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Recognition memory for tactile sequences

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In three experiments participants were required to compare the similarity in item order for two temporally separated sequences of tactile stimuli presented to the fingers of the hand. Between-sequence articulatory suppression but not tactile interference impaired recognition accuracy (Experiment 1), and the null effect of tactile interference was not due to the second tactile sequence overwriting the sensory record of the first sequence (Experiment 2). Experiment 3 showed that compared to a condition where the second sequence was presented in the tactile modality only, recognition was enhanced when the second sequence was seen presented either to the hand or on a diagrammatic representation of a hand. A final experiment showed that the effects of Experiment 1 were replicated when the underside of the forearm was used for stimulus presentation, suggesting that the data are not idiosyncratic to the first method of presentation. The pattern of results suggests memory for a sequence of tactile stimuli involves the deployment of strategies utilising a combination of verbal rehearsal and visuo-spatial recoding rather than relying solely on the retention of sensory traces. This is taken to reflect limitations in both the capacity and duration of tactile sensory memory.

INTRODUCTION

An influential account of short-term memory (STM) is provided by Baddeley and Hitch’s (1974; Baddeley, 1986) working memory model. Its emphasis on independent slave systems controlled by a general attentional component has tended to concentrate STM research on the modalities of vision and audition. Nonetheless, while not comparable in depth to either the auditory or visual literature, that concerning the tactile modality is currently quite substantial and can be distinguished along two empirical themes. The first of these is concerned with fundamental psycho-physiological issues and their application to the refinement of haptic communication techniques among the visually impaired. The other comprises a relatively small number of studies that have employed established experimental paradigms in order to determine the short-term retention characteristics of tactile stimuli. The results of these studies suggest that tactile span, the rate of forgetting of tactile material, and tactile serial recall profiles resemble those found for the auditory modality in a number of respects.

Tactile span and single-stimulus studies

An early study (Bliss, Crane, Mansfield, & Townsend, 1966) reported a tactile span of five items when jets of air (varying in number from two to twelve) were applied simultaneously to the labelled three main joints of all eight fingers. Using a different procedure, Heller (1987) traced number outlines onto the palms of both hands and found tactile span to be a function of presentation rate. A span of four items was obtained with a 1-second presentation rate, but this increased to nearly seven items with a slower, 5-second rate. Heller (1987) argued that persisting after-
sensations impair performance at fast presentation rates, whereas a slower rate allows any sensations to fade, thus increasing the perceived distinctiveness of successive items.

With respect to those attempts to estimate rates of forgetting of tactile stimuli, most authors have adopted a tactile analogue of the Brown-Peterson distractor task (Brown, 1958; Peterson & Peterson, 1959). Typically, participants are presented, unseen, with a discrete tactile stimulus to a range of possible locations on their forearms and are then required to indicate its original position after various delays. A deduction in location accuracy as a function of delay suggests the decay of a sensory trace from tactile STM. Using this paradigm, Gilson and Baddeley (1969) examined the effects of both silence and articulatory suppression on the delayed recall (varying between 0 and 60 seconds) of a single tactile stimulus. Although recall accuracy declined as a function of delay for both conditions, an activity by delay interaction was found. For articulatory suppression, the decline in accuracy was linear and reached asymptote after 45 seconds, whereas in the silent condition accuracy was maintained with delays of up to 15 seconds and thereafter declined with asymptote being reached at 60 seconds. Gilson and Baddeley (1969) interpreted their data as evidence for a dual-process model of tactile memory, involving a sensory trace immune to articulatory suppression and a sensory trace maintained by an abstract rehearsal process.

In contrast to these data, Sullivan and Turvey (1972) found that the decline in accuracy within the tactile Brown-Peterson paradigm reached asymptote after only 5 seconds for both a silent condition and a condition in which participants undertook the completion of written arithmetic tasks. Although overall performance was poorer in the arithmetic condition, there was no activity by delay interaction. Sullivan and Turvey’s (1972) data therefore suggest a tactile memory characterised by the decay of a single, transient, unrehearsable sensory trace.

More recently, Miles and Borthwick (1996) employed both silence and articulatory suppression as filler activities within the tactile Brown-Peterson paradigm. Although both conditions resulted in a systematic decline in performance, with overall accuracy being poorer in the articulatory suppression condition, no filler activity by delay interaction was found, yet in neither condition was asymptote reached even following a 20-second delay. As such, their data are consistent with Sullivan and Turvey’s (1972) decay model (with the caveat that a tactile memorial trace may persist for up to 20 seconds after presentation). In summary, although all three studies support the existence of a tactile STM, there is no firm agreement regarding either the precise rate of decay or the nature of possible rehearsal processes.

**Tactile serial recall paradigms**

Notwithstanding the assumption that recency and suffix effects are purely auditory phenomena (see Crowder & Morton, 1969), Watkins and Watkins (1974) presented eight-item tactile sequences to the labelled fingers of both hands with each finger being touched once. Half the sequences were followed by an auditory suffix and half by a tactile suffix (a brisk stroke across all eight fingers). Regardless of whether participants recalled sequences verbally or by pointing out the sequence on a diagram, reliable recency and suffix effects were found. Using a different procedure, Nairne and McNabb (1985) had participants lower their palms onto wooden blocks each of which had a different number of protruding pegs. Compared to a visual condition in which participants merely saw the blocks, tactile presentation resulted in a pronounced recency effect with written serial recall. More recently, Mahrer and Miles (1999) employed a variant of Watkins and Watkins’ (1974) paradigm, such that rather than recalling sequences either verbally or through the use of a diagram, participants recalled by moving their fingers in a sequence consistent with the presentation sequence. “Normal” presentation conditions (silent presentation, and a 1-second presentation rate) resulted in a strong recency effect that was attenuated by both a delay in recall and a same-modality suffix. However, recency following presentation conditions that impaired stimulus encoding opportunities (concurrent verbalisation, and a fast, 0.5-second presentation rate) was resistant to both a delay in recall and a tactile suffix.

Although the tactile serial recall literature provides additional evidence that modality and suffix effects can arise in conditions where both speech and visual or gestural information normally associated with language is absent (see also Campbell & Dodd, 1980; Shand & Klima, 1981), there is little agreement among authors with respect to the exact processes responsible for the
recall of the final sequence item. For instance, Watkins and Watkins (1974) argue that both recency and suffix effects within the tactile modality reflect the functioning of a modality-specific sensory memory (but see Bloom & Watkins, 1999). In contrast, Nairne and McNabb (1985) suggest that the primary determinant of recency, regardless of presentation modality, is the extent to which the final item is discriminable both from other sequence items and from the concurrent activities of STM. In an attempt to reconcile both sensory and discriminability theories of tactile recency, Mahrer and Miles (1999) propose a dual-process model that can account for recall patterns following both normal and difficult presentation conditions. Whatever the theoretical underpinnings of tactile recency, both the Brown-Peterson and serial recall paradigms are essentially concerned only with memory for a single tactile stimulus. Although most serial recall studies report the pattern of pre-terminal recall, little theoretical significance is placed on the retrieval of these earlier items in comparison to the final item. For instance, although Watkins and Watkins (1974) argue that the primacy and asymptote components of a tactile serial recall curve reflect the retrieval of verbal codes, Mahrer and Miles (1999) suggest, in contrast, that for some conditions recency can be the result of spatial encoding, and that such encoding can extend to include several pre-terminal items. However, in neither the Watkins and Watkins (1974) or the Mahrer and Miles (1999) studies are these speculations addressed empirically. Even span studies have little to say regarding the manner in which a sequence of tactile stimuli is encoded. Heller (1987) emphasises the viability of “print-on-palm” as a method of tactile communication but does not consider the improved span found with a slow, 5-second presentation rate to be a function of “higher cognitive activities”. Rather, he suggests it is the result of potentially confusing sensory traces from previous items fading during the relatively long inter-stimulus interval.

A further issue concerning span and serial recall studies relates to the type of errors that occur during sequence retrieval. With span studies, and Nairne and McNabb’s (1985) serial recall paradigm, errors may arise from both false item recall, and the loss of item order information; that is, correct items being recalled in their incorrect serial position. However, for those serial recall studies in which tactile sequences are presented to a corresponding number of fingers (Mahrer & Miles, 1999; Watkins & Watkins, 1974), errors can result only from the loss of item order information. Thus, the current series of experiments aims to examine more closely the memorial processes underpinning the retention of a complete tactile sequence with particular regard to the way in which item order is maintained. A delayed forced-choice recognition approach is adopted whereby participants are required to estimate how many items in the second of two tactile sequences retain their order of presentation compared to their order in the first sequence. Using this procedure, participants are compelled to attend to the item order within each sequence, rather than merely judge whether the second sequence is the same as or different from the first. A 10-second delay introduced between the presentation of the first and second sequence enables us to compare the extent to which different filler activities interfere with the representations of those items comprising the first sequence.

**EXPERIMENT 1**

The first experiment employed silence, articulatory suppression (repeating the word “the”), and tactile interference as filler activities. If tactile sequences are encoded verbally (Watkins & Watkins, 1974), then the rehearsal of such codes should be impaired by articulatory suppression but not by tactile interference. In contrast, if tactile sequences are represented by a sensory code (Heller, 1987), then such a code ought to be particularly vulnerable to tactile interference. Although some fading of sensory traces is expected during the 10-second delay (Heller, 1987; Sullivan & Turvey, 1972), the data of both Gilson and Baddeley (1969) and Miles and Borthwick (1996) suggest that the tactile sensory trace will persist for periods in excess of 10 seconds.

**Method**

**Participants.** Participants were 24 volunteer undergraduates (18 females, 6 males; mean age = 23 years) from the School of Psychology, Cardiff University. All participants received course credit for their time.

**Materials.** Materials comprised three blocks of 25 pairs of eight-item sequences. The first sequence in each pair comprised a random ordering of the digits 1–8. The second sequence also comprised the digits 1–8, however the
ordering of the digits in the second sequence was related to that of the first in one of five possible combinations or similarity gradients. The second sequence was either identical to the first (a similarity gradient of eight), or it was completely asynchronous (a similarity gradient of zero). Between these extremes, the second sequence could share two, four, or six items with the first sequence with respect to item order. Examples of similarity gradients are as follows:

<table>
<thead>
<tr>
<th>First sequence</th>
<th>Second sequence</th>
<th>Similarity gradient</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 3 1 7 4 8 6 5</td>
<td>8 1 6 5 7 2 4 3</td>
<td>Zero</td>
</tr>
<tr>
<td>2 3 1 7 4 8 6 5</td>
<td>1 2 8 7 6 4 5 2</td>
<td>Two</td>
</tr>
<tr>
<td>2 3 1 7 4 8 6 5</td>
<td>2 8 1 7 5 4 6 3</td>
<td>Four</td>
</tr>
<tr>
<td>2 3 1 7 4 8 6 5</td>
<td>2 3 1 8 4 7 6 5</td>
<td>Six</td>
</tr>
<tr>
<td>2 3 1 7 4 8 6 5</td>
<td>2 3 1 2 4 8 6 5</td>
<td>Eight</td>
</tr>
</tbody>
</table>

For the similarity gradients of “eight” and “zero”, all eight digits in the second sequence were either in the same order as, or were asynchronous to, those of the first sequence. However, for the remaining gradients, the location of corresponding digits in the second sequence could vary considerably. Thus, in the example provided here, the second sequence has a similarity gradient of four, as the location of its first, third, fourth, and seventh digits correspond to those of the first sequence.

During stimulus presentation, the sequence of digits corresponds to the participants’ fingers such that the digit 1 corresponds to the left hand little finger, the digit 2 corresponded to the left hand ring finger, and so on through to the digit 8 that corresponded to the little finger of the participant’s right hand (the thumb on each hand was ignored). For each block of 25 sequence pairs, there was an equal yet randomised distribution of the five second-sequence similarity gradients. The three blocks of sequence pairs were rotated around the filler activities.

**Design.** The experiment employed a 2-factor (filler activity by similarity gradient) repeated measures design. Participants identified the number of items retaining their order of presentation in a second tactile sequence compared to the item order of an initial sequence. Sequences were separated temporally by one of three possible filler activities (silence, articulatory suppression, or tactile interference). Each filler activity was blocked across 25 trials. The three filler activities combined to give six orderings, and four participants were allocated to each ordering.

**Procedure.** Participants were tested individually in a sound-proofed experimental chamber. The nature of the task was conveyed verbally and the requirements of item order were emphasised. At all times, participants’ fingers were held clear of, and parallel to, the table. For each trial, a sequence of eight tactile stimuli (in the form of a tap from the non-writing end of a pen, and at approximately the rate of one tap per 750 ms) was presented to the midphalangeal upper side region of each finger. A 10-second interval then ensued, during which time an appropriate filler activity occurred. This was followed immediately by the second tactile sequence that was presented at the same rate as the first. Participants were permitted to open their eyes only between trials. Three different filler activities occurred during the 10-second interval between sequences. For the articulatory suppression condition, participants were cued (with a tap on the table) to begin repeating aloud the word “the” immediately following presentation of the first sequence. After 10 seconds had elapsed, participants were cued to cease articulation, at which point the second sequence was presented. For the tactile interference condition, the experimenter dragged the end of a pen back and forth across the midphalangeal region of both the participants’ hands for 10 seconds before presenting the second sequence. For the silent filler condition, participants between sequences experienced a 10-second period without tactile interference or articulatory suppression. After having received the second sequence, participants were required to report verbally the number of items (zero, two, four, six, or eight) which had retained their order of presentation when compared to the item order of the first sequence. Although participants were instructed to make similarity judgements, they were not encouraged to engage in any specific strategy. In total, participants completed three blocks of 25 trials and were allowed a 2-minute rest interval between blocks.

**Results**

Participants received a score of one mark for each correct assessment (a maximum of five per similarity gradient); a mark of zero was awarded for any other response. Mean recognition scores for each filler activity as a function of similarity gradient are shown in Figure 1.
Recognition scores were subjected to a 2-factor (3 x 5) repeated measures Analysis of Variance (ANOVA), with filler activity (silence, articulatory suppression, tactile interference) and similarity gradient (zero, two, four, six, eight) as factors. There was a significant main effect of filler activity, $F(2, 46) = 5.38$, MSe = 1.00, $p < .01$; means: silence = 1.67, articulatory suppression = 1.31, tactile interference = 1.69. Further analysis (Newman-Keuls; $p < .05$) revealed that recognition was poorer following articulatory suppression compared to that following either silence or tactile interference. The main effect of similarity gradient was also significant, $F(4, 92) = 5.96$, MSe = 2.26, $p < .001$; means: zero = 1.97, two = 1.86, four = 1.68, six = 0.88, eight = 1.40. Further analysis (Newman-Keuls) showed that recognition was significantly poorer when the second-sequence similarity gradient was six compared to when the similarity gradient was either eight ($p < .05$), zero, two or four ($p < .01$). The filler activity by similarity gradient interaction was non-significant ($F = 1.72$).

Discussion

The results are unequivocal: the ability to assess the similarity of two tactile sequences is impaired by between-sequence articulatory suppression but not by either silence or tactile interference. This finding is consistent with Watkins and Watkins’ (1974) suggestion that tactile sequences are encoded verbally and subsequently rehearsed. The lack of an effect of tactile interference on performance argues against the persistence of first-sequence sensory information (Heller, 1987). Likewise, the analysis of similarity gradient reveals that neither disparate nor identical second sequences were more easily recognised than those second sequences with ambiguous similarity gradients of two or four.

The results of Experiment 1 thus offer little support for the suggestion that sensory information is necessary for the retention of a tactile sequence: post-presentation tactile interference did not impair performance in comparison to the control condition. A plausible candidate explanation for the lack of a tactile interference effect in Experiment 1 is that the second stimulus sequence acted to overwrite the sensory record of the first. By this account, similar levels of performance will be observed in both the control and tactile interference conditions because the second tactile sequence exerts an equivalent retroactive interference effect regardless of the filler activity. Support for this explanation comes from Heller (1980, 1987) who reported a span of three items when tactile sequences were traced onto one palm, but a span of six items when both palms were employed. This finding was interpreted to be the result of sensory after-sensations (or overwriting) acting to disrupt tactile perception. Heller suggests further that such disruption can be minimised by ensuring spatial separation during stimulus presentation. In Experiment 2, therefore, we manipulate the spatial separation of each tactile sequence constituting a pair.

ExPERIMENT 2

This experiment was designed to examine the prediction that sensory traces of the first tactile sequence are overwritten by the second tactile sequence. For half the trials, the second sequence was presented to the hand that received the first sequence, whereas for the remaining trials the second sequence was presented to the opposite hand. Both tactile interference and silence were employed as filler activities. Tactile interference was always presented to the hand that received the first sequence. For both conditions (tactile and
silence) articulatory suppression was undertaken during presentation of the first sequence in order to minimise reliance on verbal coding. Predictions are clear: to the extent that the task requires retention of the sensory representations from the first sequence, tactile interference between sequences should impair recognition accuracy, regardless of whether the second sequence is presented to the same or opposite hand to that which received the first sequence. However, if the second sequence acts by overwriting sensory information from the first sequence, then in the silent control condition recognition will be impaired when the second sequence is presented to the same hand that received the first sequence. Considering the generally low performance levels observed in Experiment 1, and on the basis of a brief pilot study, the number of tactile stimuli in each sequence was reduced from eight to five to avoid floor effects in this and all subsequent experiments.

Method

Participants. Participants were 24 volunteer undergraduates (19 females, 5 males; mean age = 22 years) from the School of Psychology, Cardiff University. All participants received payment and none had taken part in the previous experiment.

Method. Materials comprised four blocks of 25 pairs of five-item sequences. The first sequence in each pair comprised a random ordering of digits 1–5. The similarity gradients were such that the second sequence in each pair shared zero, one, two, three, or five digits in terms of maintained presentation order in comparison to the first sequence. There was an equal and randomised distribution of second-sequence similarity gradients within each block, and the sequence blocks were rotated around the filler activities. The digits translated onto the participants’ right hand such that the digit 1 corresponded to the thumb, through to the digit 5 which corresponded to the little finger. For other hand trials, the digit 1 in the second sequence corresponded to the participants’ left hand little finger, through to the digit 5 which corresponded to the participants’ left hand thumb. The sequence blocks were rotated around each filler activity for each hand of presentation.

Design. The experiment employed a 3-factor (hand of presentation by filler activity by similarity gradient) repeated measures design. Participants undertook a total of 100 trials: one block of 50 trials in which both sequences were presented to the same (right) hand, and another block of 50 trials in which the second sequence was presented to the other (left) hand. Half the participants received 50 same hand trials followed by 50 other hand trials, whereas for the remaining participants, this ordering was reversed. Within each 50-trial block, both silence and tactile interference filler activities were presented in two counterbalanced 25-trial blocks.

Procedure. The procedure was similar to that reported for Experiment 1 with the exception that during other hand trials, the second sequence was presented to the participants’ other (left) hand using the digit-to-finger correspondence just described. Each participant was cued verbally at the start of each trial to commence overt repetition of the word “the” 2 seconds prior to receiving the first sequence. After presentation of the first sequence, the participant was cued non-verbally to cease articulation, at which point the appropriate filler activity occurred. If the filler activity involved articulatory suppression then the participant was not cued to stop articulation until just prior to presentation of the second sequence.

Results

Data were scored as described for Experiment 1. Mean recognition scores for each hand of presentation are shown as a function of filler activity and similarity gradient in Figures 2a and 2b. Recognition scores were subjected to a 3-factor (2 × 2 × 5) repeated measures ANOVA with hand of presentation (same, other), filler activity (silence, tactile interference), and similarity gradient (zero, one, two, three, five) as factors. The main effects of both hand of presentation and filler activity were non-significant (both Fs < 1). However, the main effect of similarity gradient was significant, F(2, 92) = 5.97, MSe = 1.71, p < .001; means: zero = 1.41, one = 1.93, two = 1.66, three = 1.68, five = 2.28. Further analysis (Newman-Keuls) showed that recognition scores were significantly higher when the similarity gradient was five compared to gradients of zero, two, or three (p < .01) and, additionally when the similarity gradient was one compared to zero (p < .05). Of the main effect interactions, only that between filler activity and similarity gradient was reliable,
Further analysis (Newman-Keuls; p < .05) showed that for the silent filler condition, recognition scores were significantly higher when the similarity gradient was five than for any other similarity gradient regardless of filler activity. For the tactile interference condition, recognition scores were significantly higher when the similarity gradient was one compared to gradients of zero or three. None of the other main effect interactions, including the 3-way hand of presentation by filler activity by similarity gradient interaction reached significance.

Discussion

The results show that limiting sensory interference by presenting the second tactile sequence to the hand opposite to the one that received the first sequence does not improve performance relative to a condition where both sequences are presented to the same hand, thereby ruling out the overwriting hypothesis. Further, consistent with Experiment 1, there is no evidence that tactile interference presented as a filler activity impairs recognition performance. Although Heller (1987) has argued that performance on some tactile STM tasks improves when sensory perception is optimised, the results of both this and the previous experiment suggest that the predominant encoding format and representation in the current paradigm is non-sensory in character.

An important observation with respect to these results is that although the opportunity for verbal encoding of the first sequence was severely restricted by requiring participants to undertake articulatory suppression during its presentation, recognition performance nevertheless exceeded the 20% chance level. It seems likely that such performance was achieved by the deployment of encoding strategies other than those that are primarily verbally based. One such possible encoding strategy is the use of spatial imagery. Indeed, the relationship between touch and imagery has been well documented by several authors (see, e.g., Heller, 1991; Warren & Rossano, 1991), and many participants in Experiment 2 reported referring to a mental image of their hands when comparing sequences. Visuo-spatial codes are immune to concurrent verbalisation (Logie, 1986) and thus can be generated and sustained during an articulatory suppression condition (Carpenter & Eisenberg, 1978; Baddeley, 1993). The active use

![Figure 2a. Mean recognition score for each filler activity as a function of similarity gradient ("same hand" trials).](image1)

![Figure 2b. Mean recognition score for each filler activity as a function of similarity gradient ("other hand" trials).](image2)
of spatial imagery, therefore, maybe the preferred encoding strategy when opportunities for verbal encoding are particularly difficult (Experiment 2), and a subsidiary strategy when verbal encoding is possible (Experiment 1).

The extent to which spatial imagery is relied on within the current paradigm can be determined by varying the presentation medium of the second tactile sequence. If the first stimulus sequence is encoded (at least partially) as a visuo-spatial representation, then presenting the second sequence visually should improve recognition compared to a condition where the second sequence is presented in the tactile modality only. Access to the visuo-spatial scratch pad (VSSP) is either via a process of recoding non-visual information or is obligatory and automatic for visual stimuli (Baddeley, 1986). Visual presentation of the second sequence should therefore negate the necessity of actively encoding it into a format congruent with that of the first sequence. However, if the second sequence is presented in the tactile modality only, effortful and attentional resources would need to be allocated to the recoding process, and such a diversion of resources should impair the memorisation of the first sequence.

EXPERIMENT 3

This experiment contrasted both tactile and visual second-sequence presentation mediums. As for Experiment 2, articulatory suppression was undertaken during presentation of the first sequence, and both silence and tactile interference were used as filler activities. For one third of the trials the procedure followed that described for Experiments 1 and 2, in that both sequences were presented to the hand while participants had their eyes closed. However, for an additional third of the trials, the first sequence was presented to the hand while participants had their eyes closed, whereas the second sequence was presented on a diagrammatic representation of a hand while participants had their eyes open. For the remaining trials, both sequences were presented to the hand, but participants were able to see the presentation of the second sequence. Thus, if participants resort to the use of spatial imagery when verbal encoding is denied through articulatory suppression, then recognition should be enhanced in each of the second-sequence visual presentation conditions relative to the standard presentation condition. In addition, any reliance on residual sensory information should be apparent for that condition in which the second sequence is seen being presented to the hand. That is, a cumulative, beneficial effect of sensory and spatial coding should be evident compared to the other two presentation conditions in which second-sequence sensory information is absent (diagram condition), or the benefits of second-sequence spatial information are at the cost of recoding sensory information (standard condition).

Method

Participants. Participants were 24 volunteer undergraduates (16 females, 8 males; mean age = 20 years) from the School of Psychology, Cardiff University. All participants received course credit and none had taken part in the previous experiments.

Materials. Material comprised six blocks of 25 pairs of five-item sequences constructed in the same manner as those sequences used in Experiments 1 and 2. The correspondence of sequence digits to participants’ fingers was the same as described for Experiment 2. There was an equal and randomised distribution of second-sequence similarity gradients within each sequence block. In addition to sequence blocks, a full-size diagrammatic representation of a right hand was employed and was drawn by tracing an adult hand onto an A4 sheet of paper. The fingers of the hand were spread apart to reflect the manner in which participants were required to hold their hands during stimulus presentation.

Design. The experiment employed a 3-factor (second-sequence presentation medium by filler activity by similarity gradient) repeated measures design. Participants undertook 150 trials. The three second-sequence presentation mediums (hand/not seen; hand/seen; diagram/seen) were each blocked across 50 trials and combined to give six presentation orderings. Four participants were allocated to each of these presentation orderings. Within each 50-trial block, silent and tactile interference filler activities were presented in two counterbalanced 25-trial blocks.

Procedure. The procedure corresponded to that of Experiment 2 for those trials where both sequences were presented unseen and to the hand.
For those trials involving visual presentation of the second sequence, participants were cued non-verbally with a pen tap to open their eyes at the end of the 10-second filler activity. Participants then saw the second sequence being presented on either their own hand or the diagrammatic representation, using a digit-to-finger correspondence and presentation rate equivalent to that employed when items were presented to the hand. The orientation of the diagrammatic hand was as for the participants’ own hand; i.e., the fingers faced away from the participant.

Results

Data were scored as for the previous experiments. Mean recognition scores for each filler activity and similarity gradient under each second sequence presentation medium are shown in Figures 3a-c.

Recognition scores were subjected to a 3-factor \((3 \times 2 \times 5)\) repeated measures ANOVA with second-sequence presentation medium (hand/not seen, hand/seen, diagram/seen), filler activity (silence, tactile interference), and similarity gradient (zero, one, two, three, five) as factors. There

Figure 3a. Mean recognition score for each filler activity as a function of similarity gradient (second sequence “tactile presentation, eyes closed” trials).

Figure 3b. Mean recognition score for each filler activity as a function of similarity gradient (second sequence “tactile presentation, eyes open” trials).

Figure 3c. Mean recognition score for each filler activity as a function of similarity gradient (second sequence “diagrammatic presentation, eyes open” trials).
was a significant main effect of second-sequence presentation medium, \( F(2, 46) = 5.49, \text{MSe} = 2.09, p < .01 \); means: hand/not seen = 1.63, hand/seen = 2.05, diagram/seen = 1.97. Further analysis (Newman-Keuls) showed that compared to the hand/not seen condition, recognition was significantly enhanced in both the hand/seen \((p < .01)\) and diagram/seen \((p < .05)\) conditions. There was no difference in recognition scores between the hand/seen and diagram/seen conditions. The main effect of similarity gradient was also significant, \( F(4, 92) = 4.13, \text{MSe} = 1.94, p < .01 \); means: zero = 1.65, one = 1.93, two = 1.79, three = 1.78, five = 2.27. Further analysis (Newman-Keuls) revealed that performance was significantly better when the gradient was five compared to gradients of zero \((p < .01)\), one, two, or three \((p < .05)\). Neither the main effect of filler activity nor any of the main effect interactions proved significant.

**Discussion**

The results of Experiment 3 indicate that seeing the second sequence presented either to the hand or on a diagrammatic representation of a hand improves recognition compared to a condition where the second sequence is presented in the tactile modality only. Such findings suggest a reliance on spatial imagery when opportunities for verbal encoding are denied. Presenting the second sequence visually enables visuo-spatial codes to be formed and retained automatically within the VSSP (Logie, 1986). Thus, comparing a spatial representation of the second sequence with a spatially encoded representation of the first sequence avoids the necessity of overcoming an additional recoding process when the second sequence is presented unseen. The absence of an effect of filler activity, and in particular the lack of a cumulative effect of visual and tactile presentation (hands/seen condition), again suggests that, for this paradigm at least, tactile recognition is not based predominantly on sensory information.

It was suggested during the review process that the pattern of results across these experiments might be particular to the paradigm adopted to examine tactile sensory recognition memory. In particular, it was suggested that because the fingers were laid out in a row in order to present the tactile sequences, this provided spatial cues to the participant and/or facilitated the recoding of each tactile stimulus into an appropriately named digit. From our perspective it seems unlikely that participants recoded each tactile stimulus verbally at encoding in Experiments 2 and 3 because articulatory suppression was required during presentation of the first sequence in both. However, in Experiment 1 the first sequence was presented in silence, thereby allowing verbal recoding of each stimulus, and it is therefore plausible that the results of that study are attributable to the specific paradigm employed. In order to address this possibility empirically Experiment 1 was repeated, and the paradigm described by Miles and Borthwick (1996) was adapted. In that study a single discreet tactile stimulus was applied, unseen, to the underside of the forearm on each trial. After various delays the participant was required to indicate the location of the stimulus. Recall accuracy was impaired independently by both articulatory suppression and tactile interference presented during the delay period, suggesting that the paradigm requires both the retention of sensory tactile codes and the development of articulatory codes.

**EXPERIMENT 4**

Any paradigm that involves the comparison of two tactile sequences will, necessarily, require that stimuli within a sequence be spatially separated at presentation. It follows that both spatial and articulatory recoding opportunities will be available to the participant. In Experiment 4, therefore, we manipulated the availability of such recoding opportunities by contrasting the degree of spatial separation between successive stimuli in a sequence. Thus, using the underside of the participant’s forearm as the presentation medium, in one condition stimuli in both sequences were presented 0.5 inch apart (the “near” condition) and in the other, stimuli were presented 1 inch apart (the “far” condition). We predict that in the “near” condition, due to the spatial proximity of successive stimuli, both spatial and articulatory recoding opportunities will be restricted. To the extent that performance of the task is then dependent on the retention of sensory tactile codes, tactile interference presented between successive sequences will impair recognition accuracy. In contrast, in the “far” condition, due to the decrease in spatial proximity between successive stimuli, articulatory recoding of successive stimuli will be possible (see Miles & Borthwick, 1996). Therefore, articulatory suppression per-
formed between sequences should impair recognition accuracy in the “far” condition.

Method

Participants. Participants were 24 volunteer undergraduates (10 male and 14 female; mean age 22 years) from the School of Psychology, Cardiff University. All participants were paid a small honorarium and none had taken part in the earlier experiments.

Materials. Materials were prepared in the same way as described for Experiment 1 with the exception that each sequence comprised the digits 1–5 rather than 1–8. The digit 1 corresponded to the location closest to the wrist and the digit 5 corresponded to the location closest to the elbow. As in Experiment 1 the ordering of the digits in the second sequence was related to that of the first in one of five possible similarity gradients.

Design. The design of the experiment followed that described for Experiment 1 with the exception that 12 participants were assigned at random to the “near” condition and 12 to the “far” condition. The experiment thus comprised a 3-factor (condition by filler activity by similarity gradient) design.

Procedure. The general procedure was the same as that described for Experiment 1. Following Miles and Borthwick (1996) a scale in 1-inch units was drawn on the underside of the participant’s right forearm, extending from the elbow to the wrist. The precise number of 1-inch divisions differed between participants because of individual differences in forearm length. For all participants only the five most central locations were used. Each participant was tested individually in a sound-proofed air-conditioned experimental chamber. The participant sat at a right angle to the table with his or her arm lying flat on the table at a right angle to the body, with the forearm facing uppermost and with eyes shut. For each trial the first sequence of tactile stimuli was applied at the rate of one stimulus per 750 ms. Each location was stimulated once only during a sequence via a ballpoint pen applied briefly and gently. The second sequence was applied in the same way. The participant’s task was to make a similarity judgement (zero, one, two, three, five) as described for Experiments 2 and 3. In the “near” condition, stimulus locations were 0.5 inch apart, thus the middle 2.5 inches only of the forearm were employed. In the “far” condition, stimulus locations were 1 inch apart, thus the full 5-inch scale was employed. In the control condition, the participant sat quietly throughout the 10-second interval between sequence pairs. In the articulatory suppression condition, the participant was required to repeat the word “the” rapidly and continuously throughout the interval. In the tactile interference condition the ballpoint pen was dragged gently back and forth over the five locations on the forearm at the rate of approximately two complete drags per second throughout the interval. In total each participant completed three blocks of 25 trials and was allowed a 2-minute rest period between blocks.

Results

Data were scored as described for the earlier experiments. Mean recognition scores for each filler activity as a function of similarity gradient for the “near” and “far” conditions are shown in Figures 4a and 4b.

Recognition scores were subjected to a 3-factor (2 × 3 × 5) mixed ANOVA with condition, filler activity, and similarity gradient as factors. The
main effects of condition, $F(1, 22) = 5.0$, Mse = 3.65, $p < .04$; means: “near” = 1.44; “far” = 1.89, and similarity gradient, $F(4, 44) = 12.5$, Mse = 2.07, $p < .0001$; means: zero = 1.2, one = 1.4, two = 1.5, three = 1.7, five = 2.5, were significant. Further analysis (Newman-Keuls) of the latter effect showed recognition accuracy at similarity gradient five to be superior to each of the others ($p < .01$). The predicted interaction between condition and filler activity was significant, $F(2, 44) = 3.8$, Mse = 1.22, $p = .03$. Further analysis (Newman-Keuls) showed recognition accuracy to be higher ($p < .01$) in the “far” condition for both the control and tactile interference conditions compared to the “near” condition. Articulatory suppression impaired recognition in the “far” condition ($p < .01$). Compared to the control condition, recognition accuracy did not vary as a function of either tactile interference or articulatory suppression in the “near” condition. No further main effects or interactions achieved significance.

Discussion

Manipulation of the spatial proximity of tactile stimuli within a sequence resulted in higher recognition accuracy in the “far” condition. However, this effect was modified such that the benefit existed only for the control and tactile interference conditions: in the articulatory suppression condition accuracy for the “near” and “far” conditions was equivalent. The result suggests, consistent with predictions, that participants verbally recoded the sequences in the “far” condition. Once again there is no direct evidence supporting a prominent role for tactile sensory memory; in the “near” condition (where opportunities for both articulatory and visuo-spatial recoding were restricted) there was no difference in recognition accuracy between the three conditions. Nevertheless, even tactile interference in the “near” condition did not reduce performance to the 20% chance level, suggesting perhaps a process of abstract rehearsal (see Gilson & Baddeley, 1969). In these respects the data mirror those obtained in Experiment 1, tending thereby to argue against the view that the findings for the earlier studies are paradigm-specific.

GENERAL DISCUSSION

In contrast to our understanding of tactile recency effects and decay rates for a single stimulus, little is known of the memorial underpinnings for a sequence of tactile stimuli. The present study aimed to partially redress this current omission in the literature by employing a recognition paradigm that compelled participants to estimate the similarity of two temporally separated tactile sequences in terms of maintained item order. Loss of item order information is a possible source of error within all experimental designs that incorporate tactile sequences as the to-be-remembered stimulus material. The principal findings of the four experiments can be summarised as follows: articulatory suppression but not tactile interference impaired tactile recognition in two versions of the task (Experiments 1 and 4). The absence of an effect of tactile interference was not due to the second tactile sequence overwriting the sensory record of the first sequence (Experiment 2). Recognition was enhanced when the second tactile sequence was presented visually, thereby implying that the first sequence was subject to a form of visuo-spatial encoding (Experiment 3).

The findings of the current study broadly agree with those speculations concerning the retention of pre-terminal items within the tactile serial recall paradigm. Whereas Watkins and Watkins (1974) argue that the final item in a tactile sequence is afforded special memorial status...
within a modality-specific sensory store, pre-terminal recall is seen as reflecting the retrieval of verbal labels generated through a recoding process. In contrast to this view, Mahrer and Miles (1999) argued that tactile recency can result from spatial encoding, and that such imagery may extend to encompass earlier sequence items. Although the present data are consistent with both Watkins and Watkins' (1974) and Mahrer and Miles’ (1999) positions, they are clearly inconsistent with Heller’s (1987) suggestion that recall for a sequence of tactile stimuli does not reflect “higher cognitive activities” but instead is dependent on adequate sensory perception. The lack of a direct effect of tactile interference (Experiments 1–4) or of hand of presentation (Experiment 2) suggests at best a limited role for sensory information within the paradigms reported here. Although the ease with which identical sequence pairs were recognised implies a revivification of sensory traces, it may well be that the comparison of identical sequences is undemanding regardless of encoding format. That the recognition of tactile sequences does not rely on sensory information reinforces Watkins and Watkins’ (1974) claim that memory for tactile sensory events is limited both in capacity and duration.

In some respects, the data patterns of the present study resemble those of Keller, Cowan, and Saults (1995) who examined recognition memory for temporally separated pairs of auditory tones. For instance, as for the recognition of tactile sequences, recognition for auditory tones is impaired by a verbal distractor task; although Keller et al. (1995) doubt that extensive verbal recoding is employed in tone recognition. Nonetheless, Keller et al. (1995) report an additional distractor condition in which a series of four tones is presented before the first target tone but is recalled before the second target tone. The harmful effects of this auditory distraction on subsequent recognition are described in terms of interference to a tone rehearsal process based on “auditory imagery”. Thus, both memory for tactile sequences and that for non-verbal auditory stimuli demonstrate functional parallelism: each may be dependent on the recoding of sensory events either into a verbal or imageable format (with the caveat that auditory imagery is unlikely to be “spatial” in nature). However, Keller et al. (1995) doubt that memory for tones is as accurate as that for auditory-verbal stimuli, as the former will not have access to echoic memory. Similarly, the retention of tactile sequences is less faithful than that for a single tactile item. Whereas a discrete tactile stimulus may reside within a modality-specific sensory store, a sequence of tactile stimuli exceeds such a store’s capacity and therefore can be retained only through attention-demanding and vulnerable recoding processes.

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