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studies. These results suggest that articulatory fluency may have been prematurely excluded as a source of linguistic familiarity effects in short-term memory.

Dear Professor Greene

We have no addressed your latest comments, as set out in the response letter.

Bill Macken

Dear Professor Greene

We've now had a close look at the ms in the light of your latest comments. You are indeed correct in noting an error in the degrees of freedom reported in Experiments 3a and 3 b. It seems that this was due to using the values from within-subjects contrasts, rather than within-subjects effect. This has now been remedied, and the outcome is essentially the same.

As regards the post hoc tests in the absence of a null interaction in 3b, we should perhaps have noted our circumspection about this in the original. We consulted Keppel (1991) and Keppel et al (1992), the textbooks we use for ANOVA in the School, on this issue, and the argument there is that if there is a specific, a priori hypothesis to be tested, then post hoc pairwise comparisons may still warranted even in the absence of a significant interaction. We felt that given the presence of the critical interaction in Experiment 3a lent weight to the justification. Also, we felt more comfortable with this having added the confidence intervals in subsequent versions which indicated that only the 95% CI 'different item/different coarticulation' condition before and after familiarisation contained zero difference. We have set out this justification, with reference to Keppel in the latest revision.

As regards the ANOVAs in Experiments 1 and 2, we prefer to avoid 3-way ANOVAs where possible, more perhaps for aesthetic than statistical reasons, simply because they become cumbersome to present in a simple way, and dissecting 3-way interactions can be tricky for a reader (never mind a writer) to digest. We think that the analyses as they are still meet our ends, since for each trial type (single versus sequence) we test for the effect of familiarisation (null for singles, significant for sequences). We hope that this makes the point in a clear way to the reader.

Finally, we have indicated that Table 2 refers to the footnote, and included the number of participants in that footnote.

We hope that this meets your concerns.

Regards

Bill Macken

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Linguistic familiarity in short-term memory: A role for (co-)articulatory fluency?

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RUNNING HEAD: ARTICULATORY FLUENCY IN STM

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Abstract

Enhanced serial recall for linguistically familiar material is usually attributed to a process of item redintegration. The possibility tested here is that familiarity influences memory at the sequence level by enhancing the fluency with which items may be assembled into sequences. Experiment 1 showed that with practice, serial recall of nonwords improved more than that of words. Experiment 2 showed that the improvement in recall with practice was associated with increasing fluency in producing sequences but not with greater fluency in producing items. Experiment 3 suggested that enhanced coarticulation per se, rather than mere inter-item association led to enhanced performance for familiar lists, since the effects of familiarisation with sequences of items generalised to sequences of different items if those items shared between-item coarticulatory transitions with the familiarised items. Experiment 4 showed that real differences in articulatory processing of familiar and unfamiliar items may have been overlooked in previous studies. These results suggest that articulatory fluency may have been prematurely excluded as a source of linguistic familiarity effects in short-term memory.

Linguistic Familiarity in Short-Term Memory: A role for (co-) articulatory fluency?

Present-day understanding of short-term verbal memory comes predominantly from research using serial recall tasks, involving the recall of familiar items in an unfamiliar sequence. This research has identified some canonical effects upon short-term serial recall performance that stem from the character of the items making up the to-be-remembered lists, including those of word length (e.g. Baddeley, Thomson & Buchanan, 1975; Schweickert & Boruff, 1986), lexicality (e.g. Hulme, Maughan & Brown, 1991; Hulme, Roodenrys, Brown & Mercer, 1995; Roodenrys, Hulme & Brown, 1993), phonological similarity (e.g. Conrad & Hull, 1964; Baddeley, 1968; Schweickert, Guentert & Hersberger, 1990), and word frequency (e.g. Roodenrys, Hulme, Lethbridge, Hinton & Nimmo, 2002). In explaining these serial recall phenomena the conceptual and empirical focus has been predominantly on the properties of individual items making up a sequence rather than on the superordinate properties of the sequence, particularly as it relates to the assembly and rehearsal of that sequence.

The focus of the current paper is on what we here generically refer to as linguistic familiarity (e.g. lexicality, word frequency) and its influence on short-term memory performance. This is a factor usually characterised as operating on an item-based process, most typically through the construct of redintegration, the mechanism whereby partially-degraded, temporary representations are reconstructed at retrieval using long-term phonological knowledge of items. This redintegrative account of the effect of linguistic familiarity posits two types of phonological representation: a temporary one, subject to decay and interference, and a permanent one. The process of redintegration, therefore, is purported to operate at the phonological level whereby

a degraded temporary representation may either be reconstructed using a corresponding long-term representation, or, as is often instantiated in formal models of such a process (e.g. Burgess & Hitch, 1998; Henson, 1998; Page & Norris, 1998; Neath, 2000), the partial, temporary representation of an item is used as a retrieval cue to locate the closest match in long-term memory, with such a representation then providing the basis for output.¹ Whatever the precise mechanism, the more available and accessible such long-term phonological representations are, the better the redintegrative support for recall. For this reason, nonword recall performance is worse than that for words (Gathercole, Pickering, Hall & Peaker 2001), as is recall of high frequency words better than that of low frequency words (Hulme et al., 1991). Similarly, the recall advantage for first versus second language material in bilinguals effect is argued to arise due to more available long-term phonological knowledge for first language items than second language items (Service, 1992; Chincotta & Hoosain, 1995; Thorn, Gathercole & Frankish, 2002).

In the current article, we examine the role of a factor other than that represented by item-based, phonological-level redintegration. Specifically, we examine the possibility that the fluency with which items may be assembled into sequences of articulatory gestures may contribute to those effects previously primarily or exclusively ascribed to the operation of item redintegration. In particular, attention is focused on the role played by co-articulatory fluency at the boundaries between list items – necessarily a sequence-level rather than an item-level factor – on verbal short-term serial recall performance.

Most general accounts of short-term memory performance combine the constructs of trace decay and rehearsal in a complementary fashion. Once encoded

into a phonological format, to-be-remembered items are held in short-term memory, where they are subject to passive decay. In order to maintain material in memory, the items need to be rehearsed. Evidence for the role of rehearsal comes from the observed relationship between speech rate and memory performance: the faster the individual speaks, the more efficient the rehearsal and better short-term serial recall is (Baddeley et al., 1975; Hulme & Muir, 1985). The word length effect is thought to occur because more items of shorter articulatory duration can be rehearsed in a given amount of time than long items (Baddeley et al., 1975; Hulme et al., 1991; Schweickert & Boruff, 1986). Similarly, speakers of languages with digits (integers) of short articulatory duration have a higher memory span for digits than speakers of languages which have longer digit duration (Ellis & Hennesly, 1980; Chincotta & Underwood, 1996). Further evidence of the importance of rehearsal comes from the effect of articulatory suppression: when participants are prevented from rehearsing, then recall performance is greatly reduced (Baddeley et al., 1975; Bourassa & Besner, 1994).

Counter to this, we have recently argued that an account based on temporary phonological representations of items, cyclically refreshed via articulatory rehearsal, is an unparsimonious way to account for a range of short-term memory phenomena (e.g. Jones, Hughes & Macken, 2006; Jones, Macken & Nicholls, 2004; Macken & Jones, 2003. See also, Nairne, 2002 for critique of the trace decay plus rehearsal approach from a different perspective) and that the notion of temporary phonological storage may, in fact, be theoretically redundant. Rather, we argue that short-term memory is best regarded as a setting in which participants must opportunistically deploy whichever skills they possess that may be effective in meeting the particular demands of the task (cf., Neumann, 1989; 1996). In the case of verbal serial recall of

semantically and syntactically impoverished lists, the key skill is that of assembling a speech output plan consisting of a sequence of articulatory gestures that will allow for the reproduction of the list. As such, the rehearsal process is argued to reflect the cyclical execution of a speech output plan, rather than the cyclical revivification of separate phonological representations that are subject to decay without such revivification (Jones et al., 2006). Note that such an account shares with the redintegrative one an emphasis on the role of the long-term in short-term memory performance, but rather than focussing on the redintegration of temporary phonological representations of items via their long-term counterparts, it focuses on the skill involved in the fluent assembly of a sequence.

Notwithstanding the finding that linguistic familiarity tends to affect recall of item rather than order information (e.g. Nairne and Kelley, 2004), evidence for such an account of the role of sequence-level, articulatory output-planning processes would provide a challenge to the status of item-based processes generally, and redintegration in particular, as the sole or primary locus of the effects of linguistic familiarity on short-term memory. Indeed, much of the recent research that has been taken to point to the operation of a redintegrative process has also cast doubt on the importance of the role played by articulatory processes in determining memory performance for items differing in familiarity. In particular, the lexicality effect – better recall for words than nonwords – is found when there is no apparent difference between the articulatory duration of the words and nonwords (Hulme et al., 1991; Hulme et al., 1995; Thorn & Gathercole, 2001). Moreover, under articulatory suppression, the word length effect is diminished but the lexicality effect is not (Besner & Davelaar, 1982). The finding that lexicality and other familiarity-based effects (e.g. word frequency and bilingual language familiarity effects) are apparent even in the absence of

differences in articulatory duration has suggested that factors such as long-term memory support via redintegration, rather than via articulatory fluency, are in operation (Hulme et al., 1991; Thorn & Gathercole, 2001; Roodenrys et al., 1993).

However, while both plausible and dominant, in its focus on the item-level of representation, the redintegration account fails to consider the role of emergent properties at the sequence level arising from combining items of a particular type into a to-be-remembered sequence. One such is the effect of the articulatory complexity of certain item combinations. Aside from the articulatory character of the items themselves, the other important factor in determining articulatory complexity arises from the process of the coarticulation of adjacent items. Fluid, accomplished, sequence production is underpinned by extensive planning, not just of the order of the items and their associated gestures, but the compromises and accommodations in articulatory planning that have to be made between items (e.g., Sternberg, Knoll, Monsell & Wright, 1982). Coarticulation occurs when articulatory movements or gestures needed for adjacent gestures accommodate and anticipate each other, so that during fluent speech the final phone of one word is able to assimilate the characteristics of the first phone of the following word. Despite the adjustments made by speech planning processes, it remains the case that some transitions are more complex and time consuming than others. Importantly, the complexity of the coarticulation has an impact on serial recall performance. Words that are easier to say in sequence together, by virtue of containing less complex between-item articulatory transitions, are better recalled than words that are less easy to produce in sequence, even when individual items are matched for duration and frequency (Murray & Jones, 2002). Critical to our current concern, therefore, measuring the duration of sequences not only reflects the duration of the constituent items but it also captures the time

taken to execute the articulatory gestures necessary to negotiate the boundaries between words.

We contend that, both in particular and in general, the co-articulations required during a short-term memory task are relatively unfamiliar to the participant: in general because items are usually drawn from the same syntactic class, and therefore seldom encountered adjacently in everyday speech, and in particular because they will be encountered infrequently even within a study. It seems reasonable to expect, just as with any other skilled task involving gestures, that the fluency – and hence duration – of the gestures at the boundaries of words will improve markedly with familiarity. If articulatory duration is a determinant of short-term memory performance we may further expect improvements in fluency to be associated with improvements in recall performance.

Articulation of a sequence of familiar items could involve more familiar and less complex movement of articulators (mouth, tongue and lips) between items in a sequence than unfamiliar sequences, leading to faster and more effective assembly of items into a sequence for rehearsal. We argue here that the importance of co-articulatory fluency has been underestimated in studies assessing the contribution of articulation to verbal serial short-term memory.

One of the main reasons articulatory factors have been ruled out in explaining familiarity effects is that recall performance differences between the classes of items (e.g. high *vs.* low frequency words, words *vs.* nonwords) persist even when the items have been apparently matched on articulatory duration. However, it seems possible that the role of articulatory factors in familiarity effects at the sequence level have not been captured by measurements of articulatory duration restricted to the item level. A number of different methods have been used to measure the impact of articulatory

duration (see Mueller, Seymour, Kieras & Meyer, 2003 for a discussion), each of which in some way potentially fails to fully capture the effect of coarticulation. These include measuring counting rate (Standing & Curtis 1989), measuring articulation rates of items on their own (Caplan, Rochon & Waters, 1992; Lovatt, Avons & Masterson, 2000), or in four-word sequences (Cowan, Wood, Wood, Keller, Nugent & Keller, 1988), and commonly the measurement of rapid repetition of pairs of items (Gathercole & Adams, 1994; Baddeley & Andrade, 1994). If coarticulatory fluency is a key determinant of efficient rehearsal, measuring duration of individual or pairs of items would minimise the estimate of its potential contribution to serial recall, as most such tasks require the recall of many more items.

The purpose of the experiments that follow is to assess the contribution made by increased coarticulatory fluency to improvement in serial recall when participants become more familiar with the to-be-remembered sets of items. The experiments test the proposition that the articulatory gestures needed to produce items in unpractised sequences may be less familiar and hence less fluent than those needed for practised sequences. Results supporting this view would prompt a re-evaluation of the role of sequence-level, articulatory processes in some aspects of serial recall performance.

The present experiments adopt a methodology distinct from the usual studies examining linguistic familiarity effects in serial recall (e.g. Gathercole et al., 2001; Roodenrys et al., 1993). Instead of using items with different levels of pre-experimental familiarity (words/nonwords, high/low frequency words, etc.), the familiarity of stimuli is manipulated directly within the experimental setting. In this sense, the experiments are a microcosm of language learning.

All the experiments followed the same basic methodology. Initially, a baseline measure was taken of the articulatory duration of items spoken in isolation and in

sequence (Stage 1). This was followed by a familiarisation stage (Stage 2) that involved articulating sequences of items, either through rehearsal during serial recall or reading aloud. The familiarisation phase was followed by a post-familiarisation stage (Stage 3) in which articulatory duration measurements were again taken for items in isolation and in sequence. Finally, in some instances, a post-familiarisation serial recall task was also administered in order to test the memorability of different types of sequence (Stage 4).

Interest is focussed on two issues in relation to these experimental stages; firstly, whether familiarity with the articulation of sequences would affect the duration of items or sequences, and secondly, whether familiarity with the items or sequence will have an impact on serial recall performance. If a sequence-level factor such as coarticulatory fluency plays a role in serial recall performance it is expected that as participants become more familiar with articulating the items in sequence, their ability to produce and recall sequences containing these practised coarticulations should improve.

Experiment 1

The first experiment set out to examine the effect of familiarisation on the rate of production of words and nonwords spoken both in isolation and in sequence, as well as recall for such word and nonword sequences. Participants were familiarised with the items during a block of serial recall trials. The impact of this on the speed of production of items and sequences without a memory load – articulatory fluency – was assessed by measuring articulatory duration of both single items and items spoken in sequences before and after the memory test. The memory test was split into three blocks to monitor any improvement made on both word and nonword lists as participants progressed through the trials. In particular, the experiments investigated

whether words or nonwords benefit more from practice and whether any such benefit is manifest at the item or sequence level.

Method

Participants

Twenty-five undergraduate and postgraduate students at Cardiff University (15 female and 10 male native English speakers aged between 18 and 24) participated in the experiment in return for payment or as part of their course credit. All reported normal hearing and normal or corrected-to-normal vision.

Apparatus and Materials

The items varied in lexicality (words and non-words). All items were one-syllable CVC stimuli, which were randomly drawn from the stimulus pool used by Gathercole et al. (2001). Two different sets of words and non-words were randomly chosen. Participants were randomly assigned a set. Each participant always encountered the same six words and six nonwords throughout the experiment. The items were either, Set 1, (Words: *dog, birch, warm, soot, kerb, chuck*. Non-words: *lod, chorg, dook, jit, tudge, mern*) or Set 2, (Words: *bark, torch, learn, nod, chat, dig*. Non-words: *gerch, jal, chig, padge, darp, gan*). Six-item sequences were used for serial recall: pilot studies had found that memory performance for 7-item nonword sequences was extremely poor and at 5-item length, memory for word sequences was at ceiling.

Sets 1 and 2 were used for the familiarisation stage (Stage 2), which took the form of a serial recall task. The stimuli were from natural male speech recorded digitally to 16-bit resolution at a sampling rate of 44.1 kHz using the audio editing software *SoundForge* (*Sonic Foundry Inc., Madison, WI*). All items were compressed digitally to 400ms, which did not alter the pitch, using the same software. The lists

were six items in length with no items being repeated in any one trial. Items did not appear in the same serial positions in successive trials and there were no identical trials. The word and nonword trials were presented in a quasi-random order, with the restriction that there were no more than two of the same type of trials in succession. The sequences were presented on a Macintosh computer using the *PsyScope* experiment control system (Cohen, MacWhinney, Flatt & Provost, 1993), at the rate of one item per second. All spoken responses were recorded using a microphone and the audio editing software *SoundForge 5.0*.

Procedure

All participants were tested individually in a soundproof laboratory. During the first baseline reading stage (Stage 1) participants were instructed first to read aloud each word or nonword that appeared on the screen as quickly and accurately as possible, before pressing the spacebar for the next individual item. Each item was presented three times. Next, six-item sequences, consisting of either words or nonwords were presented simultaneously on the screen. On separate trials three six-item word sequences and three six-item nonword sequences were displayed, one at a time, in the centre of the screen. The order of the items in the sequence was randomly determined on each occasion. Participants were required to read aloud the sequence from left to right, as quickly and accurately as possible before proceeding to the next sequence.

Following the baseline reading stage (Stage 1) was the familiarisation phase and participants were given instructions for the serial recall task (Stage 2). Participants were told that they would hear sequences of six words or nonwords, spoken over the headphones. Immediately after presentation, the computer screen flashed; this was the participants' cue to recall, vocally, the items in sequence.

Participants were informed that it was important that they preserved the order of the items, so that at any place in the sequence where they were unsure of the correct item they should respond 'blank'. When the 10 s recall time was up, a tone was sounded to signal the beginning of the next trial within 2 s. The serial recall task consisted of 60 trials (30 word lists and 30 nonword lists), along with two practice trials, taking approximately 20 minutes to complete. All responses were recorded onto the computer in *SoundForge*. After the serial recall task, participants were again presented with the individual item and sequence reading task (Stage 3), which was identical to Stage 1. The procedure took just under an hour to complete.

Results and Discussion

Articulatory duration (pre-and post-familiarisation)

The sequence and item recordings were labelled and saved for each participant. Then duration of each utterance was measured in milliseconds using *SoundForge* software. Mean item duration was calculated for words and nonwords. Similarly, for the sequence recordings the duration from the start of the sequence until the end of the sequence was measured. There were three sequences of each type, and the average duration for each sequence type was divided by six, so a mean duration per item in a sequence was calculated for both words and nonwords. Table 1 shows the mean duration of words and non-words spoken in isolation and in sequence, before (Stage 1) and after (Stage 3) the serial recall task (Stage 2). There was very little difference in duration between isolated words and nonwords before familiarisation (Stage 1) and little decrease in articulation time for either type after familiarisation (Stage 3). The articulatory duration of words and nonwords spoken in sequences showed a different pattern of results. The duration of an item was much shorter when articulated within a sequence than when articulated in isolation.

Additionally, participants got quicker at articulating both word and nonwords in sequences, after completing the serial recall task.

A repeated-measures ANOVA carried out on the single-item duration data containing the factors item type (word vs. nonword) and stage (Stage 1 vs. Stage 3), established no main effect of item type on articulatory duration when spoken in isolation, $F < 1$, and no effect of stage $F(1, 24) = 1.25$, $MSE = 357.42$, $p = .35$. Participants did not get significantly faster at saying items in isolation after familiarisation, for either words or nonwords. However, the ANOVA on the sequence data established a significant main effect of item type, $F(1, 24) = 18.11$, $MSE = 742.22$, $p < .001$, indicating that it took longer to articulate a nonword in sequence than it did to articulate a word in sequence. The analysis also found a significant main effect of Stage, $F(1, 24) = 7.98$, $MSE = 1736.79$, $p < .01$ as well as a significant item type by stage interaction $F(1, 24) = 5.48$, $MSE = 447.33$, $p < .05$, indicating that nonword articulation rates improved more in sequence between stages (mean decrease in duration per item = 33.44 ms, 95% confidence interval for decrease = 12.71 ms to 54.17 ms) than did word articulation rates (mean decrease in duration per item = 13.64 ms, 95% confidence interval for decrease = -4.09 ms to 31.37 ms). In summary, after the serial recall task, improvement in speech rate was greater for nonword than word sequences, but was restricted to the production of sequences, rather than single items.

Serial recall (Stage 2)

The serial recall responses were recorded and then these were transcribed and scored with respect to serial position: only items that had been recalled in the presentation serial position were scored as correct. The serial recall task was split into

three blocks of 20, with 10 word and 10 nonword sequences in each, so that the average number correct in a block could be compared for both the words and the nonwords.

The number of items correctly recalled in each serial position was scored for each participant as a function of item type and block. These data are summarised in Figure 1, which shows the mean proportion of items correctly recalled in each block as a function of lexicality. Words were better recalled than nonwords, $F(1, 24) = 117.41$, $MSE = 125.92$, $p < .001$. ANOVA also showed that there was a main effect of block, $F(2, 48) = 17.64$, $MSE = 62.34$, $p < .001$, reflecting the fact that recall of items improved with block. There was also a significant interaction between item and block, $F(2, 48) = 9.17$, $MSE = 46.91$, $p < .001$, showing that overall, the improvement between blocks was much greater in the nonword trials (mean improvement in recall from Block 1 to Block 3 = 15.21 %, 95% confidence interval for improvement = 19.19% to 11.23 %) than the word trials (mean improvement from Block 1 to Block 3 = 3.48%, 95% confidence interval for improvement = 8.48% to -1.50%), although recall of nonwords started from a lower baseline than that for words.

To summarise the main findings of Experiment 1: Firstly, articulatory duration was longer when items were spoken in isolation than when spoken in a six-word sequence – this finding illustrates how coarticulation enables the articulatory programme to be shortened when items are spoken in sequence. Furthermore, there was no difference in the articulatory duration of words and nonwords when spoken in isolation, but, when duration of items produced in sequence was measured, words were articulated faster than nonwords. This difference in the articulatory duration of words and nonwords produced in sequence may be a reflection of the differences in the familiarity and complexity of articulatory gestures needed to coarticulate the

different types of sequence. For example, word sequences containing familiar items are perhaps easier to articulate quickly than nonword sequences that contain unfamiliar articulatory gestures making them more difficult to coarticulate and slower to produce (we return to this issue in Experiment 4). Importantly, these results suggest that measuring items in isolation may not be the best reflection of their duration when placed in a connected sequence of a length usually presented for serial recall. This has important implications for studies challenging a role for articulation in the lexicality effect. Typically, these studies have not measured the articulatory duration of sequences; rather they have used isolated words or, at best, repetition of word-pairs (Baddeley et al., 1975; Baddeley & Andrade, 1994; Gathercole & Adams, 1993).

Secondly, familiarisation was shown to have an effect on the articulatory duration of words and nonwords when they were spoken in sequence. However, there was no corresponding decrease in articulatory duration for either words or nonwords when the items were spoken in isolation. The improvement in articulatory duration observed for both words and nonwords spoken in sequence, resulting from familiarisation, suggests that it is the increase in the familiarity of the material at the sequence level which enhances fluency. Furthermore, after familiarisation, the duration of the nonword sequences decreased more in articulatory duration than the word sequences, suggesting that the nonword sequences involving unfamiliar articulatory gestures benefited more from familiarisation than the word sequences. The results of Experiment 1 have shown that there are effects of familiarisation on articulatory processing that are revealed only when measuring the duration of items spoken in sequences rather than in isolation, which in turn may determine how well they are recalled.

Finally, the serial recall data showed an effect of lexicality, with word recall performance being superior to nonword recall, a finding that has been demonstrated elsewhere many times (Gathercole et al., 2001; Hulme et al., 1991; Roodenrys et al., 1993). However, the influence of familiarisation on articulatory duration of sequences is also reflected in the serial recall results. There was a significant improvement in the recall of word and nonword sequences with practice, with nonword recall improving more than word recall. Thus, the improvement in the serial recall of nonword sequences is mirrored by the increased speed of articulation for nonword sequences after familiarisation. Taken together, these findings suggest that as the gestures involved in articulating a sequence become more familiar to the participant, the greater the ease with which they can assemble items into a sequence for rehearsal, which has consequences in the form of faster articulation rates and improved rehearsal efficiency.

However, from this experiment it is unclear what exactly is being learnt with practice: the item or the sequence? The results of Experiment 1 suggest that practice articulating sequences is associated with improved nonword recall performance. However, from a redintegration standpoint it could be argued that the reason recall of nonwords improved more with practice is that long-term phonological knowledge of nonword items is being built up, and supports the item recall. Initially, participants had no lexical representation of the nonwords, but as they get more familiar, the redintegrative support improves for the nonwords, leading to a beneficial effect for recall performance. Nevertheless, one might expect such an account to predict an effect of familiarisation on the spoken duration of nonwords in isolation, which was not the case in Experiment 1. The question of the effect of practice on sequence-level factors is further addressed in Experiment 2.

Experiment 2

The results of Experiment 1 raise the possibility that previously overlooked sequence-level factors may play a role in the effect of linguistic familiarity on short-term serial recall. The purpose of Experiment 2 was to further explore the contribution of familiarisation to articulatory fluency and memory: Is it purely the familiarity of an item at the phonological level that mediates the effect of linguistic familiarity or does the familiarity with the articulatory gestures used in coarticulating a sequence also contribute to performance? In Experiment 2 only nonwords were used, as they do not have any lexical entry in long-term memory that could initially aid recall through redintegration.

In Experiment 2, we employed an experimental procedure similar to that used by Stuart and Hulme (2000) who investigated the effect of word co-occurrence on short-term memory. In their study they divided words into two groups (A and B) and found that pre-exposure to low frequency pairs of 'A' words and 'B' words resulted in increased memory performance for sequences containing the familiarised pairings of items, but not when the sequences contained items from alternating sets. In the current study, we presented each participant with 12 different nonwords. The nonwords were taken from two closed sets of six items each (A items and B items). In the reading stages (Stages 1 & 3) participants were required to articulate different types of sequence. The types of sequence either comprised all nonwords in a single set (either all A items or all B items), referred to here as 'pure' lists, or sequences consisting of alternating items from set A and set B words, referred to as 'mixed' lists. Of course, in Stage 1 these sequence types were, from the standpoint of the participants, undifferentiated. In the familiarisation stage (Stage 2), participants were tested on serial recall of sequences of only pure lists (comprising either only-A or

only-B items). Then they were given the sequences to articulate again in Stage 3 (after familiarisation), and finally Stage 4 was another serial recall task comprised of both pure and mixed lists, in order to study what effect familiarisation had on memory for the different types of sequence. If familiarisation with coarticulating the items in sequence together is important, it would be expected that after the familiarisation stage (Stage 2), participants would be faster at reading the pure sequences (practised coarticulations) than the mixed sequences (unpractised coarticulations), even though the items in each type of sequence will have been encountered equally often during the familiarisation stage. We also predicted better recall of the pure sequences in the final serial recall task (Stuart & Hulme, 2001). However, if the establishment of permanent phonological representations of the items themselves is the key mechanism underpinning familiarity effects, then there should be no difference between the pure and mixed lists as the participant will have encountered all the individual items the same number of times. While an effect of pure versus mixed lists will not necessarily rule out the existence of an item-based influence, it will nonetheless point to the existence of some effect of familiarity with the verbal material that transcends the mere item level.

Method

Participants

Twenty-four undergraduate and postgraduate students at Cardiff University participated in the experiment, in return for payment or course credit. All reported normal hearing and normal or corrected-to-normal vision. They were 17 female and 6 male native English speakers, aged between 18 and 22. None of the participants had taken part in the previous experiment.

Design and Materials

Thirty-six nonwords from the Gathercole et al. (2001) study were assigned randomly to one of three groups comprising two sets – A and B – each of six words. Each participant experienced only one of the three groups. From each group, three types of sequence were constructed: pure A, pure B, and mixed (AB). The sequences consisted of either, all set A items, all set B items (pure lists) or alternating items from sets A and B (mixed lists). The stimuli for the serial recall task were from natural male speech recorded digitally with a 16-bit resolution at a sampling rate of 44.1 kHz using the audio editing software *SoundForge 5.0*. All items were compressed digitally to 400ms using the same software. The serial-recall task (Stage 2) consisted of 60 trials altogether (30 pure A sequences and 30 pure B sequences). The lists were six items in length with no item being repeated in any one trial.

Procedure

Participants were tested individually in a soundproof room. Stage 1 involved the baseline measurement for reading words from the screen either in isolation or as a sequence. Firstly, all single items from the set to which a participant had been allocated were displayed on the screen one at a time, participants were requested to read aloud each one as quickly as possible before pressing the spacebar and proceeding to the next item. Items to be spoken in sequence were then presented simultaneously and participants were asked to read each sequence aloud as quickly and accurately as possible from left to right, before the next sequence appeared. There were 12 sequences altogether, all six items in length: four pure A sequences, four pure B sequences and four mixed (AB/BA) sequences.

The familiarisation stage (Stage 2) comprised the serial recall task, as in Experiment 1. The to-be-remembered-items were presented auditorily at a rate of one

item per second. Only pure sequences were presented for recall. Stage 3 of the experiment was identical to the first stage; here, participants read the nonwords both in isolation and in sequences. Finally Stage 4 involved a similar serial recall task to the second stage but there were only 24 sequences, 12 sets of ‘pure trials (6 ‘A’, 6 ‘B’) and 12 sets of mixed trials in which to-be-remembered sequences involved alternations between the two sets (i.e., A,B,A,B..., or B,A,B,A...).

Results and Discussion

Articulatory duration was measured as described in Experiment 1. The mean articulatory duration of all items spoken in isolation was taken to get an average duration for a nonword uttered in isolation. The average duration of an item in a sequence, either pure or mixed, was reached by dividing the average duration of each kind of sequence by 6 (the number of items in a sequence). The pure-A sequence and pure-B sequence durations were averaged to get one ‘pure’ sequence duration. This was done for Stages 1 and 3.

There was no appreciable change in the duration of items produced in isolation: The average isolated item duration was 517ms in Stage 1 before the familiarisation in Stage 2, and 511ms in Stage 3 after familiarisation. As in Experiment 1 there was no significant difference between the isolated item duration before and after familiarisation of the items on the serial recall task, $t(23) = 0.88, p = .39$. Figure 2 shows the average duration of an item in sequence, before and after familiarisation for both pure and mixed lists. The articulatory duration of an item spoken in pure and in mixed sequences was very similar in Stage 1, that is, before the familiarisation stage. However, in Stage 3 – after the familiarisation stage – there was a decrease in the duration of items spoken in pure sequences that was not observed in the duration of items spoken in mixed sequences. A repeated measures ANOVA

established there was no significant main effect of list type (pure/mixed) or stage (before or after the serial recall task). However, there was a significant interaction between list type and stage, $F(1, 22) = 9.39$, $MSE = 362.08$, $p < .01$. A significant decrease in articulatory duration was found in pure sequences after familiarisation $t(22) = 2.58$, $p < .05$ (mean decrease = 25.55 ms, 95% confidence interval for decrease = 46.06 ms to 5.03 ms) which was not the case for mixed sequences $t(22) = 0.13$, $p > .05$ (mean decrease = 1.24 ms, 95% confidence interval for decrease = 20.44 to – 17.97). So, even though each item in both pure and mixed lists was encountered equally often during the familiarisation stage, this familiarisation only led to a reduction in articulatory duration when the sequences contained items that had been practised together (pure lists).

The serial recall responses after familiarisation were transcribed and only items that were recalled correctly in the correct serial position were scored as correct. Figure 3 shows serial position curves for recall of both pure and mixed lists. Overall, the pure lists were recalled better than the mixed lists. These results are an indication that the enhanced performance due to familiarisation cannot be exclusively attributed to increased familiarity of the individual items, as all A and B items were presented the same number of times. Rather familiarity with the sequence is clearly playing a role. A t-test showed the difference between the recall of the two types of lists to be significant, $t(22) = 4.17$, $p < .001$ (mean superiority of recall of pure over mixed lists = 6.10%, 95 % confidence interval for difference = 3.10% to 9.10%).

In summary, as with Experiment 1, the results of Experiment 2 showed that an item spoken within a sequence was articulated faster than an item spoken in isolation. In this instance, however, item familiarity was controlled across the conditions, as only nonword items were used, which did not have any lexical representation in long-

term memory. The rehearsal-based factor varied here was the familiarity with assembling the items into sequences. As in Experiment 1, there was no significant difference in articulatory duration between the items spoken in isolation before and after the familiarisation stage. Additionally, there was no significant difference between sequences of pure lists and sequences of mixed lists in the baseline stage of the experiment (Stage 1). After familiarisation with the pure sequences in the serial recall task, participants showed a significant decrease in articulatory duration of the pure lists which was not matched by the articulatory duration of the mixed lists, (in which the coarticulations had not been practised). All the items had been encountered the same number of times during the serial recall task, so the degree of ('pseudo') lexicality or familiarity with those items should be the same within pure and mixed lists. However, the results point to the role of a sequence-level factor, such as the ease with which items are assembled into a fluent sequence, in enhancing performance with pure versus mixed lists.²

In the final stage of the procedure, participants were tested on recall of both pure and mixed lists. The results showed that serial recall of sequences containing practised coarticulations (i.e. pure lists) was better than that of mixed lists (unpractised coarticulations). If, as Thorn & Gathercole (2001) have argued, item familiarity is the critical factor underpinning the effect of linguistic familiarity, the recall of all lists (pure and mixed) should have benefited from familiarisation to the same degree, as all items had been experienced the same number of times. While it might be argued that the larger set size for mixed versus pure lists (12 versus 6 items) could contribute to this difference in recall, it seems unlikely that such a set size effect, per se, could also account for the difference in fluency of production when the

items merely need to be read aloud from the screen. As such, the correspondence between the effect of pure versus mixed lists on both memory and articulatory fluency is suggestive of a common mechanism.

The present finding is similar to that of Stuart & Hulme (2000) who showed that participants familiarised with pairs of items by speaking them together performed better on a serial recall task than participants who had not been familiarised with the items in pairs. Since they claimed that their stimuli had been matched on articulatory duration, they attributed their finding to associative support for the process of redintegration, as opposed to the coarticulatory account we propose here; they argued that familiarisation created inter-item associations between items in long-term memory aiding serial recall performance via item redintegration. We turn to investigate this issue in the following Experiments 3a and 3b.

Experiment 3a

The results from the foregoing experiments suggest that familiarisation with items in sequences affects articulatory fluency and recall by increasing the readiness with which sequences of items can be assembled into a coarticulated sequence for rehearsal and recall. These results are encouraging for the idea that improvements in memory are mediated by the fluency of speech planning processes; however, an alternative explanation remains in terms of the action of other inter-item, associative processes.

Given that items from pure lists have been repeatedly presented together, the speedier production of pure lists could arise from the forging of stronger associative links between items within a given set. Elsewhere, repeated presentation of item pairings has been shown to lead to better subsequent serial recall (Stuart & Hulme, 2000). That result was explained in terms of strengthened associative links between

co-occurring items enhancing the level of redintegrative support for individual items via activation from other, associated items. So, for the experiments in the current series, the presentation together of A or B items for the serial recall task could have strengthened the associative links between the items within each set, making it easier to articulate and recall pure sequences. Nevertheless, Experiment 2 of the current series showed that practising the articulation of sequences did not improve the articulation rate for pairs of items (see Footnote 2).

The purpose of Experiment 3a was to distinguish between such effects of inter-item association and those of actual coarticulation. To achieve this we developed sets of nonwords such that, while each set contained different items, pairs of sets contained items sharing articulatory transitions between onset and offset. This enabled us to assess the effect of co-articulatory fluency independently of inter-item associations, since while the articulatory transitions were common across such lists, each list contained different items. If familiarisation with one set of items leads to enhancement in fluency that generalises to other sets containing different items but similar co-articulatory transitions, this would be strong evidence that the effect is mediated via articulatory fluency rather than any inter-item associative process. Experiment 3a involves within-groups examination of such coarticulatory generalisation while Experiment 3b assesses the influence, in a between-groups procedure, of such generalisation on serial recall performance.

Method

Participants

Twenty-four undergraduate psychology students at Cardiff University participated in this study in return for course credits. They were aged between 18 and 24 years of age, there were 8 males and 16 females. All participants reported normal

or corrected- to-normal vision and hearing and had English as their first language. None of the participants had taken part in any of the previous studies in this series.

Apparatus & Materials

Twenty-four nonwords were taken from the stimuli used by Gathercole et al., (2001). Items were selected on the basis that for each one there was a corresponding item in the Gathercole et al set which shared its onset and offset consonants. Both of the matching items were then selected (e.g. *pem* and *pim*) and assigned to different sets. Thus in total, four sets of six nonwords were used, although during testing each participant was only exposed to three out of the four sets. The four nonword sets were labelled A, B, C & D. Sets A and B contained items within which the onset and offset syllables were matched, but the vowel portion of the items were different (e.g. set A; *pem, darp, nerg, tudge, lub, bick*; and set B; *pim, derp, norg, tidge, lib, bock*). The same rule applied to sets C and D (e.g. set C; *mon, gub, chad, darch, jit, mup*; and set D; *mun, gab, chud, derch, jat, mip*). Before testing started each participant was allocated the three sets of items to which they would be exposed during the experiment, consisting of two sets with matched onsets and codas, and one set of completely different items (e.g. AB & C or AB & D or CD & A or CD & B).

For Stages 1 and 3 (pre- and post-familiarisation duration measurement) four six-item sequences were constructed from each of the three sets a participant had been allocated (e.g. four pure-A sequences, four pure-B sequences and four pure-C sequences). All items were presented visually on a computer screen.

Procedure

Participants were tested individually in a soundproof room, seated in front of a microphone. Before the experiment, each participant was allocated three sets of items to which they would be exposed. Allocation of item sets was counterbalanced across

participants, with 6 participants seeing each combination. Initially, participants were presented with every item from all the sets they had been allocated, each item appeared individually at the centre of the computer screen and participants were required to clearly read aloud each word. This part of the experiment aimed to familiarise participants with the pronunciation of the items as well as ensuring that similar items were pronounced differently. Once all the items had been presented and accurately spoken the experiment proper began with Stage 1, involving the baseline measurement for reading the different types of sequences. Items to be spoken in sequence were presented simultaneously and participants were required to read each sequence aloud as quickly and accurately as possible from left to right. Each participant read 12 sequences in total; four from each of the sets they had been allocated. All spoken responses were recorded using *SoundForge 5.0* software.

In Stage 2, the familiarisation stage, participants were presented with six-item sequences, which appeared in the centre of the computer screen. The familiarisation stage involved production of sequences from only one of the sets. Participants were required to read aloud each sequence as quickly and accurately as possible. Each of 40 different sequences were presented three times. Following the familiarisation stage was the second duration measurement stage (Stage 3), where participants were required to read sequences aloud as quickly as possible. As in Stage 1, each participant read 12 sequences; four from each of the sets they had been allocated. This meant that duration measures were taken for sequences constructed from the same items with which the participants had been familiarised, sequences constructed from different items which contained the same onsets and codas as the familiarised items, and sequences constructed from completely novel items.

Results and Discussion

The duration of each recorded utterance from Stages 1 and 3 was measured in milliseconds using *SoundForge 5.0*. Mean sequence duration was calculated for each sequence type, and then this number was divided by six to produce a mean duration per item for each sequence type. Thus, each participant provided a duration measurement for each of the three sequence conditions before and after the familiarisation stage, the three conditions being as follows; *same item* sequences, which were sequences containing the same items as those familiarised in Stage 2, *different item/same coarticulation* sequences, which were the sequences which contained different items but identical onsets and codas to the ones practiced in the familiarisation stage, and finally, *different item/different coarticulation* sequences which contained both different items and different coarticulations between items to those encountered during familiarisation. Figure 4 shows the articulatory duration of the items spoken in sequence before and after the familiarisation stage. A repeated measures ANOVA revealed a significant main effect of sequence type $F(2,48) = 4.60$, $MSE = 588.51$, $p < .005$. There was also a main effect of Stage, $F(1, 24) = 11.74$, $MSE = 2426.19$, $p < .005$, but this was qualified by a significant interaction, $F(2,48) = 12.63$, $MSE = 423.82$, $p < .001$. This interaction arose as while there was a reduction in articulatory duration for both *same item* and *different item/same coarticulation* conditions as a result of familiarisation, $t(23) = 5.25$, $p < .001$ (mean decrease in duration per item = 48.71 ms, 95% confidence interval for decrease = 29.55 ms to 67.87 ms) and $t(23) = 2.84$, $p < .01$ (mean decrease in duration per item = 26.65 ms, 95 % confidence interval for decrease = 7.26 ms to 46.03 ms) respectively, there was no such enhancement for *different item/different coarticulation* sequences from Stage 1 to Stage 3, $t(23) = 0.79$, $p = .44$ (mean decrease in duration per item = 7.34 ms, 95% confidence interval for decrease = -11.97 to 26.65).

While the actual items in the *same coarticulation/different items* condition were novel to the participant, at the post-familiarisation stage, the prior experience of producing coarticulatory transitions within a different set of items nonetheless led to an increase in the fluency with which those novel items could be assembled into sequences. Such a finding demonstrates that coarticulatory fluency may generalise across different items and again points to the operation of a sequence-level contribution to the effect of linguistic familiarity. Further, it suggests that the enhanced fluency and serial recall for items due to their co-occurrence during familiarisation, as demonstrated in Experiment 2, is not due solely to the establishment of inter-item associations providing extra redintegrative support for item retrieval, since we have shown here that the advantages of co-occurrence accrue for items that are novel in themselves, and therefore could not have become associated during the familiarisation stage. Rather, this result points to a role for familiarity with coarticulatory transitions, beyond that with items themselves, in enhancing the fluency with which items may be assembled into sequences. In Experiment 3b we investigate whether this coarticulatory generalisation also operates on serial recall, such that novel items may become better recalled if they share coarticulatory transitions with familiarised items.

Experiment 3b

While Experiment 3a demonstrated that coarticulatory fluency could generalise across sets of items, so long as those sets shared common articulatory transitions between items, in Experiment 3b, our concern was with the impact of this on actual serial recall performance. To this end, we assessed serial recall performance both before and after familiarisation. While we used the same stimuli sets as those employed in Experiment 3a, in order to reduce the extra-list intrusions that would be

likely to occur if each participant received lists for recall constructed from several different sets, we manipulated our variable of interest between groups in this instance. As such, the Stage 1 measurement of pre-familiarisation recall performance involved, for each participant, sequences constructed from only one of the sets A, B, C, or D. Participants were then familiarised, by speeded spoken production, with only sequences from a single set depending on which condition they were in, followed by post-familiarisation serial recall of sequences from the same set recalled at Stage 1. Thus, the *same item* condition might involve set A at Stage 1, 2 and 3; the *different item/same coarticulation* condition might involve set A sequences at Stage 1, familiarisation with set B at Stage 2, and serial recall of set A sequences again at Stage 3; and the *different item* condition might involve sets A, C, A at the three stages respectively. The critical question is whether Stage 2 familiarisation with items that are different to those involved in the Stage 1 and 3 serial recall tasks but which share onsets and codas will lead to improved post-familiarisation serial recall.

Method

Participants

Thirty-six undergraduate psychology students from Cardiff University took part in the study as part of their course requirement. They were aged between 18 and 24. All participants reported English as their first language and had normal or corrected-to-normal vision and hearing. None of the participants had taken part in any of the previous studies.

Materials, Design and Procedure

This study utilised a between subjects design, with each participant randomly allocated to one of the three conditions employed in Experiment 3a with 12 participants in each condition. The conditions and stimuli were identical to those used

in the previous experiment except that items were presented during the serial recall task at a rate of 2 per second, and a retention interval of 10 seconds was interpolated between the end of the list and the prompt to begin recall. Spoken recall of the lists was required and for any position where the participant was unsure of the item, they responded 'blank'. Thus, the experiment consisted of a brief familiarisation of each of the individual words, followed by a twelve trial serial recall task followed by the speeded reading task (familiarisation stage) which was identical to the previous experiment. The experiment ended with a final serial recall task identical to that prior to familiarisation.

Results & Discussion

Only items recalled in the correct serial position were scored as correct. Figure 5 shows the percentage serial recall performance for each condition before and after the familiarisation stage. ANOVA revealed no main effect of sequence condition or interaction between conditions and stage (before/after familiarisation), $F(2,33) = 0.72$, $MSE = 5.22$, $p > .05$ and $F(2,33) = 1.49$, $MSE = 1.25$, $p > .05$ respectively, although there was a significant main effect of stage, indicating better recall performance overall after familiarisation than before, $F(1, 33) = 24.20$, $MSE = 1.25$, $p < .001$. While the interaction between stage and condition was not significant, given the *a priori* nature of the prediction and the presence of the critical interaction in Experiment 3a, we conducted pairwise comparisons for each sequence condition on recall scores before and after familiarisation (see e.g. Keppel, 1991; Keppel, Saufley & Tokunga, 1992). Unsurprisingly, for the *same item* condition where the same items were presented in serial recall as those presented in the familiarisation there was a significant improvement $t(11) = 4.17$, $p < .01$ (mean improvement in recall performance = 14.92%, 95% confidence interval for improvement = 22.83% to

7.10%). However there was also a significant improvement for the *different item/same coarticulation* group, $t(11) = 3.64, p < .01$ (mean improvement in recall performance = 11.67%, 95% confidence interval for improvement = 18.75% to 4.58%). So, even though different items had been familiarised, merely practising the coarticulations lead to enhanced recall performance of the different items. Moreover in the *different item/different coarticulation* condition there was no significant improvement from the first to the second serial recall task, $t(11) = 1.29, p > .05$ (mean improvement in recall performance = 5.75%, 95% confidence interval for improvement = 15.67% to -4.17%). As indicated in the confidence intervals, therefore, a zero difference between stages only falls within the 95% range in the *different item/different coarticulation* condition.

The results of this experiment reflect those of Experiment 3a, where we showed that the fluency due to familiarisation with assembling one set of items into sequences could generalise to another set of items if that set contained the same between-item transitions as the familiar set. The results of Experiment 3b indicate that the same generalisation can lead to enhanced serial recall performance as well as enhanced fluency. They provide a further example of how effects of linguistic familiarity on serial recall may be mediated by the influence of that familiarity on the readiness with which sequences of familiar items may be assembled into sequences by virtue of such sequences containing practised coarticulatory transitions.

Experiment 4

This far, we have argued that familiarisation with a set of verbal material may have its impact on serial recall performance by enhancing the coarticulatory fluency whereby a sequence of items may be assembled, not merely by increasing the degree of redintegrative support for individual items within a sequence. Further, we have

argued that, in measuring articulatory duration for the production of singles or pairs of items, previous studies that found differences in serial recall across sets of items that appeared matched on articulatory duration may, in fact, have overlooked differences in articulatory duration that only emerge when the production of longer sequences is measured.

On the face of it, it might seem unlikely that an explanation of the effect on serial recall of factors such as word frequency could be accounted for in terms of the more familiar items benefiting from more practised coarticulatory transitions, since the types of items typically used are drawn from the same syntactic class (e.g. nouns) and therefore are unlikely to have actually been coarticulated together in normal speech. On the other hand, more frequently-occurring words will likely have occurred in more articulatory contexts than less frequently occurring words, and therefore could benefit from having been subject to a greater range of practised coarticulations than less frequent words. Similarly, there is evidence that coarticulatory processes such as vowel and consonant reduction are more evident in high than low frequency material (e.g. Fidelholtz, 1975; Stephenson, 2003). Therefore, it is at least possible that highly familiar items are more amenable to coarticulatory fluency, even within serial recall tasks, than are their low familiarity counterparts. This, coupled with the potentially insensitive measures of articulatory duration employed in previous studies, motivated us to re-examine some of the relevant stimuli used in such studies.

Simply therefore, in Experiment 4, as well as measuring serial recall performance, we replicated and extended the analysis of articulatory duration of the high and low frequency words employed by Hulme et al (1997; see also Hulme et al., 2002) when only a single item was spoken, when pairs were spoken, and when 6-item sequences were spoken. The influence of coarticulatory processes would be expected

to increase across these conditions as the number of different transitions increases from 1 to 2 to 6, and as such, we would predict that differences in articulatory duration of repeated items that may be absent when fewer transitions are required, will become evident with the longer sequences.

Method

Participants

Eighteen undergraduate psychology students from Cardiff University took part in this study in return for course credit. They were all aged between 18 and 23 years. All participants had normal or corrected-to-normal vision and hearing and had English as their first language.

Design & Materials

Eight high frequency and eight low frequency words used by Hulme et al., (1997) were used in this study. The high frequency set comprised words with a frequency of 103 words per million or more according to the norms of Kučera and Francis (1967), they were; *hour, colour, game, fear, view, art, unit, order*. The low frequency set comprised words with a frequency of 5 words per million or less, they were; *foal, vow, truce, vet, crock, elf, dolt, lisp*. Hulme et al., (1997) indicated that these words were matched on articulatory duration and concreteness ratings.

Procedure

Participants were seated in a soundproof laboratory in front of a microphone. Initially they were presented with each of the high frequency and low frequency items in a random order, which they were required to read aloud, thus enabling the experimenter to check their pronunciation before the serial recall task and to familiarise the participant with the items that they would be presented with throughout the rest of the experiment. After this they were given instructions for the serial recall

task. They were presented with twenty types of each sequence (words and nonwords). Each sequence was six items long and each item was presented at a rate of one item per second. When the whole sequence had been presented participants were required to recall the sequence aloud in its order of presentation. Participants were instructed that the order was very important and if they were unsure of any item they were to respond 'blank'. No item was repeated in any one trial and no more than two types of the same type appeared successively. All responses were recorded into *SoundForge* for subsequent scoring.

Once the serial recall part of the experiment had finished, measures of articulatory duration of the different sets and sequence lengths were taken. The ordering of the three types of sequence (1-, 2-, and 6-item sequences) was counterbalanced across participants.

For the individual item duration, each item was presented individually at the centre of the computer screen and participants were instructed to repeat the word 10 times as quickly as possible, while monitored by the experimenter. When they had uttered 10 repetitions the word disappeared and the next item was presented.

For the pair duration measurement, participants were presented with four randomly-constructed pairs of high frequency and four low frequency pairs, one at a time. Again, participants were instructed to rapidly repeat each pair as quickly as possible. They were monitored by the experimenter and when they had completed ten repetitions of the pair, the pair disappeared from the screen and the next pair was presented. The order of high and low frequency pairs was alternated. Two practice pairs were presented at the beginning, consisting of novel words.

Finally, to measure sequence duration participants were presented with four high frequency and four low frequency, six-word sequences which were presented

alternately. Participants were required to articulate each sequence as quickly as possible. Again, all responses were recorded onto *SoundForge* and the mean times of the separate measurements could be converted into articulatory duration for the high and low frequency conditions. The experiment was conducted in a single session, which lasted about 45 minutes.

Results and Discussion

Serial Recall

Serial recall responses were transcribed for each participant and scored according to a strict serial recall criterion; only items that had been correctly recalled in the correct serial position were scored as correct. Figure 6 shows the mean percentage correct of items at each serial position for the high frequency and low frequency sequences. High frequency word recall was significantly better than low frequency word recall over all serial positions. 65% of high frequency words were recalled correctly compared to 48% low frequency word sequences. This difference was significant $t(17) = 5.77, p = < .001$. Hulme et al., (1997; Hulme et al., 2003) reported a similar result with the same sets of items that high frequency words are recalled significantly better than low frequency words.

Articulatory Duration

The participants' voice was recorded during each of the duration measurement tasks and the time taken to articulate the individual items or pairs 10 times or the sequences in the high and low frequency conditions was measured from the visual waveform in *SoundForge 5.0*. The mean of these measures was converted into mean articulatory duration for a single high or low frequency item spoken in each of the three sequence types (i.e., single item, pair of items, and 6-item sequences); these data are shown in Figure 7. A repeated-measures ANOVA, with the factors sequence type

(individual/pair/6-item) and word frequency (high/low frequency) was carried out. This showed a significant main effect of frequency, $F(1, 17) = 49.84$, $MSE = 6813.79$, $p < .001$, with high frequency words having shorter durations overall than low frequency words. However, while there was not a significant main effect of sequence type $F < 1$, there was a significant interaction between sequence type and word frequency, $F(2, 34) = 17.94$, $MSE = 378.03$, $p < .001$. This reflects the fact that, while the high frequency items used here and by Hulme et al. (1997) were articulated more rapidly than low frequency items in all cases (mean effect of frequency for individual words = 6.64 ms, 95% confidence interval = 12.16 ms to 1.11 ms; mean effect of frequency for pairs = 28.07 ms, 95 % confidence interval = 38.77 ms to 17.38 ms; mean effect of frequency for 6-item sequences = 45.55 ms, 95% confidence interval = 68.35 ms to 26.75 ms), there was a much smaller effect of frequency in the individual articulation condition than there was in either the pair or the sequence condition $t(17) = 2.53$, $p < .05$, $t(17) = 5.54$, $p < .001$, and $t(17) = 5.11$, $p < .001$ respectively.

Hulme et al., (1997) found in their first experiment, when short, medium and long items were examined and articulatory duration was measured in pairs there was a significant difference between high and low frequency duration, although the differences in recall were not believed to be attributable to speech rate differences when an ANCOVA was carried out. However, in their second experiment only short words were used, and articulatory duration was measured from individual repetition of items, there was no difference found with this measure. The results of the present experiment (where only short items were used) indicates that there are bigger differences in articulatory duration between high and low frequency items when pair and sequence duration is examined than when individual word repetition is

considered. This further suggests that there are coarticulatory differences involved in articulating high and low frequency words which have been overlooked in studies of linguistic familiarity effects. Certainly, the results cast doubt on the claim that differences in recall performance for different classes of items have been demonstrated in the absence of differences in the articulatory character of those items. This is particularly so in relation to how that character is likely to manifest itself within serial recall, a situation in which relatively long sequences of items have to be assembled into a rehearsal cohort.

General Discussion

These experiments investigated whether linguistic familiarity effects observed in serial recall experiments – commonly attributed primarily to the item-based process of redintegration – may also be due to differential fluency with which sequences of more and less familiar items can be articulated. The first three experiments showed that as serial recall performance improved with familiarisation, the articulatory duration of sequence production decreased, whereas the duration of singles or pairs of items did not show this facilitation. These findings suggest that as coarticulations became more practised – increasing the articulatory fluency with which the sequence may be produced – serial recall performance improves. Furthermore, the results also suggest that inter-item coarticulation rather than the formation and strengthening of associative links between items that led to the observed decrease in articulatory duration and enhanced recall performance of pure sequences. Further, we demonstrated that some effects of linguistic familiarity previously attributed to redintegrative processes may in fact be due to articulatory fluency.

Typically, short-term serial recall research has focussed on the properties of individual items making up a sequence rather than the articulatory demands involved

in producing items in sequence. The experiments reported here have shown that factors which necessarily transcend the mere item level of representation, in particular the coarticulatory processes involved in the assembly of a whole sequence, affects the articulatory duration and recall performance of those items. Traditionally models of short-term memory concentrate on the importance of rehearsal for serial recall performance (e.g. Baddeley, 1986; 2001) but the rehearsal of items at the sequence level and related factors involved in articulating sequences of items – such as coarticulation – are not usually specified. Further, such models see rehearsal as a process of cyclical revivification of temporary phonological representations of individual items. In contrast, we regard rehearsal as a process of cyclical, pre-output implementation of a plan for the output of the entire sequence. As such, our account emphasises sequence-level factors in a way essentially ignored by traditional models of verbal short-term memory. The demonstration of the importance of such factors in the experiments reported here lends weight to this view of rehearsal.

The apparent absence of articulatory differences between stimuli with different degrees of familiarity (e.g. lexicality, high versus low frequency) which nonetheless lead to differences in serial recall performance has been used to argue the existence of an item-based processes of redintegration (Hulme et al., 1991; Hulme et al., 1995; Thorn & Gathercole, 2001). The results of the current experiments have shown that sequences where items had been articulated together were recalled better and articulated faster than exactly the same items placed in unpractised sequence forms. Despite all the items being equally familiar to the participant and therefore presumably having an equal degree of redintegrative support, only the items in sequences where coarticulations were familiar sustained better recall performance. Also, the advantage accrued due to familiarisation was only evident when the duration

of items within relatively long sequences was measured, with the duration of pairs or single items unaffected by familiarisation.

The demonstration that the effects of familiarisation with transitions within a particular set of items could generalise to a new set of items containing the same transitions again suggests a role for sequence-level, rather than merely item-level, factors in giving rise to the recall advantage for linguistically familiar material. This raises the possibility that articulatory fluency accounts for at least some of the linguistic familiarity effects observed in short-term serial memory. Importantly, in showing that articulatory differences between familiar and unfamiliar linguistic materials may become increasingly evident as the number of different coarticulatory transitions within spoken output increases, the results also undermine some of the evidence which has in the past been used to argue against the role of articulatory processes in linguistic familiarity effects. Clearly, the results of these experiments enable us to question the ways articulatory rate and duration should be measured in serial recall experiments (see also Mueller et al., 2003) if articulatory factors are to be ruled out as an explanation of the effects of linguistic familiarity.

To date, few other studies have taken into account the complexity of articulatory gestures needed to coarticulate separate items together. However, one comprehensive study into speech errors and serial recall involved presenting adults with a serial recall task consisting of spoken nonsense syllables (Treiman & Danis, 1988). The authors examined recombination errors and found that vowel liquid rimes (items ending with /l/r/w/y/h) were more likely to be retained than vowel obstruent rimes (items ending with /p/b/t/d/k/). This could be because the articulatory gestures are more complex for vowel obstruent rimes than vowel liquid rimes which are easier to coarticulate. Manipulations of the wordlikeness of nonwords have found recall for

wordlike nonwords to be superior to the recall of less wordlike nonwords (Vitevitch, Luce, Charles-Luce & Kemmerer, 1997; Gathercole, Frankish, Pickering & Peaker, 1999). This is usually attributed to better redintegrative support for wordlike nonwords. However it is possible that items with common sound sequences are repeated more quickly than those with less common sound sequences due to the articulatory gestures involved being more familiar, making the items easier to assemble into sequences and consequently better recalled. Therefore, the wordlikeness effect in serial recall may not have its locus solely in redintegration but also in articulatory differences between wordlike and less wordlike nonwords.

The findings of the present experiments lend further weight to the view that serial recall performance and the retention of items in working memory is parasitic on general perceptual and motor planning processes, rather than reflecting the operation of bespoke stores and processes (Jones, Macken & Nicholls, 2004; Jones, Hughes & Macken, 2006; Macken & Jones, 2003). In the case of verbal material, the processes involved in serial recall tap into the same operations that exist to process speech. So, the closer the to-be-remembered material matches a person's language skills or speech habits the more efficient the recall performance achieved (Macken & Jones, 2003). The proposal that the underlying articulatory control processes at work in language and serial memory are the same in both cases has been highlighted by the finding that errors in natural speech are very similar to errors made in serial recall experiments (Ellis, 1980; Treiman & Danis, 1988). Coarticulation is one specific feature of fluent speech that in previous verbal serial recall experiments has been largely overlooked. The complexity of the articulatory gestures needed to make the transition from the end of one item into the beginning of another item in a sequence affects recall performance (Murray & Jones, 2002). The current experiments have shown that the

opportunity to practice assembling novel items into sequences for rapid production (during rehearsal in a serial recall task, or speeded reading) leads to an increase in the articulatory fluency with which sequences of such items may be produced, but does not lead to greater fluency in the production either of the individual items or in the production of sequences within which the items are familiar, but the transitions between them are not. The specificity of this effect of familiarity on articulatory duration is precisely mirrored in the effect of familiarity on serial recall performance, and while the evidence presented here is correlational in nature, it is none the less strongly suggestive in implicating the factor of coarticulatory fluency in the effect of linguistic familiarity on serial recall.

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Author Notes

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Figure Captions

Figure 1. Percentage of correctly recalled words and nonwords for each block of ten trials. Error bars show SE.

Figure 2. Articulatory duration of pure and mixed lists before and after the serial recall task Error bars show SE.

Figure 3. Serial position curves for percentage of items correctly recalled in each serial position for pure and mixed sequence trials in Stage 4.

Figure 4. Articulatory duration of items in milliseconds before and after practice of reading sequences. Error bars show S.E.

Figure 5. Percentage of items recalled correctly before and after familiarisation with the different sequence types. Error bars show S.E.

Figure 6. Mean percentage of high and low frequency (HF and LF) words recalled as a function of serial position.

Figure 7. Mean articulatory duration of high frequency (HF) and low frequency (LF) words when repeated individually, in pairs or in 6-item sequence. Error bars represent S.E.

Footnotes

In its focus on the phonological level, such a long-term contribution to short-term memory may be distinguished from others, such as for example, the advantage that may occur when all list items come from a single taxonomic category (e.g. St. Aubin & Poirier, 1999), an effect likely mediated by semantically driven search strategies.

²Two factors which we overlooked in Experiment 2 are the effect of familiarisation on the time taken to articulate pure and mixed pairs of items (potentially significant, given the use of pair-repetition rate in some studies examining the contribution of articulatory duration), and the latency between the prompt to read the material at Stages 1 and 2 and the actual onset of output. As such, we conducted a full replication, with 20 participants, of Experiment 2 as described above, but with the addition of said onset latency measures and measures of onset latency and duration for pairs of items. We found exactly the same pattern of results for items spoken in isolation and in 6-item sequences as reported above, i.e., a decrease in articulatory fluency after familiarisation only for pure sequences, with no effect on either mixed sequences or items spoken in isolation (See Table 2). Despite the enhanced fluency of articulation of pure 6-item sequences, the articulatory duration of both mixed and pure pairs did not decrease as a function of familiarisation, again pointing to the potentially insensitive nature of some prior measures of articulatory duration. On the other hand,

familiarisation did lead to shortened onset times, but in this case, only for items spoken in isolation, with onset latency for sequences and pairs unchanged from Stage 1 to Stage 2, regardless of sequence type (pure versus mixed). The likelihood is that this decrease in onset latency reflects the fact that at the beginning of the experimental session, when the measures for isolated items are taken, the novelty of the nonwords means that some decision about pronunciation needs to be made before the stimuli can be spoken. However, such an item-familiarisation effect cannot account for the enhanced fluency found for duration of pure sequences, since mixed sequences, which contain identically familiar items, do not show this enhanced fluency.

Table 1

Mean articulatory duration in milliseconds of an item spoken in isolation and within a sequence, before (Stage 1) and after (Stage 3) familiarisation on a serial recall task

Item	Isolation (ms)		Sequences (ms)	
	Before	After	Before	After
	M (SD)	M (SD)	M (SD)	M (SD)
Words	511 (54)	508 (53)	425 (74)	411 (64)
Nonwords	512 (51)	508 (57)	458 (79)	425 (63)

Note. Sequence duration is calculated by dividing whole sequence duration by six (the number of items in a sequence)

Table 2

Summary of Mean Onset and Duration Times for Items, Pairs and Sequences, Before and After the Serial Recall Task (see Footnote 2)

	ONSET(ms)		DURATION(ms)	
	<i>Before</i>	<i>After</i>	<i>Before</i>	<i>After</i>
	<i>Mean (SD)</i>	<i>Mean (SD)</i>	<i>Mean (SD)</i>	<i>Mean (SD)</i>
Isolation	706 (161)	604 (161)	555 (70)	551 (64)
Pairs				
<i>Pure</i>	752 (154)	718 (167)	408 (82)	415 (89)
<i>Mixed</i>	761 (194)	711 (175)	411 (93)	407 (94)
Sequences				
<i>Pure</i>	849 (211)	853 (202)	405 (88)	370 (71)
<i>Mixed</i>	826 (204)	798 (212)	408 (86)	406 (87)

Figure 1

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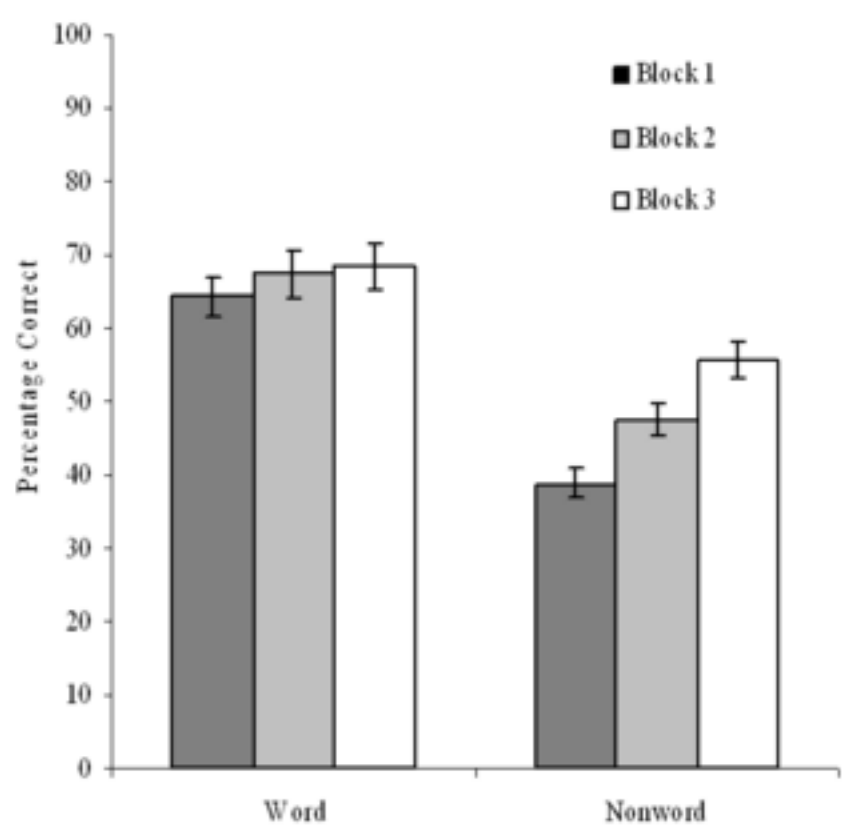


Figure 2

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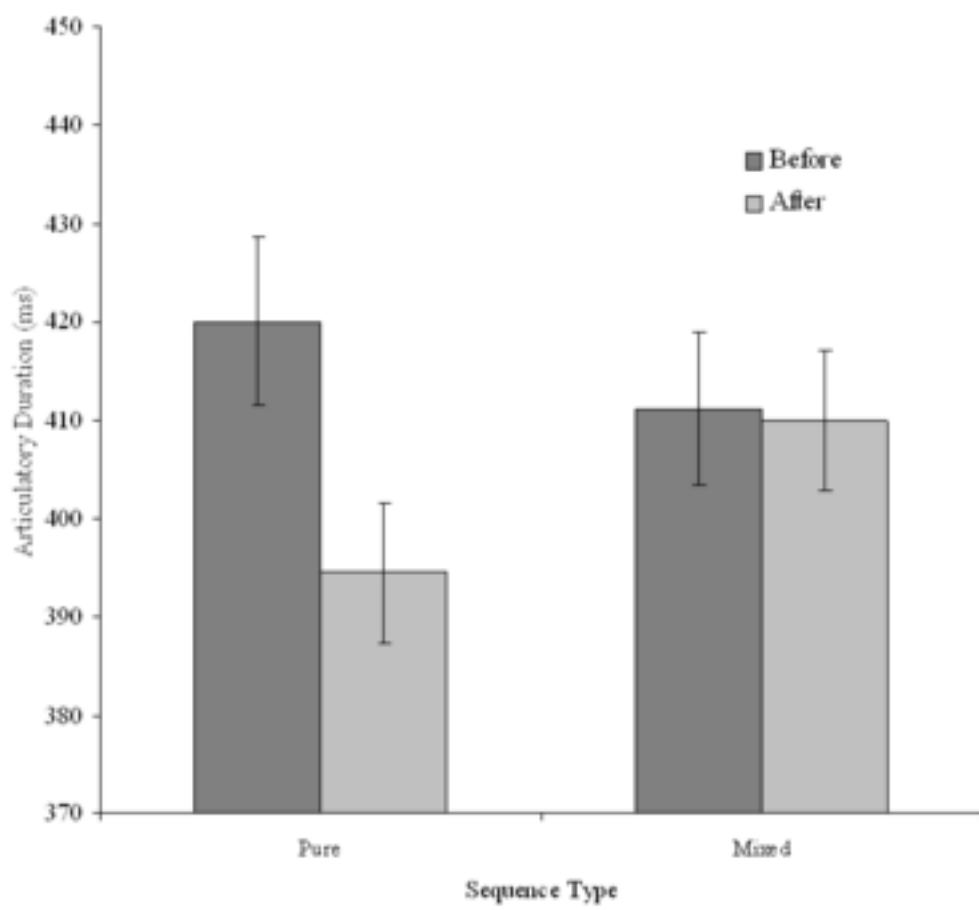


Figure 3
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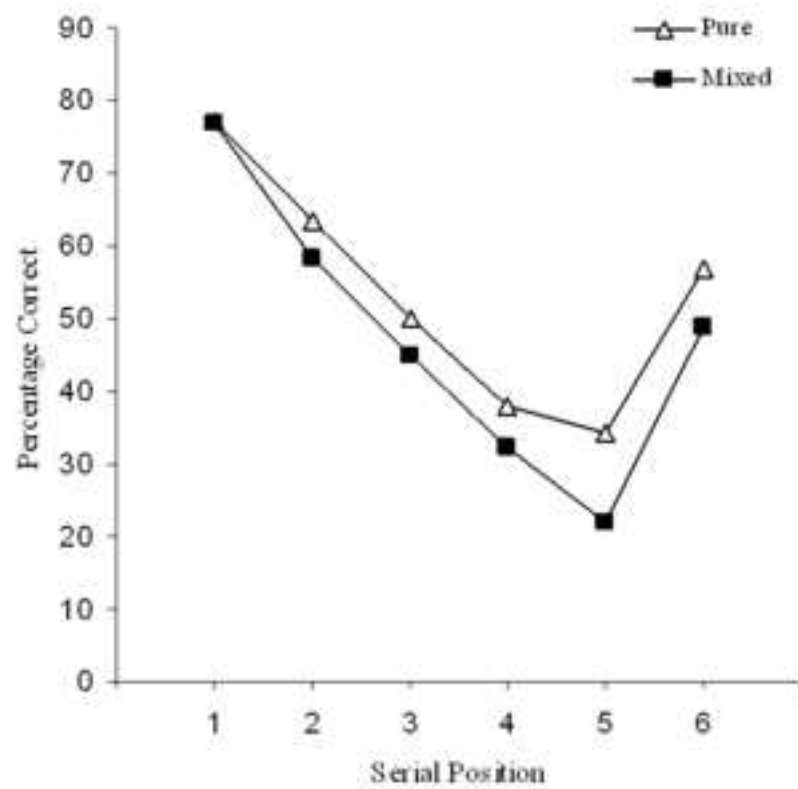


Figure 4

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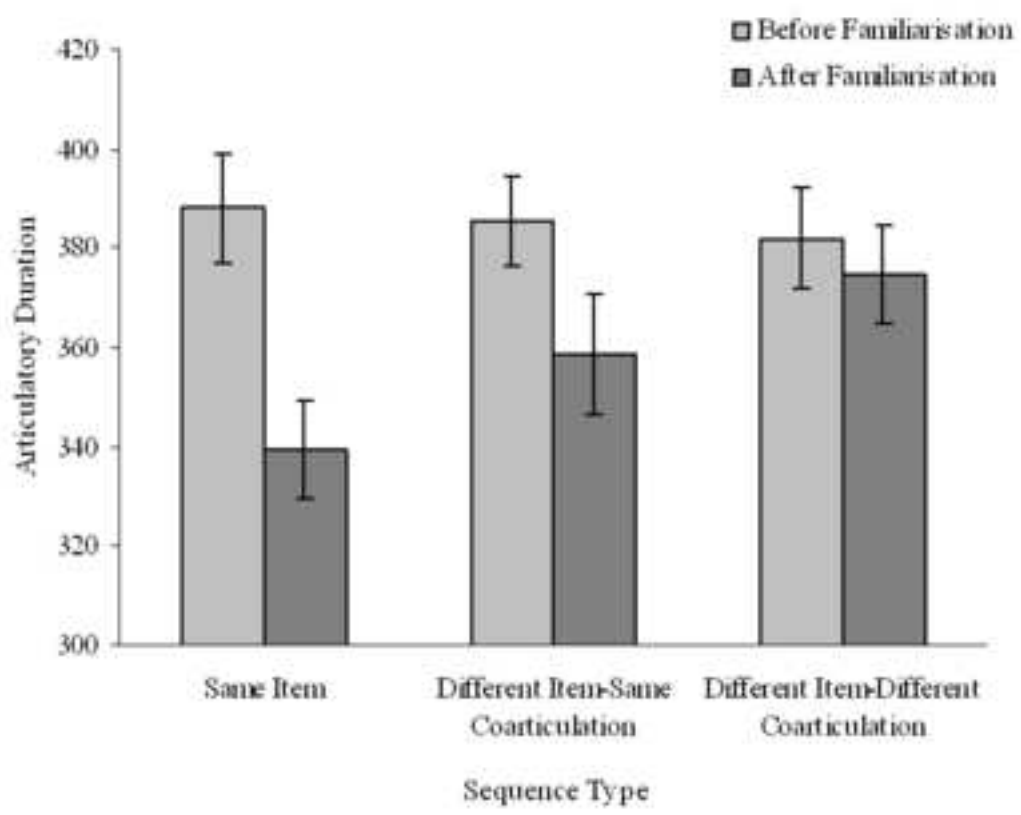


Figure 5

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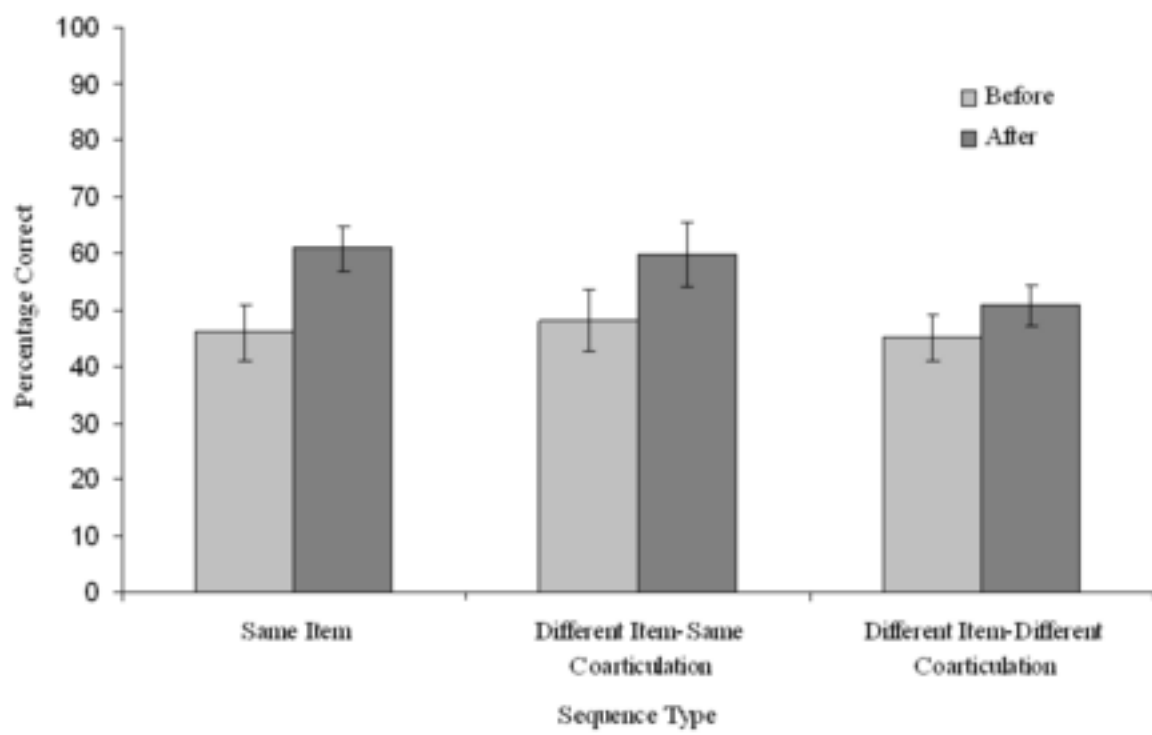


Figure 6
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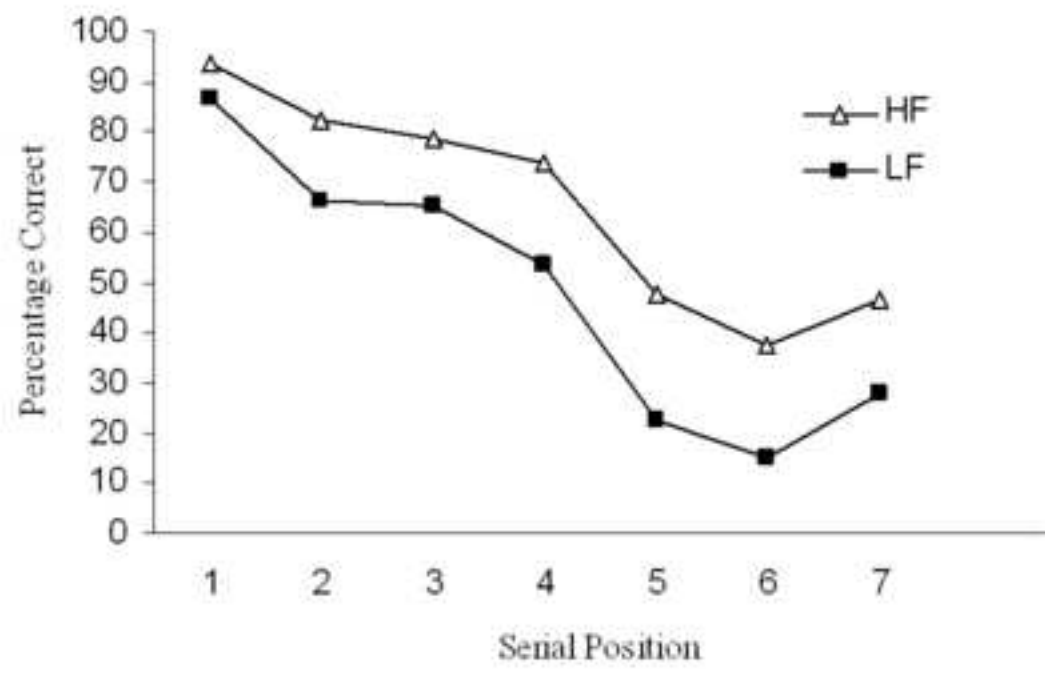


Figure 7

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