Priming of Pop-out does not provide reliable measures of target activation and distractor inhibition in selective attention: Evidence from a large-scale online study

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Abstract

Lamy, Antebi, Aviani, and Carmel (2008) reported that in a simple search task where participants located an odd coloured circle, the inter-trial relations could be used to derive robust and independent measures of target activation and distractor inhibition. When a target feature repeated there was a benefit, and when the previous target feature became the distractor feature there was a cost. These two measures correlated and were taken to reflect a measure of target activation. When the distractor feature repeated there was a benefit and when the previous distractor feature became the current target feature there was a cost, these two measures correlated and were taken to reflect a measure of distractor inhibition. In the current study we examined the same colour search task online on a large group of 312 participants. The results revealed significant effects of target and distractor repetition and switching. However, the correlations reported by Lamy et al. (2008) were non-significant. Instead we found the correlations between the two measures of repetition and the two measures of switching.

The visual environment presents the human visual system with a vast amount of information; more information than can be fully processed at any one time (Broadbent, 1958; Tsotos, 1990). As a consequence, effective human behaviour requires mechanisms that enable efficient selection of relevant stimuli for detailed processing; collectively known as selective attention. The visual search task in which an observer must find a target amongst a set of irrelevant distractors has been used extensively as a tool to characterise these mechanisms of selective attention. In particular, the relative contribution of positive activation of potential targets and negative inhibition of distractors to efficient target selection have been extensively debated (see, Dent, Allen, Braithwaite, & Humphreys, 2012 for a review). Some authors (e.g. Duncan & Humphreys, 1989; Treisman & Sato, 1990; see also Moher, Lakashmanan, Egeth, & Ewen; 2014) have argued for a major role for distractor suppression. In contrast other authors (e.g. Wolfe, Cave, & Franzel, 1989) have emphasised the importance of target activation. Some authors (e.g. Tsal & Makovski 2006; McLeod, Dodd, Sheard, Wilson, & Bibby, 2003) even challenge the possibility of inhibition of distractor representations.

The priming of pop out (PoP) effect

The operation of visual selective attention is influenced not only by the characteristics of the current stimulus, but also by previous events and behaviours. Maljkovic and Nakayama, (1994; 1996) demonstrated that even responses in a fast and efficient search task were strongly influenced by prior trials. In particular, in bicoloured displays where the target is the item coloured differently to the distractors, participants responded faster when the targets and distractors remained the same on two consecutive trials relative to when they switched, an effect they referred to as Priming of Pop-out (PoP).

Explaining how and why PoP occurs and what it tells us about the visual system has become the focus of a sustained research effort, but remains controversial (see Kristjansson, 2008; Kristjanson & Campana, 2010; Lamy & Kristjansson, 2013, for reviews). It is clear that there are multiple possible contributing factors to the global PoP effect. Firstly, there are the effects of repeating or changing the target and distractor features. Secondly, there are the additional effects of switching the roles of the features involved, target to distractor colour and vice versa. These “role reversals” may have effects additional to those of simple repetition. Maljkovic & Nakayama (1994) compared target or distractor feature repetitions against a baseline with new rather that reversed feature values. RTs remained facilitated and facilitation grew larger with a greater number of repetitions, consistent with roles for both distractor and target repetition in PoP. Maljkovic & Nakayama (1996) localise these repetition effects to changes in the attentional priority or valence that is associated with particular features, these values being increased or decreased as appropriate by recent events, easing the selection of a target. However, Maljkovic & Nakayama (1994; 1996) did not isolate the effect of role reversal. Subsequently, by using four different stimulus items, and allowing all possible combinations of these stimuli to occur over trials, Kristjansson and Driver (2008) were able to demonstrate effects of both target and distractor repetition and role reversals. However, although Kristjansson and Driver provide an empirical demonstration of role reversal and simple repetition effects, they do not offer a full theoretical account of the relationships between these different components. Can these repetition effects and role reversals be explained by a common mechanism?

Priming of pop-out, target activation and distractor inhibition

Lamy, Antebi, Aviani, & Carmel (2008) also provided evidence for the existence of distractor and target repetition and role reversal effects. Importantly, they argued that the effects of intertrial relations in visual search can be used to identify processes of target activation and distractor inhibition, and that these processes can explain both repetition benefits and switch costs. In particular, they argued that both target activation and distractor inhibition can manifest and be measured in search in a manner invariant with respect to the method used to measure them. In the experiments reported by Lamy et al. (2008) participants searched for an odd coloured target circle and reported the direction of tilt of an embedded letter T target. The target and distractor colours could repeat, could exchange roles (target colour becomes distractor colour or vice versa), between trials, or could be new (not presented on the preceding trial). The results showed that both target and distractor repetitions and switches affected performance. Lamy et al. (2008) went on to examine the correlations between each of these component effects, and reported two significant correlations: one between the target repetition effect, and the distractor switching effect (when the distractors take the previous target value), and one between the distractor repetition effect, and the target switching effect (when the target takes the previous distractor value). The pattern of correlations was explained by suggesting that one pair of variables (target repetition and distractor switching) measures activation of target features, and the other pair (distractor repetition and target switching) measures inhibition of distractor features in search.

In terms of repetition, activation of a target on trial n-1 assists the activation of the same target on trial n, inhibition of distractor features on trial n-1 assists the inhibition of distractor features on trial n. In terms of switch effects, when the current distractors take the value of the previously activated target, they are more difficult to inhibit, and when the current target takes the value of the previously inhibited distractors it is more difficult to activate. This explanation recruits similar mechanisms to those suggested by Maljkovic & Nakayama (1996). This explanation also meshes well with the broader literature where the idea that different visual representations may have different levels of activation or weights has been influential (e.g. Duncan & Humphreys, 1989; Wolfe, Cave, & Franzel, 1989; Houghton & Tipper, 1994).

If it were true that this identification between these different intertrial effects and processes of activation and inhibition could in fact be made then this would be a very important and quite neat finding. However, it is perhaps equally compelling on a priori theoretical grounds to draw a distinction between repetition effects (for both targets and distractors), and switch effects (for both targets and distractors). Some accounts of PoP emphasise perceptual mechanisms attributing faster performance to improved processing for selection or rejection of target and distractor features (e.g. Maljkovic, & Nakayama, 1994;1996). More recent neurophysiological evidence also supports the existence of relatively early attentional-perceptual contributions to PoP. Kristjansson, Vuilleumier, Schwartz, Macaluso, & Driver (2007) for example demonstrated changes of brain activity in areas associated with perceptual processing of colour as a function of PoP.

Priming of pop-out, perception, selection, and decision

In contrast, some accounts of PoP emphasise later mechanisms related to episodic retrieval, decision making, and response selection. Lamy, Yashar, and Ruderman (2010) propose that both perceptual and non-perceptual mechanisms affect performance, but for the non-perceptual component they emphasise selection of the overt motor response (see also, Yashar & Lamy, 2011). According to this dual stage account, both target and distractor representations may be modulated at a perceptual level, and response repetition also acts to facilitate selection of the appropriate motor response. However, of greater relevance to the current article are accounts which emphasise processes intermediate between perception and response selection. In particular, the process of determining if an item should be attributed target status and used to drive a response or not, a stage of processing prior to overt motor response selection.

Huang & Pashler (2004) localize all PoP effects to a decisional stage that seeks to verify whether a selected candidate target is indeed a target. This verification process takes the form of consulting retrieved episodes that match the current trial in various ways, when targets and distractors match over trials performance is fast but costs occur when there is a mismatch. Other authors (Meeter & Olivers 2006; Olivers & Meeter 2006) suggest that ambiguity regarding which item should be attributed target status can be a key factor in determining the presence of priming effects (implemented as role reversals). However, in this ambiguity resolution account priming does not stem from an explicit checking process, occurring following target selection, rather mechanisms sensitive to trial history play a greater role in situations of ambiguity, and this can include calculations of perceptual salience.

Tseng, Glaser, Caddigan, and Lleras, (2014; see also Lleras & Buetti, 2014) explicitly suggest that priming effects in pop-out search should be understood in the context of “attention decision making”. In particular, these authors attribute particular importance to assigning target and distractor status to features present in the display. For example, in the context of search for an odd coloured item, in red and green displays, there is ambiguity in determining whether red is target feature and green a distractor or vice versa. Resolution of this ambiguity results in target or distractor tags being assigned to features prior to target selection, and response execution (Lleras & Buetti, 2014; see also Neil et al., 1997). Tseng et al. (2014) also suggest that similar mechanisms may also underlie the related Distractor Preview Effect (DPE). The DPE refers to the finding that target responses are slowed when the current target feature was previously a distractor feature even though no target was present. Note that this decision stage of processing may be particularly important in the compound search tasks typically used to study PoP, since here it is not sufficient to make this assignment, this information must then be used subsequently to drive selection of the target to determine its response relevant feature. When status switches between trials there is conflict which must be resolved and RT costs result. This account is reminiscent of the proposals of Hillstrom (2000) who suggested that priming could be thought of as stemming from the reinstatement of selection rules (essentially mapping features to target and distractor status), however

Hillstrom did not explicitly model this mechanism as a formal decision process.

In summary, an alternative to the idea that repetition and switch components in PoP map cleanly onto activation and inhibition of features is that the more important distinction is between earlier perceptual effects and later decision making effects. In particular, we propose that repetition effects when measured against a baseline of new features, and without target-distractor role reversals, may reflect the relatively passive accumulation of attentional priority in early feature representations; a perceptual effect. In contrast switch effects when assessed against a baseline of new features, may primarily reflect costs in the decision making process of determining which feature should be attributed target status and which is a distractor. This two process account of PoP suggests that rather than correlations between associated pairs of repetition and switch effects (as reported by Lamy et al., 2008), we should be more likely to observe correlations between two measures of repetition (target and distractor) indicating greater reliance on bottom up processes of attentional priority or salience, and two measures of switch costs, indicating greater influence of “attention decision making”.

Measuring target activation and distractor inhibition in PoP

If the above analysis is correct and the analysis of Lamy et al. (2008) incorrect why did these authors observe the pattern of correlations they did? The answer may be found in close reading of the papers or Lamy et al. (2008) and Yashar and Lamy (2010). Essentially, the method used to calculate the indices of activation and inhibition in Lamy et al. (2008) is flawed. These flaws were explicitly acknowledged by Yashar and Lamy (2010) however the implications of these flaws for their earlier conclusions were not explored. The issue concerns the way in which the baseline new target and new distractor conditions were calculated. The baselines in Lamy et al. (2008) included a contribution from all three possible conditions in which either the target or distractor colour was new (see Table 1 for the baselines used across papers). Thus in the case of the new target baseline trials, new, repeated, and switched distractor colour values are included. Likewise, in the case of new distractor baseline trials new, repeated, and switched target colour values were included. However, only two trial types ever contributed to the non-baseline index means. This is because the design employed is incomplete, since it is impossible for certain combinations of repetition and switching to occur, for example a target feature cannot be switched from a distractor if the distractor repeats. The upshot of this is that none of the measures taken are pure measures of target or distractor repetition or switching.

Consider the supposed activation related components, that is target repetition and distractor switches (see Table 1). The target repetition effect is generated by *two* types of trials in which the target repeats and the distractor either also repeats or is new, assessed against a baseline of *three* types of trials in which the target is new but the distractor can either be repeated, new or switched. The distractor switch effect is generated by *two* types of trials in which the distractor switches and the target either also switches or is new, assessed against a baseline of *three* types of trials in which the distractor is new but the target can either be repeated, new or switched. The target repetition effect is thus contaminated with a distractor switch effect, and the distractor switch effect is contaminated with a target repetition effect. The same analysis applies to supposed measures of distractor inhibition. The contamination is such that the measures of activation identified by Lamy et al. (2008) in fact both measure the same two effects (target repetition and distractor switches). Likewise, the measures of inhibition identified by Lamy et al. (2008) both measure the same two effects (distractor repetition and target switches). Thus the pattern of correlations observed falls out naturally from the way the measures were computed, not necessarily from the way in which target activation and distractor inhibition may each be measured by one switch and one repetition effect.

Yashar and Lamy (2010, see also Lamy, Yashar, & Ruderman, 2013) removed the contamination of their measures of target and distractor repetition and switching, by only including the relevant two types of trials in their baselines, such that the measures corresponded to the main effects computed in ANOVA. However, they did not report on the consequences of this correction for the correlations between the different measures. The current paper provides these data.

Method

The experiments was carried out in accordance with the Code of Ethics of the World Medical Association (Declaration of Helsinki).

Participants

A total of 354 participants completed all 400 trials online, and provided valid demographic data. Any participant with less than 90% accuracy in the to be analysed trials was removed leaving 312 participants. There were 233 Male and 79 Female participants, aged between 16 and 70 years, mean age, 26. Participants were sourced from students at the University of Essex, from posting the software on the Inquisit website, and from invitations sent using social media and internet bulletin boards (reddit) dealing with topics of interest to the researchers.

Equipment

The experiment was implemented using Inquisit Web software. Participants took part over the web using computers of their choice. Participant IP addresses were logged, and there was no evidence that participants were providing multiple sets of data.

Stimuli

The stimuli took the form of displays of five coloured circles (see Figure 1 for an illustration). The circles were generated using upper case letter O's presented in 50 point Arial font. The colours of the circles were selected from four possible colours red, green, blue, and yellow (specified in Inquisit using RGB values, 255,0,0; 0,255,0; 0,0,255; and 255,255,0 respectively). In any one display one circle (the target) was always coloured differently to the remaining four circles (the distractors). The pair of colours used on any one particular trial were selected at random from the four possibilities. Each circle was positioned at one of 8 possible locations, selected from a 3 x 3 grid excluding the central location which was reserved for fixation. Positions were specified as a proportion of the horizontal and vertical screen dimensions, each position was separated by 5% horizontally, and 8% vertically, this corrected for typical widescreen 16:9 displays. The exact size of the stimulus would vary and would scale according to the screen size used. Each circle had at its centre a letter T (measuring 16 x 20 pixels, with lines 2 pixels wide) that was rotated either 90 degrees clockwise or counter clockwise (T orientation was selected at random). A fixation cross appeared at the centre of the search display (plus sign + presented in 12 point Arial font).

Procedure

The experiment began with a statement of consent, after which participants provided age and gender information. Instructions were then presented as text and figures. Participants then completed a block of 40 practice trials, in which they were given feedback on incorrect trials (the text “INCORRECT” displayed in red 50 point Arial font, for 500 ms) immediately after the response. They then completed six blocks of 60 experimental trials, without feedback. In between each block the experiment paused, participants were reminded how many blocks were remaining, and had to press the space bar to continue. Each individual trial began with the presentation of a fixation cross for 500 ms followed by the search display until response. The task of participants was to determine the orientation left tilted or right tilted of the letter T by pressing one of two buttons on their keyboard, s for left and d for right. The next trial followed immediately after a response.

Design

From the sequence of trials all instances of target repetition, distractor repetition, target switch, and distractor switch over consecutive trials were identified. Two repeated measures factors were of primary interest: target status (target feature: repeated, new, or switched from previous distractor) and distractor status (distractor feature: repeated, new, or switched from previous target). However, a completely crossed 3x3 design was not possible since it is impossible for target repetitions to co-occur with distractor switches and vice versa, such combinations would result in displays with one colour only. Following Lamy et al. (2008) the results were thus analysed with two separate ANOVAs one focussed on repetition effects with the factors target repetition (target repeat vs. target new) and distractor repetition (distractor repeat vs. distractor new), and one focussed on switch effects, target switch (target switch vs. target new) and distractor switch (distractor switch vs. distractor new).

Results

All incorrect responses (3.9% of the data), and responses more than two seconds or 2.5 standard deviations from the mean of each cell, of each participant were removed (an additional 2.3 % of the data).

Repetition analysis:

2x2 repeated measures ANOVA with the factors target repetition (target repeat vs. target new) and distractor repetition (distractor repeat vs. distractor new) was used to analyse the data. Mean RT is illustrated in Figure 2, and accuracy in Table 2. The RT analysis revealed significant main effects of target (17 ms) and distractor repetition (14 ms) ($F(1, 311)= 118.311$, $p<0.0001$, and $F(1, 311)= 84.885$, $p<0.0001$ respectively). The interaction between the two types of repetition was not significant $F(1, 311)<1$. There were no significant effects on accuracy, $Fs<1.3$.

Switching analysis:

2x2 repeated measures ANOVA with the factors target switch (target switch vs. target new) and distractor switch (distractor switch vs. distractor new) was used to analyse the data. Mean RT is illustrated in Figure 3, and accuracy in Table 2. The RT analysis revealed significant main effects of target (21 ms) and distractor (40 ms) switches ($F(1, 311)= 123.115$, $p<0.0001$, and $F(1, 311)= 393.227$, $p<0.0001$ respectively). The interaction between the two types of switch was also significant $F(1, 311)= 13.768$, $p<0.0001$. The interaction was superadditive, such that the effects of target and distractor switching whilst significant at each level of the other factor, were largest when two switches were simultaneously present (role reversal). There were no significant effects on accuracy, $Fs<1.1$.

Correlation analysis

The analysis of repetition benefits yielded a pattern of two independent effects of target and distractor repetition without an interaction. It is therefore justifiable to examine the correlations between these independent effects and the interpretation is not complicated. In contrast the analysis of switch costs revealed a significant interaction indicating that the two effects of target and distractor switching are not independent of one another, this makes interpretation of any correlation between these two effects more complicated.

We report these correlations below for completeness but they do not feature heavily in our interpretation.

Correlation analysis after Lamy et al. (2008):

Following the method of Lamy et al. (2008, see table 1 for description) we calculated four critical measures of target and distractors repetition and switching. The results revealed four significant correlations: The correlations reported by Lamy et al. (2008) were significant. Target activation as indexed by the correlation between Target repetition and Distractor switching ($r(310)=0.452$, $p<0.0001$). Distractor inhibition as indexed by the correlation between distractor repetition and target switching ($r(310)=0.331$, $p<0.0001$). In addition, we observed that the two repetition benefits ($r(310)=0.346$, $p<0.0001$) and the two switch costs were significantly correlated ($r(310)=0.374$, $p<0.0001$).

Correlation analysis after Yashar and Lamy (2010):

Following the method of Yashar and Lamy (2010, see table 1 for description) we calculated four critical measures of target and distractors repetition and switching, that correspond to the four main effects in the above analyses (see Figure 4 for the relevant scatterplots). The results revealed two significant correlations: The two measures of switching were correlated ($r(310)=0.219$, $p<0.0001$). There was a weaker but significant correlation between the two repetition measures ($r(310)=0.157$, $p<0.005$). The correlations equivalent to those reported to be significant by Lamy et al. (2008) were not significant:

target activation $r(310)=.099$, $p=.081$, distractor inhibition $r(310)=-.002$, $p=.976$[1].

Discussion

Lamy et al. (2008) reported that priming of pop out reflected two components: target activation, and distractor inhibition. They claimed 1) that the cost of the current target taking the colour of the previous distractor (target switch) and the benefit of repeating the previous distractor value were correlated and measured distractor inhibition, and 2) that the cost of the current distractors taking the value of the previous target (distractor switch) and the benefit of target repetition were correlated and measured target activation. However, the measures used by Lamy et al. (2008) used inappropriate baselines in the calculations, as discussed above.

The results of the current study revealed that participants showed robust repetition benefits and switch costs, for both targets and for distractors, a pattern of results very similar to those observed by Lamy et al. However, in the current study we found a significant interaction between the two switch measures but not between the two repetition measures, we turn to this shortly. Most importantly, we observed a radically different pattern of correlations depending on how we calculated our measures of target and distractor repetition and switching.

When we calculated our measures using the method of Lamy et al. (2008) we observed significant correlations between target repetition and

[1] Whilst these non-significant correlations are critical for the arguments presented it should be noted that they are the outcome of a very powerful analysis, and do not occur as a result of an inadequate sample size.

distractor switching (indexing target activation), and between distractor repetition and target switching (indexing distractor inhibition), in addition to correlations between the two switching and two repetition measures. However, when we calculated our measures using the methods of Yashar and Lamy (2010), using uncontaminated baselines, we obtained a quite different outcome. The measures supposed to represent distractor inhibition did not correlate at all, nor did the measures supposed to represent measures of target activation. Instead we observed a significant relationship between the two measures of switching, and a smaller but significant relationship between the two measures of repetition. If Lamy et al., were correct and the PoP effect can be reduced to two components (activation and inhibition) then we should not observe the correlations we observe. On the account of Lamy et al. the measures that we found to correlate should be measuring completely independent components.

One complication here is that our analysis of switch costs revealed a significant interaction between target and distractor switches. Lamy et al. (2008) did not observe such an interaction. The reason for this discrepancy likely stems from the substantially greater power in the current study. Indeed inspection of the data of Lamy et al. (2008) reveals a trend towards and interaction. Given that this interaction indicates that these effects are not statistically independent a significant correlation may be expected. However, this interaction does not have implications for the correlation *between* measures of switch costs and repetition benefits, and it is these correlations that are crucial to the account of Lamy et al. (2008). Furthermore, the presence of the interaction by itself supports the idea that the effects of target and distractor switching are not independent measures of target activation and distractor inhibition, as we discuss below.

In order to explain our pattern of data we suggest an alternative two component account. Firstly, the correlation between the two repetition measures. The repetition effects most likely stem from earlier perceptual stages of processing, in which representations of target and distractor features passively increase or decrease in activation or valence as a function of repetition. Whilst the target and distractor representations involved may be relatively independent they both affect the efficiency by which the target may be selected, likely by spatial selective attention (e.g. see Kim & Cave, 1995). This explanation is essentially the same as that suggested by Maljkovic and Nakayama (1996), and has the virtue of consistency with the broader literature on visual cognition, in which the general idea that selective attention may be guided by feature representations that may exist in different states of activation has been highly influential (see, Horowitz & Wolfe, 2004, for the case of search). This idea is also consistent with patterns of data from neurophysiological studies of PoP which show activation changes in brain areas associated with perceptual processing as a function of repetition (e.g. Kristjansson et al., 2007).

Secondly, turning to the two switch measures. Critically neither of these two measures correlated with the measures of repetition, suggesting they measure a separable source of difficulty. These two switch measures also interacted, and on the basis of additive factors logic (e.g. Sternberg, 1969), this is consistent with the involvement of a common stage of processing. That these two measures are related makes intuitive sense, in that both measures measure the effect of conflict caused by repairing a colour feature and the target or distractor status. Several theoretical accounts (e.g. Meeter & Olivers, 2006; Hillstrom, 2000; Tseng, & Lleras 2014; Huang & Pashler, 2004) propose that ambiguity concerning which feature should be treated as the target feature and used to drive the orienting of attention is critical in PoP. In particular in sparse displays with few items all items target and distractor will be salient competitors for selection (see Rangelov, Müller, & Zehetleitner, 2013). One way to think of this is that the attentional system must make a decision about which feature should be used to drive target selection (e.g. Hillstrom, 2000; Tseng & Lleras, 2014). This process may be sensitive primarily the history of how target and distractors were associated with colour values in previous trials. Relative to when no features repeat target – distractors switches will create a situation where trial history is misleading, conflicting with the requirements on the current trial. The superadditive interaction is then explained since the common decision making stage is particularly slowed when confronted with two sources of conflict. If the two switch costs reflected independent sources of guidance as suggested by Lamy et al., then they should not interact.

Note that this attention decision making account has the virtue of linking together the related but separately studied phenomena of PoP and the Distractor Preview Effect (DPE). On this account (see, Tseng et al., 2014) the same process that is responsible for switch costs in PoP are also responsible for the cost that occurs when the current target takes the value present in the distractors on a previous target absent trial. Thus this account has the potential to provide a general account of multiple types of inter-trial effect.

One perspective on this attention decision making stage suggests that conflict between the competing ways of categorising the features present in the display is crucial. The theory of cognitive control espoused by Botvinick, Braver, Barch, Carter, & Cohen (2001) includes a key role for conflict, such that when conflict between multiple tasks is detected, cognitive control must intervene to ensure appropriate responses. Likewise, in the theory of attention networks proposed by Posner and Peterson (1990) alerting, orienting, an executive control networks are distinguished, and a key function of the executive network is to resolve cognitive conflict. When targets and distractors repeat or when they are new no conflict in the categorisation of features will be present, and here activation of perceptual representation is likely to be key in explaining performance. When targets and distractors switch relative to when new values are used conflict will be maximal. Under these conditions of switching conflict between what was the case on the previous trial and what is currently the case will be present. This conflict may then trigger executive systems to intervene and implement a decision making process (e.g. Tseng & Lleras, 2014) to determine what the appropriate assignment of features to target and distractor is.

Lamy, Yashar, and Ruderman (2013) investigated repetition and switch components of PoP in the context of search for oriented line segments. The results revealed distractor repetition and target switch effects, without target repetition or distractor switch effects. The authors argued that the results are consistent with an absence of activation in search for orientation, and further that this supports the the idea that activation and inhibition are both reflected in a coupled switch cost and repetition benefit. However, I would contend that the reason for this pattern of results is not necessarily that target activation and distractor inhibition are reflected in one switch cost and one repetition benefit, but due instead to an asymmetry in the coding of target and distractor features in orientation search. Search for oriented line segments is likely to be a special case. In displays of oriented line segments interrelations between items are known to play an important role in search (e.g. Moralgia, 1989; Utochkin & Yurevich, 2016). Such displays are likely to promote grouping between distractor elements, in addition to iso-orientation suppression (e.g. Knerim & Van Essen, 1992) in ways less likely with colour or shape. Thus in these displays participants may group the distractor elements and code their orientation feature value and then detect the presence of a target as a break in an otherwise uniform field (see Duncan & Humphreys, 1989; Humphreys & Muller, 1993). Thus the distractors may be well represented without the specific target feature being represented. As a result switch costs and repetition benefits related to distractor features are observed without those related to target features. However, it does not follow that these two components must reflect a common inhibitory mechanism. The crucial correlation between these two measures that might support this interpretation is not reported. The data of Lamy et al. (2013) thus do not invalidate the current perception plus decision framework.

It is important to be clear here about what we can and can not claim from these data. The argument is that the differences between switch costs and repetition benefits is more important than their similarities, and the mechanisms here can not simply be reduced to target activation + distractor inhibition. Indeed, we suggest that target activation and distractor inhibition contribute to performance here, and that these processes are picked up by target and distractor repetition effects. Additionally, we speculate that switch costs stem from an additional process of “attention decision making” in assigning target and distractor status. It is important to note that on switch trials there is likely to be some small perceptual contribution driven by the previous status of the features involved. However, any such contribution is likely to be small, and in the current data swamped by the much larger decision related effect. Carefully designed experiments may tease out this smaller perceptual contribution to switch trials.

The suggestion that switch trials involve cognitive conflict and its resolution could be tested by recruiting some of the manipulations used in the literature on cognitive control. In particular, Botvinick et al. (2001) suggest that when an observer has been recently exposed to conflict and has recruited cognitive control to resolve it, they are subsequently primed to engage the same control processes and thus behavioural costs that result from conflict trials are reduced (e.g. Gratton, Coles, & Donchin, 1992). It would be of interest in the current paradigm to investigate how prior exposure to conflict in the form of a switch, impacts on future switch costs, the conflict account might suggest reduced switch costs, in the context of recent conflict. A key component of the current framework is the idea that uncertainty regarding which feature should be attributed target status and which should be attributed distractor status, is critical particularly on switch trials, where current and past assignments are in conflict. Previous research (e.g. Meeter & Olivers 2006; Rangelov et al. 2013) has shown how manipulations of display density that may act to increase ambiguity increase the global PoP effect. It will be of interest to examine how display density impacts on the switch and repetition effects that are distinguished in the current paradigm. The current framework predicts that switch costs should be more susceptible to manipulations of display density compared to repetition benefits.

Summary

The current pattern of results is at odds with the suggestion of Lamy et al. (2008) that PoP is driven by two primary factors one related to distractor inhibition and one related to target activation, with each reflected in one switch and one repetition effect. Instead the current data suggest important differences between the processes measured by switch costs and repetition benefits. We suggest that repetition benefits likely reflect perceptual processing, whereas switch costs stem from a distinct stage of attentional decision making.

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RT measure	Component	Index mean	Baseline	
			Lamy et al., (2008)	Yashar & Lamy (2010)
Target Repetition	Activation	TrDn + TrDr	TnDn + TnDr **+TnDs**	TnDn + TnDr
Target Switch	Inhibition	TsDn + TsDs	TnDn **+ TnDr** +TnDs	TnDn + TnDs
Distractor Repetition	Inhibition	TnDr + TrDr	TnDn + TrDn **+TsDn**	TnDn + TrDn
Distractor Switch	Activation	TnDs + TsDs	TnDn **+ TrDn** +TsDn	TnDn + TsDn

Table 1: The combinations of trial types used to extract the RT measures, and the theoretical interpretation in terms of activation or inhibition components. Upper case letter indicates the item type T = target D = distractor, lower case letter indicates intertrial relation r = repeated, n = new, s = switch. Terms highlighted in bold indicate sources of contamination present in the Lamy et al. (2008) procedure.

Trial Relation	TrDr	TrDn	TnDr	TnDn	TnDs	TsDn	TsDs
% Error	4.19	4.15	4.02	3.83	3.67	3.65	3.93

Table 2: Mean percentage error as a function of target (T) and distractor (D) status (r = repeated, n = new, s = switched).

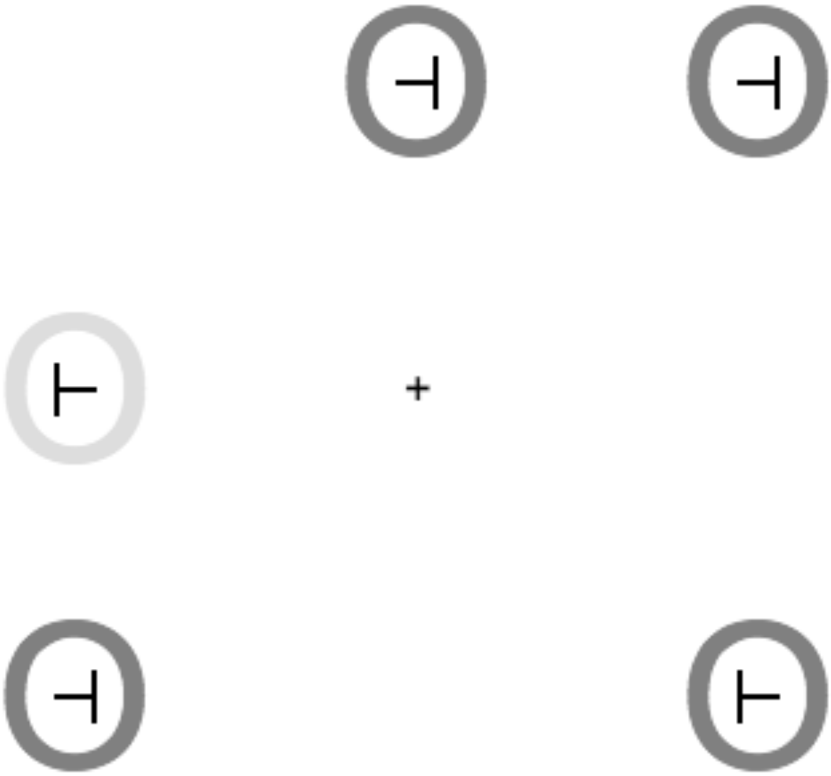


Figure 1: Example of the stimuli used in the experiment. Light grey represents red and darker grey green.

Figure 2: RT as a function of target (separate lines) and distractor (x axis) feature repetitions between trial n and n-1. Error bars show standard error of the mean.

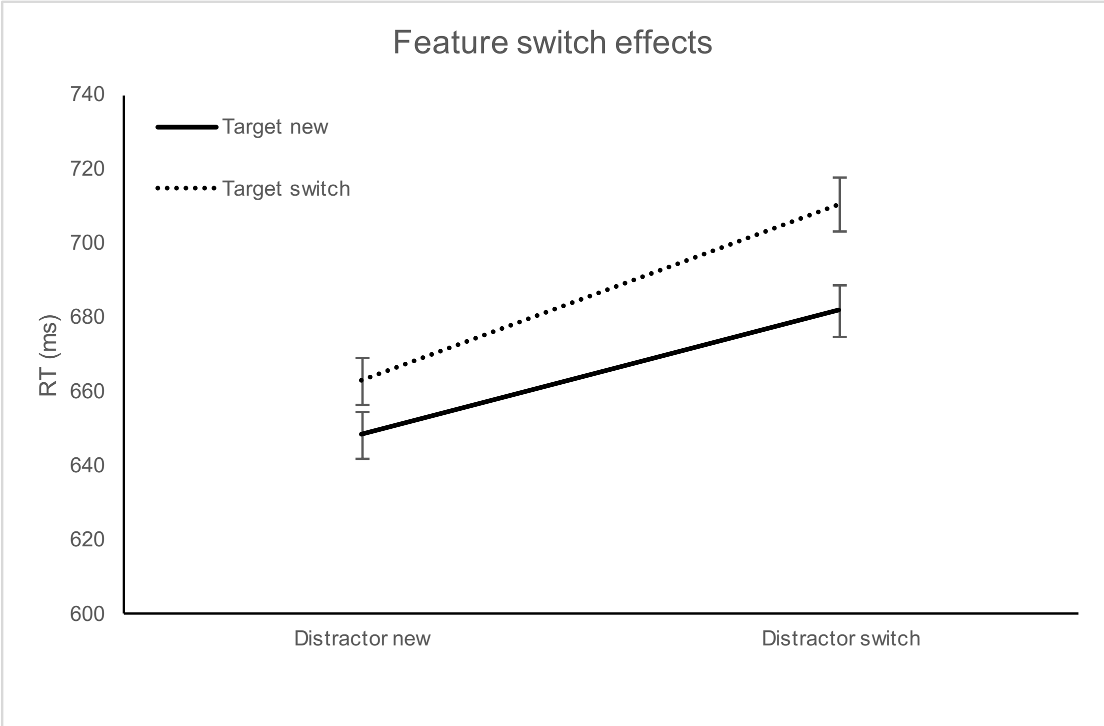
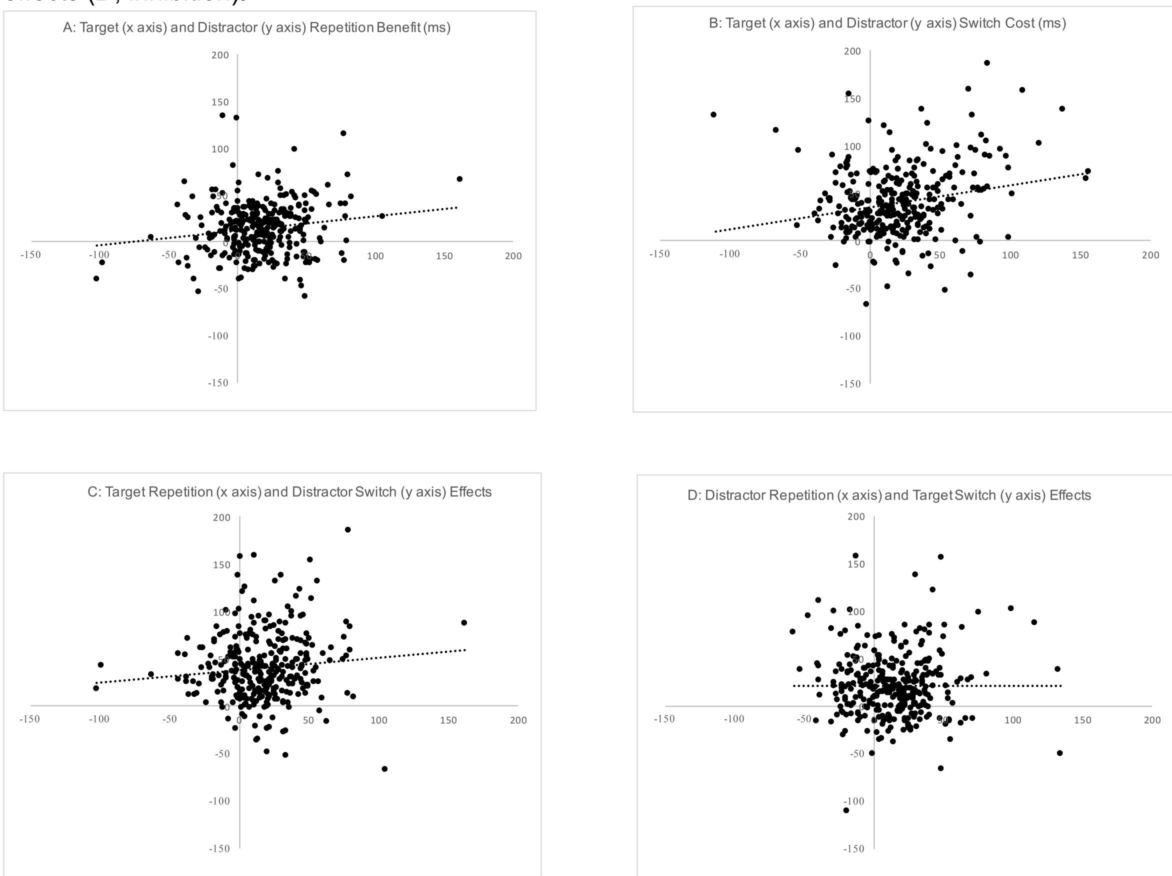


Figure 3: RT as a function of target (separate lines) and distractor (x axis) feature switches between trial n and n-1. Error bars show standard error of the mean.

Figure 4: Scatterplots of the significant relationships between target and distractor repetition (A) and switch (B) effects, and the non-significant relationships between target repetition and distractor switch (C, activation) and distractor repetition and target switch effects (D, inhibition).



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