

Tactile Ranschburg Effects:
Facilitation and Inhibitory Repetition Effects Analogous to Verbal Memory

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Abstract

The present paper examines the effect of within-sequence item repetitions in tactile order memory. Employing an immediate serial recall (ISR) procedure, participants reconstructed a 6-item sequence tapped upon their fingers by moving those fingers in the order of original stimulation. In Experiment 1a, within-sequence repetition of an item separated by 2-intervening items resulted in a significant reduction in recall accuracy for that repeated item (i.e. the Ranschburg effect). In Experiment 1b, within-sequence repetition of an adjacent item resulted in significant recall facilitation for that repeated item. These effects mirror those reported for verbal stimuli (e.g. Henson, 1998a). These data are the first to demonstrate the Ranschburg effect with non-verbal stimuli and suggest further cross-modal similarities in order memory.

118 words

Keywords: tactile memory; order memory; Ranschburg effect; response suppression; serial position effects;

Introduction

Immediate serial recall (ISR) requires participants to recall an earlier presented sequence of typically over-learned (or familiar) items, e.g. digits or letters, in their order of original presentation. At recall, the task is characterised by both a serial position function which exhibits strong primacy and moderate recency (e.g. Bhatarah Ward, & Tan, 2008; Drewnowski & Murdock, 1980; Grenfell-Essam & Ward, 2012; Spurgeon, Ward, & Matthews, 2014; Tan & Ward, 2007; 2008) and a low proportion of erroneous within-trial repetitions (estimated at between 2-5% of all responses, Henson, Norris, Page & Baddeley, 1996; Vousden & Brown, 1998). This latter effect is typically interpreted via a response-suppression mechanism (e.g. Brown, Neath, & Chater, 2007; Burgess & Hitch, 1999; Farrell & Lewandowsky, 2002; Page & Norris, 1998); for which, once an item has been recalled, it is then suppressed to prevent recall-perseveration, and, thereby enable recall of items with lower activation levels (e.g. Page & Norris, 1998).

A phenomenon illustrative of the disinclination to repeat item recall within a sequence is the Ranschburg effect (e.g. Crowder, 1968; Jahnke, 1969). Here, participants are disinclined to recall within-sequence repeated items when such repetitions were present at encoding (e.g. Armstrong & Mewhort, 1995; Crowder, 1968; Duncan & Lewandowsky, 2005; Jahnke, 1969; Henson, 1998a; Maylor & Henson, 2000). For short presentation rates (approximately 100ms) the effect has been attributed to encoding failure (i.e. repetition blinding, Kanwisher, 1987). In contrast, for longer presentation rates (e.g., 400ms on-time, Henson, 1998a) the effect has been attributed to response suppression at test (Armstrong & Mewhort, 1995; Vousden & Brown, 1998). That is, following recall of the first repeated item, the item is suppressed, thus inhibiting recall of its second occurrence. Support for the suppression model is evidenced by those studies showing an absence of the Ranschburg

effect following probed or partial recall (e.g. Armstrong & Mewhort, 1995; Jahnke, 1970). For example, when partial recall of the sequence necessitates only recall of the second presentation of the repeated item (and not the first), recall for that item is not reduced (Armstrong & Mewhort, 1995). This finding suggests that the effect is not a result of the items being repeated at encoding but due to the repetition of items at retrieval.

That the effect of within-trial repetition is not exclusively inhibitory is demonstrated by Henson (1998a, see also Crowder, 1968; Lee, 1976) who showed that when the repeated items are adjacent (i.e. massed repetition), recall facilitation is observed. Such facilitation has been interpreted via a process of participant awareness, such that adjacent repetitions are more salient to the participant. Repetition salience activates a process of mental ‘tagging’ the item for repeated retrieval at test (Jahnke, 1969; Henson, 1998a). Indeed, Henson (1998a) observed very few trials in which the repeated item was correctly recalled twice, but the repetitions at learning were not detected. This suggests that repetition detection is a requirement for facilitative effects.

With the exception of Melwaldt and Hinrichs (1973), who manipulated the visual and auditory presentation modalities, the Ranschburg effect has not been examined cross-modally (Hurlstone, Hitch, & Baddeley, 2014). Indeed, the effect has thus far been confined to verbal stimuli. One might predict that the Ranschburg effect is observable with other stimulus types as, more generally, there is compelling evidence supporting similarities in order memory cross-modally. For example, serial order reconstruction (SOR), a task in which the list items are re-presented at test and participants are required to reconstruct the order in which those items were originally presented, produces strong primacy and moderate recency for visual-verbal (Guèrard & Tremblay, 2008; Ward, Avons, & Melling, 2005; Ward, Tan, Grenfell-Essam, 2010), auditory-verbal (Ward et al., 2005), non-verbal visual (Avons, 1998; Smyth, Hay, Hitch, & Horton, 2005; Ward et al., 2005), visuo-spatial (Guèrard & Tremblay, 2008;

Jones, Farrand, Stuart & Morris, 1995), and auditory-spatial (Parmentier & Jones, 2000) stimuli. Moreover, the distribution of order memory errors for both visual (Guérard & Tremblay, 2008; Smyth et al., 2005) and tactile (Johnson, Shaw, & Miles, 2016) stimuli is closely aligned to that found for verbal stimuli (e.g. Farrell & Lewandowsky, 2004; Guérard & Tremblay, 2008). Finally, the Hebb repetition effect, the gradual improvement in order memory following surreptitious representation of a sequence (Hebb, 1961), is present across a range of stimuli types including, for example, unfamiliar faces (Horton, Hay, & Smyth, 2008), the spatial position of dots (Couture & Tremblay, 2006), odours (Johnson, Cauchi, & Miles, 2013), and tactile stimuli (Johnson et al., 2016).

Cross-modal behavioural similarities in order memory may suggest that the representation of order is amodal. Indeed, whilst selective interference is the classical evidence for modularity in working memory (e.g. Guérard & Tremblay, 2008; Logie, Zucco & Baddeley, 1990), such selective interference effects are removed when the secondary task necessitates order memory. Vandierendonck (2016, see also Depoorter & Vandierendonck, 2009) showed that both visuospatial and verbal ordered recall was disrupted by a secondary order memory task despite that secondary task being undertaken in a different modality. Vandierendonck (2016) argued that this supported modality independent order memory (cf. Saito, Logie, Morita, & Law, 2008).

The present study seeks to further our understanding of cross-modal order memory by examining evidence for the Ranschburg effect with non-verbal stimuli. As noted by Hurlstone et al. (2014), there is, to date, no work examining the presence of the Ranschburg effect with non-verbal stimuli. Presence of the effect would support the cross-modal existence of a response suppression mechanism purportedly underpinning the effect in verbal stimuli (e.g. Armstrong & Mewhort, 1995; Vousden & Brown, 1998). In contrast, absence of the effect would suggest a lack of response suppression; this would create problems for

ordinal models of serial order memory that utilise a primacy gradient and rely upon response suppression in order to prevent perseveration (e.g. the Primacy Model, Page & Norris, 1998; see also Hurlstone et al., 2014, for a comprehensive review). In these models order is coded along a single activation dimension, whereby the item with the highest level of activation is recalled and then suppressed. Without response suppression, individuals would perseverate on the item with the highest activation level (typically the first item in the list). In contrast to ordinal models, the absence of the Ranschburg effect could be accommodated by positional based models of serial order memory (e.g. the Start-End Model, Henson 1998b). For these models, recall of the sequence is less reliant upon suppression as order is recalled through a dynamic retrieval cue (e.g. participants attempt to recall the item represented as third in the list).

In the present study we use tactile stimuli and there exists evidence to predict that the Ranschburg effect will be present using tactile stimuli. For example, Johnson et al. (2016) reported low levels of erroneous within-trial repetitions (4.2% of responses), in a tactile serial order task suggesting the utilisation of a mechanism which inhibits perseveration (potentially response suppression). Furthermore, when those erroneous repetitions did occur, the interval between repetitions was large (mean interval = 3.338 items), suggesting a possible attenuation of response suppression. The present design maximises our opportunity to detect the Ranschburg effect by presenting the tactile stimulation to the same six fingers in every trial; prior work has shown that the effect is accentuated when using a small stimulus set size (Jahnke, 1972, 1974). We include a massed repetition condition (adjacent repetitions; Experiment 1b), to examine the extent to which facilitative effects are also found with tactile stimuli. Thus, to the extent that the process underpinning order memory for tactile sequences mirrors that for verbal sequences, we predict i) a reduction in correct recall for the second

presentation of the repeated item when repetition is spaced (Experiment 1a) and, ii) a facilitation in recall of that item when repetition is massed (Experiment 1b).

Method

Participants. *Experiment 1a:* Twenty Bournemouth University Psychology undergraduates (mean age = 19.80 years; 17 female and 3 male), participated in exchange for research participation credits.

Experiment 1b: Twenty Bournemouth University Psychology undergraduates (mean age = 20.25 years; 19 female and 1 male), participated in exchange for research participation credits. None had participated in Experiment 1a.

Ethical approval was obtained from the Bournemouth University Psychology Ethics Committee.

Materials. Throughout the experiment a wooden obfuscation screen was used to prevent participants from viewing the tactile stimulations. A single tactile stimulation was administered to the intermediary phalange of the *digitus secundus*, *digitus thertius*, and *digitus quartus* on the dorsal aspect of both the right and left hands, via a plastic pen probe. A video camera (Panasonic V750, Japan) recorded the participants' motor responses and these were coded and scored off-line.

Design. A 2x6 within-participants design was adopted for both Experiment 1a and 1b. The first factor refers to sequence type (repetition trial versus matched control trial) and the second to serial position (1-6). All participants completed 40 experimental trials comprising 20 repetition trials and 20 matched control trials.

Experiment 1a: In the repetition trials, the item at position 5 was a repetition of the item at position 2 (i.e. the Ranschburg trials). Each Ranschburg trial had a corresponding

matched control trial; this sequence was identical with the exception that the item at position 5 was replaced by an unrepeated item. Each of the Ranschburg sequences was unique. The order of the 40 trials was randomised for each participant.

Experiment 1b: In the repetition trials the repetitions were adjacent (massed repetition condition). The 20 repetition trials were divided into 10 adjacent repetitions for positions 2 and 3, and 10 adjacent repetitions for positions 4 and 5. These variations were included to ensure some similarity with Experiment 1a, i.e. for 50% of the trials the first presentation of the repeated item was in position 2 and in the remaining 50% of trials the second presentation of the repeated item was in position 5 (as in Experiment 1a).

The control sequences were determined via the random generation of the numbers 1-6 (with these numbers corresponding to the left hand *digitus quartus*, the left hand *digitus thertius*, the left hand *digitus secundus*, the right hand *digitus secundus*, the right hand *digitus thertius*, and the right hand *digitus quartus*, respectively). Sequences comprising three or more adjacent fingers were excluded. The repetition sequences were generated by changing the fifth item in each control list to a repetition of position two for Experiment 1a, and by changing either the third or the fifth item in each control list to a repetition of position two or position five respectively for Experiment 1b.

As described previously (e.g. Armstrong & Mewhort, 1995; Duncan & Lewandowsky, 2005; Henson, 1998a) the dependent variable for the repetition analysis was delta (d). This is calculated by computing the proportion of trials for which the two repeated items were correctly recalled in the correct position [$P(r)$] and subtracting the proportion of trials for which the corresponding items in the control trials were correctly recalled in the correct position [$P(c)$]. In addition, as described by Henson (1998a), critical items in the control trials were considered as correct if they exchanged positions.

Procedure. Participants were tested individually in a quiet laboratory and sat facing the experimenter across a table with each hand placed palm down on the table. The participant positioned their forearm beneath a wooden obfuscation screen in order to visually obscure presentation of the tactile sequences. Participants received 10 practice trials followed by 40 experimental trials. Practice trials were used to mitigate the claim that poor tactile memory scores can result from unfamiliarity with such tasks (Bliss & Hämäläinen, 2005). Each trial was initiated by a verbal signal from the experimenter and comprised the experimenter stimulating each intermediary phalange of the dorsal aspect of the hand. Tactile stimulations were presented at an approximate rate of 1 per second aided by a digit clock on the table. Following presentation of the sixth tactile stimulation, participants were required to immediately reconstruct the preceding sequence by lifting each finger in the order of original stimulation. There was an approximate 5s inter-trial interval, with breaks offered every 10 trials. The participants' hands were video-recorded throughout the experiment, with responses coded offline.

Results

Serial Position Analysis. For the serial position analysis a strict scoring criterion was adopted such that a response was recorded as correct only if the correct finger was moved at the correct serial position within the reconstructed sequence.

Figure 1(a-b) shows the serial position functions for the control and repetition trials in both Experiments 1a and 1b. The serial position functions exhibit strong primacy. In Experiment 1a, a decline in correct recall is apparent for the repeated item in the Ranschburg condition (i.e. serial position 5). In Experiment 1b an elevation in correct recall is apparent at both serial positions 2 and 3 in the 2-3 massed repetition condition and serial positions 4 and 5 in the 4-5 massed repetition condition.

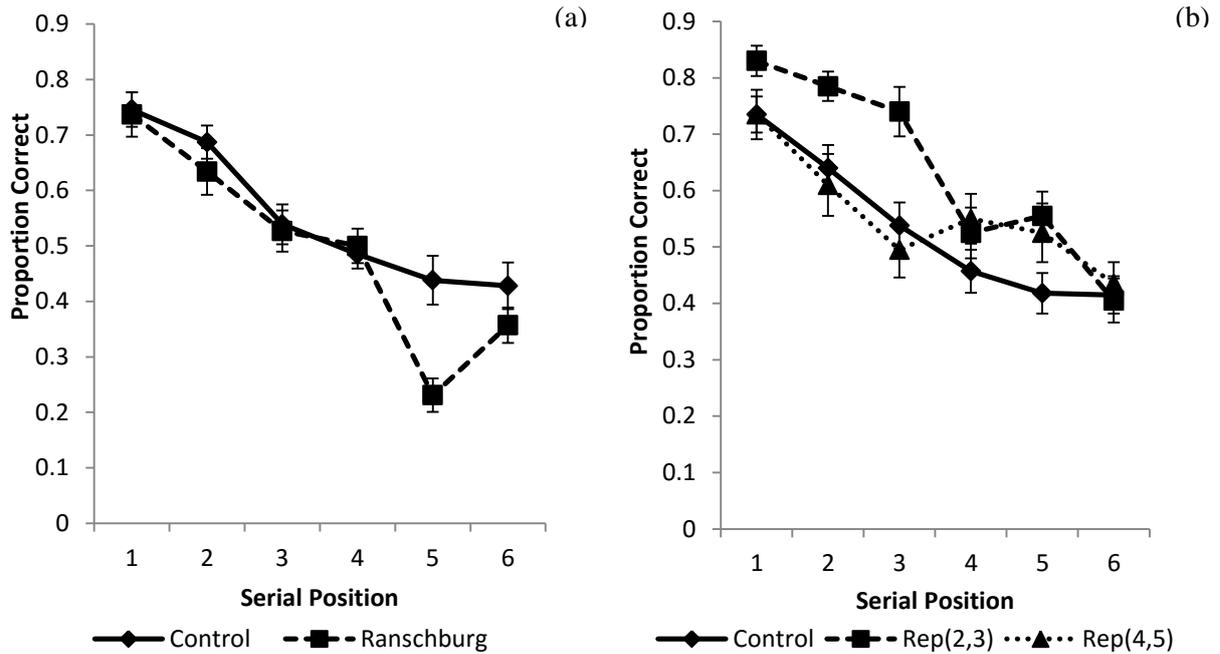


Figure 1(a-b). Mean proportion correct for the control and repetition conditions as a function of serial position for Experiment 1a (A) and 1b (B). Errors bars denote the mean standard error.

For Experiment 1a, serial position functions were analysed by a 2-factor (2x6) within-participants ANOVA with the factors sequence type (control versus Ranschburg) and serial position (1-6). The ANOVA revealed main effects for both sequence type, $F(1,19)=6.660$, $MSE = .028$, $p=.018$, $\eta_p^2 = .260$ (mean proportion correct and 95% CI for the control and Ranschburg sequences = .554 [.503, .604] and .498 [.443, .553], respectively), and serial position, $F(2.872,54.577)=59.325$, $MSE = .028$, $p<.001$, $\eta_p^2 = .757$. Importantly, the sequence type by serial position interaction was significant, $F(2.925,55.582)=4.576$, $MSE = .024$, $p=.007$, $\eta_p^2 = .194$. Post-hoc Bonferroni-corrected ($\alpha= .008$) pairwise comparisons exploring the interaction revealed that the control and Ranschburg conditions differed only at serial position 5, with impaired recall for the repeated item, $t(19)=5.947$, $p <.001$, $r = .807$.

For Experiment 1b, the serial position function analysis was altered to accommodate the predicted spikes in performance at positions 3 and 5 following the two different massed

repetition conditions. A 2-factor (3x6) within-participants ANOVA was employed with the factors sequence type (control, 2-3 massed repetition, and 4-5 massed repetition) and serial position (1-6). The ANOVA revealed a main effect for sequence type, $F(2,38)=10.335$, $MSE = .036$, $p<.001$, $\eta_p^2 = .352$. Mean recall for the 2-3 massed repetition condition was significantly greater (following Bonferroni correction, $\alpha = .017$) than both the control and 4-5 massed repetition conditions (mean proportion correct and 95% CI for the control, 2-3 massed repetition, and 4-5 massed repetition conditions = .534 [.469, .599], .640 [.590, .690] and .558 [.490, .627], respectively). The main effect of serial position was significant, $F(3.037,57.711)=46.391$, $MSE = .035$, $p<.001$, $\eta_p^2 = .709$. Importantly, the sequence type by serial position interaction was significant, $F(5.580,106.017)=3.888$, $MSE = .033$, $p=.002$, $\eta_p^2 = .170$, reflecting accentuated recall for the repeated positions relative to the control condition. To explore the interaction, separate one-way ANOVAs (comparing control, 2-3 massed repetition, and 4-5 massed repetition) were conducted at each serial position. Differences were found at positions 1 ($F(2,38)=3.944$, $MSE = .015$, $p=.028$, $\eta_p^2 = .172$), 2 ($F(2,38)=8.359$, $MSE = .021$, $p=.001$, $\eta_p^2 = .306$), 3 ($F(2,38)=13.300$, $MSE = .026$, $p<.001$, $\eta_p^2 = .412$), and 5 ($F(2,38)=3.477$, $MSE = .030$, $p=.041$, $\eta_p^2 = .155$) only, showing that the effect of repetition was not found uniformly across the sequence.

Repetition Analysis: The dependent variable delta (d) is the difference between the proportion of trials in which the repeated items [$P(r)$] and matched critical items in the control trials [$P(c)$] were recalled in the correct serial position. Scoring criterion was more liberal than that employed for the serial position analysis since critical items in the control trials were considered as correct if they exchanged positions.

Delta (d) was calculated by $P(r) - P(c)$. Negative d scores demonstrate inhibition as a result of the repetition (as shown for Experiment 1a); whereas positive d scores demonstrate facilitation as a result of the repetition (as shown for Experiment 1b). For Experiment 1a,

mean $d = -.218$ (95% CI [-.280,-.155]), and was significantly different to 0, $t(19) = -6.651$, $p < .001$, $r = .836$. This demonstrates significant retrieval inhibition for the repeated item. For Experiment 1b, mean d score = $.100$ (95% CI [.040, .160]), and was significantly different to 0, $t(19) = 3.063$, $p = .006$, $r = .575$. This demonstrates significant retrieval facilitation for the repeated item.

Discussion

We provide the first demonstration of a Ranschburg effect with non-verbal stimuli. Consistent with previous work (e.g., Crowder, 1968; Duncan & Lewandowsky, 2005; Henson, 1998a; Jahnke, 1969; Maylor & Henson, 2000), we showed inhibition of response (the Ranschburg effect) when the repeated items within a sequence were separated by two intervening items (Experiment 1 a). Again, consistent with previous work (e.g. Crowder, 1968; Henson, 1998a; Lee, 1976), we showed response facilitation for massed (adjacent) repetitions (Experiment 1b). Given the consistency of our findings using tactile sequences with those employing verbal sequences (e.g. Crowder, 1968; Henson, 1998a), we suggest that this effect is a common function of serial order memory.

However, one caveat regarding our data is the possibility that the tactile stimuli are re-coded into verbal (or visuo-spatial) representations (as suggested by Mahrer & Miles, 2002). Verbal recoding would result in the present Ranschburg effect merely serving as a replication of the established effect with verbal stimuli (e.g. Henson, 1998a). However, we argue that the present tactile stimuli are not verbalised due to prior effects found with concurrent articulation (CA). Mahrer and Miles (1999) found that tactile ISR survived concurrent backward counting, and that the canonical serial position function persisted despite CA. This suggests that tactile order memory can operate without verbal processing. However, we concede that it remains possible that participants were supplementing task performance with

verbal recoding and future replications of the effect should seek to minimise labelling opportunities through the inclusion of CA.

For verbal stimuli, the Ranschburg effect has been explained by a response suppression mechanism (Armstrong & Mewhort, 1999; Duncan & Lewandowsky, 2005). The present data set, together with those reported by Johnson et al. (2016) who found low levels of perseveration (4.2% of responses comprised erroneous repetitions) in tactile serial order recall, provide further evidence for the existence of a response suppression mechanism in tactile memory. The facilitative effects of massed repetition have been linked to an increase in salience of the repeated item leading to the participants mental ‘tagging’ the item for repeated retrieval at test (Henson, 1998a). The present data supports the existence for such a repetition tagging mechanism in tactile memory.

More broadly, the present tactile Ranschburg effect contributes to a growing body of evidence suggesting that order memory for tactile sequences operates in a manner analogous to that for other modalities. Specifically: (1) The serial position curve for ISR of sequences of tactile stimuli (Johnson et al., 2016; Mahrer & Miles, 1999; Watkins & Watkins, 1974) matches closely that found for sequences of verbal stimuli (e.g. Bhatarah et al., 2006; Drewnowski & Murdock, 1980; Grenfell-Essam & Ward, 2012; Spurgeon et al., 2014; Tan & Ward, 2007, 2008). (2) Immediate free recall (IFR) serial position functions and recall strategies for sequences of tactile stimuli (i.e. initiating recall with the early list items and later list items for short and long lists, respectively) mirror those observed for sequences of verbal stimuli (Cortis, Dent, Kennett, & Ward, 2015). (3) The distribution of ISR transposition errors (Johnson et al., 2016) corresponds to that observed for visuo-spatial and verbal stimuli (Guèrard & Tremblay, 2008). (4) The Hebb repetition effect is apparent for ordered recall of sequences of tactile stimuli (Johnson et al., 2016). Such similarities provide

strong support for the idea of commonality of function across stimulus types with respect to the maintenance of serial order.

Cross-modal commonality in order memory is becoming an increasingly parsimonious explanation (see Hurlstone et al., 2014, for review) given the behavioural similarity across domains in order memory. Indeed, whilst it is possible that item information may be stored in domain specific slave systems (as proposed by the working memory model, e.g. Baddeley, 1986; Baddeley & Hitch, 1974; Logie, 2011; Logie et al., 1990), the representation of order may operate independently of modality. Strong evidence for order memory commonality is demonstrated by the detrimental effect of undertaking two order memory tasks, irrespective of whether those tasks employ stimuli from different modalities (Vandierendonck, 2016). This suggests task-selective, rather than stimulus-selective, interference.

Moreover, that common sequencing principles operate across memory modules is proposed by Hurlstone et al. (2014). They argue that central to this principle is a primacy gradient, such that those items appearing early in a sequence possess the highest activation levels. At recall those items are recalled first (competitive queuing), and subsequently suppressed to prevent recall preservation. The suppression mechanism thus allows items with lower levels of activation to be recalled. Our present behavioural data complement such a viewpoint, since we show (1) strong primacy effects with tactile stimuli (see also Johnson et al., 2016; Mahrer & Miles, 1999; Watkins & Watkins, 1974) consistent with the suggestion of higher activation for early list items, and, (2) the Ranschburg effect, consistent with response suppression.

In summary, the present study is the first to examine the Ranschburg paradigm with non-verbal stimuli. We have shown that tactile stimuli produce both response inhibition and

response facilitation effects, following spaced and massed repetitions, respectively. These effects are consistent with those apparent for verbal stimuli and add to a growing body of evidence suggested commonality of order memory function.

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