Demonstrating the effects of phonological similarity and frequency on item and order memory in Down syndrome using process dissociation

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Abstract

It is important to distinguish between memory for item and order information when considering the nature of verbal short-term memory (vSTM) performance. While other researchers have attempted to make this distinction between item and order memory in children, none have done so using process dissociation. This study shows that such an approach can be particularly useful and informative. Individuals with Down syndrome (DS) tend to experience a vSTM deficit. These two experiments explored whether phonological similarity (Exp 1) and item frequency (Exp 2), affected vSTM for item and order information in a group of individuals with DS compared to typically developing (TD) vocabulary-matched children. Process dissociation was used to obtain measures of item and order memory, via Nairne and Kelley's (2004) procedure. Those with DS were poorer than the matched TD group for recall of both item and order information. However, in both populations phonologically similar items reduced order memory but enhanced item memory, while high frequency items resulted in improvements in both item and order memory; effects that are in line with previous research in the adult literature. These results indicate that, despite poorer vSTM performance in DS, individuals experience phonological coding of verbal input, and a contribution of LTM knowledge to recall. These findings inform routes for interventions for those with DS, highlighting the need to enhance both item and order memory. Moreover, this work demonstrates that process dissociation is applicable and informative for studying special populations and children.

Keywords: Verbal short-term memory, Item memory, Order Memory, Down syndrome, Process dissociation, Phonological similarity effect, Frequency

Demonstrating the effects of phonological similarity and frequency upon item and order memory in Down syndrome, using process dissociation

Verbal short-term memory (vSTM) refers to the limited capacity system for the storage and maintenance of short-term verbal information. A distinction between vSTM for item and order information is acknowledged in the literature (Bjork & Healy, 1974; Brown, Preece, & Hulme, 2000; Burgess & Hitch,1992), it is thus beneficial to explore both of these components, to effectively understand the nature of vSTM. Research has implicated a role of vSTM in syntax acquisition (Ellis & Sinclair, 1996), language comprehension (Vallar & Baddeley, 1984), and possibly reading and mathematics development (Gathercole, Pickering, Knight, & Stegmann, 2004; Leather & Henry, 1994). The link between vSTM and vocabulary acquisition is particularly well established (Baddeley, Gathercole, & Papagno, 1998; Baddeley, Papagno, & Vallar, 1988; Gathercole & Baddeley, 1990; Papagno, Valentine, & Baddeley, 1991). Studies have shown superior receptive vocabulary in individuals with better vSTM skills (Gathercole, Service, Hitch, Adams, & Martin, 1999; Gathercole, Willis, Emslie, & Baddeley, 1992), as well as superior new word learning ability (Gathercole, Hitch, Service, & Martin, 1997; Jarrold, Baddeley, Hewes, Leeke, & Phillips, 2004), and superior second language acquisition (Service, 1992), in these individuals. Furthermore, Baddeley, Papagno, and Vallar, (1988) provided neurological evidence for the role of vSTM in the learning of new phonological forms. Although some researchers have suggested that verbal memory and language problems are simply likely to co-occur, with the former being an inevitable consequence of the latter (Hulme & Roodenrys, 1995; Van der Lely & Howard, 1993), other evidence supports the notion that experiencing a vSTM deficit may have a causal effect upon these related domains, such as vocabulary and syntax (Gathercole & Baddeley, 1990; Jarrold, Baddeley, Hewes, Leeke, & Phillips, 2004). This shows the need to understand vSTM and to distinguish between item and order memory contributions to these relationships (Majerus, Metz-Lutz, Van der Kaa, Van der Linden, & Poncelet, 2007; Majerus, Poncelet, Greffe, & Van der Linden, 2006a).

One population among whom vSTM problems are extremely common is those with Down syndrome (DS). DS is the most prevalent of genetic developmental disorders in the population worldwide, with an approximate prevalence of 1 in every 737 live births (Parker et al., 2010), and is caused by an extra copy (either complete or partial) of chromosome 21. Intellectual ability level varies widely in those with DS (Tsao & Kindelberger, 2009), with individuals experiencing varying degrees of general learning difficulties. However, beyond this, evidence consistently points to a tendency toward specifically poorer vSTM in this population (Jarrold & Baddeley, 1997; Jarrold, Baddeley, & Hewes, 2000) that becomes apparent in childhood (Chapman & Hesketh, 2001). While not strictly observed in every single individual with DS (Vallar & Papagno, 1993), this very common tendency for poorer vSTM performance is relative to performance in comparable visuo-spatial STM tasks and compared to matched control groups, of both typically developing children and other learning disabled groups (Brock & Jarrold, 2005; Hulme & Mackenzie, 1992; Jarrold & Baddeley, 1997; Jarrold, Baddeley, & Hewes, 2000; Jarrold, Cowan, Hewes, & Riby, 2004; Laws & Bishop, 2003; Vicari, Marotta, & Carlesimo, 2004).

Impairments in vocabulary are also observed in individuals with DS, however there is an apparent distinction, whereby receptive vocabulary ability is relatively less impaired (Chapman, Kay-Raining Bird & Schwartz, 1990, Laws, 1998), in contrast to greater impairments in expressive vocabulary (Næss, Halaas Lyster, Hulme, & Melby-Lervåg, 2011). Chapman (1995) suggested that expressive language problems in particular may be a result of poorer vSTM (see also Jarrold, Thorn, & Stephens, 2009). Chapman and Hesketh (2001) argued, on the basis of longitudinal modelling, that vSTM contributed to both receptive and expressive language in DS, but that age and visual memory additionally contributed to receptive but not expressive language. Research by Mosse and Jarrold (2008, 2010) also indicates that there may be a domain-general route to learning words that those with DS rely on in addition to the domain-specific route supported by vSTM, and that this additional domain-general route may explain their relatively less impaired receptive vocabulary ability. Fowler (1990) also reported a specific syntactic delay in DS, this too may be owing to vSTM impairments, since there is some evidence in the literature for a role of phonological working memory in syntax acquisition (Adams & Gathercole, 1995; Ellis & Sinclair 1996).

Given the above findings, improving vSTM may positively impact on these associated areas of language development. To potentially improve vSTM in DS, a comprehensive understanding of vSTM in this population is essential. Hence the current study aims to gain a clearer picture of the processes affecting vSTM recall in DS as well as possible sources of the difficulties observed. Such research ought to also enhance our understanding of vSTM more generally. While the underlying source of vSTM difficulties in DS is not yet entirely understood, previous research has ruled out numerous possible causes. Studies controlling for hearing ability and output demands have shown a persisting vSTM deficit in DS (Jarrold & Baddeley, 1997; Marcell & Weeks, 1988). Poorer vSTM is not sufficiently accounted for by slower speech rates in those with DS (Seung & Chapman, 2000), or by a lack of possible behavioural markers of rehearsal (Jarrold, Baddeley, & Hewes, 2000). Phonemic discrimination difficulties in DS are also unable to account for the extent of vSTM problems observed (Purser & Jarrold, 2013). Furthermore, Purser and Jarrold (2005) provided evidence to suggest that vSTM problems in DS are not a result of rapid decay of memoranda, with their findings instead pointing to a capacity limitation. Purser and Jarrold (2010) found that individuals with DS were only able to hold one item in vSTM when this was defined purely in terms of phonological rather than both phonologically and semantically coded storage. Typical estimates that do not make this differentiation between semantic and phonological storage have found that individuals with DS have a vSTM capacity of 2-3 items (Jarrold, Baddeley, & Phillips, 2002). Regardless of the precise size of vSTM capacity, given these low estimates, it would be helpful to further understand what processes individuals with DS rely upon during tasks involving vSTM. This could inform the development of interventions; for instance, existing findings would suggest that rehearsal training alone may not be sufficient for individuals to overcome their vSTM problems. Likewise, identifying areas of vSTM that are relatively unimpaired may allow researchers to build on these strengths. In particular, exploring separate components of vSTM may reveal whether there is a particular impairment underlying vSTM difficulties in those with DS.

In the short-term memory field; researchers acknowledge the distinction between memory for item and for order information (Bjork & Healy, 1974). Such a distinction has been made in computational models, such as Burgess and Hitch (1992) and Brown, Preece, and Hulme's, (2000) 'OSCAR' model; with the suggestion that there are different systems to encode the differential types of information, e.g., temporal context nodes to encode serial order specifically (Burgess & Hitch, 1992). While there are differing views on the degree of separation of these systems (Farrell & Lewandowsky, 2002, 2004), the concept of separate or independent item and order memory is supported by substantial evidence showing that specific variables have differential effects upon item and order memory respectively (Baddeley, 1966; Burns, 1996; Conrad & Hull, 1964; Delosh & McDaniel, 1996; Nairne & Kelley, 2004; Poirier & Saint-Aubin, 1996; Wickelgren, 1965). This claim also has some support from imaging data (Giraud et al., 2000; Majerus et al., 2006b), as well as neuropsychological evidence for selective item/order impairments (Majerus et al., 2007). Thus it is possible that individuals with DS have a decreased capacity for either item information, order information, or indeed both of these components. Furthermore, this distinction is particularly relevant for the DS population, as Rosin, Swift, Bless, and Vetter

(1988), argued that language difficulties may be caused by broader difficulties with serial order processing. There is also evidence to suggest that serial order STM is a predictor of vocabulary development (Attout, Van der Kaa, George, & Majerus, 2012; Majerus & Boukebza, 2013; Leclercq & Majerus, 2010), more so than item memory (Majerus et al., 2006a). In line with this suggestion, there is some evidence for specific problems in order memory in DS (Brock & Jarrold, 2005; but also see Kay-Raining Bird & Chapman, 1994). However, item memory problems cannot be ruled out, as there is also evidence from other studies for problems with item memory in DS (Brock & Jarrold, 2004; Marcell, Harvey, & Cothran, 1988). Given this, a clearer picture of memory specifically for item and order information in those with DS is vital for understanding the precise nature of vSTM problems in this population, and for targeting interventions accordingly.

Typically, researchers employ a reconstruction type task to test order memory (Brock & Jarrold, 2005; DeLosh & McDaniel, 1996; Majerus, et al., 2006a; Nairne, 1990a), whereby participants are provided with the items from the memory list post-presentation and their task is to reconstruct the order in which these items were presented. Memory for item information on the other hand is typically tested with a free recall task, or a recognition task, in which memory for the items is recorded with no serial order required. Whilst these measures are logical routes to obtain separate measures of memory for item and order, they are not necessarily pure indices of each construct. As highlighted by Nairne and Kelley (2004) these measures may well be contaminated by one another; for instance, performance on order reconstruction tasks has been shown to be influenced by item characteristics such as concreteness (Neath, 1997). Likewise, while order memory is not required during free recall, it could contribute to performance in this task, e.g., remembering that the item ‘chair’ came after the item ‘mouse’.

To overcome this test purity problem Nairne and Kelley (2004) adapted the process dissociation procedure (Jacoby, 1991) to calculate recall of item and order information in typically developing adults. The process dissociation procedure involves two conditions, an inclusion condition and an exclusion condition. For the means of dissociating memory for item and order, Nairne and Kelley used the following inclusion and exclusion tasks; the inclusion task was essentially a serial recall task, with correct recall of a given item requiring both accurate memory of item and order information. In the exclusion task participants were instructed to recall all items in any order except for one item (referred to as item X); just prior to recall the participant was informed of the serial position of item X, e.g., recall all items except for the item that occurred in serial position 4. If participants subsequently recall item X then this indicates intact item memory but incorrect order memory. The position of item X changed from one trial to the next. Recall/non-recall of each item X in the exclusion task was compared to recall/lack of recall of the corresponding item in position X in the inclusion task.

The logic behind this approach is that in one task (inclusion) both processes should facilitate recall, whereas in the other task (exclusion) these processes work in opposition. This allows for the mathematical dissociation of the two processes. In this sense, the occasions when participants recall the to-be-excluded item during the exclusion task, showing intact item memory in contrast to impaired order memory, are of most interest. By comparing performance across the inclusion and the exclusion tasks one can then use a simple formula to calculate proportions of memory for item and for order information, as shown in Equation 1. Memory for item information is calculated via total correct serial recall of items in position X in the inclusion task + items recalled in position X in the exclusion task, (note this is divided by the number of trials to provide a proportion). Memory for order information is calculated via the following: Total correct serial recall of items in position X in the inclusion task divided by Item memory (as calculated above), thereby accounting for the proportion of order errors.

Equation 1. Calculations for item memory (*I*) and order memory (*Or*).

I = Inclusion (recalling item X in correct serial position) + Exclusion (order error: recalling item X when instructed not to)

Or = Inclusion / *I*

To validate this method, Nairne and Kelley (2004) tested the effects of a number of variables that have selective effects upon item and order memory respectively. They also produced predicted models for the effects of these variables. Among the variables they explored were frequency and phonological similarity. Presenting lists in which all of the items are phonologically similar typically has a detrimental effect on memory for order of the items, but no detriment, or indeed a beneficial effect upon memory for items (Baddeley, 1966; Conrad & Hull, 1964; Gupta, Lipinski, & Aktunc, 2005; Watkins, Watkins, & Crowder, 1974). According to their Feature Model (Nairne, 1990b), representations of the items in the similar list necessarily contain overlapping features, resulting in interference at recall whereby an item with similar features is erroneously selected. Thus order errors are made, but it is likely that the erroneous selection will be a similar sounding item, and if that similar sounding item is in the presentation list then this enhances item memory (see also Gupta et al., 2005). Increasing item frequency tends to result in item memory benefits (Poirier & Saint-Aubin, 1996), whereby existing LTM representations support reconstruction of degraded STM traces. Higher frequency word representations in LTM are argued to have increased accessibility (Roodenrys, Hulme, Alban, Ellis, & Brown, 1994), and these items are thus more likely to be reconstructed at recall. There is some evidence that frequency also leads to enhanced memory for order (Deese, 1960; DeLosh & McDaniel, 1996). It has been suggested that for pure lists of high frequency words, associations based on word meanings are more likely to occur than is the case for pure lists of low frequency words (Stuart & Hulme, 2000; Tulving & Patkau, 1962), with resulting inter-item associations enhancing order memory. However, other researchers found an absence of order recall benefits for higher frequency items (Poirier & Saint-Aubin, 1996), thus the item memory benefit of frequency is more consistently observed. In their study using the process dissociation approach, Nairne and Kelley (2004) found the predicted patterns of effects of these variables upon memory for item and for order information. Given this, using this method to tease apart the specific effects of variables upon memory for item and order information would allow us to ask valid questions about the memory coding processes that are used in those with DS compared to those without DS, this may indicate the potential source of the vSTM difficulties often observed in this condition.

Experiment 1

The differential influence of phonological similarity upon item and order memory is a particularly well-established finding in the typical population. There is evidence suggesting poor explicit awareness of phonology in those with DS (Verucci, Menghini, & Vicari, 2006), including poor ability to explicitly detect rhyme (Snowling, Hulme, & Mercer, 2002). Research by Hulme and Mackenzie (1992) indicates that the effect of phonological similarity however, is in fact reliably present in this population, though attenuated. This attenuation may account for some of the previously mixed evidence of phonological similarity effects in DS; while some studies have not detected an effect (Varnhagen, Das, & Varnhagen, 1987), other research has shown that those with DS do show significant effects of phonological similarity (Broadley, MacDonald, & Buckley, 1995; Comblain, 1996). This suggests that suitably sensitive methods are preferable for testing such effects in DS (cf. Jarrold & Citroën, 2013). The effect of phonological similarity upon item and order memory has not been explored previously with the process dissociation method in any developmental studies. In fact, to our knowledge, there are no existing developmental studies employing process dissociation to explore item and order memory.

Thus, the aim of Experiment 1 was to explore the effect of phonological similarity upon item and order memory in those with DS compared to a matched TD group. The two populations were matched for vocabulary rather than a general mental age measure, since vocabulary is distinct from, but strongly linked to, vSTM, and thus individuals with the same vocabulary score would usually be expected to display no significant differences in vSTM performance. Note, however, that in the current study the tendency of individuals with DS to show a specific vSTM deficit means that we expect to see poorer vSTM performance in this population compared to the vocabulary matched group. It was hypothesised that a typical phonological similarity effect (PSE) would be observed in the TD group whereby phonological similarity is detrimental to order memory, but not to item memory. If a similar pattern is observed in the DS group then this will indicate that those with DS also process information phonologically. Alternative patterns in the DS group compared to the TD group would indicate that differential memory processes are relied upon and, specifically, would indicate a lack of effective phonological coding of the input. The comparison of the two populations' recall of item information and order information respectively, as well as the interaction of item and order with phonological similarity aimed to highlight potential underlying sources of vSTM difficulties in the DS group.

Method

Design

This study used a 2 x 2 x 2 mixed design, the between participants variable of population had two levels: DS and TD. The within participants variable of phonological similarity had two levels: dissimilar and similar, and the within subjects variable of item/order had two levels: recall of item information and recall of order information. Memory for item/order was treated as a within subjects variable rather than separate dependent variables. This was in line with the original analysis carried out by Nairne and Kelley (2004), which in turn was based on their assumption of the independence of these two constructs. The dependent variable was proportion of recall, calculated via process dissociation in line with Nairne and Kelley's method, as shown previously in Equation 1.

Participants

15 individuals with Down syndrome (mean age: 20 years, 10 months, *SD* = 7 years, 3 months, range = 9 years, 1 month – 30 years, 0 months) and 15 typically developing children (mean age: 6 years, 1 month, *SD* = 12.8 months, range = 4 years, 7 months – 8 years, 2 months) were tested. The TD group and the DS group were matched for vocabulary, DS: *M* = 89.27, *SD* = 21.03, TD: *M* = 88.47, *SD* = 21.01, (*t* = .104 *p* = .918, Cohen's *d* = .038), using the British Picture Vocabulary Scale (BPVS II; Dunn, Dunn, Whetton, & Burley, 1997). Participants with Down syndrome were recruited from local Down syndrome support groups in the Bristol area and contacts from previous studies. All participants required the ability to comprehend simple instructions and verbalise responses, and any participants judged by the experimenter not to meet these requirements were not assessed. The typically developing control children were recruited from a local primary school and consisted of all children for whom parental consent was obtained.

Procedure

The experiment was created using Revolution studio 2 software and was presented on a laptop computer (screen size: 9 x 15 inches). On any trial participants were presented with lists of four items. Since verbal spans of approximately two or three items are typically observed in DS (Jarrold et al., 2002), presenting lists of more than four items may well have resulted in floor effects for this population; likewise less than four items would be expected to result in ceiling effects for a number of those in the TD group (Gathercole & Pickering, 2000). Four items thus served as a suitable trial length for this study. Four patches of grass were displayed on the screen evenly spaced (see Appendix A), and each of the four items were then presented one at a time in audio format, with 1 second between each item and with the screen unchanging. There were two recall tasks, the inclusion task and the exclusion task, and instructions were given accordingly. The inclusion task was a serial recall task; after presentation of the fourth audio item in the list a cartoon mole then popped up in serial position one (appearing out of the first patch of grass, starting from the left side of the screen) to prompt the participant to recall the first word. Upon recall of the first word (or the participant saying 'pass' to indicate that they did not remember the first word) a button press from the Experimenter caused the first mole to disappear and the mole at serial position two to pop up, prompting the participant to recall the second word from the list. Participants were subsequently prompted to recall the third word and the fourth word via the same method. Upon recall/attempted recall of the fourth word, participants were presented with a screen saying 'next'. When ready, participants clicked the next button to continue onto the next trial. Participants completed 8 inclusion trials, each trial consisting of four audio items. In the exclusion task, after presentation of the fourth audio item in a given trial, 3 moles would pop up in three of the serial positions; the serial positions of the three moles changed on each trial. Participants were instructed to recall the items from only the three serial positions that the moles appeared in, but not to recall the item from the serial position at which the mole did not pop up on a given trial; this item is referred to as item X. There were 8 exclusion trials. Prior to the experimental trials participants practiced each task. Initial practice trials included only two items to simplify the task. All participants found it very easy to recall the two items in order (inclusion task), and they then received practice trials of four items. For the exclusion task, in the two item practice trials participants heard two words and then only one mole popped up, participants were instructed to only recall the word from the position of the mole that popped up. Again, participants were able to do this task very easily. This was important to clarify as inhibition could play a role in the exclusion task and inhibition problems have been highlighted previously in DS (Borella, Carretti, & Lanfranchi, 2013). Thus, we were confident that the participants were capable of inhibiting their response for the item X, with recall errors in the exclusion task representing actual order errors rather than a more general problem with inhibiting responses in this task. Participants then moved onto the four item practice trials for the exclusion task. Participants only began the experimental trials once the experimenter was satisfied that they were able to follow the instructions for the task.

The same items used in the inclusion trials were used in the exclusion trials. First participants completed four trials following inclusion instructions, they then completed these same four trials of items with exclusion instructions, however the arrangement of the items within each of the trials was re-ordered (see Appendix B). Participants then completed four more exclusion trials with new items, followed by the inclusion task again with these same four trials, rearranged (see Appendix B). On half of the inclusion trials and half of the exclusion trials the items were all phonologically similar, e.g., sand, hand, land, band. In the other half of the trials all of the items were phonologically dissimilar. A closed pool of items was used, the phonologically dissimilar lists consisted of the same items as the similar trials, reorganised to create phonologically dissimilar items within each trial (see Appendix C); the similar compared to dissimilar lists were therefore identical with regards to all other characteristics. The experimenter recorded the participants' responses by hand using a simple recording form, (see Appendix C). Completion of the experiment took approximately 10-15 minutes.

Results

A 2 x 2 x 2 Anova was carried out exploring the two levels of phonological similarity (similar vs. non similar), and two levels of memory recall (recall of item vs. order information), in the two populations (DS and TD). Corresponding descriptive statistics are shown in Table 1.

Table 1

Means and standard deviations for each level of phonological similarity (similar vs. dissimilar) for proportions of memory for item vs. order information, in the two populations (TD and DS).

	TD (*M*, *SD*)	DS (*M*, *SD*)	Grand Mean:
Phonologically dissimilar:			
Item	.77 (.22)	.35 (.18)	.56
Order	.93 (.26)	.74 (.37)	.84
Grand Mean:	.85	.55	
Phonologically Similar:			
Item	.80 (.25)	.57 (.31)	.69
Order	.66 (.29)	.40 (.29)	.53
Grand Mean:	.73	.49	

The between participants effect of population was significant, $F(1, 28) = 22.46$, $p < .01$, $\eta p^2 = .45$, reflecting significantly poorer overall performance in the DS group compared to the TD group. The main effect of phonological similarity was not significant, $F(1, 28) = 2.52$, $p = .12$, $\eta p^2 = .08$, there was also no significant main effect of item/order memory, $F(1, 28) = 2.61$, $p = .12$, $\eta p^2 = .09$. There was however a significant interaction of phonological similarity x item/order memory, $F(1, 28) = 23.67$, $p < .01$, $\eta p^2 = .46$, such that similarity had differential effects upon item and order memory proportions. Phonological similarity of items had a detrimental effect upon order memory, $F(1, 28) = 14.22$, $p < .01$, $\eta p^2 = .34$, with phonologically similar lists of items resulting in significantly poorer recall of order information than non-similar lists of items. In contrast, improved recall of item information for similar sounding items compared to non-similar sounding items was observed, with this improvement nearing significance, $F(1, 28) = 3.93$, $p = .06$, $\eta p^2 = .12$. There were also no other significant interactions involving population: phonological similarity x population, $F(1, 28) = 0.27$, $p = .61$ $\eta p^2 = .01$, item/order x population, $F(1, 28) = 1.76$, $p = .20$, $\eta p^2 = .06$, and no significant 3 way interaction of population x phonological similarity x item/order, $F(1, 28) = 1.90$, $p = .18$, $\eta p^2 = .06$.

Bayesian analyses:

Our sample size is relatively small due to the nature of testing special populations; in light of this we recognize the possibility that the null interaction effects observed, may simply reflect a lack of power to detect differences. To further validate these null interactions and allow for stronger conclusions, an additional Bayesian analysis was carried out. Unlike null-hypothesis statistical testing that depends upon a binary decision regarding the null hypothesis (reject or fail to reject), the Bayesian analysis instead allows us to explore the *degree of evidence* in favour of the respective models. Based on the data obtained, probabilities are computed comparing the likelihood of each model (i.e., the null or the alternative), (see Masson, 2011, for a more detailed explanation). This is useful in samples that have a small N, as failing to reject the null hypothesis can be the result of a lack of power. The Bayesian analysis instead provides information quantifying the degree of evidence in favour of either model.

Computations provided by Masson (2011), were used to calculate an estimate of the Bayes factor, and subsequent posterior probabilities for the two hypotheses, (corresponding calculations are shown in Appendix D). According to Raftery's (1995) categorization of degrees of evidence, posterior probability values above .75 indicate positive evidence for the model, and values of .95 and above are considered strong evidence. First, regarding the interaction of population x phonological similarity, a posterior probability value of .83 was calculated for the null model, this is considered positive evidence in favour of the null model, indicating no difference between the two populations in the degree of phonological similarity effect. The likelihood of the alternative hypothesis of a difference between the two populations in degree of phonological similarity effect was substantially lower (posterior probability = .17). Second, regarding the interaction of population x item/order, posterior probabilities were again calculated for the two models. Evidence was in favour of the null model, with a posterior probability of .69, for the alternate model the posterior probability value calculated was .31. Hence, the evidence is in favour of no difference in the degree of item memory problems compared to order memory problems in those with DS, relative to the TD matched group.

Discussion

Experiment 1 aimed to explore the effect of phonological similarity upon item and upon order memory in a group of individuals with DS compared to a vocabulary matched TD group, using Nairne and Kelley's (2004) process dissociation procedure. This was done to investigate whether those with DS are using phonological coding to maintain verbal information. A second aim was to explore whether any effects upon memory for item and order respectively were the same or different in the two populations.

When analysed across populations, an interaction of phonological similarity x item/order memory was observed, whereby similarity resulted in a significant detriment to order memory in contrast to an item memory benefit that neared significance. The significant detriment on memory for order is as predicted in TD individuals based on previous findings (Baddeley, 1966; Conrad, 1964; Nairne & Kelley, 2004; Wickelgren, 1965). This therefore validates the process dissociation technique for use with children, something that is important to note, as such an approach has never been previously adapted for use with children, or indeed, special populations. In the current study similar sounding items also resulted in enhanced item memory; although only nearing significance, this finding is also supported by previous literature (Fallon, Groves, & Tehan, 1999; Gupta, et al., 2005; Watkins, Watkins, & Crowder, 1974). Fallon, Groves, and Tehan (1999) suggested that rhyme enhances item memory as a result of category cueing. Fallon et al. found that adults' recall of item information was significantly higher for rhyming lists, e.g., 'mat, cat, sat', compared to 'similar non rhyming' lists, i.e., 'cat, man, map'. Both conditions consisted of the same items across the lists, so Fallon et al. were able to conclude that organisation of lists into the same rhyme category cues item recall. This may explain previous mixed findings, whereby studies not observing item memory benefits tend to use similar sounding but non-rhyming item lists.

These effects of similarity did not interact significantly with population, thus the process dissociation technique provided sufficient sensitivity to detect these differential effects upon item and order memory in a special population as well as in TD children. Hence, this approach may allow us to ask particularly informative and valid questions about the use of phonological coding in Down syndrome. The findings show that those with DS are affected by phonological similarity. This is in line with previous findings (Hulme &

Mackenzie, 1992; Vicari et al., 2004). The interaction of phonological similarity x item/order did not further interact with population, indicating no strong evidence for a difference in the phonological similarity by item/order interaction across the two populations. This suggests that while the phonological capacity of individuals with DS may be considerably limited (Purser & Jarrold, 2005), those with DS are employing similar phonological coding processes to a matched TD group. Previous research nonetheless indicates that rhyme detection is poor in this condition (Snowling, et al., 2002; Verucci, et al., 2006). Detecting rhyme requires phonological awareness; according to Wright and Jacobs (2003) phonological awareness is assumed to be 'explicit awareness of the phonological structure of spoken words' (p. 18). This suggests that while individuals with DS appear to lack explicit awareness of certain phonological components of verbal input, in comparison to TD individuals, the verbal input is nonetheless being coded and represented phonologically, with individuals' recall being significantly influenced by the sounds of the words.

With regards to memory for item and order more generally, there was no reliable interaction of population x item/order memory. This indicates that the difficulties experienced by those with DS on tasks involving vSTM (including the significant main effect of population overall in the current Experiment) are not a result of problems specifically due to item memory, or specifically due to memory for order, but are likely to reflect a contribution of both. To strengthen these conclusions an additional Bayesian analysis was carried out, to explore the degree of evidence in favour of the respective models. For the interaction of population x phonological similarity, the likelihood of a difference between the two populations in degree of phonological similarity effect was substantially lower than the likelihood of the null model. Second, regarding the null model for the interaction of population x item/order, the evidence was in favour of no difference in the degree of item memory problems compared to order memory problems in those with DS, relative to the TD matched group.

There is also existing support for the suggestion that individuals with DS have problems in recalling both item and order information, for instance Brock and Jarrold (2004) also found evidence for impairments in recall of both item and order information in those with DS. Our findings are consistent with the likelihood that problems exist in both domains.

Experiment 2

To provide additional validation for the process dissociation procedure, and to further explore the processes affecting memory recall in DS, Experiment 2 was carried out using the same methodology as employed in Experiment 1, but with the manipulation of an alternative variable. Specifically, Experiment 2 explored the effect of item frequency upon item and order memory.

High frequency items tend to result in an enhancement of item memory in TD groups, compared to lists of low frequency items (Gregg, 1976; Poirier & Saint-Aubin, 1996). The effect of frequency in STM tasks is thought to reflect the influence of LTM mechanisms (Hulme, Maughan, & Brown, 1991), and there is substantial evidence showing that TD groups' recall ability is affected by their LTM knowledge of items during STM tasks (Allen & Hulme, 2006; Caza & Belleville, 1999; Cohen, 1990; Hulme, et al., 1997; Majerus & Van der Linden, 2003; Paivio, Clark, & Khan, 1988).

While a number of studies report no effect of frequency upon memory for order information (Mulligan, 2001; Poirier & Saint-Aubin, 1996; Whiteman, Nairne, & Serra, 1994), other researchers have reported beneficial effects of high frequency items upon order memory (Deese, 1960; DeLosh & McDaniel, 1996; Mulligan, 2001). It has been suggested that for pure lists of high frequency words, associations based on word meanings are more likely to occur than for lists of low frequency words (Hulme, Stuart, Brown, & Morin, 2003; Tulving & Patkau, 1962), with resulting inter-item associations enhancing order memory.

In individuals with DS, previous research has shown evidence for a large effect of lexicality (reflecting LTM word knowledge), upon vSTM recall (Brock & Jarrold, 2004), which may reflect an influence of semantic word properties as well as the familiarity and frequency of the words. However, many studies, including Experiment 1 here, have shown that those with DS continue to display significantly poorer vSTM performance than a TD group even when matched for receptive vocabulary (Jarrold, et al., 2002). Thus when the two groups (DS and TD) can be expected to have similar word knowledge, those with DS nonetheless perform poorer. Additionally, Carlesimo, Marotta, and Vicari, (1997) suggested that individuals with DS are particularly poor at using LTM knowledge regarding category information to organise verbal memoranda. If so, then individuals with DS may not be influenced by their LTM knowledge regarding words, such as the frequency of items, (or frequency of item co-occurance), to the same degree as TD individuals during vSTM tasks. Less influence of LTM knowledge may therefore be a possible contributor to the poorer vSTM performance observed in DS.

Experiment 2 was therefore carried out to explore the effect of the frequency of items upon memory for item information and for order information in those with DS compared to a TD matched group. It was hypothesised that lists of high frequency items would result in significantly better recall than lists of low frequency items in the TD group. Higher frequency was expected to result in a significant enhancement in item memory, and a possible benefit to order memory. A comparable pattern in the DS group would indicate that those with DS are also influenced by their LTM knowledge regarding the frequency of items during tasks involving vSTM.

Method

Design

Experiment 2 again used a 2 x 2 x 2 mixed design, the between participants variable of population had two levels: DS and TD. The within participants variable of frequency had two levels: high frequency and low frequency, and the within participants variable of item/order had two levels: recall of item information and recall of order information. The dependent variable was proportion of recall, calculated via process dissociation, as shown previously in Equation 1.

Participants

The same 15 individuals with Down syndrome and 15 typically developing children tested in Experiment 1, matched for vocabulary via the BPVS II, were tested in Experiment 2. This second experiment was completed either on the same day or within the same week as Experiment 1 for each participant.

Procedure

The method employed in Experiment 2 was identical to that of Experiment 1, with the exception that the items presented were instead manipulated for frequency. In half of the trials (8 trials) all of the items were of high frequency, in the other half of the trials all of the items were of low frequency. The MRC psycholinguistic database (Coltheart, 1981), was used to gather ratings for item frequency, those items with a Thorndike-Lorge written frequency rating below 150 were deemed low frequency, whilst those items with Thorndike-Lorge written frequency ratings of 400 and above were deemed high frequency. There were no significant differences between the two sets of items in ratings of concreteness or imageability, ($p > .05$), via the MRC psycholinguistic database (Coltheart, 1981). The items presented were from an open pool, such that participants were never presented with the same item more than once, this was crucial to avoid superficial frequency effects.

Results

A 2 x 2 x 2 Anova was carried out to explore the effect of the two levels of frequency (low frequency vs. high frequency lists of items) upon the two levels of memory recall (item and order), in the two populations (DS and TD). Corresponding descriptive statistics are shown in Table 2.

Table 2

Means and standard deviations for low frequency and high frequency items upon the two levels of item/order memory, in the two populations (TD and DS).

	TD (*M*, *SD*)	DS (*M*, *SD*)	Grand Mean:
Low Frequency:			
Item	.77 (.31)	.47 (.23)	.62
Order	.84 (.29)	.52 (.41)	.68
Grand Mean:	.81	.50	
High Frequency:			
Item	.87 (.19)	.60 (.40)	.74
Order	.99 (.05)	.55 (.39)	.77
Grand Mean:	.93	.58	

The between participants effect of population was significant $F(1, 28) = 27.99$, $p < .01$, $\eta p^2 = .50$. The effect of frequency neared significance, $F(1, 28) = 4.15$, $p = .051$, $\eta p^2 = .13$. The difference between item and order memory was not significant, $F(1, 28) = 0.82$, $p =$

.37, ηp^2 = .03; there was also no significant interaction of item/order x frequency, $F(1, 28)$ = 0.07, p = .79, ηp^2 = .00. There were also no significant interactions involving population: frequency x population, $F(1, 28)$ = 0.18, p = .68, ηp^2 = .01; item/order x population, $F(1, 28)$ = 0.73, p = .40, ηp^2 = .03; frequency x item order x population, $F(1, 28)$ = 0.47, p = .50, ηp^2 = .02.

Bayesian analyses:

To enhance our ability to interpret these null interactions more confidently, posterior probabilities were again compared for these models, using a Bayesian approach as carried out in Experiment 1 (calculations are shown in Appendix D). First, for the interaction of population x frequency, for the null model a posterior probability value of .83 was calculated, this is classified as positive evidence (Raftery, 1995) for the model in which frequency does not interact with population. In contrast, the posterior probability value calculated for the alternative model was much lower (.17). Regarding the interaction of item/order x frequency, a posterior probability value of .84 was calculated for the likelihood of the null model, compared to a probability value of .16 for the alternative model, again this provides positive evidence in favour of no difference in the degree of frequency effect upon item and order memory respectively. Regarding population x item/order, for the null model the posterior probability = .79, compared to the likelihood of the alternative model (posterior probability = .21). This again provides relatively positive evidence in favour of the notion that item/order memory does not meaningfully interact with population.

Discussion

Experiment 2 aimed to investigate whether vSTM recall in individuals with DS is influenced by the frequency of items, in comparison to a matched TD group. A second aim was to examine the effect of frequency upon memory for item and for order information respectively in those with DS, compared to TD children, to further explore whether there are specific item or order memory problems in the DS group.

Lists of high frequency items resulted in a greater proportion of recall, compared to lists of low frequency items, with this benefit nearing significance (p = .051). The effect of frequency did not interact reliably with memory for item/order information, thus both item memory and memory for the order of items were enhanced as a result of higher word frequency; a finding that is consistent with previous research (Deese, 1960; DeLosh & McDaniel, 1996; Nairne & Kelley, 2004; Poirier & Saint-Aubin, 1996). Since, this overall effect of frequency, when analysing across populations and across item and order memory, was only close to significant, the implications that can be drawn from it are somewhat limited. However, the pattern of findings does suggest that both the DS group and the matched TD group are influenced to a similar extent by the level of frequency of the items presented. When exploring the overall effect of item/order recall, there was no significant difference across the two populations. Thus, and as observed in Experiment 1, there were no specific item or order memory problems in those with DS, but, instead, these individuals showed generally poorer recall in both of these domains.

This study indicates then, no meaningful difference for those with compared to without DS for the effects of frequency upon vSTM, whereby frequency enhances both item and order memory. However, to enhance our confidence interpreting these null interactions, we again used a Bayesian approach to calculate posterior probabilities for these models. For the interaction of population x frequency, there was positive evidence in favour of the null model, in which frequency does not interact with population. Hence, the null model, whereby those with and without DS are similarly affected by frequency is far more likely compared to the degree of evidence in favour of the alternative model. Likewise, with regards to item/order x frequency, there was again positive evidence in favour of no difference in the degree of frequency effect upon item and order memory respectively. This strengthens our conclusion and supports previous studies also showing frequency effects upon order memory, in contrast to those who report no frequency related benefits for recalling order.

Finally, regarding population x item/order, there was again relatively positive evidence in favour of the null model, in contrast to the alternative model. This supports the notion that item/order memory does not interact with population, in line with the findings of Experiment 1. Hence, the poorer vSTM performance observed in those with DS is not likely to be a result of difficulties in one of these specific domains, but rather a contribution of both.

The Bayesian analysis provides support for the notion that individuals with DS are influenced by the effect of frequency to a degree that is not significantly different to that observed in TD matched individuals. This suggests, in line with findings from Brock and Jarrold (2004), that those with DS experience top-down influences of long-term knowledge during vSTM recall. This appears contrary to the findings of Carlesimo, et al., (1997), who found poor use of category knowledge for recalling verbal items in those with DS. This disparity may be due to the DS and TD group being matched for vocabulary knowledge in the current study (participants were matched for mental age using the Wechsler intelligence scale in the Carlesimo et al., 1997 study), thus the similar size effect of frequency in the current study could be a consequence of similar vocabularies in the two groups. Moreover, it is likely that the effect of frequency does not involve any active strategic organisation, leaving open the possibility that those with DS may be poor at actively organising verbal memoranda into categories.

General Discussion

Across Experiments 1 and 2, the process dissociation technique was used to explore the effects of phonological similarity and frequency upon memory for item and for order information in individuals with DS, and a comparison sample of TD children. Importantly, in both Experiments we replicated previous effects, finding patterns one would predict with regards to both of these factors. Specifically, the results showed a detriment to order memory and a benefit to item memory as a result of phonological similarity (Experiment 1), coupled with a benefit to both item and order memory as a result of item frequency (Experiment 2). This highlights that such effects can be detected in children and special populations with the use of a process dissociation procedure.

Despite the DS group performing significantly more poorly than the TD group in both experiments, there were nonetheless no significant interactions between population and the other experimental manipulations. Thus, there were no significant differences in the patterns of the effects observed upon item and order memory in the DS group compared to the TD group. To further increase interpretability of any null interactions, a Bayesian approach was used in each Experiment to calculate posterior probability values for the respective models. This allowed us to explore the likelihood of the null model in contrast to the alternate model (of a significant interaction) and to derive firmer conclusions. For the interactions of both population x phonological similarity, and of population x frequency, there was positive evidence in favour of the null models, to a much larger degree than the extremely small likelihood of the alternate models. This suggests that there was no significant underlying difference between the two populations in the way that they were affected by these main effects.

These findings together indicate that the poorer performance of those with DS in tasks involving vSTM is not a result of fundamentally differential memory processes taking place during maintenance and recall. Individuals with DS are coding incoming verbal input phonologically. They are also influenced by their existing LTM representations of the items. The presence of a typical frequency effect in DS supports the idea suggested by Mosse and

Jarrold (2010) that the use of repetition in learning (as a relative strength) may be useful in DS to compensate for vSTM limitations. Frequency effects result from repeated exposure to those words that occur more often; repetition of input may thus result in artificial frequency effects for those with DS. The finding of phonological coding in the DS group indicates that poorer performance on tasks such as tests of rhyme awareness in DS (Snowling, et al., 2002) is not likely to be the result of an absence of phonological coding taking place, other factors not addressed in the current study, may instead play a role. Roch and Jarrold (2008) showed that individuals with DS rely on visual whole word recognition during reading (rather than a phonological approach) to an atypical degree. It is similarly possible that during vSTM recall tasks, those with DS avoid using phonological strategies or are unable to use them, instead relying on other, perhaps visuo-spatially based, approaches or existing knowledge. Given that individuals with DS do process verbal input phonologically, it may be helpful to enhance their attention to and awareness of the phonological properties of the verbal input during vSTM tasks. Gilliam and Van Kleeck (1996) reported that training in phonological awareness resulted in improvements in phonological segmentation skills and non-word repetition in TD children

Along with training individuals' awareness of the phonological properties of verbal input, future training programmes could focus on maximising individuals' ability to benefit from their LTM knowledge, and to be aware of these influences, during vSTM tasks. McNamara and Scott (2001) observed significant benefits as a result of training TD adults to use chaining strategies to meaningfully link to-be-recalled words together; they reported that use of semantic strategies (using LTM knowledge) was more effective than rehearsal strategies. Given that those with DS are influenced by their LTM knowledge during vSTM recall, such training could have potential.

Across both experiments, poorer memory recall performance was not specific to either item memory or order memory, and both of these components of memory were affected by the experimental manipulations in the same way as that observed in the TD group. The observed Bayesian posterior probabilities indicate that the evidence supporting the null model of no interaction for population x item/order in both of the experiments was around the boundary of weak to positive. This does indicate that the null model for the interaction, whereby the relative deficit of item memory is no different to the relative deficit of order memory in the DS group, has a considerably higher likelihood than the model in which one domain is reliably more impaired. However, taking into consideration that the probability values indicate only weak/just within positive evidence for the null models, and also acknowledging the existence of some previous research findings showing specific problems in recalling either item information or recalling order information respectively in the DS population (Brock & Jarrold, 2004; Brock & Jarrold, 2005; Kay-Raining Bird & Chapman, 1994; Marcell, et al., 1988), future research would be useful to strengthen this argument further.

Given both item and order memory problems, memory interventions with individuals with DS need to focus on improving both of these aspects of memory. One possibility is that there is some general process/capacity underpinning both item and order memory. However, the findings from the current set of Experiments further support the notion that these two types of memory (for item and for order information) are separable, in particular, in Experiment 1, phonological similarity had significantly contrasting effects upon item and order memory in both populations. This is also in line with STM models (Brown et al., 2000; Burgess & Hitch, 1992) and previous research suggesting that these are two distinct capacities (Majerus et al., 2006a; Majerus et al., 2006b).

Brock and Jarrold (2005) previously found problems in both domains in DS, but suggested that memory for order was particularly poor. It may be that variation in tasks leads to variation in the extent of any item or order memory impairment observed. The poorer recall of item information in the DS group compared to the TD group may reflect the fact that although individuals are storing verbal input phonologically, fewer items are effectively encoded. It is therefore possible that a lack of efficiency in encoding item properties contributes to poorer item memory, perhaps partially compounded by poor phonological discrimination as previously suggested by Brock and Jarrold (2004).

The poorer recall of order information in the DS group, compared to the TD group, on the other hand, may reflect an impairment in retaining the temporal context of phonological input. Problems recalling order information in the vSTM domain may hinder vocabulary abilities in those with DS. This is certainly possible given the findings of Majerus and colleagues showing that performance on tasks of order memory are strongly linked with vocabulary acquisition and language development (Attout et al., 2012; Leclercq & Majerus, 2010; Majerus & Boukebza, 2013; Majerus et al., 2006a). The expressive vocabulary problems observed in DS (Chapman & Hesketh, 2001) may therefore be due to problems regarding vSTM for order (though see also Mosse & Jarrold, 2008, 2010).

Intervention studies need to carefully consider routes to enhance item memory and routes to enhance order memory. For example, increasing attention to item properties (e.g., phonological and semantic features of verbal input) could improve item encoding. Memory for order could be enhanced by additionally training individuals to attend to the rhythm of the input, and providing methods to help individuals temporally structure verbal input, e.g., techniques to enhance representations of order, with visuospatial support. Item association approaches, such as that used by McNamara and Scott (2001), may enhance encoding and retrieval of items as well as providing order benefits as a result of inter-item associations.

A final important point to reiterate is that the effects of the two variables tested upon item and order memory were in the expected directions. Using process dissociation to explore such effects in special populations and among young children is a novel approach. We have shown that this approach is applicable and adaptable for such groups. This has important implications for future studies as this approach has the potential to provide purer measures of memory for item and order information than more standard methodologies. Future studies with larger samples of individuals would be particularly useful. This technique could be applied to explore other memory processes in TD children. Similarly, its application in other special groups would considerably enhance our understanding of the source of differential abilities in these developmental disorders.

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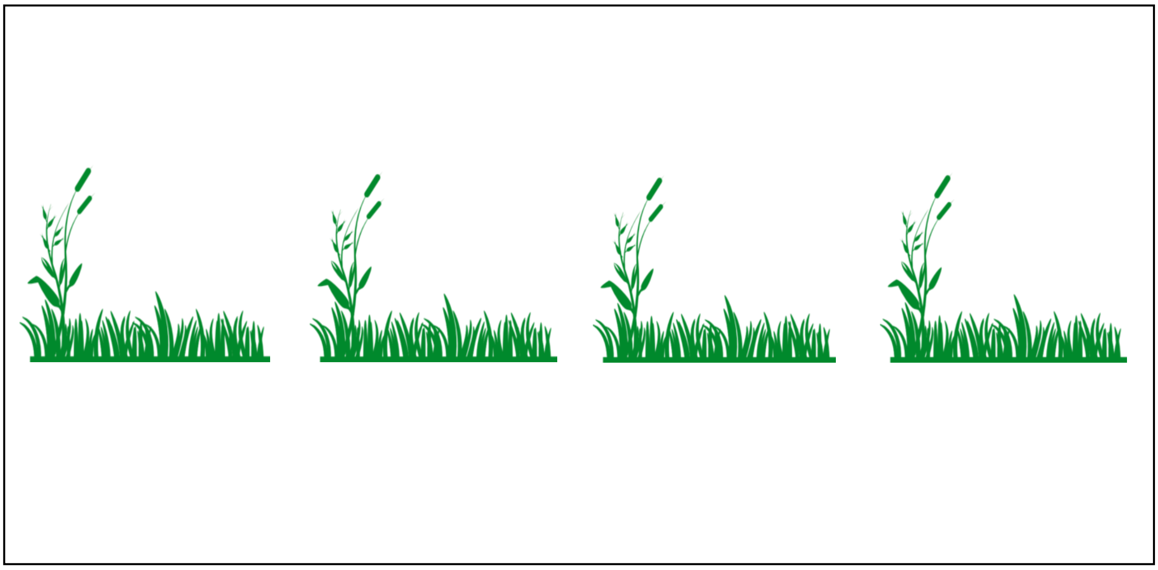
Appendix

A. Screen display during verbal presentation of items



B. Arrangement of items for Inclusion and Exclusion conditions.

Inclusion:

Trial: A, B, C, D

Exclusion:

Trial: C, D, A, B

C. Recording Forms

Phonological Similarity Recording Form:

Inclusion(1):

Hair	Bear	Chair	Fare
Truck	Bat	Sand	Bear
Hat	Hook	Fare	Band
Bat	Hat	Cat	Mat

Exclusion:

Chair	Fare	Hair	Bear
Sand	Bear	Truck	Bat
Fare	Band	Hat	Hook
Cat	Mat	Bat	Hat
Hand	Duck	hair	Mat
Land	Band	Sand	Hand
Duck	Hook	Book	Truck
Book	Hat	Land	Chair

Inclusion(2):

Hair	Mat	Hand	Duck
Sand	Hand	Land	Band
Book	Truck	Duck	Hook
Land	Chair	Book	Hat

Frequency Recording Form:

Inclusion(1):

Map	Dent	Zoo	Shark
Baby	Car	House	Table
Window	Bed	Watch	Garden
Chalk	Frost	Owl	Pear

Exclusion:

Zoo	Shark	Map	Dent
House	Table	Baby	Car
Watch	Garden	Window	Bed
Owl	Pear	Chalk	Frost
Money	Dog	Tree	Horse
Snail	Towel	Sponge	Vase
Torch	Chin	Goat	Peg
Food	Paper	Door	Flower

Inclusion(2):

Tree	Horse	Money	Dog
Sponge	Vase	Snail	Towel
Goat	Peg	Torch	Chin
Door	Flower	food	Paper

D. Full bayesian calculations for posterior probabilities, as provided in Masson (2011).

Calculation for ΔBIC value:

ΔBIC = *n* ln (SSE1/SSE0) + (*k*1 – *k*0) ln (*n*)

Calculation for estimate of bayes factor, using ΔBIC value:

BF = *P*BIC (D|H0) / *P*BIC (D|H1) = e (ΔBIC)/2

Calculation to convert bayes factor into posterior probabilities:

*P*BIC (H0|D) = BF / BF + 1

*P*BIC (H1|D) = 1 - *P*BIC (H0|D)

Bayesian posterior probabilities data from excel spreadsheet, formulas provided by Masson (2011):

1. Population x Phonological similarity

n	30	SSE1	2.815	3.114824339	deltaBIC
df effect	1	SSE0	2.842	4.746522144	BF01
SS effect	0.027			0.825981702	p(HO D)
SS error	2.815			0.174018298	p(H1 D)

2. Phonological similarity: Population x Item/Order

n	30	SSE1	1.313	1.562305111	deltaBIC
df effect	1	SSE0	1.396	2.183987983	BF01
SS effect	0.083			0.685928463	p(HO D)
SS error	1.313			0.314071537	p(H1 D)

3. Frequency x Population

n	30	SSE1	2.112	3.217104286	deltaBIC
df effect	1	SSE0	1.125	4.995573113	BF01
SS effect	0.013			0.833210273	p(HO D)
SS error	2.112			0.166789727	p(H1 D)

4. Frequency x Item/Order

n	30	SSE1	2.547	3.330609114	deltaBIC
df effect	1	SSE0	2.553	5.287283283	BF01
SS effect	0.006			0.840948792	p(HO D)
SS error	2.547			0.159051208	p(H1 D)

5. Frequency: Population x Item/Order

n	30	SSE1	2.54	2.631625451	deltaBIC
df effect	1	SSE0	2.606	3.727779417	BF01
SS effect	0.066			0.78848421	p(HO D)
SS error	2.54			0.21151579	p(H1 D)

6. Population x Frequency x Item/Order

n	30	SSE1	2.54	2.89894699	deltaBIC
df effect	1	SSE0	2.59	4.260870555	BF01
SS effect	0.043			0.809917391	p(HO D)
SS error	2.54			0.190082609	p(H1 D)