Tactile memory Ranschburg effects under conditions of concurrent articulation

Andrew J. Johnson*, Rachel Skinner, Pwamoti Takwoingi, & Christopher Miles

Department of Psychology,
Faculty of Science & Technology,
Bournemouth University,
Poole, UK

*Corresponding author

Address for Correspondence:
Department of Psychology
Bournemouth University
Poole House
Talbot Campus
Fern Barrow
Poole, UK
Tel: +0044 (0)1202 965977
Email*: andjohnson@bournemouth.ac.uk
ORCHID: orcid.org/0000-0003-4138-9115

Twitter: @Psychology_Andy

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Abstract

In a single experiment we investigate the Ranschburg effect for tactile stimuli. Employing an immediate serial recall (ISR) procedure, participants recalled sequences of 6 rapidly presented finger stimulations by lifting their fingers in the order of original stimulation. Within-sequence repetition of an item separated by 2-intervening items resulted in impaired recall for the repeated item (the Ranschburg effect), thus replicating the findings of Roe et al. (2017). Importantly, this impairment persisted with concurrent articulation, suggesting that the Ranschburg effect is not reliant upon verbal recoding. These data illustrate that the Ranschburg effect is evident beyond verbal memory and further suggest commonality in process for both tactile and verbal order memory.

110 words

Keywords: Ranschburg effect; tactile memory; immediate serial recall; response suppression; concurrent articulation

Introduction

Immediate serial recall (ISR) requires participants to recall an earlier presented sequence in its order of original presentation. The Ranschburg effect is an ISR phenomenon characterised by the disinclination to recall repeated items from the previously presented sequence (e.g. Crowder, 1968; Henson, 1998a; Jahnke, 1969). Thus, when an item is repeated during the presentation phase of an ISR trial, and that repetition is spaced (i.e. non-adjacent), participants are disinclined to recall the second presentation of the repeated item (e.g. Armstrong & Mewhort, 1995; Crowder, 1968; Duncan & Lewandowsky, 2005; Jahnke, 1969; Henson, 1998a; Maylor & Henson, 2000). The Ranschburg effect has been attributed to a response suppression mechanism acting at test (Armstrong & Mewhort, 1995; Vousden & Brown, 1998), such that, following recall of the first presentation of the repeated item, that item is then suppressed, thereby inhibiting recall of its second presentation. When sequences do not contain a repetition, a response suppression mechanism is of utility because it discourages perseveration at recall, as evidenced by the low proportion of erroneous within-trial repetitions (estimated at between 2-5% of all responses, Henson, Norris, Page & Baddeley, 1996; Vousden & Brown, 1998). In contrast, when an item is repeated in the sequence, response suppression acts to inhibit recall of its second presentation. That the effect reflects the operation of an output suppression process is evidenced by those studies showing an absence of the Ranschburg effect for either probed or partial recall tasks (e.g. Armstrong & Mewhort, 1995; Jahnke, 1970). That is, when a partial recall task requires recall only of the second presentation of the repeated item (and not the first), recall for the second presentation is not impaired (Armstrong & Mewhort, 1995).

Response suppression (from which the Ranschburg effect is thought to be epiphenomenal) is a feature common to several models of order memory (e.g. Burgess &

Hitch, 2006; Henson, 1998b; Page & Norris, 1998). This is of particular importance for ordinal models of serial order in which activation along an exponentially declining primacy gradient is used uniquely to determine sequence recall (e.g. the Primacy Model, Page & Norris, 1998). For such ordinal accounts, in the absence of response suppression, early list items (possessing high activation levels) will be retrieved repeatedly (perseveration), thus preventing retrieval of latter list items (possessing lower activation levels). Although such ordinal models were developed within the context of verbal memory, as noted by Hurlstone, Hitch & Baddeley (2014), experimental evidence examining the extent to which these models are applicable to non-verbal stimuli is absent. Whilst a number of order memory phenomena, for example, serial position curves (e.g. Avons, 1998; Guérard & Tremblay, 2008; Parmentier & Jones, 2000; Ward, Avons & Melling, 2005), error distributions (e.g. Guérard & Tremblay, 2008; Smyth, Hay & Hitch, 2005), and the Hebb repetition effect (e.g. Couture & Tremblay, 2006; Horton, Hay, & Smyth, 2008; Johnson, Cauchi & Miles, 2013; Johnson, Shaw & Miles, 2016; Page, Cumming, Hitch & McNeil, 2006), demonstrate comparable functioning across both verbal and non-verbal stimuli, evidence for a cross-modal Ranschburg effect is limited. Given that the operation of a response suppression mechanism is central to accounts of serial order memory, it is, therefore, of theoretical importance to test for its presence with ISR of non-verbal stimuli.

A recent study, Johnson, Hawley & Miles (2018), examined the Ranschburg effect for ISR of visually presented consonant sequences under conditions of both quiet and concurrent articulation (CA). Under the CA condition, the phonological similarity effect (PSE) was abolished; a finding taken to reflect disruption to the process of phonological recoding of the visually presented consonant sequences (e.g. Baddeley, Lewis & Vallar, 1984). Importantly, despite the purportedly degraded phonological representations of the consonant sequences,

Johnson et al. (2018) demonstrated a Ranschburg effect of comparable magnitude under conditions of both quiet and CA.

Notwithstanding the use of CA, and the resilience of the Ranschburg effect in Johnson et al. (2018), their to-be-remembered sequences comprised verbal stimuli. In an attempt to minimise further the probability for verbal recoding of the to-be-remembered sequences, Roe, Miles & Johnson (2017), tested ISR for tactile sequences. Here, for the presentation phase, visually obfuscated participants received sequences of 6-individual stimulations to each of six fingers. For the test phase, participants were required to recall the sequence by lifting individual fingers in the order of original presentation. A Ranschburg effect was evident such that for sequences containing spaced repetitions (i.e. positions 2 and 5 in the sequence were repeated), recall for the second presentation of the repeated item was inhibited. This epiphenomenal evidence for response suppression in tactile memory is supported further by earlier data showing low levels of erroneous within-trial repetitions in tactile order memory (4.2% of responses, Johnson et al., 2016). Moreover, on those infrequent trials in which an erroneous repetition did occur, the interval between repetitions was large (mean interval = 3.34 items), a finding consistent with attenuation of item suppression.

Roe et al. (2017) argued that their finding reflected processes within non-verbal memory, and was, therefore, evidence in support of a cross-modal Ranschburg effect. However, one caveat to their argument is the possibility that their pattern of data merely reflected a process in which the tactile sequences were re-coded into verbal representations (as originally supposed by Mahrer & Miles, 2002). Against this verbal re-coding interpretation, Roe et al. (2017) point to earlier data from Mahrer and Miles (1999) demonstrating robust tactile ISR under conditions of both backward counting and CA. However, the Mahrer and Miles (1999, 2002) studies were not designed explicitly to examine the Ranschburg effect and thus, the possibility remains that participants in Roe et al. (2017)

were supplementing sequence recall via verbal recoding strategies and, that the reported Ranschburg effect was (at least, partially) a product of verbal re-coding.

In the light of the above, the current experiment was designed to test directly the possibility that the tactile Ranschburg effect reported by Roe et al. (2017) was a product of verbal re-coding. Participants completed two 20-trial blocks, with each trial comprising a sequence of 6 tactile stimulations, under conditions of both quiet and CA. CA was employed to minimise the possibility for verbal recoding of the tactile stimuli (e.g. Baddeley et al., 1984; Saito, Logie, Morita, & Law, 2008). Each block comprised an equivalent number of repetition trials, containing a repetition (at positions 2 and 5), and matched non-repetition control trials. To the extent that the tactile Ranschburg effect manifests independently of those processes controlling verbal recoding and rehearsal, then a reduction in correct recall for the second presentation of the repeated item is predicted under conditions of both quiet and CA. In addition, and in response to a suggestion during the reviewing process, we analyse the pattern of error responses in order to further our understanding of the processes underpinning the Ranschburg effect. First, given the proposal that both the Ranschburg effect and the associated low frequency of erroneous within-trial repetitions are direct products of response suppression (e.g. Vousden & Brown, 1998), we predict a significant correlation between these two effects. That is, to the extent that a participant exhibits high response suppression, then this should be reflected by both a strong Ranschburg effect and a reduction in the number of within-trial repetition errors. Second, we examine the pattern of responses for those trials in which the participant fails to recall the repeated item within a Ranschburg sequence. Since response suppression should reduce the likelihood of recalling an item that has already been outputted, we predict that participants will exhibit an increased probability of recalling the item from the stimulus set omitted from that particular sequence. That is,

when failing to recall the repeated item, that item will be replaced at recall by retrieval of the finger not used in that specific trial.

Method

Participants. Twenty Bournemouth University Psychology undergraduates (mean age = 19.90 years; 4 male, 15 female, and 1 non-binary), participated in exchange for research participation credits or an honorarium. 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. Each sequence item comprised a single tactile stimulation administered to the intermediary phalange of the *digitus secondus, 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.

Design. A 2x2x6 within-participants design was employed with the factors concurrent task (quiet and CA), trial type (control versus repetition), and serial position (1-6). Participants undertook two blocks of 20 trials, with one block undertaken in each of the quiet and CA conditions during the presentation phase. The order of block presentation was counterbalanced across participants.

For each block, 10 unique 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 tertius*, the left hand *digitus secundus*, the right hand *digitus secundus,* the right hand *digitus tertius*, and the right hand *digitus quartus*, respectively). Sequences comprising three or more adjacent fingers were excluded. Each repetition

(Ranschburg) sequence was generated by changing the number in serial position five for each control sequence to match (and therefore repeat) the number in serial position two. Within each block, the order of control and repetition trials was randomised for each participant.

As described previously (e.g. Armstrong & Mewhort, 1995; Duncan & Lewandowsky, 2005; Henson, 1998a; Johnson et al., 2018; Roe et al., 2017), the dependent variable for the repetition analysis was delta. This is calculated by computing the proportion of trials for which the two repeated items were recalled in their correct serial positions [P(*r*)] and subtracting the proportion of trials for which the corresponding items in the control trials were correctly recalled in their correct serial positions [P(*c*)]. In addition, as described by Henson (1998a), critical items in the control trials were scored as correct if they exchanged serial positions at recall.

Procedure. Participants were tested individually in a quiet laboratory booth and sat facing the experimenter across a table with each hand placed palm down on the table. Participants positioned their forearms beneath a wooden obfuscation screen in order to obscure visual presentation of the tactile sequences. Participants completed two blocks of 20 experimental trials, with each block preceded by 10 practice trials. Practice trials were employed to mitigate the possibility that atypical 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 individually stimulating the intermediary phalange of the dorsal aspect of each hand. Tactile stimulations were presented at an approximate rate of 1 per second aided by a digital 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. The participants' finger movements were video-recorded throughout the experiment and coded offline.

In the CA condition, participants were instructed to repeat aloud and continuously the digits "1, 2, 3, 4" (at a rate of 2-3 digits per second) during the presentation phase of each trial. In the quiet condition, participants were instructed to remain silent during the presentation phase.

There was a 5-minute interval between block presentation and the total experiment lasted approximately 30-minutes.

Results

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

Figure 1(a-b) shows the serial position functions for the control and Ranschburg trials under conditions of both quiet (1a) and CA (1b). The functions demonstrate both primacy and recency together with a reduction in recall accuracy for the repeated item (i.e. serial position 5) under both conditions.

- Figure 1(a-b) about here please -

A 3-factor (2x2x6) within-participants ANOVA was computed with the factors concurrent task (quiet and CA), trial type (control and Ranschburg), and serial position (1-6). The main effect of concurrent task was significant, $F(1,19)=6.938$, $MSE = .102$, $p=.016$, $\eta_p^2 = .267$, demonstrating impaired recall for the CA condition (mean proportion correct and 95% CI for the quiet and CA conditions = .511 [.440, .583] and .435 [.371, .498],

respectively). The main effect of trial type was non-significant, $F(1,19)=1.364$, $MSE = .057$, $p=.257$, $\eta_p^2 = .067$. The main effect of serial position was significant, $F(5,95)=52.036$, $MSE = .042$, $p<.001$, $\eta_p^2 = .733$, reflecting strong primacy and a suggestion of recency. The 2-factor interactions between concurrent task and trial type ($F<1$), and concurrent task and serial position ($F(5,95)=1.337$, $MSE = .019$, $p=.255$, $\eta_p^2 = .066$) were non-significant. Importantly, the predicted interaction between trial type and serial position was significant, $F(5,95)=3.589$, $MSE = .023$, $p=.005$, $\eta_p^2 = .159$. Paired comparisons were conducted comparing the control and Ranschburg conditions at serial positions 1-6. These comparisons included Bayes Factors computed using default priors with JASP (JASP Team, 2018). The control and Ranschburg conditions did not significantly differ at serial positions 1 ($t(19) = 0.167$, $p = .869$, $d = .037$, $BF_{10} = 0.235$), 2 ($t(19) = 0.045$, $p = .964$, $d = .010$, $BF_{10} = 0.233$), 3 ($t(19) = -0.509$, $p = .617$, $d = -.114$, $BF_{10} = 0.261$), 4 ($t(19) = -0.828$, $p = .418$, $d = -.185$, $BF_{10} = 0.315$), and 6 ($t(19) = 0.910$, $p = .374$, $d = .204$, $BF_{10} = 0.336$). However, performance was significantly reduced at serial position 5 for the Ranschburg condition ($t(19) = 3.336$, $p = .003$, $d = .746$, $BF_{10} = 12.500$), consistent with inhibition for the repeated item. Of primary theoretical importance is the finding that the Ranschburg effects was resistant to CA, as evidenced by the non-significant 3-way interaction, $F(5,95)=1.553$, $MSE = .010$, $p=.181$, $\eta_p^2 = .076$. This finding is consistent with the view that the Ranschburg effect persists in the absence of verbal recoding of the sequence items.

Repetition Analysis. The dependent variable delta reflects the difference between the proportion of trials in which both repeated items [P(*r*)] and both matched critical items in the control trials [P(*c*)] are recalled in the correct serial position. That is, the analysis focuses on recall of serial positions 2 and 5 only. 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 serial positions (see Henson, 1998a).

Delta was calculated by P(r) – P(c). Negative delta scores demonstrate inhibition as a result of the repetition, whereas positive delta scores demonstrate facilitation as a result of the repetition. We report single sample *t*-tests comparing delta to the null hypothesis of 0 and report Bayes Factors for these comparisons. For the quiet condition, delta = -.130 (95% CI [-.232,-.028]), and was significantly different to 0, $t(19) = -2.668$, $p=.015$, $d = -.597$, $BF_{10} = 3.623$. For the CA condition, delta = -.152 (95% CI [-.251,-.051]), and was significantly different to 0, $t(19) = -3.164$, $p=.005$, $d = -.707$, $BF_{10} = 8.998$. Importantly, delta did not differ significantly between the quiet and CA conditions, $t<1$ ($BF_{10} = 0.246$), thus demonstrating equivalent inhibition for both.

Error Analysis. Given that the Ranschburg effect has been linked to a response suppression mechanism (Armstrong & Mewhort, 1995; Vousden & Brown, 1998), we conducted additional analyses on the pattern of errors to examine evidence in support of this mechanism. First, erroneous within-trial repetitions were computed. Erroneous within-trial repetitions have been previously shown to be relatively infrequent (Henson et al., 1996; Johnson et al., 2016; Vousden & Brown, 1998), purportedly due to response suppression (Vousden & Brown, 1998). For the control (non-repetition) trials, the proportion of all responses that were incorrect within-trial repetitions was 9.0% and 10.5% for the quiet and CA conditions, respectively, and these proportions did not differ significantly, $t(19) = -1.110$, $p = .281$, $d = -.248$, $BF_{10} = 0.399$. In order to test whether there is an association between the Ranschburg effect and erroneous within-sequence repetitions, the average delta value for each participant was correlated to their average number of erroneous within-trial repetitions for the control trials, and revealed a significant positive correlation, $r(20) = .449$, $p = .047$, $BF_{10} = 1.743$ (although the Bayes Factor provides only anecdotal evidence for the relationship). That is, the stronger the Ranschburg effect, the less erroneous within-trial repetitions that were performed in the control trials. This provides tentative evidence in

support of a similar mechanism underpinning response inhibition (i.e. the Ranschburg effect) and the low levels of erroneous within-trial repetitions.

Second, we examine how participants respond when they fail to recall the repeated item at serial position 5 for the Ranschburg trials. As highlighted during the review process, one might expect participants to replace this item with either a response omission or the retrieval of an item not used in this sequence, since response suppression should limit erroneous repetitions of items already recalled in the trial. We find that a substantial proportion of the increase in errors for the repeated item can be accounted for by participants lifting (therefore, retrieving) the finger that was omitted from the sequence (this response was observed on 25.7% of all serial position 5 Ranchburg trial errors). Such a finding is consistent with response suppression limiting erroneous within-trial repetitions. However, it is worth noting that the most common response for this error was recall of serial position 6 (this response was observed on 28.4% of all serial position 5 errors; compared to 13.5%, 15.4%, and 17.2% of errors in which participants responded with position 1, 3, and 4, respectively). An adjacent transposition error, in this instance between serial positions 5 and 6, is a common error (e.g. Farrell & Lewandowsky, 2004; Guérard & Tremblay, 2008; Johnson et al., 2016); however, as noted during the review process, such an error creates an issue as to what participants then recall as the sixth item in the list. Specifically, response suppression should prevent participants from repeating serial position 6, as that item has just been recalled. Indeed, when we examine the trials in which serial position 6 is erroneously recalled as the fifth item in the Ranschburg trial, that item is immediately repeated on only 2.2% of those trials (consistent with response suppression for that item). In contrast, on 48.9% of these trials participants either recall the finger that was not included in this trial or omit a response for the sixth item in the list (indeed, more generally, there was a non-significant trend towards more response omissions for the Ranschburg trials compared to control trials, occurring in

9% and 6% of all trials, respectively, $Z = 12$, $p = .061$, $BF_{10} = 1.285$). Whilst erroneous within-sequence repetitions clearly occur when participants fail to recall the repeated item in the Ranschburg trial, these data illustrate some disinclination to repeat items at output through the employment of both response omissions and retrieval of the item not presented in the current sequence.

Discussion

Two important findings are signalled from this experiment. First, it has replicated the only previous demonstration of the Ranschburg effect (i.e. the inhibitive effect of spaced within-sequence repetitions) for recall of non-verbal sequences (Roe et al., 2017). Specifically, using a tactile ISR task we have demonstrated recall inhibition for a repeated item when that item is separated by two intervening items (the Ranschburg effect). This finding is consistent with a number of studies showing the effect for recall of verbal sequences (e.g. Crowder, 1968; Duncan & Lewandowsky, 2005; Henson, 1998a; Jahnke, 1969; Johnson et al., 2018; Maylor & Henson, 2000). Second, we have reported a Ranschburg effect of equivalent magnitude under conditions of both quiet and CA. The latter finding is important as we argue that, for CA, verbal recoding of the tactile stimulations is disrupted, and, despite such disruption, the Ranschburg effect persisted. Survival of the effect points to the conclusion that the tactile Ranschburg effect cannot be regarded as merely reflecting those processes underpinning verbal memory. Rather we argue our finding to be bona fide evidence for a non-verbal Ranschburg effect. Moreover, since the present Ranschburg effect matches that found for verbal materials, parsimony would suggest, therefore, that a mechanism common to both tactile and verbal memory underpins these data.

An additional contribution of the current study is the analysis of both response errors and response omissions, and how this informs our understanding of processes underpinning

the Ranschburg effect. It has been suggested that both the low frequency of erroneous within-sequence repetitions and the Ranschburg effect reflect the action of a common process (e.g. Vousden & Brown, 1998). Specifically, they are each a function of a response suppression mechanism for which inhibition of an item post-retrieval reduces the likelihood of subsequent recall of that item within a trial. In order to test this proposal, we correlated the average proportion of erroneous within-sequence repetitions for the control sequences with the average delta score (our measure of the Ranschburg effect). We report a significant positive correlation between these two variables, providing tentative support for supposing that both effects are determined by a common 'suppression' mechanism (notwithstanding the finding that the Bayes Factor evidence was anecdotal). We note, in addition, that the proportion of within-sequence repetitions in the control condition was somewhat greater (9.0% and 10.5% for the quiet and CA conditions, respectively) than that which we reported previously for ISR of tactile sequences (4.2% of all responses, see Johnson et al., 2016). Of course, the current experiment included Ranschburg trials (i.e. the trials containing within-sequence repetitions) which Johnson et al. (2016) did not. It is plausible to suggest that the current inclusion of within-sequence repetitions acted to 'prime' participants to output a greater proportion of repetitions at test.

A second error analysis examined what it is that participants recall when there is a failure to recall the repeated item in the Ranschburg trial. We find that for 25.7% of the erroneous responses, participants recall the item (i.e. finger) not included in the sequence. That is, given that we employ a set size of 6 to create all the sequences in the present experiment (i.e. the same 6 fingers), a Ranschburg trial utilises only 5 of the fingers (because a repetition is included in those trials). Thus, for those occasions when participants erroneously fail to recall the repeated item, they recall the finger omitted from the sequence in over a quarter of trials. However, as highlighted in the error analysis, the most common

response error for the repeated item was erroneous retrieval of serial position 6 (28.4% of all serial position 5 errors in the Ranschburg trials). Importantly, this recall error was infrequently followed by correct recall of serial position 6 (on 2.2% of these trials), consistent with response suppression of serial positon 6. Instead, on 48.9% of these trials, this recall error was followed by either a response omission or retrieval of the item not included in the sequence. That is, a response that was not an erroneous within-sequence repetition. There are a number of reasons why these findings are of consequence with regard to the control processes underpinning the Ranschburg effect. First, if the elevated proportion of errors at serial position 5 for the Ranschburg trials was entirely due to participants erroneously repeating another sequence item, then this would contradict the response suppression explanation simply because logic dictates that those erroneous repetitions should also have been suppressed post-retrieval. Our analysis demonstrates that for a substantial proportion of trials participants recall a non-repeated item (i.e. an item that was not suppressed). In addition, we report that participants failed to recall the entire sequence (i.e. outputting <6 items) to a greater extent in the Ranschburg trials (9% of trials) compared to the control trials (6% of trials). Although this difference did not reach statistical significance (p = .061), it does plausibly provide another route by which participants avoided repeating items when making an error in recalling the Ranschburg sequence. In summary, whilst participants do produce erroneous within-sequence repetitions following errors in the Ranschburg trials, there is evidence for some disinclination in the outputting of such repetitions.

Second, a tendency to recall the omitted finger rather than the repeated finger in the Ranschburg trial does lend some support for the guessing account of the Ranschburg effect. Greene (1991) suggested that, rather than reflecting a memory phenomenon, the Ranschburg effect reflects the strategies that participants employ when guessing. Specifically, the idea here is that when a participant is uncertain of the correct response, and, therefore, their

response constitutes a guess, that guess tends not to be recall of an already outputted item, but rather recall of a yet-to-be recalled item from the stimulus set. This strategy acts to greatly reduce the likelihood of recalling the repeated item by chance, and explains why recall of that repeated item is impaired (although see Henson, 1998a, who demonstrated that guessing cannot fully account for the effect).

Third, a tendency to recall the omitted finger rather than the repeated finger in the Ranschburg trial might be taken as evidence for 'transfer of learning' of the matched control sequence to the Ranschburg trial. As noted during the review process, for 50% of the trials the matched control trial precedes the Ranschburg trial (these two trials are identical but for the repetitions at serial positions 2 and 5). It is possible that some initial learning of the control sequence occurs following that single presentation (i.e. the Hebb effect, as reported by Johnson et al., 2016) and therefore when outputting the Ranschburg trial, the failure to recall the repeated item is a result of participants falsely identifying the Ranschburg trial as the initial control trial and attempting to recall that sequence. We argue against this explanation for the follow reason. In the 50% of trials where the Ranschburg trial precedes the control trial, we would also predict a drop in accuracy for serial position 5 due to learning of the Ranschburg sequence. These reciprocal effects should therefore even out any difference between the control and Ranschburg trials at serial position 5; however, this difference persists. Moreover, when we look at the errors for the matched control trials that follow the corresponding Ranschburg trial, there is not a single trial in which participants erroneously repeat the serial position 2 item at serial position 5. This contradicts 'transfer of learning' from the Ranschburg list to the matched control list.

That ISR for tactile sequences exhibits a Ranschburg effect mirroring that found for ISR of verbal sequences is consistent with a range of data reflecting functional similarity for verbal and tactile memory processes. First, the serial position function for ISR of tactile

stimuli (Johnson et al., 2016; Mahrer & Miles, 1999; Watkins & Watkins, 1974; see also Experiments 1 and 2), matches closely that reported for verbal sequences (e.g. Bhatarah, Ward & Tan, 2008; Drewnowski & Murdock, 1980; Grenfell-Essam & Ward, 2010; Spurgeon, Ward & Matthews, 2014; Tan & Ward, 2007, 2008; Ward & Grenfell-Essam, 2012). Second, the distribution of transposition errors in tactile ISR (Johnson et al., 2016) matches closely that observed for verbal and spatial sequences (Guèrard & Tremblay, 2008). Third, both the serial position function and the list length related shifts in recall strategy for immediate free recall of tactile sequences match closely those observed for verbal sequences (Cortis, Dent, Kennett, & Ward, 2015). Fourth, the Hebb repetition effect is observed for ISR of tactile sequences, mirroring that observed for verbal sequences (Johnson et al., 2016). Taken together, we argue that these findings add to that body of work (Cortis et al., 2015; Johnson et al., 2016; Roe et al., 2017) consistent with the thesis that order memory for tactile stimuli is functionally equivalent to that for verbal memory.

The present data, combined with that of Roe et al. (2017) and Johnson et al. (2018), support the notion that the Ranschburg effect is not confined to phonological memory. As an effect purportedly epiphenomenal to response suppression, demonstrating the Ranschburg effect cross-modally is an important step in testing the applicability of models of order memory beyond the verbal domain. Indeed, Hurlstone et al. (2014) suggest that common sequencing principles operate across different domains of memory, particularly with respect to competitive queuing and response suppression. Notwithstanding the present findings, it is, therefore, important to examine evidence for the Ranschburg effect in other non-verbal domains (e.g. visual/ visuo-spatial memory). Such work provides methodological challenges because non-verbal visual stimuli cannot be applied to ISR, with serial order reconstruction (SOR) used as an alternative (e.g. Avons, 1998; Guérard & Tremblay, 2008; Ward et al., 2005). In SOR, all list items are re-presented at test, and plausibly, such re-presentation may

act to prime participant awareness of the repetition based upon the number of items re-presented in the testing array. In addition, item generation is not required at test in SOR, because participants are only required to reconstruct order by selecting the items in the order of original presentation. It remains an empirically testable question the extent to which response suppression only follows item generation/recall at test (as is required in ISR), or whether order reconstruction can induce response suppression for an item.

In summary, the present study shows the Ranschburg effect with non-verbal stimuli. Specifically, we have demonstrated that this response inhibition effect is not an artefact of verbal recoding, and add to a body of work suggesting functional equivalence across verbal and tactile order memory.

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References

Armstrong, I. T., & Mewhort, D. J. K. (1995). Repetition deficit in rapid-serial-visual-presentation displays: Encoding failure or retrieval failure? *Journal of Experimental Psychology: Human Perception and Performance, 21*(5), 1044-1052. doi:10.1037/0096-1523.21.5.1044

Avons, S. E. (1998). Serial report and item recognition of novel visual patterns. *British Journal of Psychology, 89*(2), 285-308.

Baddeley, A. D., Lewis, V., & Vallar, G. (1984). Exploring the articulatory loop. *The Quarterly Journal of Experimental Psychology A: Human Experimental Psychology, 36A*(2), 233-252. doi:10.1080/14640748408402157

Bhatarah, P., Ward, G., & Tan, L. (2008). Examining the relationship between free recall and immediate serial recall: The serial nature of recall and the effect of test expectancy. *Memory & Cognition, 36*(1), 20-34. doi:10.3758/MC.36.L20

Bliss, I., & Hämäläinen, H. (2005). Different working memory capacity in normal young adults for visual and tactile letter recognition task. *Scandinavian Journal of Psychology, 46*(3), 247-251. doi:10.1111/j.1467-9450.2005.00454.x

Burgess, N., & Hitch, G. J. (2006). A revised model of short-term memory and long-term learning of verbal sequences. *Journal of Memory and Language, 55*(4), 627-652. doi:10.1016/j.jml.2006.08.005

Couture, M., & Tremblay, S. (2006). Exploring the characteristics of the visuospatial Hebb repetition effect. *Memory and Cognition, 34*(8), 1720-1729.

Cortis, C., Dent, K., Kennett, S., & Ward, G. (2015). First things first: Similar list length and output order effects for verbal and nonverbal stimuli. *Journal of Experimental*

Psychology: Learning, Memory, and Cognition, 41(4), 1179-1214. doi:10.1037/xlm0000086

Crowder, R. G. (1968). Intraserial repetition effects in immediate memory. *Journal of Verbal Learning & Verbal Behavior, 7*(2), 446-451. doi:10.1016/S0022-5371(68)80031-3

Drewnowski, A., & Murdock, B. B. (1980). The role of auditory features in memory span for words. *Journal of Experimental Psychology: Human Learning and Memory, 6*(3), 319-332. doi:10.1037/0278-7393.6.3.319

Duncan, M., & Lewandowsky, S. (2005). The time course of response suppression: no evidence for a gradual release from inhibition. *Memory, 13*(3-4), 236-246.

Farrell, S., & Lewandowsky, S. (2004). Modelling transposition latencies: Constraints for theories of serial order memory. *Journal of Memory and Language, 51*, 115-135. doi:10.1016/j.jml.2004.03.007

Greene, R. L. (1991). The Ranschburg effect: the role of guessing stratgies. *Memory & Cognition, 19*(3), 313-317.

Grenfell-Essam, R., & Ward, G. (2012). Examining the relationship between free recall and immediate serial recall: the role of list length, strategy use, and test expectancy. *Journal of Memory and Language, 67*(1), 106-148.

Guérard, K., & Tremblay, S. (2008). Revisiting evidence for modularity and functional equivalence across verbal and spatial domains in memory. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 34*(3), 556-569. doi:10.1037/0278-7393.34.3.556

Henson, R. N. A. (1998a). Item repetition in short-term memory: Ranschburg repeated. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 24*(5), 1162-1181. doi:doi.org/10.1037/0278-7393.24.5.1162

Henson, R. N. A. (1998b). Short-term memory for serial order: The Start-End Model. *Cognitive Psychology, 36*, 73-137. doi: 10.1006/cogp.1998.0685

Henson, R. N. A., Norris, D. G., Page, M. P. A., & Baddeley, A. D. (1996). Unchained memory: error patterns rule out chaining models of immediate serial recall. *Quarterly Journal of Experimental Psychology: Section A, 49*(1), 80-115. doi:10.1080/027249896392810

Hinrichs, J. V., Mewaldt, S. P. & Redding, J. (1973). The Ranschburg effect: repetition and guessing factors in short-term memory. *Journal of Verbal Learning & Verbal Behavior, 12*, 64-75. doi.org/10.1016/S0022-5371(73)80061-1

Horton, N., Hay, D. C., & Smyth, M. M. (2008). Hebb repetition effects in visual memory: The roles of verbal rehearsal and distinctiveness. *Quarterly Journal of Experimental Psychology, 61*(12), 1769-1777. doi:10.1080/17470210802168674

Hurlstone, M. J., Hitch, G. J., & Baddeley, A. D. (2014). Memory for serial order across domains: An overview of the literature and directions for future research. *Psychological Bulletin, 140*(2), 339-373. doi:10.1037/a0034221

Jahnke, J. C. (1969). The Ranschburg effect. *Psychological Review, 76*(6), 592-605. doi:10.1037/h0028148

Jahnke, J. C. (1970). Probed recall of strings that contain repeated elements. *Journal of Verbal Learning & Verbal Behavior, 9*(4), 450-455. doi:10.1016/S0022-5371(70)80087-1

Jahnke, J. C. (1972). The effects of intraserial and interserial repetition on recall. *Journal of Verbal Learning & Verbal Behavior, 11*(6), 706-716. doi:10.1016/S0022-5371(72)80005-7

Jahnke, J. C. (1974). Restrictions on the Ranschburg effect. *Journal of Experimental Psychology, 103*(1), 183-185. doi:10.1037/h0036816

JASP Team (2018). JASP (Version 0.9.0.1) [Computer software]. Retreived from https://jasp-stats.org/

Johnson, A. J., Cauchi, L., & Miles, C. (2013). Hebbian learning for olfactory sequences. *Quarterly Journal of Experimental Psychology, 66*(6), 1082-1089. doi:10.1080/17470218.2012.729068

Johnson, A. J., Hawley, R., & Miles, C. (2018). Repetition inhibition and facilitation effects for visual-verbal stimuli under conditions of concurrent articulation. *Quarterly Journal of Experimental Psychology*. doi:10.1080/174702018.2017.1313873

Johnson, A. J., Shaw, J., & Miles, C. (2016). Tactile order memory: evidence for sequence learning phenomena found with other stimulus types. *Journal of Cognitive Psychology, 28*(6), 718-725. doi.org/10.1080/20445911.2016.1186676

Lee, C. L. (1976). Short-term recall of repeated items and detection of repetitions in letter sequences. *Journal of Experimental Psychology: Human Learning and Memory, 2*(2), 120-127. doi:10.1037/0278-7393.2.2.120

Mahrer, P., & Miles, C. (1999). Memorial and strategic determinants of tactile recency. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 25*(3), 630-643. doi:10.1037/0278-7393.25.3.630

Mahrer, P., & Miles, C. (2002). Recognition memory for tactile sequences. *Memory, 10*(1), 7-20. doi:10.1080/09658210143000128

Maylor, E. A., & Henson, R. N. A. (2000). Aging and the Ranschburg effect: No evidence of reduced response suppression in old age. *Psychology & Ageing, 15*(4), 657-670.

Page, M. P. A., Cumming, N., Norris, D., Hitch, G. J., & McNeil, A. M. (2006). Repetition learning in the immediate serial recall of visual and auditory materials. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 32*(4), 716-733. doi:10.1037/0278-7393.32.4.716

Page, M. P. A., & Norris, D. (1998). The primacy model: A new model of immediate serial recall. *Psychological Review, 105*(4), 761-781. doi:10.1037/0033-295X.105.4.

Parmentier, F. B. R., & Jones, D. M. (2000). Functional characteristics of auditory temporal—spatial short-term memory: Evidence from serial order errors. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 26*(1), 222-238. doi:10.1037/0278-7393.26.1.222

Roe, D., Miles, C., & Johnson, A. J. (2017). Tactile Ranschburg effects: facilitation and inhibitory repetiion effects analogous to verbal memory. *Memory, 25*(6), 793-799. doi:10.1080/09658211.2016.1222443

Saito, S., Logie, R. H., Morita, A., & Law, A. (2008). Visual and phonological similarity effects in verbal immediate serial recall: A test with kanji materials. *Journal of Memory and Language, 59*, 1-17. doi:10.1016/j.jml.2008.01.004

Smyth, M. M., Hay, D. C., Hitch, G. J., & Horton, N. J. (2005). Serial position memory in the visual—spatial domain: Reconstructing sequences of unfamiliar faces. *Quarterly*

Journal of Experimental Psychology: Section A, 58(5), 909-930. doi:10.1080/02724980443000412

Spurgeon, J., Ward, G., & Matthews, W. J. (2014). Examining the relationship between immediate serial recall and immediate free recall: Common effects of phonological loop variables but only limited evidence for the phonological loop. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 40*(4), 1110-1141. doi:10.1037/a0035784

Tan, L., & Ward, G. (2007). Output order in immediate serial recall. *Memory & Cognition, 35*(5), 1093-1106.

Tan, L., & Ward, G. (2008). Rehearsal in immediate serial recall. *Psychonomic Bulletin & Review, 15*(3), 535-542.

Vousden, J. I., & Brown, G. D. A. (1998). To repeat or not to repeat: The time course of response suppression in sequential behaviour. In J. A. Bullinaria, D. W. Glasspool, & G. Houghton (Eds.), *Proceedings of the Fourth Neural Computation and Psychology Workshop: Connectionist Representations*. London: Springer-Verlag.

Ward, G., Avons, S. E., & Melling, L. (2005). Serial position curves in short-term memory: functional equivalence across modalities. *Memory, 13*(3-4), 308-317.

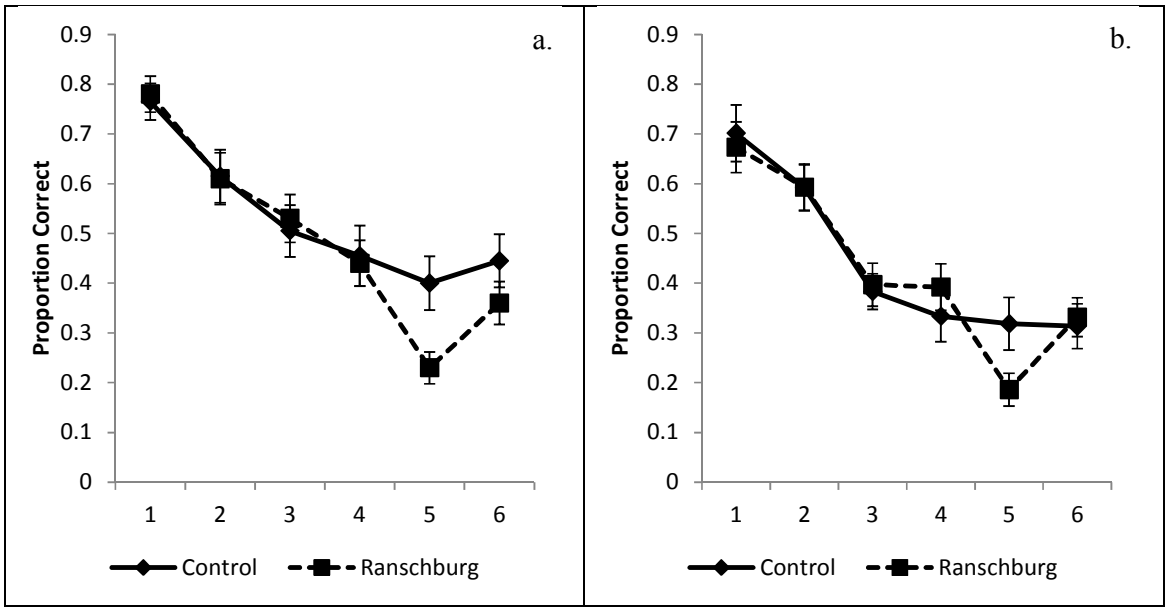
Ward, G., Tan, L., & Grenfell-Essam, R. (2010). Examining the relationship between free recall and immediate serial recall: The effects of list length and output order. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 36*(5), 1207-1241. doi:10.1037/a0020122

Watkins, M., & Watkins, O. (1974). A tactile suffix effect. *Memory & Cognition, 2*(1), 176-180.

Legends

Figure 1 (a-b). Mean proportion correct for the control and Ranschburg trials as a function of serial position under conditions of quiet (a) and CA (b). Errors bars denote the mean standard error.

Figure 1 (a-b)


a.
b.
Proportion Correct
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1
2
3
4
5
6
Control
Ranschburg