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Single-probe serial position recall: Evidence of modularity for olfactory, visual, and auditory short-term memory

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Single-probe serial position recall: Evidence of modularity for olfactory, visual, and auditory short-term memory

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The present study examined and compared order memory for a list of sequentially presented odours, unfamiliar faces, and pure tones. Employing single-probe serial position recall and following a correction for a response bias, qualitatively different serial position functions were observed across stimuli. Participants demonstrated an ability to perform absolute order memory judgments for odours. Furthermore, odours produced an absence of serial position effects, unfamiliar faces produced both primacy and recency, and pure tones produced recency but not primacy. Such a finding is contrary to the proposal by Ward, Avons, and Melling (2005) that the serial position function is task, rather than modality, dependent. In contrast, the observed functions support a modular conceptualization of short-term memory (e.g., Andrade & Donaldson, 2007; Baddeley & Hitch, 1974), whereby separate modality-specific memorial systems operate. An alternative amodal interpretation is also discussed wherein serial position function disparities are accommodated via differences in the psychological distinctiveness of stimuli (Hay, Smyth, Hitch, & Horton, 2007).

Keywords: Short-term memory; Order; Serial position effects; Modularity.

Ward, Avons, and Melling (2005) reported qualitatively equivalent serial position functions for both unfamiliar faces and nonwords when applied to a two-alternative forced-choice (2AFC) recognition task and a serial order reconstruction task. The recognition task demonstrated single-item recency whilst the reconstruction task demonstrated both primacy and recency. On the basis of these...
analogous functions, Ward et al. (2005) proposed that the serial position function is task, rather than stimulus or modality, dependent. That is, if the task is held constant, manipulating either the stimulus type or the modality of stimulus presentation will not qualitatively impact the serial position function.

To date, the pattern of data regarding serial position function equivalence across different stimulus types is limited to those studies requiring a visual component at test (see Ward et al., 2005). For example, the extent to which the memory function for olfactory stimuli parallels that observed for other hard-to-name stimuli is yet to be determined empirically. However, there is some evidence for serial position function equivalence for olfactory and visual 2AFC recognition. Following a series of 2AFC recognition tests probing the list items in the reverse order of original presentation, Johnson and Miles (2007) observed single-item recency in the absence of primacy for olfactory stimuli: a finding consistent with that for both abstract matrices (Phillips & Christie, 1977) and unfamiliar faces (Ward et al., 2005). Testing list items in the same order of presentation, Johnson and Miles (2007) observed a flat serial position function: a finding again consistent with that of Avons (1998) using abstract matrices.

One of the few studies incorporating an order component for olfactory memory is that reported by White and Treisman (1997) who compared order memory for both olfactory and verbal stimuli. The order-based task comprised a single 2AFC relative recency test-pair from which the participant was required to state which was presented most recently in the preceding sequence. Recency was extended for the verbal stimuli but not the olfactory stimuli, possibly reflecting the operation of a separate olfactory memory process. Indeed, Andrade and Donaldson (2007), using a dual-task paradigm, showed olfactory recognition memory to be impaired by a secondary olfactory task in comparison to a secondary verbal or visual memory task: a finding consistent with the idea of an independent, olfactory-specific, memory system. Furthermore, Miles and Jenkins (2000) trained participants to serially recall sequences of odour names. They showed a stimulus-specific suffix effect—that is, recency was impaired by an olfactory suffix in comparison to a verbal suffix. Such findings are contradictory to an amodal memory account within which both the effect of a secondary olfactory task and the effect of an olfactory suffix should be equivalent. Rather, such differences are better accommodated by a modality-specific memory account—for example, the working memory model (Baddeley & Hitch, 1974).

One limitation of the Miles and Jenkins’s (2000) study points to its reliance upon verbal labelling of the stimuli. A more appropriate paradigm for assessing olfactory order memory is the single-probe serial position recall task (e.g., Kerr, Ward, & Avons, 1998; Korsnes & Magnussen, 1996). In this task, participants are presented with a sequence of items and at test are presented with a single test-item taken from the previous sequence. The participant is required to state the position of that item within the previous sequence. This task has been applied to both unfamiliar faces (Kerr et al., 1998) and abstract matrices (Korsnes & Magnussen, 1996); at immediate testing the task produced recency but not primacy for both stimulus types.

In the present experiment we assess further the status of olfactory memory via a comparison of absolute serial order memory for odours, unfamiliar faces, and pure tones via the single-probe serial position recall paradigm. In addition, we assess the error distributions for the three stimulus types; Smyth, Hay, Hitch, and Horton (2005) have shown that participants most frequently allocate erroneous responses to positions adjacent to the probed item. Consistent serial position functions and error distributions will support the proposition by Ward et al. (2005) that the serial position function is task, rather than stimulus, dependent.

Method
Participants
A total of 72 participants (6 male and 66 female; mean age 19 years and 7 months) were each
assigned at random, and in equal numbers, to one of three experimental conditions. All were Cardiff University volunteer psychology undergraduates who participated in exchange for course credit. Of those 24 participants assigned to the odour group, all were nonsmokers.

**Materials**

**Olfactory stimuli.** A set of 54 odour pots supplied by Dale Air Limited, UK, was employed (see Appendix for a complete list of the odours). Each odour was presented as a liquid soaked in cotton wool contained in a vortex cube. Each cube was blue in appearance with identical dimensions of 50 mm × 50 mm × 50 mm. One face of the cube contained six perforations from which the odour was inhaled. The integrity of the odour within each pot was maintained by a protective sticker placed over the perforations.

**Visual stimuli.** A set of 54 colour faces of Caucasian adult males with short hair and a neutral facial expression was obtained from the Stirling University database. Each face was presented frontally and centrally on a computer screen with a white background. The faces were of equivalent size, and each appeared within a rectangular frame with the dimensions 115 mm × 140 mm.

**Auditory stimuli.** A set of 54 pure tones (1,000 ms each in duration) was synthesized using Cool Edit 96 software. Following the methodology reported by Suprenant (2001), each tone was generated by increasing the frequency of the previous tone by 4.5%. This allowed the creation of a set of pure tones ranging from 300–4,024 Hz. The tones were presented through headphones at a volume of 75 dB.

**Design**

A (3 × 6) mixed design was employed. The first factor refers to the between-subjects variable of stimulus type (olfactory, visual, and auditory). The within-subjects independent variable was serial position (1–6). For each stimulus type there were 36 trials, each divided into blocks of 6. Within each block, the six serial positions were tested once in a randomized order.

**Procedure**

All participants were tested individually in a well-ventilated, sound-proofed laboratory.

**Olfactory stimuli.** Participants sat facing the experimenter with a fan blowing across their face. In order to minimize visual cues, the participant was instructed to fixate on a red spot located on the table 30 cm in front of them throughout the trials. For each trial the participant was presented with a sequence of six odours. Each odour was presented over a wooden screen located 40 cm in front of the participant and held under the nose of the participant for a period of 1 s. The participant was instructed to inhale deeply through both nostrils for the duration of each stimulus odour presentation. The odour was then replaced behind the screen during which time the participant exhaled. There was an interstimulus interval (ISI) of approximately 1 s, after which the next odour was presented. This procedure continued to the presentation of the last list odour (see Miles & Hodder, 2005, Exp. 2, describing a precedent for this presentation rate).

A retention interval of approximately 3 s followed sequential presentation of the odours. For the test phase the participant was represented with a single odour from the previous sequence for a period of 1 s and was instructed to state verbally the serial position of that item within the previously presented sequence.

**Visual stimuli.** Participants sat at a desk facing a computer screen at a distance of 50 cm. Prior to the commencement of each trial a message appeared on the screen instructing the experimenter to press a key to begin. The experimenter then initiated the trial. The experimental procedure followed closely that described for the odours. A sequence of six unfamiliar faces was presented, with each face presented for 1 s followed by a 1-s ISI. Following presentation of the last face in the sequence a message appeared on the screen indicating the start of the test phase. Following a
3-s retention interval, a single face taken from the previous sequence was then presented for a period of 1 s, and the participant was instructed to state verbally the serial position of that item within the previously presented sequence.

Auditory stimuli. The presentation of auditory stimuli followed directly that described for the unfamiliar faces with the exception that the stimuli were presented via headphones at 75 dB. An additional constraint within sequence construction was that any sequence tone should not be within a frequency range of 4.5% of any other tone within that sequence. Such a constraint limited similarity between sequence tones.

Results and discussion
Nonstandardized data
Figure 1 shows the mean percentage correct recall following single probe serial position recall for odours, unfamiliar faces, and pure tones. A main effect of serial position is present for both faces ($F = 13.09$) and tones ($F = 49.06$) but is absent for odours ($F = 1.77$). However, Kerr et al. (1998) demonstrated that this paradigm can induce a response bias, thereby producing a disingenuous memory function. The response distribution for each stimulus type was therefore examined.

Response bias
Figure 2 (a–c) demonstrates the mean response frequency for each serial position following single-probe serial position recall for odours, unfamiliar faces, and pure tones. The response distribution is uneven across the three stimulus types: odours ($F = 7.11$), unfamiliar faces ($F = 11.70$), and pure tones ($F = 16.54$).

Biases in the response distribution were found for all three stimulus types. An increase in the total response frequency for a particular serial position increases the probability of a correct response for that serial position. Conversely, the probability of correctly responding for a serial position that receives fewer responses is reduced. Therefore, the data were corrected for response bias. Kerr et al. (1998) provide an equation for this correction: $k = (Ck/X) \times (Ck/Nk)$, where $Ck$ is the number of correct responses at the serial position of $k$, $X$ is the average number of responses for each serial position, and $Nk$ is the total number of position $k$ responses. Additionally, across the three stimulus types performance differed substantially (mean recall accuracy = 37.4%, 56.5%, and 47.2% for odours, unfamiliar faces, and pure tones, respectively). To accommodate these quantitative differences between the stimulus types, the corrected data were standardized to $Z$-scores.

Serial position analysis
Figure 3 demonstrates the mean $Z$-scores for the three stimulus groups. Qualitatively different functions are apparent for odours (relatively flat function), unfamiliar faces (primacy and recency), and pure tones (recency only). A two-factor 3 (modality) $\times$ 6 (serial position) mixed design analysis of variance (ANOVA) revealed a main effect of serial position, $F(5, 69) = 46.15$, $MSE = 0.71$, together with a significant interaction between serial position and modality, $F(10, 69) = 14.92$, $MSE = 0.71$.

Further analysis of the interaction (Newman–Keuls, $p < .05$) revealed no significant differences between serial positions for odours. For unfamiliar faces, the score at Serial Position 6 was significantly greater than that at Serial Positions 1, 2, 3, 4, and 5. Additionally, the score at Serial Positions 1, 2, 3, and 4 were significantly greater than Serial Position 5.
Position 1 was significantly greater than that at Serial Positions 2, 3, 4, 5, and 6. For pure tones, the score at Serial Position 6 was significantly greater than that at Serial Positions 2, 3, 4, and 5. Additionally, the score at Serial Position 5 was significantly greater than that at Serial Position 4. In summary, these data demonstrate an absence of serial position effects for odours, both primacy and recency effects for unfamiliar faces, and extended recency in the absence of primacy for pure tones.

The absence of serial position effects for the olfactory stimuli contradicts Johnson and Miles (2007) who reported recency in the absence of primacy following a backward series of 2AFC recognition tests. It is unlikely that differences in stimulus exposure times (3 s in Johnson & Miles, 2007, vs. 1 s in the present experiment) can account for the contradictory findings. Despite the reduced exposure time, performance in the current experiment was substantially above chance (mean correct recall = 37.4%, chance = 16.7%). Support for the ability of participants to provide successful odour judgments following 1-s exposure can be found in Miles and Hodder (2005, Exp. 2) who demonstrated 2AFC odour recognition performance in excess of 70% with a 1-s presentation rate. Alternatively, the absence of recency between the present study and that of Johnson and Miles (2007) may be explicable in terms of two clear task differences. First, in Johnson and Miles (2007) participants provided a binary familiarity judgment; in contrast, for the present study participants were required to recollect the exact positional location of the test probe. The task, therefore, necessitates a qualitatively different memory representation. Second, in Johnson and Miles (2007) each trial comprised a series of 2AFC test-pairs, whereas in the present study a single test-probe was
employed. Johnson and Miles (2007) found some evidence to suggest that an increase in the number of items intervening between presentation and test of an item negatively predicted recognition accuracy. Consequently, increased interference for pre-recency items in Johnson and Miles (2007) may have resulted in the development of single-item recency. Such test-induced interference is absent for the present study, thereby preventing the development of recency.

The primacy and recency effects observed for unfamiliar faces is inconsistent with the findings of both Korsnes and Magnussen (1996) and Kerr et al. (1998) who reported recency only following single-probe serial position recall for sequences of four unfamiliar faces and four abstract matrices, respectively. Unpublished data from our laboratory have demonstrated that the bowed function is robust with this particular stimulus set as both primacy and recency have been found with sequences of four and five faces. Furthermore, we considered the possibility that the primacy evident in our data is an artefact of participants assigning arbitrary verbal labels to the unfamiliar faces and rehearsing these labels subvocally. A pilot study \( (n = 24) \) found that articulatory suppression during presentation did not remove primacy for single-probe serial position recall of four-face sequences compared to a quiet condition. One possible explanation for the qualitative differences in serial position function between Kerr et al. and the present data rests on the type of stimuli employed. It has been argued (e.g., Hay, Smyth, Hitch, & Horton, 2007) that increases in the psychological distinctiveness of stimuli (associated with specialized encoding processes) increases the magnitude of both primacy and recency. In Kerr et al. (1998) faces were presented in greyscale; in contrast, colour faces were employed in the present study. The use of colour faces may have increased their psychological distinctiveness (since individuals have greater familiarity in encoding colour faces), and this may have led to the development of primacy in the present study.

The single-item recency reported for pure tones is consistent with the function reported by Kerr et al. (1998) for unfamiliar faces. However, as previously stated the current data set was unable to replicate this function with odours or faces: a finding at odds with the proposition that the serial position function is task, rather than stimulus, dependent (Ward et al., 2005). The finding of strong recency for pure tones is consistent with the duplex account (Phillips & Christie, 1977), whereby the recognition/recall of the terminal item in a sequence benefits from its representation in a fragile, yet highly accurate, short-term memory store.

**Error analysis**

Following Smyth et al. (2005), mean displacement distances for erroneous responses were computed. A single-factor within-subjects ANOVA with 5 levels revealed a main effect of displacement distance for odours, \( F(4, 92) = 10.74, \text{MSE} = 0.12 \), unfamiliar faces, \( F(4, 92) = 62.65, \text{MSE} = 0.04 \), and pure tones, \( F(4, 92) = 30.78, \text{MSE} = 0.08 \). Further analysis (Newman–Keuls, \( p < .05 \)) revealed that a displacement distance of 1 serial position was significantly more frequent than displacement distances of 2, 3, 4, and 5 positions for all stimulus types. The response distributions for olfactory, visual, and auditory stimuli are analogous and support the findings of Smyth et al. (2005), in showing that erroneous responses are more frequently attributed to serial positions adjacent to the probed position. The finding demonstrates that participants code these three stimulus types in relative rather than absolute codes (see Henson, 1999). Such a finding is consistent with models of short-term memory that code position along a continuous spectrum relative to markers (e.g., the start–end model; Henson, 1998).

**GENERAL DISCUSSION**

The aim of the current experiment was to assess serial position function congruence for olfactory, visual, and auditory stimuli for an order-based task. In contrast to the Ward et al. (2005) proposition, our data suggest qualitatively different functions for these stimuli despite the common
application of a single-probe serial position recall paradigm. One possible explanation for this disparity points to the fact that, in the Ward et al. study, both stimulus types (unfamiliar faces and nonwords) had a visual representation at test. It is possible, therefore, that the commonality in serial position is a consequence of testing in the same visual modality and not due to task identity.

In contrast to Ward et al. (2005) our data suggest that the function for single-probe serial position recall is stimulus, rather than task, dependent. Such a finding is, therefore, consistent with a modularity account of short-term memory, in which separate memorial systems operate for different stimulus types (e.g., see Baddeley & Hitch, 1974). Indeed, the finding that the serial position function for the olfactory stimuli differs from that for both unfamiliar faces and pure tones complements Andrade and Donaldson (2007). They found that olfactory recognition performance was selectively impaired by an olfactory secondary task, whereas verbal recognition performance was selectively impaired by a verbal secondary task. Furthermore, they proposed that a dedicated olfactory subsystem of working memory exists analogous to the visuo-spatial scratchpad and phonological loop. Our data would support such a contention. Moreover, the strong recency observed only in the auditory experiments suggests that an auditory-specific short-term store (acoustic echo) may be in operation (e.g., duplex; Phillips & Christie, 1977).

It is possible that our pattern of data might alternatively be accommodated within an amodal, unitary memorial framework. One component of the scale-invariant, memory, perception, and learning (SIMPLE) model (Brown, Neath, & Chater, 2007; see also Neath & Brown, 2006, 2007) focuses on the psychological distance between the to-be-remembered stimuli. Closer psychological distance between items increases confusability and consequently impairs retrieval. Hay et al. (2007) refer to this as the psychological distinctiveness of items, and it is determined by factors such as familiarity with the stimuli and how effectively the stimulus is processed. Sequences comprising items high in psychological distinctiveness (e.g., faces) encourage the development of both primacy and recency components within the serial position functions (Hay et al., 2007).

Indeed, if low, intermediate, and high weightings of psychological distinctiveness are applied to our stimulus sequences of odours, pure tones, and unfamiliar faces, respectively, then SIMPLE produces serial position functions remarkably similar to our own, empirically derived, functions. Hay et al. (2007) argue that faces as a class of stimuli, in particular, have high psychological distinctiveness due to their frequent and specialized processing inherent to everyday life. This high psychological distinctiveness, in comparison to that for pure tones and odours, may account for the primacy and recency effects evident for faces in the current study.

There is, however, an important caveat to this SIMPLE-based explanation. Hay et al. (2007) suggest that the lack of a primacy component in their own empirically derived serial position functions using a yes/no recognition paradigm is due to proactive interference caused by items in the previously presented sequence. Presumably, recognition of the first item in a particular sequence is impaired due to interference from items in the preceding sequence thereby negating primacy. It appears, therefore, something of an empirical paradox that proactive interference does not produce a similar diminution in primacy in our serial position function for faces. Indeed, evidence of proactive interference (i.e., lack of primacy) in the present set of data is not found despite successive trials occurring in close temporal proximity.

In summary, the present experiment demonstrates qualitatively different serial position functions following single-probe serial position recall for odours, unfamiliar faces, and pure tones. These data are taken to provide tentative evidence for modularity—that is, separate processing systems underpinning memory for different stimuli types.
Such a finding is consistent with Andrade and Donaldson (2007) who proposed an additional olfactory-specific subsystem of the working memory model. However, SIMPLE provides tentative evidence that such serial position function disparities for different stimulus types may be accommodated within a unitary framework.

REFERENCES


APPENDIX

Odour stimulus set

The stimulus set was provided by Dale Air Ltd and comprised 120 non-food-related odour boxes. The odours are listed below; however, it should be noted that for replication purposes some of the odours are arbitrarily labelled, with the label of limited utility if one intended to independently reproduce the odour (e.g., “dragon’s breath”).

<table>
<thead>
<tr>
<th>Alpine laundry powder</th>
<th>Eau de cologne</th>
<th>Man-o-war</th>
<th>Sandalwood</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baby powder</td>
<td>Egyptian mummy</td>
<td>Methane</td>
<td>Sea breeze</td>
</tr>
<tr>
<td>Beauty soap</td>
<td>Eucalyptus</td>
<td>Mahogany</td>
<td>Sea shore</td>
</tr>
<tr>
<td>Bergamot</td>
<td>Factory</td>
<td>Mixed spice</td>
<td>Ships canon</td>
</tr>
<tr>
<td>Boiler room</td>
<td>Farmyard</td>
<td>Mountain heather</td>
<td>Smoke</td>
</tr>
<tr>
<td>Bouquet</td>
<td>Fish market</td>
<td>Mummy</td>
<td>Sports rub</td>
</tr>
<tr>
<td>Brewery</td>
<td>Flatulence</td>
<td>Mustard gas</td>
<td>Stable/horses</td>
</tr>
<tr>
<td>Burning peat</td>
<td>Flowery</td>
<td>Musty</td>
<td>Star's dressing room</td>
</tr>
<tr>
<td>Burnt wood</td>
<td>Forest</td>
<td>Oak</td>
<td>Steam/oil/ships</td>
</tr>
<tr>
<td>Camomile</td>
<td>Fox</td>
<td>Old drifter</td>
<td>Steam/oil/trains</td>
</tr>
<tr>
<td>Cannon</td>
<td>Freesia</td>
<td>Old inn</td>
<td>Street bomb</td>
</tr>
<tr>
<td>Carbolic soap</td>
<td>Fresh air</td>
<td>Old smithy</td>
<td>Sun, sand, &amp; coconut</td>
</tr>
<tr>
<td>Caribbean holiday</td>
<td>Frosty</td>
<td>Old river</td>
<td>Swamp</td>
</tr>
<tr>
<td>Cedar wood</td>
<td>Garden shed</td>
<td>Out at sea</td>
<td>Sweaty feet</td>
</tr>
<tr>
<td>Christmas tree</td>
<td>Grass/hay</td>
<td>Ozone</td>
<td>Sweet peas</td>
</tr>
<tr>
<td>Church incense</td>
<td>Gun smoke</td>
<td>Peat</td>
<td>Tobacco leaf</td>
</tr>
<tr>
<td>Cinnamon</td>
<td>Havana cigar</td>
<td>Pencil shavings</td>
<td>Train smoke</td>
</tr>
<tr>
<td>Clinic/hospital</td>
<td>Hawaiian</td>
<td>Peppermint</td>
<td>Tropical</td>
</tr>
<tr>
<td>Cloisters</td>
<td>Heather/bracken</td>
<td>Phosgene gas</td>
<td>Tropical rain forest</td>
</tr>
<tr>
<td>Coal face</td>
<td>Honeysuckle</td>
<td>Pine</td>
<td>Urine</td>
</tr>
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<td>Coal fire</td>
<td>Hyacinth</td>
<td>Pineapple plantation</td>
<td>Victoria lavender</td>
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<tr>
<td>Coal gas</td>
<td>Incense</td>
<td>Pine/heather/peat</td>
<td>Violets</td>
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<tr>
<td>Coal/soot</td>
<td>Iron smelting</td>
<td>Pit ponies</td>
<td>Volcano</td>
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<tr>
<td>Cut grass</td>
<td>Jaguar spray</td>
<td>Polish-wax</td>
<td>Vomit</td>
</tr>
<tr>
<td>Deep heat</td>
<td>Jasmine</td>
<td>Pot-pourri</td>
<td>Wallflower</td>
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<tr>
<td>Dentist–clove oil</td>
<td>Lavender</td>
<td>Riverbank</td>
<td>Washday</td>
</tr>
<tr>
<td>Dinosaur</td>
<td>Leather</td>
<td>Rope/tar</td>
<td>Wild stag</td>
</tr>
<tr>
<td>Dirty linen</td>
<td>Leather/hide</td>
<td>Roses</td>
<td>Wine cask-oak</td>
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<tr>
<td>Dragon's breath</td>
<td>Lemon, eucalyptus, &amp; mint</td>
<td>Rotten egg</td>
<td>Woodsmeke</td>
</tr>
<tr>
<td>Earthy</td>
<td>Machine oil</td>
<td>Rubbish acrid</td>
<td>Ylang jasmine and myrrh</td>
</tr>
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</table>