, but a third target (T3) presented directly after T2 would likewise benefit from the appearance of T2, and so on. The threaded cognition framework recently proposed by Taatgen, Juvina, Schipper, Borst, and Martens (2010) argues that the AB arises due to a control rule that prioritizes memory consolidation over target detection. As a result, when T2 follows T1 closely in time, its detection is prevented while consolidation of T1 is ongoing. The exception to this is when targets follow one another directly, in which case target detection occurs before consolidation of T1 begins, thereby protecting the new target. Again, it is expected that this protection would continue as long as targets are presented, thereby explaining lag-1 sparing as well as improved detection at later lags. Finally, the Episodic Simultaneous Type Serial Token (eSTST) account of Wyble and colleagues (Bowman & Wyble, 2007; Wyble, Bowman, & Nieuwenstein, 2009; see also Nieuwenstein, Potter, & Theeuwes, 2009) suggests that the appearance of a target initiates a "blaster" which deploys resources to incoming representation. As long as targets continue to appear, the blaster continues to be activated, sustaining deployment of attention, and thereby leading to sparing.

Although the notion that lag-1 sparing and extended sparing share underlying mechanisms is both intuitive and parsimonious, there have not yet been any direct tests of this proposal. In fact, there are some differences between second- and third-target sparing that might point to variance in underlying mechanisms. First, in lag-1 sparing, the accuracy benefit seen for the second target is often accompanied by a decrement for the immediately preceding target (i.e., the first target). In contrast, the benefit for the third target in extended sparing is accompanied by a decrement in first target accuracy, but a benefit for the immediately preceding target (Di Lollo et al., 2005; Kawahara, Enns, & Di Lollo, 2006; Kawahara, Kumada, & Di Lollo, 2006). This suggests that the addition of a third item alters target processing in ways that do not occur in lag-1 sparing. Second, Dell'Acqua et al. (2009) showed that the performance advantage for the third target in the Uniform condition was significantly ameliorated when accuracy was conditionalized on correct identification of prior targets. In contrast, lag-1 sparing occurs reliably even when conditional scoring is employed. This implies that extended sparing may depend on resource trade-offs between targets (Dell'Acqua et al., 2009; see also Dux, Asplund, & Marois, 2008, 2009) while lag-1 sparing may not. Finally, on a similar note, direct manipulations of resource allocation to T1 have been shown to modulate T3 performance (Dux, Asplund, & Marois, 2008, 2009), but this seems to have produced inconsistent effects on T2, with some evidence for a decrement in accuracy, and other evidence that it is unaffected (compare Dux et al., 2008 Figure 2 with Dux et al., 2009 Figure 2). This inconsistency again opens up the possibility that extended sparing may be dissociable from lag-1 sparing.

To examine whether extended sparing and lag-1 sparing depend on common mechanisms, we went back to the analysis of lag-1 sparing conducted by Visser et al. (1999), which concluded that certain types of attentional switches eliminate lag-1 sparing, while others do not. We reasoned that if extended sparing shares common mechanisms with lag-1 sparing, then the conditions that promote or eliminate lag-1 sparing should have an identical effect on extended sparing. For example, if a switch in spatial location between T1 and T2 eliminates lag-1 sparing then a third target should also be denied sparing if it is presented in a different location than T1 and T2.

In the following experiments, we pursue this logic by systematically examining the impact of spatial switches, task switches, and category switches (i.e, digit vs. letter targets) on extended sparing. Specifically, we presented observers with target sequences similar to the Uniform and Varied conditions employed by Di Lollo et al. (2005), and then varied the presence/absence of various switches. In addition, to examine the generalizability of the results of Dell'Acqua et al. (2009), we analyzed unconditional target accuracy as in earlier studies (e.g., Di Lollo et al., 2005) as well as conditional target accuracy to see how this impacted the presence of extended sparing. Based on this earlier work, we expected that conditional accuracy scores for the final target would be lower than unconditional accuracy scores in the Uniform condition.

EXPERIMENT 1: Spatial Switch

In the first experiment, we examined the impact of a spatial switch on extended sparing. To do this, we compared performance on three types of trials: those with two central targets separated by a single distractor (TDT condition; as in the Varied condition of Di Lollo et al., 2005); those with three consecutive central targets (TTT condition; as in the Uniform condition of Di Lollo et al., 2005), and those with two central targets, followed by a single target presented in the periphery (TTTss condition). To the extent that extended sparing and lag-1 sparing share underlying mechanisms, we expected that the location switch in the TTTss condition would significantly disrupt third-target accuracy compared to the TTT condition, just as this spatial switch reliably eliminates lag-1 sparing when T2 falls outside the focus of attention at the T1 location (Visser et al., 1999).

Participants. Eighteen participants (12 female) were recruited through advertisements on university notice boards and web-based software. Informed consent was obtained from all participants as per standard ethical guidelines. All participants received a small honorarium of $10 or bonus credit towards their grade in a Psychology course to compensate them for their time and effort, and reported normal or corrected-to-normal vision.

Apparatus and Stimuli. Stimuli were presented on a 19-inch (viewing size: 17.75 inches) NEC monitor (MultiSync FE992) running at a refresh rate of 100Hz, attached to a Pentium computer running Presentation software (Version 9.20; Neurobehavioral Systems). The software was also responsible for recording response times and accuracy from a computer keyboard.

Testing was conducted in a quiet, dark laboratory with only dim lighting provided by keys on an illuminated keyboard. All stimuli subtended a visual angle of approximately 1^{o} at a viewing distance of 60 cm. Targets were shown in Arial font (28 point; RGB: 170, 170, 170) and consisted of the Arabic numerals from 1 to 8. Distractors consisted of all letters of the English alphabet except I, O, Q and Z, which were omitted due to their structural similarity to the digits 1, 0, 2 and 7. Distractor letters were shown in upper-case Arial font (28 point; RGB: 170, 170, 170).

Procedure. The experiment comprised 360 trials evenly divided between three blocks of 120 trials corresponding to each experimental condition. In the TDT block, observers were presented with a central target, a central distractor, and then a second central target. In the TTT block, observers were presented with three consecutive central targets. Finally, in the TTTss block, two central targets were presented, followed by a single target presented approximately 2° above, below, left or right of this central location. The location of this eccentric target was chosen randomly. Participants were informed at the beginning of each block, how many targets would be presented on each trial, and given details about where they would appear (i.e., centrally or eccentrically). The order in which each participant received the blocks was counterbalanced.

All trials began with a fixation cross, presented at the centre of the screen. Participants focused their gaze at fixation and pressed the spacebar to initiate a trial. Following a 250 ms pause during which the display was blank, a sequence of five to eight letter distractors was displayed in the centre of the screen. Depending on the condition, distractors were followed by a three-item sequence consisting of: a central target, a central distractor, and a second central target (TDT); three central targets (TTT); or, two central targets and an eccentric third target (TTTss). A single distractor presented at the same spatial location always followed the final target. Targets and distractors were presented for 70 ms, and separated from the next item by a 30 ms blank display. Targets were chosen randomly with the proviso that each target was a different digit. Distractors were chosen randomly with replacement with the proviso that identical distractors were never presented in succession.

After the mask disappeared, there was a 200 ms blank display, followed by prompts (e.g., “T1 digit?”) that signalled participants to report each of the digits that had been presented by pressing an appropriate key on the keyboard. Participants were asked to report targets in the order they had been presented, although response order was not considered when scoring accuracy. Participants were also instructed to guess if they were not sure of a target’s identity, as a response was required to each digit. Once their last response had been made, the fixation cross re-appeared and participants began the next trial at their leisure by pressing the spacebar.

Results

Unconditional Data. Mean target accuracy was calculated separately for each condition. This yielded percentage accuracy scores of 82.27, 90.36, and 78.06 in the TTT condition [comparison between targets: $F(2, 34) = 20.84$, $p < .001$, $\eta^2 = .55$], 81.16, 96.45, and 58.98 in the TTTss condition [comparison between targets: $F(2, 34) = 69.90$, $p < .001$, $\eta^2 = .80$], and 90.58 and 67.77 in the TDT condition. Replicating previous results (e.g., Di Lollo et al., 2005), these means show a robust AB occurred in the TDT condition, and that performance was highly accurate for the first two targets in the TTT and TTTss conditions. However, a clear discrepancy emerged for the final target with continued high accuracy in the TTT condition, but substantially reduced performance in the TTTss condition. To confirm these impressions, accuracy scores were analyzed in a 2 (Target Position) x 3 (Condition: TDT, TTT, TTTss) within-subjects analysis of variance (ANOVA). Only scores from the first and final targets, which were presented at identical time points, were included in the ANOVA (see Figure 1) following the analytical model employed in previous extended sparing studies (e.g., Di Lollo et al., 2005). The results revealed significant main effects of Position, $F(1, 17) = 98.92$, $p < .001$, $\eta^2 = .85$, indicating that final target accuracy was generally lower than first target accuracy, and Condition, $F(2, 34) = 14.17$, $p < .001$, $\eta^2 = .46$, indicating that performance was worse in the TTTss condition than in the other conditions where no spatial shift was required to the final target. Most importantly, there was also a significant interaction between Position and Condition, $F(2, 34) = 13.72$, $p < .001$, $\eta^2 = .45$.

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Insert Figure 1 about here

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In order to interpret the Position x Condition interaction, we conducted separate t-tests to compare first and final target accuracy in the TDT, TTT, and TTTss conditions. As in previous extended sparing studies, final target accuracy was significantly lower than first target accuracy in the TDT condition, t (17) = 7.52, $p < .001$, indicating the presence of an AB, while this difference failed to reach significance in the TTT condition, t (17) = 1.72, $p > .10$, indicating extended sparing. In the TTTss condition, however, final target accuracy was again significantly lower than first target accuracy, t (17) = 7.29, $p < .001$. This suggests that, as in the case with lag-1 sparing, introduction of a spatial shift of attention eliminates extended sparing and re-introduces the AB.

To bolster this conclusion further, we conducted separate Position x Condition analyses comparing performance in the TTTss and TTT conditions, and the TTTss and TDT conditions. As expected, we found a significant interaction between Position and Condition when comparing TTTss and TTT conditions, F(1, 17) = 18.42, $p < .001$, $\eta^2 = .52$, but not when comparing the TTTss and TDT conditions, F(1, 17) = 0.02, $p > .88$, $\eta^2 < .01$. This indicates that performance was significantly better across position in the TTT condition compared to the TTTss condition (i.e., extended sparing), while a roughly equivalent AB was obtained in the TTTss and TDT conditions.

C*onditional Data.* Target accuracy here and in subsequent experiments was conditionalized on accurate identification of all prior targets (i.e, T2|T1 and T3|T2 & T1). Mean percentage target accuracy was 82.27, 90.36, and 73.95 in the TTT condition [comparison between targets: F(2, 34) = 28.94, $p < .001$, $\eta^2 = .63$], 81.16, 96.45, and 53.02 in the TTTss condition [comparison between targets: F(2, 34) = 67.62, $p < .001$, $\eta^2 = .80$], and 90.58 and 66.19 in the TDT condition. These results were similar to those from the unconditional data, with some suggestion of a greater decline in accuracy for the final target in each condition. Accuracy scores were analyzed in a 2 (Target Position) x 3 (Condition) within-subjects ANOVA. The results revealed significant main effects of Position, $\underline{F}(1, 17) = 97.87$, $\underline{p} < .001$, $\eta^2 = .85$, indicating that final target accuracy was substantially lower than first target accuracy, and Condition, $\underline{F}(2, 34) = 14.03$, $\underline{p} < .001$, $\eta^2 = .45$, indicating that overall performance was again worse in the TTTss condition than in the other conditions. There was also a significant interaction between Position and Condition, $\underline{F}(2, 34) = 12.38$, $\underline{p} < .001$, $\eta^2 = .42$.

To follow up the Position x Condition interaction, we conducted separate t-tests to compare first and final target accuracy in the TDT, TTT, and TTTss conditions. Final target accuracy was significantly lower than first target accuracy in the TDT condition, $\underline{t}$ (17) = 7.16, $\underline{p} < .001$, and TTTss conditions, $\underline{t}$ (17) = 7.77, $\underline{p} < .001$. Moreover, unlike the unconditional data, this difference was also significant in the TTT condition, $\underline{t}$ (17) = 3.45, $\underline{p} < .01$. However inspection of Figure 1 indicates that the difference here was about 3x smaller than in the other two conditions, suggesting that both the TDT and TTTss showed similar and larger ABs than the TTT condition. Consistent with this conclusion, separate Position x Condition analyses comparing performance in the TTTss and TTT conditions, and the TTTss and TDT conditions, revealed a significant interaction when comparing TTTss and TTT conditions, $\underline{F}(1, 17) = 19.23$, $\underline{p} < .001$, $\eta^2 = .53$, but not when comparing the TTTss and TDT conditions, $\underline{F}(1, 17) = 0.63$, $\underline{p} > .43$, $\eta^2 < .04$.

The results of Experiment 1 support the theoretical links that have been made between lag-1 sparing and extended sparing in previous papers (e.g., Di Lollo et al., 2005; Olivers & Meeter, 2008; Taatgen et al., 2009; Wyble et al., 2009). Specifically, a location shift between consecutive targets that has been demonstrated to eliminate lag-1 sparing also eliminated extended sparing. This suggests that common mechanisms underlie both phenomena. Also of relevance, conditional target accuracy scores in the

TTT condition revealed a small but significant AB, whereas unconditional scores did not. This dissociation replicates the findings of Dell'Acqua et al. (2009) and suggests that while consecutive target presentation significantly ameliorates the AB, this may be partly due to resource tradeoffs with other targets in the sequence (see also Dux et al., 2008; 2009).

Experiment 2: Category+Task Switch

In Experiment 2, we aimed to extend the parallel between lag-1 sparing and extended sparing seen in the first experiment by examining the impact of a combined task and category switch for the final target in the TTT sequence. As reviewed by Visser et al. (1999), such combination switches are known to eliminate lag-1 sparing. Given current theories of extended sparing, and the results of Experiment 1, we expected to find a similar effect on extended sparing.

Participants. Fifteen participants (13 female) were recruited through advertisements posted on web-based sign-up software. Informed consent was obtained from all participants as per standard ethical guidelines. All participants received bonus credit towards their grade in a Psychology course to compensate them for their time and effort, and reported normal or corrected-to-normal vision. None had participated in the previous study.

Apparatus and Stimuli. Stimuli were presented on a Pentium computer, connected to a 19" CRT monitor (Acer AC716) running at a refresh rate of 100Hz, using the Presentation software package (Version 12.20; Neurobehavioral Systems). Testing was conducted in a quiet and dimly lit room. All other aspects of the apparatus and stimuli were identical to Experiment 1.

Procedure. The TDT and TTT conditions were identical to Experiment 1. In the TTTct condition, the final target was presented in the same location as the previous targets. However, the category of the final target was changed from a digit to a letter. In addition, the associated task was changed from identification to vowel/consonant categorization. To accommodate the use of letter targets, we used “pseudo-letter” characters as distractors (see Visser, 2007). We also employed only six letters as targets, equally divided between vowels and consonants (N, F, V, A, E, U). All other aspects of Experiment 2 were identical to Experiment 1.

Results

Unconditional Data. Mean percentage target accuracy was 88.46, 92.46, and 89.16 in the TTT condition [comparison between targets: $F(2, 28) = 1.55$, $p > .22$, $\eta^2 = .10$], 88.75, 94.78, and 79.65 in the TTTct condition [comparison between targets: $F(2, 28) = 13.87$, $p < .001$, $\eta^2 = .50$], and 96.87 and 89.62 in the TDT condition. These results replicate those obtained in Experiment 1 and earlier studies, and suggest that a category switch had only a modest effect on third target accuracy. To bolster this interpretation, accuracy scores were analyzed in a 2 Target Position) x 3 (Condition: TDT, TTT, TTTct) within-subjects ANOVA (see Figure 2) that revealed significant main effects of Position, $F(1, 14) = 11.26$, $p < .01$, $\eta^2 = .45$, indicating that final target accuracy was significantly lower than first target accuracy, and Condition, $F(2, 28) = 12.44$, $p < .001$, $\eta^2 = .47$. Follow-up pairwise comparisons indicated that this main effect stemmed from significant overall differences between all conditions ($p < .03$). Finally, there was a marginally significant interaction between Position and Condition, $F(2, 28) = 2.80$, $p < .08$, $\eta^2 = .17$.

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Insert Figure 2 about here

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On the basis of *a priori* predictions, we followed up the Position x Condition interaction by conducting separate t-tests to compare first and final target accuracy in the TDT, TTT, and TTTct conditions. As expected, final target accuracy was significantly lower than first target accuracy in the TDT condition, $\underline{t}$ (14) = 2.66, $\underline{p} < .02$, indicating the presence of an AB, while this difference failed to reach significance in the TTT condition, $\underline{t}$ (14) = 0.22, $\underline{p} > .82$, indicating extended sparing. Critically, in the TTTct condition, final target accuracy was also significantly lower than first target accuracy, $\underline{t}$ (14) = 2.91, $\underline{p} < .02$. This suggests that the combined category and task switch eliminated extended sparing as it does with lag-1 sparing.

To bolster this conclusion, we conducted separate Position x Condition analyses comparing performance in the TTTct and TTT conditions, and the TTTct and TDT conditions. We found a significant interaction between Position and Condition when comparing TTTct and TTT conditions, $\underline{F}(1, 14) = 6.04$, $\underline{p} < .03$, $\eta^2 = .30$, but not when comparing the TTTct and TDT conditions, $\underline{F}(1, 14) = 0.15$, $\underline{p} > .70$, $\eta^2 < .02$. This indicates that performance was significantly better across position in the TTT condition compared to the TTTct condition (i.e., extended sparing), while a similar AB was obtained in the TTTct and TDT conditions.

Conditional Data. Mean percentage target accuracy was 88.46, 92.69, and 88.54 in the TTT condition [comparison between targets: $\underline{F}(2, 28) = 1.87$, $\underline{p} > .17$, $\eta^2 = .12$], 88.75, 95.86, and 79.58 in the TTTct condition [comparison between targets: $\underline{F}(2, 28) = 14.72$, $\underline{p} < .001$, $\eta^2 = .51$], and 96.87 and 89.46 in the TDT condition. The results from the 2 (Target Position) x 3 (Condition) within-subject ANOVA showed significant main effects of Position, $\underline{F}(1, 14) = 9.80$, $\underline{p} < .01$, $\eta^2 = .41$, indicating that final target accuracy was substantially lower than first target accuracy (see Figure 2), and Condition, $\underline{F}(2, 28) = 11.78$, $\underline{p} < .001$, $\eta^2 = .46$, indicating that overall performance again differed between all three conditions ($\underline{p} < .01$). There was also a marginally significant interaction between Position and Condition, $\underline{F}(2, 28) = 2.60$, $\underline{p} = .08$, $\eta^2 = .16$.

On the basis of *a priori* predictions, separate t-tests were again conducted to compare first and final target accuracy in the TDT, TTT, and TTTct conditions. Final target accuracy was significantly lower than first target accuracy in the TDT condition, $\underline{t}$ (14) = 2.59, $\underline{p} < .03$, indicating the presence of an AB, while this difference was not significant in the TTT condition, $\underline{t}$ (14) = 0.03, $\underline{p} > .97$, indicating extended sparing. Again, in the TTTct condition, final target accuracy was significantly lower than first target accuracy, $\underline{t}$ (14) = 2.83, $\underline{p} < .02$, indicating a significant AB was present in the presence of a combined category and task switch.

We also conducted separate Position x Condition analyses comparing performance in the TTTct and TTT conditions, and the TTTct and TDT conditions. This showed a significant interaction between Position and Condition when comparing TTTct and TTT conditions, $\underline{F}(1, 14) = 5.36$, $\underline{p} < .04$, $\eta^2 = .28$, but not when comparing the TTTct and TDT conditions, $\underline{F}(1, 14) = 0.13$, $\underline{p} > .71$, $\eta^2 < .01$. This indicates that performance was significantly better across position in the TTT condition compared to the TTTct condition (i.e., extended sparing), while a similar AB was obtained in the TTTct and TDT conditions.

In sum, the present findings further support the argument that lag-1 sparing and extended sparing reflect a common mechanism. Specifically, as is the case with lag-1 sparing (see Visser et al., 1999), a combined category and task switch eliminated extended sparing. Unlike Experiment 1, however, a comparison of conditional and unconditional accuracy scores did not reveal a significant difference in the magnitude of sparing in the TTT condition, although a trend in this direction was still present.

In Experiments 3-5, we tested whether any kind of switch would eliminate extended sparing. To the extent that extended sparing and lag-1 sparing share underlying mechanisms, we would expect this not to be the case. Specifically, either a task switch alone or a category switch alone should not eliminate extended sparing, as is true for lag-1 sparing (Visser et al., 1999). We tested this prediction in Experiments 3 and 4, by employing only a task switch between the second and third targets, and in Experiments 5a and 5b, by using only a category switch between the second and third targets.

Experiment 3: Task Switch Only

Participants. Eighteen participants (12 female) were recruited in the same manner as Experiment 1. All participants reported normal or corrected-to-normal vision, and none had participated in the previous studies.

Apparatus and Stimuli. Apparatus and stimuli were identical to Experiment 1.

Procedure. The TDT and TTT conditions were identical to Experiment 1. In the TTT task switch (TTTt) condition, presentation conditions were identical to those in the TTT condition, except that observers were asked to determine whether the final digit was odd or even, rather than to report its identity. All other aspects of Experiment 3 were identical to Experiment 1.

Unconditional Data. Mean percentage target accuracy was 78.64, 86.42, and 71.98 in the TTT condition [comparison between targets: $F(2, 34) = 11.30$, $p < .001$, $\eta^2 = .40$], 69.42, 71.06, and 59.27 in the TTTt condition [comparison between targets: $F(2, 34) = 13.03$, $p < .001$, $\eta^2 = .43$], and 87.34 and 61.59 in the TDT condition. As in Experiment 2, there was a robust AB in the TDT condition, but evidence for relatively spared performance in the TTT and TTTt conditions. To analyze these effects, accuracy scores for the first and final position were analyzed in a 2 (Target Position) x 3 (Condition: TDT, TTT, TTTt) within-subjects

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Insert Figure 3 about here

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ANOVA. The results (see Figure 3) revealed significant main effects of Position, F(1, 17) = 27.60, p < .001, η^2 = .62, indicating that final target accuracy was generally lower than first target accuracy, and Condition, F(2, 34) = 14.66, p < .001, η^2 = .46, indicating that performance was worse in the TTTt condition than in the other conditions where no task switch was required. Finally, there was also a significant interaction between Position and Condition, F(2, 34) = 13.66, p < .001, η^2 = .45.

In order to interpret this interaction, we conducted separate t-tests to compare first and final target accuracy in the TDT, TTT, and TTTt conditions. Final target accuracy was significantly lower than first target accuracy in the TDT condition, t (17) = 6.48, p < .001, but not in the TTT condition, t (17) = 1.64, p > .11. In the TTTt condition, final target accuracy was also significantly reduced, t (17) = 4.68, p < .001. However inspection of Figure 3 suggests that even though an AB was present in the TTTt condition, it was much smaller than that in the conventional TDT condition. Consistent with this conclusion, separate Position x Condition analyses were non-significant when comparing TTTt and TTT conditions, F(1, 17) = 1.21, p > .27, η^2 = .07, indicating no significant differences in AB magnitude with and without a task switch, but were significant when comparing the TTTt and TDT conditions, F(1, 17) = 13.31, p < .01, η^2 = .44, suggesting a difference in AB magnitude (i.e. extended sparing occurred in the TTTt condition).

Conditional Data. Mean percentage target accuracy was 78.64, 85.57, and 67.07 in the TTT condition [comparison between targets: $\underline{F}(2, 34) = 14.83$, $\underline{p} < .001$, $\eta^2 = .47$], 69.42, 65.59, and 68.38 in the TTTt condition [comparison between targets: $\underline{F}(2, 34) = 1.00$, $\underline{p} > .37$, $\eta^2 = .06$], and 87.34 and 60.30 in the TDT condition. Accuracy scores were analyzed in a 2 (Target Position) x 3 (Condition) within-subjects ANOVA. The results revealed significant main effects of Position, $\underline{F}(1, 17) = 17.33$, $\underline{p} < .01$, $\eta^2 = .51$, indicating that final target accuracy was significantly worse than first-target accuracy, and a significant interaction between Position and Condition, $\underline{F}(2, 34) = 21.52$, $\underline{p} < .001$, $\eta^2 = .56$. The main effect of Condition was marginally significant ($\underline{p} < .10$, $\eta^2 = .14$)

In order to interpret the Position x Condition interaction, we conducted separate t-tests to compare first and final target accuracy in the TDT, TTT, and TTTt conditions. Final target accuracy was significantly lower than first target accuracy in the TDT condition, $\underline{t}$ (17) = 6.28, $\underline{p} < .001$, and in the TTT condition, $\underline{t}$ (17) = 2.59, $\underline{p} < .02$, but, unlike the unconditional data, this difference was not significant in the TTTt condition, $\underline{t}$ (17) = 0.38, $\underline{p} > .71$. Separate Position x Condition analyses were significant both when comparing TTTt and TTT conditions, $\underline{F}(1, 17) = 8.66$, $\underline{p} < .01$, $\eta^2 = .36$, and TTTt and TDT conditions, $\underline{F}(1, 17) = 34.28$, $\underline{p} < .001$, $\eta^2 = .67$. These interactions confirm that performance was better in the TTTt condition than either the TDT or TTT conditions.

The chief goal of Experiment 3 was to examine whether a task switch alone would impair extended sparing or leave it relatively unaffected, as is the case with lag-1 sparing. The results showed that a task switch did little to impair extending sparing, supporting the case for common mechanisms across sparing types. As in earlier experiments, calculating conditional accuracy values seemed to diminish the magnitude of extended sparing in the TTT condition, consistent with the claim that resource tradeoffs are a key requirement for sparing. Interestingly, however, more sparing was found in the TTTt condition when conditional scores were calculated. This pattern likely arose because in the unconditional calculations, third target accuracy is frequently based on trials where observers errantly misjudged the order of digits and thus made their odd/even decision about the wrong digit. On the other hand, when accuracy is calculated conditionally, it guarantees that the first two digits have been correctly identified and thus that the odd/even judgment is made on the correct third item (thereby improving overall third-target performance).

Before leaving the issue of whether a task switch impairs third target performance, however, an alternative option must be considered. Namely, it is possible that differences in task difficulty masked an adverse impact of the task switch on performance. To whit, even if the task switch impaired target processing in the TTTt condition, this might go unnoticed if the odd/even judgment in the TTTt condition was easier than the identification task in the TTT condition, thus buoying T3 performance. To test this possibility, it is necessary to compare performance in the TTTt condition to a condition with two central targets separated by a single distractor where the final target also requires an odd/even judgment (TDTt). If the task switch does not interfere with extended sparing then third-target accuracy in the TTTt condition should be significantly better than in the TDTt condition, where a robust AB would be expected.

Experiment 4: Task Switch Only (TTTt vs. TDTt)

Participants. Nineteen participants (15 female) were recruited in the same manner as Experiment 1. All participants reported normal or corrected-to-normal vision, and none had participated in the previous studies.

Apparatus and Stimuli. Apparatus and stimuli were identical to Experiment 3, except that pseudo-letter distractors were employed as in Experiment 2.

Procedure. The TTT and TTTt conditions were identical to Experiment 3. In the TDT task switch (TDTt) condition, presentation conditions were identical to those in the TTTt condition, except that the item intervening between targets was replaced with a distractor as in the TDT condition of earlier experiments. All other aspects of Experiment 4 were identical to Experiment 3.

Unconditional Data. Mean percentage target accuracy was 86,19, 91.68, and 84,78 in the TTT condition [comparison between targets: $F(2, 32) = 3.96$, $p < .03$, $\eta^2 = .20$], 80.62, 75.45, and 61.33 in the TTTt condition [comparison between targets: $F(2, 32) = 32.23$, $p < .001$, $\eta^2 = .67$], and 93.64 and 77.09 in the TDTt condition. As in Experiment 3, there was evidence for spared performance in the TTT condition. However, the data also revealed impairments for the final target in both the TTTt and TDTt conditions. To analyze these effects, accuracy scores for the first and final position were analyzed in a 2 (Target Position) x 3 (Condition: TDTt, TTT, TTTt) within-subjects ANOVA. The results (see Figure 4) revealed significant main effects of Position, $F(1, 16) = 37.25$, $p < .001$, $\eta^2 = .70$, indicating that final target accuracy was generally lower than first target accuracy, and Condition, $F(2, 32) = 27.01$, $p < .001$, $\eta^2 = .63$, indicating that performance was worse in the TTTt and TDTt conditions than in the TTT condition. Finally, there was also a significant interaction between Position and Condition, $F(2, 32) = 23.95$, $p < .001$, $\eta^2 = .60$.

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Insert Figure 4 about here

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In order to interpret this interaction, we conducted separate t-tests to compare first and final target accuracy in the TDTt, TTT, and TTTt conditions. Final target accuracy was significantly lower than first target accuracy in the TDTt condition, t (16) = 7.35, $p < .001$, and TTTt condition, t (16) = 8.56, $p < .001$, but not in the TTT condition, t (16) = 0.45, $p > .66$. Indeed, inspection of Figure 4 suggests a similar AB was obtained in the TTTt and TDTt conditions, while TTTt performance was much poorer than in the TTT condition. Consistent with this conclusion, separate Position x Condition analyses were non-significant when comparing TTTt and TDTt conditions, $F(1, 16) = 1.32$, $p > .26$, $\eta^2 = .08$, but were significant when comparing the TTTt and TTT conditions, $F(1, 16) = 54.61$, $p < .001$, $\eta^2 = .77$.

Conditional Data. Mean percentage target accuracy was 86.19, 92.06, and 81.86 in the TTT condition [comparison between targets: $F(2, 32) = 5.25$, $p < .02$, $\eta^2 = .25$], 80.62, 71.98, and 73.49 in the TTTt condition [comparison between targets: $F(2, 32) = 4.76$, $p < .02$, $\eta^2 = .23$], and 93.64 and 78.40 in the TDTt condition. As in Experiment 3, the conditional data showed significantly better final target performance in the TTTt condition compared to the unconditional data. As a result, in stark contrast to the unconditional data, there was evidence for sparing in the TTTt and TTT conditions. To confirm this, accuracy scores were analyzed in a 2 (Target Position) x 3 (Condition) within-subjects ANOVA. The results revealed significant main effects of Position, $F(1, 16) = 10.49$, $p < .01$, $\eta^2 = .40$, indicating that final target accuracy was significantly worse than first-target accuracy, a main effect of Condition, F (2, 32) = 8.38, $p < .01$, $\eta^2 = .34$, indicating performance was lower in the TTTt and TDTt conditions than in the TTT condition, and a significant interaction between Position and Condition, $F(2, 32) = 6.28$, $p < .01$, $\eta^2 = .28$.

In order to interpret the Position x Condition interaction, we conducted separate t-tests to compare first and final target accuracy in the TDT, TTT, and TTTt conditions. Final target accuracy was significantly lower than first target accuracy in the TDTt condition, t (16) = 5.94, $p < .001$, but only marginally lower in the TTTt condition, t (16) = 2.10, $p > .05$, and no different in the TTT condition, t (16) = 1.13, $p > .27$. Separate Position x Condition analyses confirmed that similar performance was found in the TTTt and TTT conditions, $F(1, 16) = 0.98$, $p > .33$, $\eta^2 = .06$, while performance was significantly better in the TTTt condition than the TDTt condition, $F(1, 16) = 7.03$, $p < .02$, $\eta^2 = .31$.

Experiment 4 examined whether the failure to find an effect of a task switch on extended sparing in Experiment 3 was due to switching to an easier task. To do this, we compared performance in a TDTt condition, where an AB was expected to occur, with the TTTt condition used in Experiment 3 where evidence for relatively extended sparing was obtained. Because these conditions had identical final tasks, any relative benefits for final target accuracy in the TTTt condition would indicate extended sparing. Surprisingly, the results yielded contradictory findings: unconditional analysis of target accuracy suggested a task switch eliminated sparing, with both the TTTt and TDTt conditions showed a similar AB, while conditional data analysis suggested sparing occurred in the TTTt condition.

Close inspection of the data, however, suggests a simple explanation for this discrepancy that neatly affirms the findings from Experiment 3. Both here and in Experiment 3, T3 performance was greater when accuracy was calculated conditionally than when it was not. This is because the conditional analysis guaranteed that participants' scores reflected odd/even judgments made on the correct digit, whereas performance suffered in the unconditional analysis, which included trials where participants errantly misperceived the order of digits and thus made their judgment about the wrong item. This fact is critically important in interpreting the present results because the critical comparison is between the TTTt condition where errant misperceptions of target order are likely to be frequent, and the TDTt condition where misperceptions of order are quite infrequent. In light of this, to truly equate final target conditions in the TTTt and TDTt conditions, conditional accuracy scores must be used in order to eliminate the unequal contribution of order confusions to performance. When this is done, it is clear that TTTt accuracy is considerably spared relative to TDTt accuracy. This replicates the principal finding of Experiment 3, and shows that as with lag-1 sparing, extended sparing is unaffected by a single switch in task alone.

Experiment 5a: Category Switch Only

In Experiment 5, we examined the impact of introducing a category switch on extended sparing, by changing the final target in the sequence from a digit to a letter. Previous research has suggested that such switches do not interfere with lag-1 sparing (Visser et al., 1999). The goal here was to determine whether this result also would be obtained for extended sparing.

Participants. Sixteen participants (14 female) were recruited as in Experiment 2. All participants reported normal or corrected-to-normal vision and none had participated in the previous studies.

Apparatus and Stimuli. Apparatus and stimuli were identical to Experiment 2.

Procedure. The TDT and TTT conditions were identical to Experiment 1. In the TTT category switch (TTTc) condition, the final target was changed from a digit to a letter. As in Experiment 2, we used pseudoletters as distractors. We also employed the same six letters as targets that were used in Experiment 2 (although the task was to identify these letters). All other aspects of Experiment 4 were identical to Experiment 1.

Results

Unconditional Data. Mean percentage target accuracy was 88.48, 93.53, and 89.07 in the TTT condition [comparison between targets: F(2, 30) = 3.14, $p < .06$, $\eta^2 = .17$], 87.06, 94.56, and 75.10 in the TTTc condition [comparison between targets: F(2, 30) = 18.84, $p < .001$, $\eta^2 = .56$], and 97.01 and 90.92 in the TDT condition. The results in the TDT and TTT conditions were similar to those in previous experiments. Surprisingly, however, third target accuracy in the TTTc condition seemed to show a marked decline. To confirm this impression, accuracy scores were analyzed in a 2 (Target Position) x 3 (Condition: TDT, TTT, TTc) within-subjects ANOVA. The results (see Figure 5) revealed significant main effects of Position, F(1, 15) = 14.86, $p < .01$, $\eta^2 = .50$, indicating that final target accuracy was generally lower than first target accuracy, and Condition, F(2, 30) = 19.47, $p < .001$, $\eta^2 = .57$. Follow-up comparisons indicated that overall performance differed significantly between all three conditions ($p < .01$). Finally, there was a significant Position x Condition interaction, F(2, 30) = 5.11, $p < .02$, $\eta^2 = .25$.

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Insert Figure 5 about here

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In order to interpret this interaction, we conducted separate t-tests to compare first and final target accuracy in the TDT, TTT, and TTTc conditions. Final target accuracy was significantly lower than first target accuracy in the TDT condition, t (16) = 3.65, $p < .01$, but not in the TTT condition, t (16) = 0.23, $p > .82$. Moreover, as can be seen in Figure 4, final target accuracy was also significantly reduced in the TTTc condition, t (16) = 3.37, $p < .01$, suggesting a robust AB of similar magnitude to the TDT condition. Consistent with this conclusion, separate Position x Condition analyses were significant when comparing TTTc and TTT conditions, F(1, 15) = 10.44, $p < .01$, $\eta^2 = .41$, indicating a significant increase in AB magnitude when a category switch was present, but not significant when comparing the TTTc and TDT conditions, F(1, 15) = 1.70, p > .21, η^2 = .10, suggesting a similar AB magnitude.

Conditional Data. Mean percentage target accuracy was 88.48, 93.24, and 88.43 in the TTT condition [comparison between targets: F(2, 30) = 2.97, p < .07, η^2 = .17], 87.06, 94.69, and 75.09 in the TTTc condition [comparison between targets: F(2, 30) = 18.28, p < .001, η^2 = .55], and 97.01 and 90.78 in the TDT condition. A 2 (Target Position) x 3 (Condition) within-subjects ANOVA showed a significant main effect of Position, F(1, 15) = 16.26, p < .01, η^2 = .52, indicating that third target accuracy was significantly worse than first-target accuracy. There was also a significant effect of Condition, F(2, 30) = 18.56, p < .001, η^2 = .55. Follow-up analyses showed that overall accuracy was significantly different between all three conditions (p < .01). Finally, there was a significant interaction between Position and Condition, F(2, 30) = 4.48, p < .03, η^2 = .23.

Separate t-tests to compare first and final target accuracy in the TDT, TTT, and TTTc conditions showed that final target accuracy was significantly lower than first target accuracy in the TDT condition, t (15) = 3.61, p < .01, and in the TTTc condition, t (15) = 3.35, p < .01, but not in the TTT condition, t (15) = 0.02, p > .98. Again, the indication that a significant AB was obtained in the TTTc condition was supported by a significant Position x Condition interaction when comparing TTTc and TTT conditions, F(1, 15) = 9.07, p < .01, η^2 = .38, but not when comparing TTTc and TDT conditions, F(1, 15) = 1.57, p > .22, η^2 = .10. The first interaction confirms the AB was greater in the TTTc condition than in the TTT condition, while the second interaction confirms that the AB was statistically indistinguishable in the TTTc and TDT conditions.

The present results represent the first departure between the effect of an attentional switch on lag-1 sparing and extended sparing. This opens up the possibility that these two types of sparing could be mediated by different mechanisms. However, before considering this option in more detail, it is important to confirm that a category switch alone would not interfere with lag-1 sparing under our experimental conditions. If this were the case, then the results of earlier experiments would be reaffirmed, suggesting that both extended sparing and lag-1 sparing are mediated by the same mechanisms. To investigate these options, in Experiment 5b, we compared four conditions: two digit targets (TT; expected to yield lag-1 sparing), a digit and a letter target (TTc), three digit targets (TTT), and two digit targets and a letter target (TTTc). The final two conditions were identical to those in Experiment 5a, and allowed an opportunity to replicate these findings. The first two conditions allowed us to test the impact of a category switch on lag-1 sparing under the current experimental conditions.

Experiment 5b: Category Switch in Lag-1 sparing & Extended sparing

In Experiment 5b, we examined the impact of introducing a category switch on both extended and lag-1 sparing, by changing the final target in a two- or three-target sequence from a digit to a letter. This was designed to determine whether the significant impact of this switch on extended sparing shown in Experiment 5a would also be found when evaluating lag-1 sparing. If this were the case, it would suggest that both types of sparing are mediated by similar mechanisms.

Participants. Seventeen participants (12 female) were recruited as in Experiment 5a. All participants reported normal or corrected-to-normal vision, and none had participated in the previous studies.

Apparatus and Stimuli. Apparatus and stimuli were identical to Experiment 5a.

Procedure. There were 400 trials evenly divided between four blocks corresponding to each experimental condition. The TTT and TTTc conditions were identical to Experiment 5a. The TT and TTc conditions were similar to these conditions as well, but consisted of two consecutive targets, rather than three. All other aspects of Experiment 5b were identical to Experiment 5a.

Results

Unconditional Data. Mean percentage target accuracy was 89.78, 94.18, and 90.33 in the TTT condition [comparison between targets: $F(2, 32) = 6.26$, $p < .01$, $\eta^2 = .28$], 89.78, 93.54, and 74.24 in the TTTc condition [comparison between targets: $F(2, 32) = 16.53$, $p < .001$, $\eta^2 = .51$], 96.34 and 97.58 in the TT condition, and 94.73 and 89.59 in the TTc condition. As was the case in Experiment 5a, examination of this data suggests that the category switch yielded poorer target accuracy. To clarify this impression, accuracy scores for TT and TTc conditions were first analyzed in a 2 (Target Position) x 2 (Condition) within-subjects ANOVA. The results (see Figure 6, left panel) revealed a marginally-significant main effect of Position, $F(1, 16) = 4.18$, $p < .06$, $\eta^2 = .21$, indicating overall second-target performance was lower than first-target performance, and a significant main effect of Condition, $F(1, 16) = 19.63$, $p < .001$, $\eta^2 = .55$, indicating that overall performance was worse in the TTc condition. There was also a significant Position x Condition interaction, $F(1, 16) = 18.60$, $p < .01$, $\eta^2 = .54$. Follow-up t-tests showed that the second target was identified more accurately than the first in the TT condition, t

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(16) = 2.50, $\underline{p} < .03$, while second target accuracy was significantly diminished in the TTc condition, $\underline{t}$ (16) = 3.15, $\underline{p} < .01$, indicating an AB deficit.

An identical ANOVA conducted on the TTT and TTTc conditions (see Figure 6; right panel) showed a significant main effect of Position, $\underline{F}(1, 16) = 6.39$, $\underline{p} < .03$, $\eta^2 = .29$, consistent with an overall drop in accuracy between the first and third targets. There was also a significant main effect of Condition, $\underline{F}(1, 16) = 20.05$, $\underline{p} < .001$, $\eta^2 = .56$, indicating that overall performance was worse in the TTTc condition. Finally, there was a significant Position x Condition interaction, $\underline{F}(1, 16) = 15.07$, $\underline{p} < .01$, $\eta^2 = .49$. Follow-up t-tests showed that there was no difference between first- and third-target accuracy in the TTT condition, $\underline{t}$ (16) = 0.38, $\underline{p} > .70$, indicating the presence of extended sparing, while there was a significant accuracy difference between these targets in the TTTc condition, $\underline{t}$ (16) = 3.17, $\underline{p} < .01$, indicating the presence of an AB.

Conditional Data. Mean percentage target accuracy was 89.78, 94.42, and 89.34 in the TTT condition [comparison between targets: $\underline{F}(2, 32) = 6.30$, $\underline{p} < .01$, $\eta^2 = .28$], 89.78, 95.30, and 74.04 in the TTTc condition [comparison between targets: $\underline{F}(2, 32) = 15.59$, $\underline{p} < .001$, $\eta^2 = .49$], 96.34 and 97.57 in the TT condition, and 94.73 and 90.74 in the TTc condition. A 2 (Target Position) x 2 (Condition) within-subjects ANOVA revealed a non-significant main effect of Position ($\underline{p} > .15$), and a significant main effect of Condition, $\underline{F}(1, 16) = 19.94$, $\underline{p} < .001$, $\eta^2 = .56$, indicating that overall performance was worse in the TTc condition (see Figure 5; left panel). There was also a significant Position x Condition interaction, $\underline{F}(1, 16) = 13.67$, $\underline{p} < .01$, $\eta^2 = 46$. Follow-up t-tests showed that the second target was identified more accurately than the first in the TT condition, $\underline{t}$ (16) = 2.42, $\underline{p} < .03$, while there was a significant AB in the TTc condition, $\underline{t}$ (16) = 2.54, $\underline{p} < .03$.

An identical ANOVA conducted on the TTT and TTTc conditions showed a significant main effect of Position, F(1, 16) = 6.45, $p < .03$, $\eta^2 = .29$, indicating an overall drop in accuracy between the first and third targets (see Figure 5; right panel). There was also a significant main effect of Condition, F(1, 16) = 17.77, $p < .01$, $\eta^2 = .53$, indicating that overall performance was worse in the TTTc condition. Finally, there was a significant Position x Condition interaction, F(1, 16) = 14.35, $p < .01$, $\eta^2 = .47$. Follow-up t-tests showed that there was no difference between first- and third-target accuracy in the TTT condition, t (16) = 0.26, $p > .79$, indicating the presence of extended sparing, while there was a significant accuracy difference between these targets in the TTTc condition, t (16) = 3.10, $p < .01$, indicating the presence of an AB.

The results of Experiment 5b clearly show that a category switch between targets interfered with both lag-1 sparing and extended sparing. As in Experiments 1-3, this pattern of results is consistent with an account of both types of sparing in terms of common mechanisms (e.g. Di Lollo et al., 2005; Olivers & Meeter, 2008). On a different note, the fact that a category switch alone eliminated lag-1 sparing in Experiment 5b is inconsistent with the meta-analysis of lag-1 sparing reported by Visser et al. (1999). A closer examination of this earlier paper, however, shows that only five experiments in their corpus employed a category switch alone (by comparison, 44 papers reviewed had no switch, 16 had a location switch, 12 had a task switch, and 33 had multiple switches). Moreover, of these five experiments, one did show a small decrement in performance at Lag 1 relative to later lags (i.e., an absence of lag-1 sparing; Duncan, Martens, & Ward, 1997). Thus, it may be that the failure to find evidence for an effect of a category switch on lag-1 sparing in Visser et al. (1999) stems from a lack of power, rather than the actual absence of such an effect. This suggests a fruitful area for future investigations.

GENERAL DISCUSSION

Despite the vast processing resources at our disposal, we often suffer from an inability to process multiple sensory inputs. This is clearly illustrated in the attentional blink: a failure to consciously identify the second of two sequential targets when they are separated by less than about 500 ms. Paradoxically, however, many published reports have shown that both targets can be identified with high accuracy when they follow one another directly – a phenomenon known as lag-1 sparing (Potter et al., 1998; Visser et al., 1999) – and that such sparing can be "extended" to four or five consecutive targets under some conditions (Olivers et al., 2007).

To explain this, a number of recent papers have proposed a unified account for both lag-1 sparing and extended sparing (e.g., Di Lollo et al., 2005; Olivers & Meeter, 2008; Taatgen et al., 2009; Wyble et al., 2009), arguing that they spring from a common set of mechanisms. The present paper tested this assertion by examining the effect of various types of attentional switches on extended sparing. This work follows directly from a review of lag-1 sparing by Visser et al. (1999) which examined how switches in target position, task, category, modality, and combinations of these switches, impacted the occurrence of lag-1 sparing. We reasoned that if common mechanisms underlie both extended sparing and lag-1 sparing that attentional switches should exert identical effects on both phenomena.

Across five experiments, we found a high degree of uniformity between the impact of switches on lag-1 sparing and extended sparing. As with lag-1 sparing, multiple switches (task and category) as well as switches in location only eliminated extended sparing. Similarly, a switch in task alone failed to eliminate extended sparing, as is true with lag-1 sparing. The one surprise result here was that a category switch alone eliminated both types of sparing (Experiment 5B). This is consistent with suggestions that sparing is supported by a common set of mechanisms, but refutes the claim by Visser et al. (1999) that a category switch alone does not eliminate lag-1 sparing. The reasons for this discrepancy may simply come down to a limited corpus of studies reviewed by Visser et al. (1999) who reviewed only five instances of a category switch in isolation, one of which failed to yield lag-1 sparing. The results of Experiment 5B are also important in that they provide direct evidence for a common mechanism underlying lag-1 sparing and extended sparing. That is, the same group of participants showed identical effects of a category switch on both types of sparing. This bolsters the indirect evidence obtained for common mechanisms from the other experiments where participants did not complete a comparable lag-1 sparing condition.

In sum, the evidence here strongly supports the view that lag-1 sparing and extended sparing are attributable to the same mechanisms. In the following section, we consider the implications of this conclusion for understanding the mechanisms underlying sparing, and the relationship between sparing and resource tradeoffs. We also discuss how the present results impact theories of temporal object perception more generally.

The relationship between extended sparing and resource tradeoffs

In a recent paper, Dell'Acqua and colleagues (2009) showed suggestive evidence that extended sparing depends substantially on participants allocating fewer resources to early targets in favour of those later in the stream. Specifically, they found that third target performance dropped precipitously under Uniform presentation conditions when T3 accuracy was conditionalized on accurate identification of prior targets in the sequence. Previous extended sparing studies, such as those of Di Lollo and colleagues, have calculated unconditional accuracy scores for each target. In contrast, in conventional AB studies, it is common practice to calculate conditional scores on the grounds that this ensures that only trials where participants attended to T1 are analyzed. It follows from this logic then that the spared performance seen when unconditional accuracy was calculated may have been at least partially due to trials where prior targets were missed and therefore may not have been attended (i.e., had resources allocated to them).

The present results generally showed a less striking impact of calculating conditionalized accuracy scores on the magnitude of extended sparing than those demonstrated by Dell'Acqua et al. (2009). We suspect that this stems from the fact that T1 accuracy was quite high (~80-90%) compared to Dell'Acqua et al. (2009) where accuracy was in the 70-80% range, thus offering more opportunity for conditionalized and unconditionalized accuracy scores to diverge. Though smaller, however, in each experiment, T3 accuracy was reliably lower for conditionalized than unconditionalized scores in the TTT condition.

There is other evidence for the impact of resource tradeoffs on extended sparing in our data as well. Recent reports by Dux and colleagues (Dux et al., 2008, 2009) showed that emphasizing T1 processing by making it "pop-out" from the RSVP stream with a unique colour increased T1 accuracy and reduced T3 accuracy (Dux et al., 2008; see also Dux & Harris, 2007). They showed similar results when they manipulated resource allocation by task instructions: participants instructed to report T1 on all trials and T2 and T3 on some trials showed poorer T3 accuracy and better T1 accuracy than those instructed to report T3 on all trials and T1 and T2 on some trials (Dux et al., 2009). These findings are similar to those reported here. When comparing data from the TDT and TTT conditions, in each experiment, T3 sparing in the TTT condition was reliably associated with a significant decline in T1 accuracy compared to the TDT condition. While this difference does not necessarily reflect a causal relationship between T1 and T3 (see Olivers, Spalek, Kawahara, & Di Lollo, 2009), it is nonetheless suggestive in light of evidence from other paradigms that such tradeoffs do occur (Dux et al., 2008, 2009) and given the existing evidence for tradeoffs obtained here by comparing conditionalized and unconditionalized T3 scores.

The discussion of resource tradeoffs above also serves to highlight another commonality between extended sparing and lag-1 sparing: namely, they are both characterized by the frequent occurrence of resource tradeoffs. In the context of lag-1 sparing, this can be seen in numerous examples where sparing for T2 is accompanied by reduced T1 accuracy compared to later lags (e.g., Ferlazzo, Lucido, Di Nocera, Fagioli, & Sdoia, 2007; Dell'Acqua, Jolicoeur, Pascali, & Pluchino, 2007, Olivers & Nieuwenhuis, 2006; Akyurek & Hommel, 2005; Visser, Boden, & Giaschi, 2004; Visser, Davis, & Ohan, 2009). Such tradeoffs are also key to the success of the eSTST model of the AB (Wyble et al., 2009) which simulates weak interference between coactive type nodes to provide for competition amongst consecutive targets as they race to be bound to a specific token. This interference is essential for correctly simulating the empirically observed reduction in T1 accuracy that accompanies lag-1 sparing and extended sparing (Wyble et al., 2009). In sum, the presence of resource tradeoffs in both lag-1 and extended sparing suggests these tradeoffs are integrally linked to these phenomena.

An explanation for extended sparing

In coming to an explanation for why sparing occurs in temporal object perception, we believe two key points must be taken into account. First, although resource tradeoffs may not necessary for sparing to occur, they clearly occur with great frequency, and they do seem to impact the magnitude of sparing. Second, as suggested by the present work, common mechanisms underlie lag-1 sparing and extended sparing. Consideration of these points leads us to suggest that the conventional account for lag-1 sparing, based on the notion of a sluggish attentional gate whose entry is controlled by an input filter (Raymond & Shapiro, 1994; Chun & Potter, 1995; Visser et al., 1999; Visser, Bischof, & Di Lollo, 2004), is also the best candidate for providing a unified account for sparing in temporal perception more generally.

The suggestion that consecutive targets may enter the same attentional gate has its origins in early AB theories of Shapiro and colleagues (Raymond & Shapiro, 1994) and has been adopted by many subsequent theories of temporal object perception (e.g., Chun & Potter, 1995; Jolicoeur & Dell'Acqua, 1998; Olivers & Meeter, 2008). Although this explanation has been criticized for being ad-hoc in the context of AB theorizing (Di Lollo et al., 2005), the notion that attention might be deployed slowly across rapid sequential inputs builds upon repeated demonstrations of the visual system's poor temporal resolution. These limits are manifest in relatively low-level visual phenomena such as integration masking (Turvey, 1973), and visible persistence (e.g., Di Lollo, 1980; Coltheart, 1980), and are also hinted at in failures of object awareness such as object substitution masking (Di Lollo Enns, & Rensink, 2000; Goodhew, Visser, Lipp, & Dux, in press) and repetition blindness (Kanwisher, 1987; Chun, 1997; Morris & Harris, 2004).

An additional bonus of postulating that a sluggish attentional gate operates during sequential object perception is that it provides a natural explanation for resource tradeoffs found here and elsewhere (e.g., Dux et al., 2008, 2009; Dell'Acqua et al., 2009). Namely, when multiple objects simultaneously gain access to high level processing, they must compete for limited available resources. In the context of lag-1 sparing, this competition would naturally explain why T2 performance at lag 1 is improved, but often is not as good as outside the "blink" period (typically a lag of around 700 ms) where there is no competition for resources. It also accounts for why T1 performance at lag 1 is typically less accurate than at later lags, where again there is no competition for resources. This idea is also compatible with demonstrations of Dux and colleagues that prioritizing targets leads to differential performance, as establishing such priorities would presumably involve differential resource allocation to items that pass the attentional gate.

Finally, the very existence of the AB deficit makes it clear that although a gate or input filter may exist that can admit consecutive targets, not all items are admitted through this egress. Rather, the present experiments make the general case that items must possess certain similarities to pass the same gate. Namely, they must share a common task, and spatial location (although perhaps spatial region may be more apt; see for example Jefferies et al., 2007; Williams et al., 2008; Lunau & Olivers, 2010). In contrast, items that are different across multiple dimensions such as category and task, or possibly in category only, are not able to pass a common gate. The existence of such contingencies provides strong support for the notion that a simple attentional gate is not sufficient to explain the occurrence of sparing.

Implications for current theories of the AB

The experiments here were designed to investigate whether current theories of sparing in temporal object perception were warranted in assuming common mechanisms for conventional lag-1 sparing and extended sparing up to four or five consecutive items. To this question, our work indicates a clear affirmative. However, the phenomenon of extended sparing has also spawned several accounts of the AB phenomenon more generally that refute conventional models based on capacity-limitation (e.g., Chun & Potter, 1995; Giesbrecht & Di Lollo, 1998; Jolicoeur & Dell'Acqua, 1998) and which have been the subject of extensive debate. This includes the TLC account of Di Lollo and colleagues (Di Lollo et al., 2005; Kawahara et al., 2006ab), the "boost-and-bounce" model of Olivers & Meeter (2008), and the eSTST model of Wyble and colleagues (Wyble et al., 2009). One might naturally wonder, then, whether our results have any bearing on this discussion.

Although our experiments do not contribute novel direct evidence to this debate, there are several elements that may be germane: in particular, our replication of the results of Dell'Acqua et al., (2009) showing that calculating conditional third target accuracy attenuated extended sparing. The apparent importance of resource allocation to prior targets in moderating extended sparing is inconsistent with models that propose no role for capacity-limitations in the AB (e.g., Olivers & Meeter, 2008). However, it may be explained in the eSTST model by the inhibitory effect of target encoding on the "blaster" (effectively a capacity limit on stimulus encoding; Wyble et al., 2009) and in the TLC account, which posits capacity limits on input filtering. That said, with respect to the TLC model, it is unclear whether failures of extended sparing in the presence of attentional switches are explained by active disruption of the input filter settings (as suggested by the model) or simply by the closing of the attentional gate in response to an incongruent stimulus.

As discussed above, the repeated occurrence of third-target sparing accompanied by declines in first-target accuracy found in our extended-sparing experiments also points to resource tradeoffs. However, it is notable that the boost-and-bounce model can also simulate this specific pattern if it is assumed that the decline in T1 performance reflects a boost to later targets, rather than the negative effects of resource competition on T1 (Olivers & Meeter, 2008; see Figure 8). Does this imply that resource tradeoffs do not occur when processing consecutive targets? We suggest that although this account may explain declines in T1 accuracy in this particular context, it falls short of explaining similar patterns of tradeoffs in conventional experiments where T1 performance is impaired at lag 1 compared to later lags where targets are separated by distractors. Here, the boost account would suggest that T1 accuracy should remain constant across lags, while only T2 accuracy should change as a function of whether it is “boosted” or “bounced”. Thus, while the extended sparing case with multiple consecutive targets can be simulated in the absence of capacity limits, other evidence indicates that the reduction of T1 accuracy here also is likely to reflect the negative effects of resource tradeoffs.

Concluding comments

Recent work in the field of sequential object perception has demonstrated that participants may successfully identify as many as five consecutive targets with ease under some conditions, whereas they may fail to perceive even two targets under other conditions. The present work evaluated the rules that govern this “extended sparing” and showed that they are identical to those that account for a more established phenomenon of “lag-1 sparing”. This suggests a common underlying set of mechanisms can explain successful identification of sequential targets. The results here also argue for a role for capacity-limitation in failures of target recognition. Taken together, this implies a comprehensive model of sequential object perception may need to incorporate several explanatory notions including input filtering, attentional gating, and limited access to central resources in order to fully explain the phenomena.

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Author Notes

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Figure Captions

Figure 1. Mean target identification accuracy as a function of Target Position and experimental condition in Experiment 1. Dashed lines indicate accuracy scores calculated conditionally on accurate identification of previous target(s). Solid lines indicate unconditional accuracy scores. Error bars represent 95% within-subjects confidence intervals calculated as per Masson & Loftus (2003).

Figure 2. Mean target identification accuracy as a function of Target Position and experimental condition in Experiment 2. Dashed lines indicate accuracy scores calculated conditionally on accurate identification of previous target(s). Solid lines indicate unconditional accuracy scores. Error bars represent 95% within-subjects confidence intervals calculated as per Masson & Loftus (2003).

Figure 3. Mean target identification accuracy as a function of Target Position and experimental condition in Experiment 3. Dashed lines indicate accuracy scores calculated conditionally on accurate identification of previous target(s). Solid lines indicate unconditional accuracy scores. Error bars represent 95% within-subjects confidence intervals calculated as per Masson & Loftus (2003).

Figure 4. Mean target identification accuracy as a function of Target Position and experimental condition in Experiment 4. Dashed lines indicate accuracy scores calculated conditionally on accurate identification of previous target(s). Solid lines indicate unconditional accuracy scores. Error bars represent 95% within-subjects confidence intervals calculated as per Masson & Loftus (2003).

Figure 5. Mean target identification accuracy as a function of Target Position and experimental condition in Experiment 5A. Dashed lines indicate accuracy scores calculated conditionally on accurate identification of previous target(s). Solid lines

indicate unconditional accuracy scores. Error bars represent 95% within-subjects confidence intervals calculated as per Masson & Loftus (2003).

Figure 6. Mean target identification accuracy as a function of Target Position and experimental condition in Experiment 5B. Dashed lines indicate accuracy scores calculated conditionally on accurate identification of previous target(s). Solid lines indicate unconditional accuracy scores. The left panel depicts accuracy in the two-target conditions. The right panel depicts accuracy in the three-target condition. Error bars represent 95% within-subjects confidence intervals calculated as per Masson & Loftus (2003).

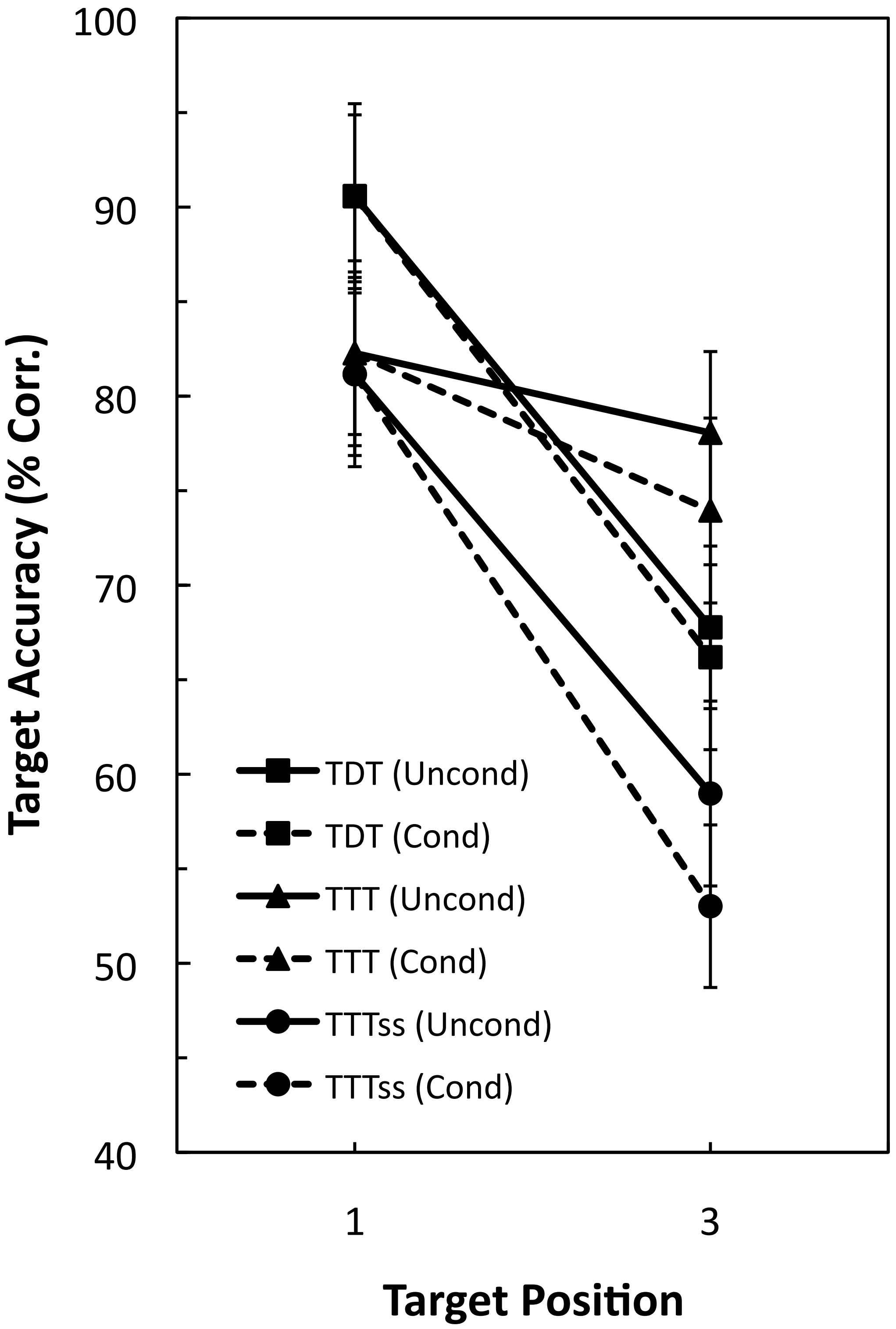
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Figure 1

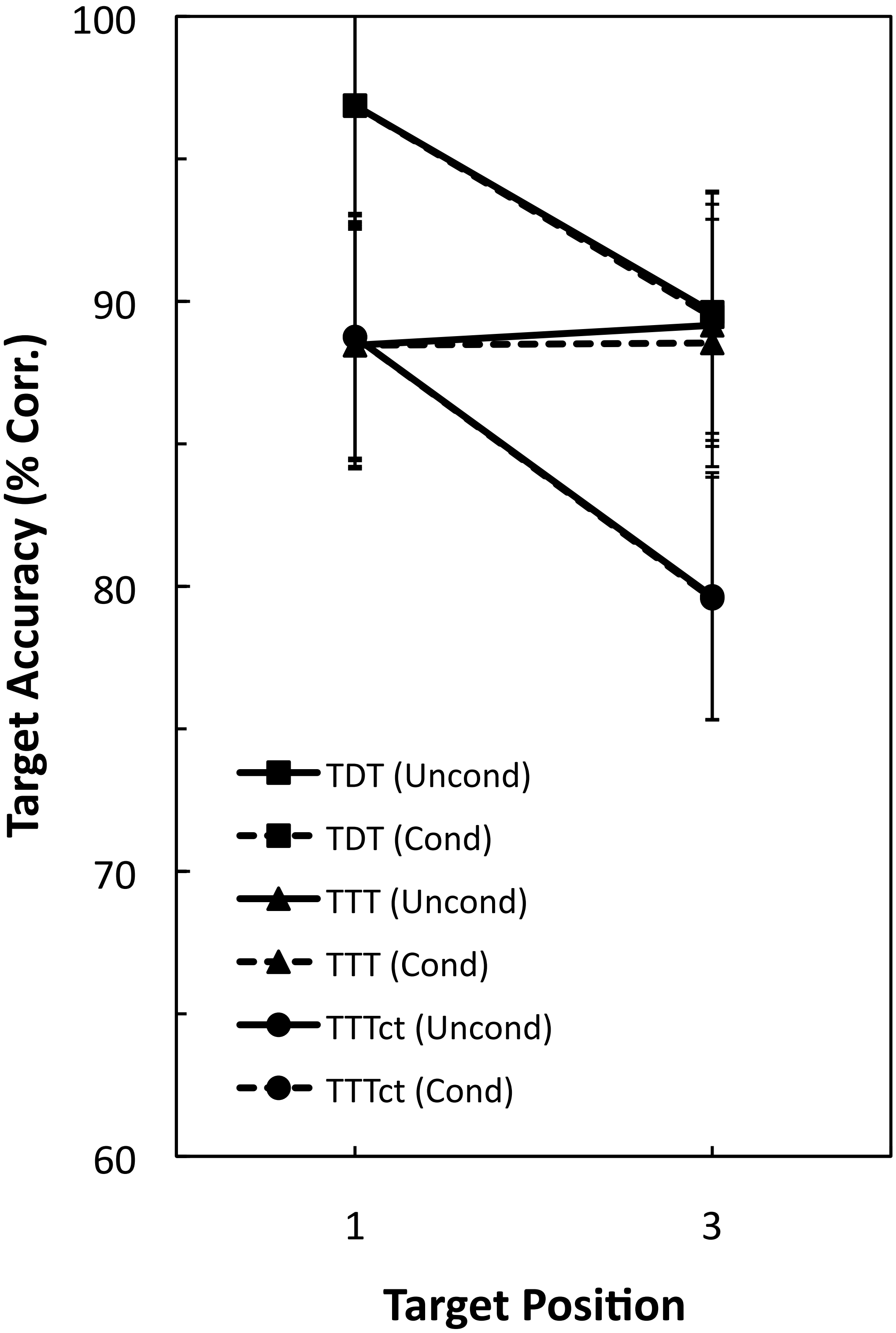
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Figure 2

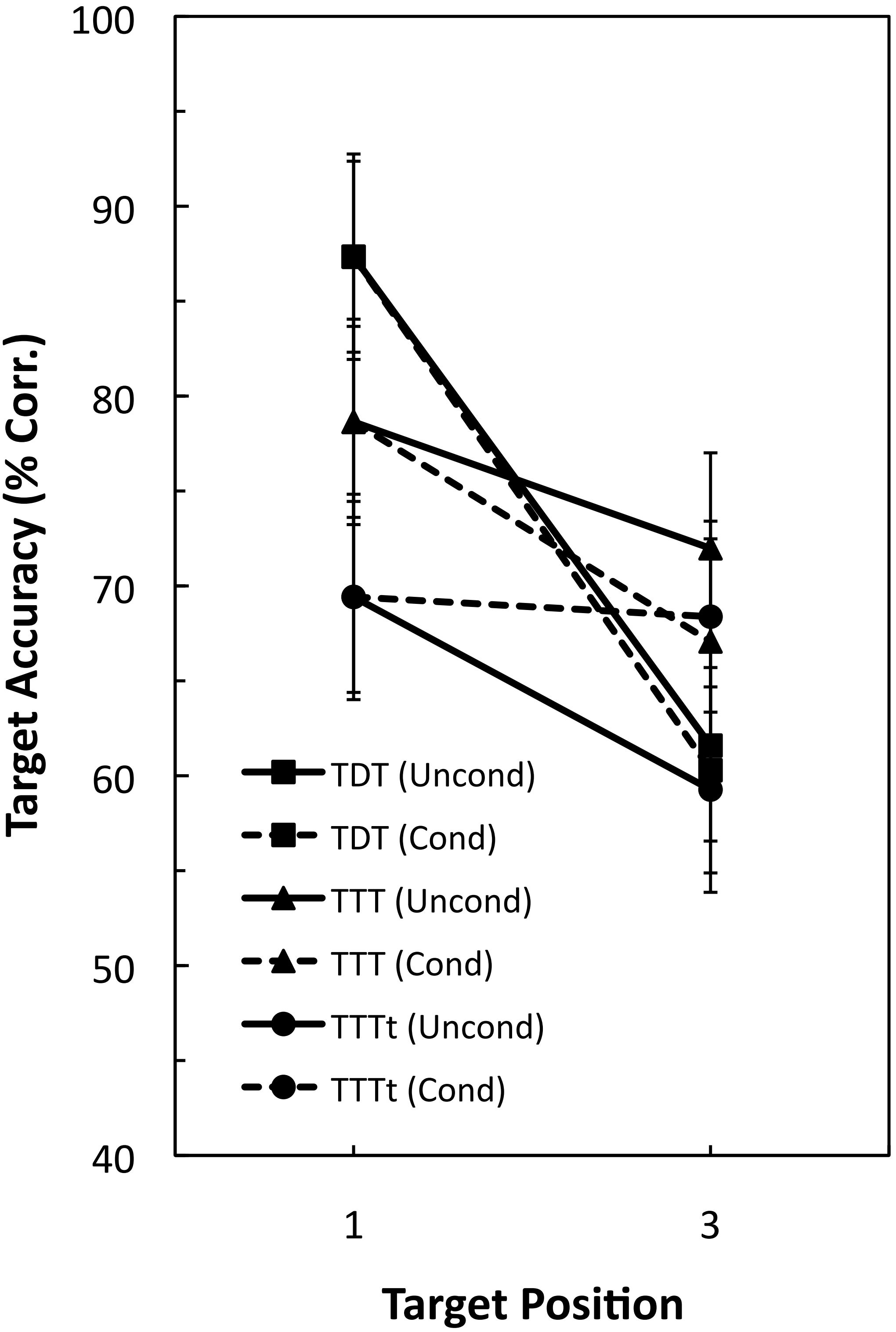
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Figure 3

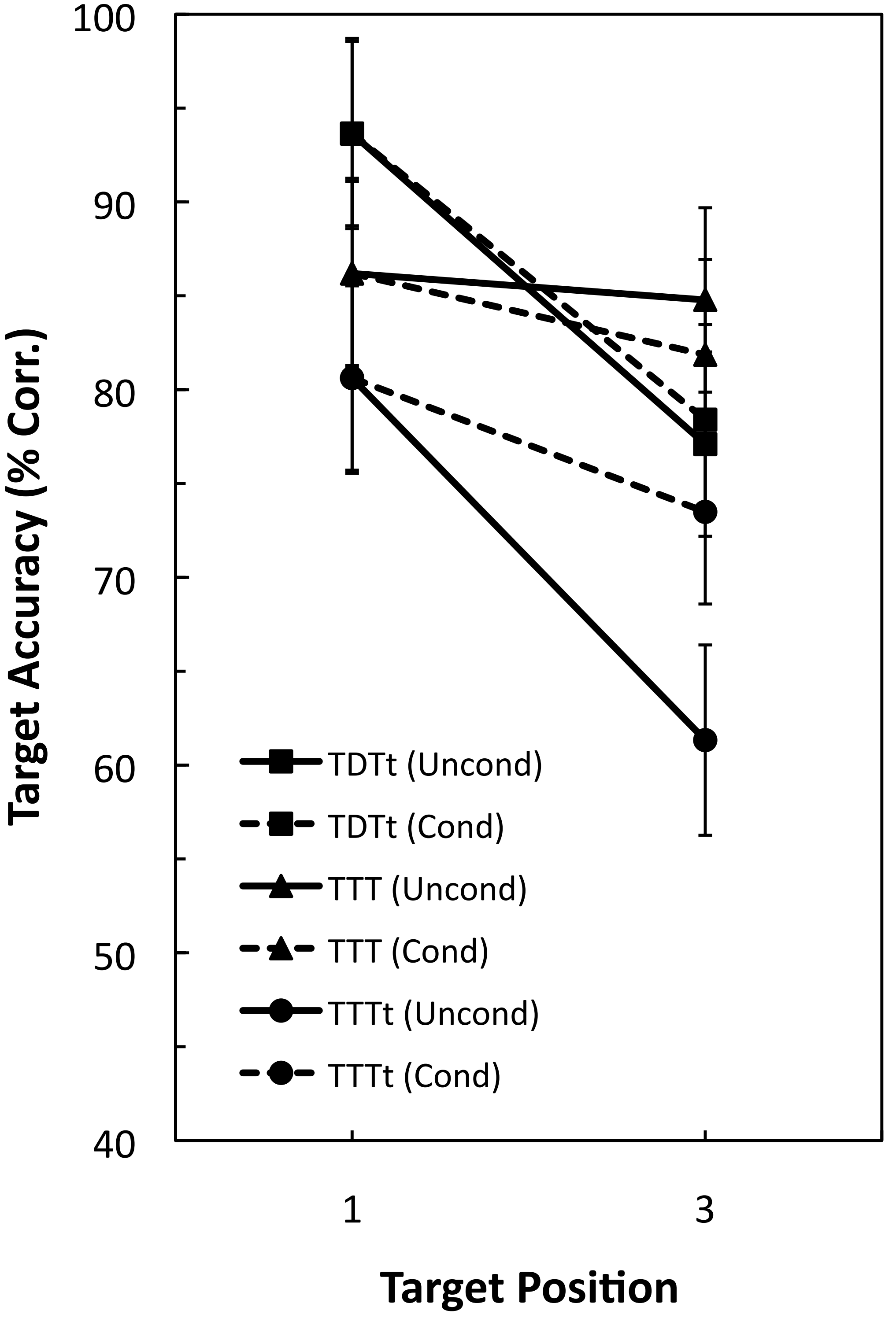
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Figure 4

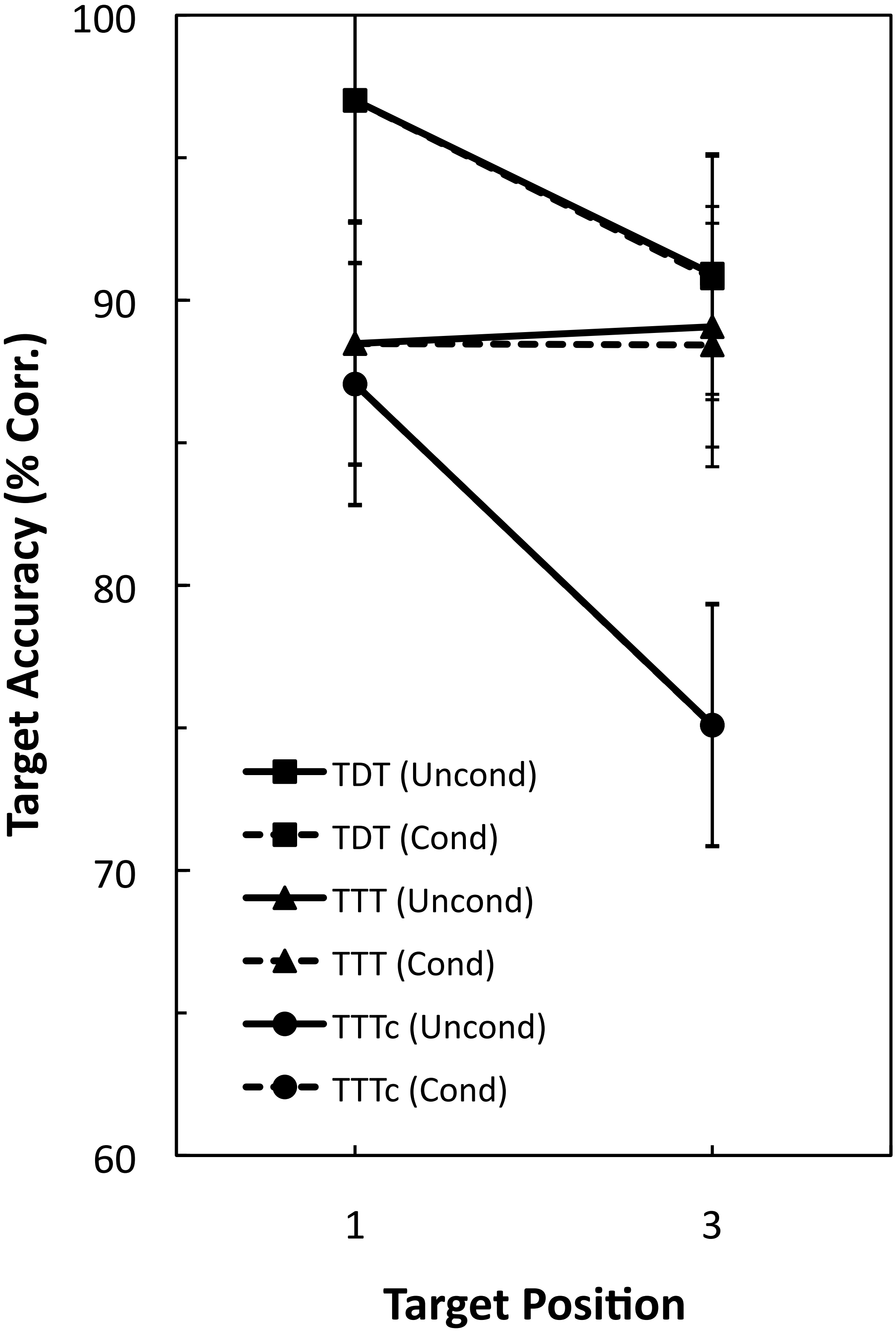
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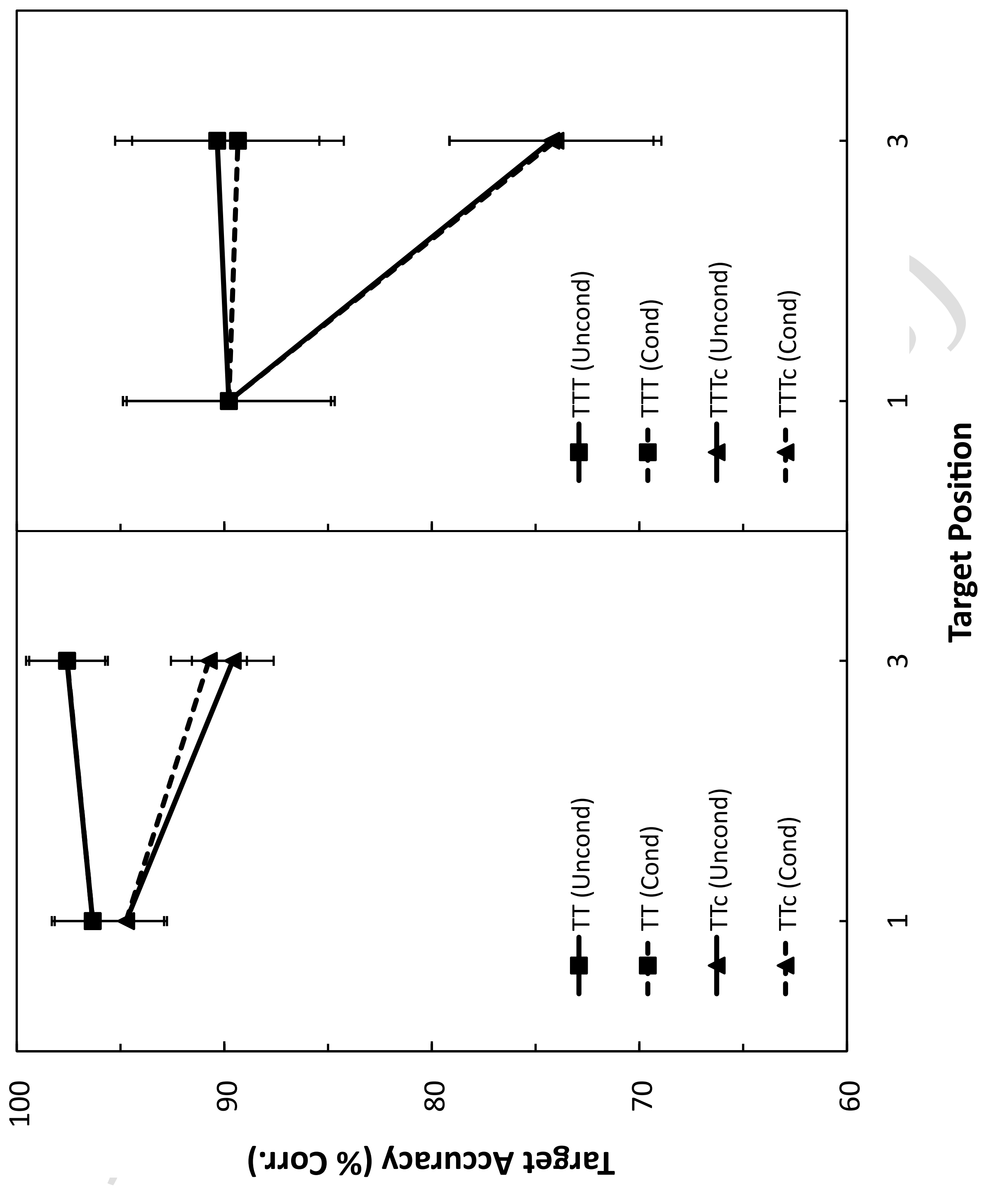
Figure 5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Target Position

Figure 6