From Brown-Peterson to Continual Distractor via Operation Span:

A SIMPLE Account of Complex Span

Ian Neath

Memorial University of Newfoundland

Lisa A. VanWormer

University of West Florida

Tamra J. Bireta

The College of New Jersey

Aimée M. Surprenant

Memorial University of Newfoundland

Ian Neath
Department of Psychology
Memorial University of Newfoundland
St. John's, NL
A1B 3X9
Canada

Phone: (709) 864-8159
Fax: (709) 864-2430
Email: ineath@mun.ca

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Abstract

Three memory tasks – Brown-Peterson, complex span, and continual distractor – all alternate presentation of a to-be-remembered item and a distractor activity, but each task is associated with a different memory system, short-term memory, working memory, and long-term memory, respectively. SIMPLE, a relative local distinctiveness model, has previously been fit to data from both the Brown-Peterson and continual distractor tasks; here we use the same version of the model to fit data from a complex span task. Despite the many differences between the tasks, including unpredictable list length, SIMPLE fit the data well. Because SIMPLE posits a single memory system, these results constitute yet another demonstration that performance on tasks originally thought to tap different memory systems can be explained without invoking multiple memory systems.

Key words: SIMPLE, complex span, serial position functions, memory systems, serial recall

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One approach to the study of human memory invokes a unitary account in which there exist general principles that apply widely over different time scales, different tests, and different hypothetical underlying memory systems (Surprenant & Neath, 2009a). Evidence proffered in support of this approach includes demonstrations of similarities in paradigms that have otherwise been considered as tapping different memory systems. For example, the characteristic bow-shaped serial position function can be observed in tasks thought to tap many different episodic memory systems including sensory memory, short-term memory, working memory, and long-term memory. Importantly, all of these instances can be explained by a unitary model of memory called SIMPLE (Scale Independent Memory, Perception, and Learning; Brown, Neath, & Chater, 2007; Neath & Brown, 2006). In addition, the same account explains the bow-shaped serial position function observed when the memory task taps semantic memory (Kelley, Neath, & Surprenant, 2013, in press; Neath, 2010; Neath & Saint-Aubin, 2011). In this paper, we examine whether SIMPLE can also explain the bow-shaped serial position functions observed in complex span tasks.

Complex Span, Continual Distractor Tasks, and Brown-Peterson

Span tasks can be divided into two types, simple and complex. In a simple span task, such as digit span, the subject sees or hears a list of items and is then asked to recall those items in order immediately after presentation ends. Complex span tasks are similar except that subjects are asked to engage in a second activity between each of the to-be-remembered items. For example, in the operation span task (Turner & Engle, 1989), the subject reads a mathematical question out loud (e.g., "Is ten divided by 2 plus 4 equal to 9?"), answers the question, and then sees the first item in the list. The math problems alternate with the to-be-remembered items. At the end of the list, which typically varies from 2 to 6 words, the subject is asked to recall the words in strict serial order. There are a number of complex span (also called working memory span) tasks including reading span (Daneman & Carpenter, 1980), in which subjects read sentences out loud and then recall the last word of each sentence; counting span (Case, Kurland, & Goldberg, 1982), in which subjects count the dots on a series of cards and are asked to recall the sums; and spatial span (Shah & Miyake, 1996), in which subjects are asked to recall the spatial orientation of letters while doing mental rotation. One important difference between simple and complex span tasks is that the latter correlate better with higher-order cognitive tasks such as reading comprehension, problem solving, and reasoning (see Conway, Kane, Bunting, Hambrick, Wilhelm, & Engle, 2005).

Complex span tasks originated from Baddeley and Hitch's (1974) formulation of working memory. The key feature was that complex span "measures were, therefore, created to require not only information storage and rehearsal… but also the simultaneous processing of additional information" (Conway et al., 2005, p. 771). However, two other historically significant tasks have exactly the same characteristic: subjects are asked to remember a list of items separated by a demanding distractor task. These are the Brown-Peterson task (Brown, 1958; Peterson & Peterson, 1959; see also Daniels, 1895) and the continual distractor task (Murdock, 1965; Silverstein & Glanzer, 1971). Like complex span, both Brown-Peterson and continual distractor tasks alternate presentation of a to-be-remembered item with distracting activity, but there are a number of differences.

First, the number of to-be-remembered items differs among the three tasks. In the typical Brown-Peterson task, there is a single learning and a single distracting episode, whereas in complex span and continual distractor tasks, there are multiple learning and distracting episodes. For example, subjects in a Brown-Peterson task might be asked to remember a consonant trigram (e.g., Peterson & Peterson, 1959), a single word (e.g., Murdock, 1961), or multiple words (e.g., Fuchs & Melton, 1974), but there is only one period of distracting activity before recall. In the typical continual distractor task, there are multiple learning and distracting episodes; indeed, there can be up to a dozen or more words alternating with the distractor task (e.g., Watkins, Neath, & Sechler, 1989). In complex span tasks, there are typically between 2 and 6 learning and distracting episodes.

A second difference is that the number of learning episodes varies from trial to trial in a complex span task but is fixed and therefore known to subjects ahead of time in both Brown-Peterson and continual distractor tasks. On any given trial, subjects in Brown-Peterson and continual distractor tasks know the number of to-be-remembered items prior to presentation of the list; in the typical operation span task, they do not.

Two more differences involve the distractor task itself. In both Brown-Peterson and continual distractor, the distractor activity comes second; in complex span tasks, it typically occurs first. In addition, the tasks differ in the duration of the distractor tasks. Both Brown-Peterson and continual distractor tasks routinely have distracting activity occur for up to 18 s in the former and 30 s or even longer in the latter. In contrast, the distracting activity in complex span task is rarely longer than a few seconds, the time necessary to verify a simple arithmetic problem.

A fifth difference concerns the original purpose of the task. The Brown-Peterson task was designed specifically to examine short-term retention of an individual trigram (Peterson & Peterson, 1959), and was thus seen as a test of short-term memory (for a review, see Crowder, 1976). The continual distractor task was designed to examine free recall when short-term memory could not be used because it was occupied by the distractor task (Murdock, 1965). Because of this, it became a benchmark test of long-term memory, and is still frequently viewed as such (e.g., Davelaar, Goshen-Gottstein, & Ashkenazi, 2005). As noted above, complex span tasks originated from Baddeley and Hitch's (1974) formulation of working memory and are therefore seen as tests of working memory, a memory system that is separate from long-term memory (Baddeley, 2010).

The claim advanced here is that despite the differences noted above, all three tasks are essentially the same: Memory performance is tested and some distractor activity is being performed. Unsworth and Engle (2006) have previously noted the similarity between complex span and continual distractor tasks and suggested that the type of temporal-contextual account that addressed performance in the continual distractor task might also account for memory performance on complex span tasks. They specifically discuss Glenberg's (1987; Glenberg & Swanson, 1986) Temporal Distinctiveness Theory, but do not report any model fits. We take inspiration from their suggestion, but use a different distinctiveness model, SIMPLE (Brown et al., 2007; Neath & Brown, 2006) to explain the data.

Currently, one influential account of memory divides it into multiple memory systems, each of which operates according to different rules and principles and each of which is responsible for supporting memory in different situations (e.g., Foster & Jelicic, 1999; Schacter, Wagner, & Buckner, 2000; Wang & Morris, 2010). Although there is no consensus on the exact number of memory systems, there is consensus that there exists separate systems for storing information over the short-term (short-term or working memory) and for storing information over the long-term (long-term memory). While a review of this area is beyond the scope of the current article, one foundation of this approach is searching for differences, whether in the form of dissociations or the duration of memories or some other aspect. It is the presence of these myriad differences that warrant drawing a distinction between the various systems. Indeed, if there were no differences, then the distinctions would be unnecessary.

In contrast, the principles approach noted in the introduction advocates searching for similarities and in particular, general principles of memory (see Surprenant & Neath, 2009a). How does this account explain the numerous differences between, for example, short-term and long-term memory? One way is to suggest that the differences are more apparent than real. For example, Surprenant and Neath (2009b) documented 9 ways in which multiple systems theorists had argued, at one time or another, why short-term or working memory differed from long-term memory, but which subsequent research had shown to be no longer viable. As the number of differences between the two systems decrease, the support for the idea that the two systems are separate and follow different rules and work differently also decreases.

The approach taken in this paper is related: To the extent that phenomena from different systems can be explained in the same way using the same fundamental principles, the rationale for positing separating systems is weakened. A multiple systems theorist might respond that because short-term/working memory and long-term memory are all episodic memory systems, there should be some similarities and shared processes. While this may be a valid point, it does not address the fundamental question of how similar two memory systems can be while still being separate. One goal of the principles approach is to keep searching for similarities between different systems. As more and more similarities are observed, the position that the systems are separate – and thus different – becomes less tenable. Our aim in this paper is to provide one such similarity by showing thatthe recall data from a complex span task can be explained by the same model that explains data from the continual distractor task.

SIMPLE and Brown-Peterson, Complex Span, and Continual Distractor Tasks

According to SIMPLE (Brown et al., 2007; Neath & Brown, 2006), memory is best conceived as a discrimination task: To-be-remembered items are represented as positions along one or more dimensions in psychological space and in general, those items with fewer close neighbors on the relevant dimensions at the time of test are more likely to be recalled than items with more close neighbors. In the typical episodic memory task, the experimenter carefully chooses a set of to-be-remembered stimuli so that they are equated on as many dimensions as possible (e.g., frequency, familiarity, concreteness, and so on). In the usual case, then, the primary systematic variation concerns when in time the item occurred. According to SIMPLE, items in these sorts of tasks are represented on a temporal dimension. The zero point is the time the item is retrieved, and each item's value is the time since presentation, relative to the time of retrieval.

It is important to note that SIMPLE does *not* require that people must always use temporal information in all tasks. Depending on the task, other dimensions may be more relevant. For example, Neath, Brown, McCormack, Chater, and Freeman (2006) used tasks in which the main dimension in one task was frequency (Hz); in another, length (mm); and in a third, weight (g). It is also possible, in principle, to get more objective information about the dimensions. For example, Surprenant, Neath, and Brown (2006) used multidimensional scaling to obtain the main dimensions, and then used those derived dimensions in the model. Whereas their MDS solution yielded only 2 dimensions, such procedures can be extended to include more than 2 dimensions.

Here, we focus on those aspects of SIMPLE that are relevant to the tasks under consideration. In a typical immediate serial recall task, the to-be-remembered list items might be presented at a rate of 1 s each. Therefore, at the time of test, a six-item list would have the temporal values of 6 5 4 3 2 and 1 for items 1 to 6, respectively. These values undergo a log transform (see Brown et al., 2007, for a discussion), and then the similarity, $\eta_{i,j}$, between two log-transformed temporal memory representations, T_i and T_j, can be equated using Equation 1:

$$\eta_{i,j} = e^{-c\left|T_i - T_j\right|} \qquad 1.$$

In Equation 1, then, the similarity between two given list items is computed based on the log-transformed temporal values. The main free parameter in SIMPLE is c. Higher values of c correspond to greater distinctiveness of memory traces (i.e., less influence of more distant items). As c increases, a given difference between two values results in a lower similarity value.

Serial recall requires that the first item be recalled first, the second item recalled second, and so on, so the probability of recalling item 1 is calculated first. Remembering is cue driven, as is the case in other models (see Surprenant & Neath, 2009a, for a discussion). The nature of the cues can differ depending on the task. In an absolute identification task, for example, the cue is the item itself and the appropriate response is the identification of the cue (e.g., tone 1; see Neath et al., 2006). When the task makes use of a temporal dimension appropriate, the cue is the item's location on that dimension (see Brown et al., 2007; Brown, Chater, & Neath, 2008). Although SIMPLE does not provide a specific mechanism, Brown et al. have suggested that something like the oscillator-based mechanisms in OSCAR (Brown, Preece, & Hulme, 2000) may be one way of making this more explicit.

The probability of producing the response associated with item i, R_i, when given the cue for stimulus j, C_j, is given by Equation 2, in which n is the number of items in the set:

$$P\left(R_i \mid C_j\right) = \frac{\eta_{i,j}}{\sum_{k=1}^{n} \eta_{j,k}} \qquad 2.$$

Once this value is calculated, the temporal values need to be updated to account for the fact that time is passing. Assuming (for the sake of simplicity) that it takes 1 s to recall the first item, the temporal values at the time that item 2 is to be recalled will now be 7 6 5 4 3 and 2. When recalling the third item, the values are again updated to reflect the time taken to output the second item. Ideally, the actual output times are used (e.g., Bireta et al., 2010), but if these are unknown, an estimated output time is used.

The above is sufficient to produce not only appropriate serial position curves but also the correct pattern of errors; that is, when an item is recalled in the wrong position, it is more likely to be recalled in adjacent positions than in more distant positions (see Brown et al., 2007; Neath & Brown, 2006). Moreover, this version is SIMPLE has only one free parameter, c, and is the version that will be used to model the complex span data, because the task did not allow for omissions.

In the typical Brown-Peterson and continual distractor tasks, however, omissions occur. To induce omissions in the model, a sigmoid function is used which increases recall probabilities that are already high, and reduces recall probabilities for items whose recall probabilities are already low. Equation 3 shows the implementation, which calculates output probability, P_o, based on the estimated recall probability, P, from Equation 2:

$$P_o = \frac{1}{1+e^{-s(P-t)}} \quad 3.$$

The parameter t is the threshold and parameter s is the slope of the transforming function (which can be interpreted as the noisiness of the threshold). For example, if t is set to 0.8 and s is very large, the transformation will approximate a system that recalls all items with relative strengths greater than 0.8, and omits all items with strengths less than 0.8. As s becomes smaller, the transition from low to high recall probabilities becomes more gradual.

With this addition, SIMPLE can now model data from Brown-Peterson tasks.[2] There are two main assumptions. First, SIMPLE views the Brown-Peterson task as a standard immediate serial recall task. The three consonants of the consonant trigram are viewed as separate list items (e.g., a list of three consonants), and for performance to be scored as correct, all three need to be correctly recalled in the correct order. Note that SIMPLE makes a number of predictions from this assumption, including that serial position functions will be observed if the scoring is changed from the traditional all-or-none to scoring each consonant with respect to its position.

The second assumption is that a certain number of prior lists have been presented and are represented on the same temporal dimension as the current list. This assumption allows proactive interference to affect performance (see Brown et al., 2007, p. 552, for additional details). Consider a trial from a Brown-Peterson task on which the duration of the distractor task is 3 s. If there is a 15 s inter-trial interval, then the trigram for the current trial will be well separated from the previous trials, and recall will be good. Now consider a trial on which the duration of the distractor activity is 18 s. Now, the trigram for the current list will have receded substantially along the temporal dimension, making it closer to the representation of the previous trial; therefore, recall will be poor. Note further that if the inter-trial interval is increased sufficiently in duration, there should be no interference from previous trials because temporal separation between the items will be so large. This is exactly what Loess and Waugh (1967) showed: as the trials become more separated, recall improves because there is less interference from previous items.

SIMPLE also correctly predicts equivalent levels of recall on the first trial of a Brown-Peterson task regardless of the duration of the distractor activity (e.g., Keppel & Underwood, 1962; see Brown et al., p. 552-553). The reason for this is that there are no prior trials to interfere. It also accounts for release from proactive interference when the type of item changes for the same reason (e.g., Gardiner, Craik, & Birtwistle, 1972; see Brown et al., p. 554-555). Finally, it accounts for the findings reported by Baddeley and Scott (1971), who demonstrated that forgetting on the first trial of Brown-Peterson task increases as the list length increases (see Neath & Brown, 2012). Increases in list length can produce intra-list interference even in the absence of proactive interference. In essence, there are fewer neighbors to be confused with the middle letter on a 3-item list than on a 5-item list.

Note that in the case of the Brown-Peterson task, the distractor activity served, according to SIMPLE, to separate trials from one another. In the continual distractor task, the main function of the distractor activity is to separate the items. However, to fit data from the continual distractor task, one additional assumption is needed to reflect the difference between free and serial recall (see Brown et al., 2008). (Parenthetically, no change would be needed to fit the continual distractor task if strict serial recall were required.)

In free recall, the subject can recall any item first, any item second, and so on. In terms of the model, if the subject is trying to recall the third item but happens to recall the fourth item instead, that is still a correct response because the fourth item was on the list. Thus, performance in the model is scored differently for free than for serial recall. If the exact output order is known, then that information plus the output time can be used and the model produces appropriate recall. When output time and order data are not known, a simplifying assumption is to assume a mean output time for all items (see Brown et al., 2007, pp. 545-549).

In SIMPLE, the distractor activity serves to distribute the items along the temporal dimension. Thus, it does not matter if the distractor tasks all take 1 second or 1 minute or 1 week, the ratios are all the same (see Glenberg et al., 1980). What does matter is if there are differential amounts of distractor activity or if the distractor activity occurs at different times. For example, if shorter durations are mixed with longer durations this will result in some items having many close neighbors (and thus poorer recall) and some items having fewer close neighbors (and thus better recall). SIMPLE produces the appropriate results when the duration of the distractor task systematically increases and when it systematically decreases throughout the list (Neath & Crowder, 1990; see Neath & Brown, 2006, pp. 212-216). Similarly, SIMPLE predicts a smaller or no recency effect when a list contains distractor activity only after the final item (Postman & Phillips, 1965; see Brown et al., 2007, p. 548) but predicts a robust recency effect when distractor activity occurs after every item (Bjork & Whitten, 1974; see Neath & Brown, pp. 232 onwards).

In terms of SIMPLE, then, nothing new needs to be added to fit the recall data from a complex span task. The question is whether the same one-parameter model can fit the current data as well as the previously-mentioned data which has been variously identified as arising from short-term or long-term memory systems.

Experiment

The purpose of the experiment was to provide serial position data from a standard complex span task that could be modeled. We combined the materials and design of the operation span task described by Conway and Engle (1996) with the computer-based implementation described by Unsworth, Heitz, Schrock, and Engle (2005).

Method

Subjects. One hundred and twenty one undergraduates from Purdue University volunteered to participate in exchange for credit in introductory psychology courses. All were native speakers of English.

Stimuli. The math problems and words were provided by Conway (personal communication, May 11, 2000), and were similar to those used in previous studies involving operation span (e.g., Conway & Engle, 1996; Engle, Tuholski, Laughlin, & Conway, 1999; Turner & Engle, 1989).

Design and Procedure. Subjects were informed that we were interested in how accurately they could remember the order in which a series of words had been presented whilst solving simple math problems. First, a math question was shown (e.g., Is (10/2) + 4 = 9 ?) and subjects were asked to read it out loud (e.g., "Is ten divided by two plus four equal to nine?"). They then clicked on a button (yes or no) to answer the question. A word then appeared for 2 s and the subjects were instructed to read the word aloud. Math problems and words alternated until the desired number of words (2, 3, 4, 5, or 6) had been presented. Then, response buttons became active and were labeled with the words in alphabetical order. The subjects were asked to indicate the presentation order of the words by clicking on appropriately labeled buttons on the screen using the mouse. There were 3 practice trials (not scored) with list length 2, and these were followed by 15 scored trials, 3 lists at each length from 2 to 6. The order of list lengths was randomly determined for each subject.

Data from an additional 5 subjects were discarded because accuracy on the math portion was less than 85% (i.e., more than 8 math problems were answered incorrectly). OSPAN is defined as the sum of all correctly recalled stimuli from lists in which all items were correctly recalled. For example, a subject who correctly recalled all 3 lists of length 2, all 3 lists of length 3, but none of the lists of length 4, 5, or 6, would have an OSPAN of 15. The maximum value is 60.

Results and Modeling

The mean OSPAN was 34.71 (*SD* = 13.03, range 4-60) and the mean accuracy on the math tasks was 96.99% (*SD* = 2.75, range 86.67 to 100). These values are comparable to those reported elsewhere (e.g., Unsworth et al., 2005).

The data were also scored using standard strict serial recall scoring: Figure 1 shows the proportion of times each word was recalled in each serial position (open circles), that is, scored as if the data came from a standard immediate serial recall task. As can be see, not only are standard serial position curves evident, but the position error gradients appear indistinguishable from those typically seen with immediate serial recall in both short-term (e.g., Healy, 1974) and long-term (e.g., Nairne, 1991) tasks, replicating Unsworth and Engle (2006).

To fit SIMPLE to the data, it was assumed, as in other simulations (e.g., Brown et al., 2007; Neath & Brown, 2006; Surprenant, Neath, & Brown, 2006), that items were represented on a temporal dimension reflecting time until recall. We assumed that the to-be-remembered words were presented with a 5 s stimulus onset asynchrony (SOA), made up of 2 s presentation of the to-be-remembered word followed by 3 s to read and answer the math problem. We further assumed that each item took 1.5 s to recall. These values ignore the individual variation that did occur (e.g., some math problems are easier than others), but the values are plausible. Thus, the main temporal dimension at the time that recall of the first item of the 6-item list was attempted had the following values: 27, 22, 17, 12, 7, and 2. When recall of the second item was attempted, these values had become 28.5, 23.5, 18.5, 13.5, 8.5, and 3.5, respectively.

Because the experiment used a strict serial reconstruction of order task, omissions were not possible, and so equation 3 was not used. SIMPLE therefore has only one free parameter, c. The predictions of the model are shown as lines in Figure 1; the data are the points. As can be seen, SIMPLE is capturing all of the major characteristics of the data, not only the proportion correct but the distribution of errors as well. With $c = 4.358$, the model gave quite good fits to the data; for list lengths 2-6 respectively, R^2 was 0.999, 0.997, 0.990, 0.969, and 0.912. Note that the value of c was the same for all list lengths; that is, all 90 data points are being accounted for by a single free parameter.[2]

SIMPLE produces the appropriate position error gradients for operation span using the same core ideas implemented to account for recall in standard serial recall tasks and tasks thought to tap other memory systems including sensory, short-term, working, and long-term memory (see Brown et al., 2007; Neath & Brown, 2006). The distractor activity in the operation span task serves the same function as in the continual distractor task: it spaces the to-be-remembered items out in time, and it is the distinctiveness of each item, relative to its near neighbors, at the time of test that determines recall probability. In addition, end items have a slight advantage by not having neighbors to one side.

General Discussion

Is the continual distractor task a working memory span task? Is operation span a long-term memory task? Is the Brown-Peterson task simultaneously a long-term memory task, a short-term memory task, and a working memory task? According to SIMPLE, the answer is yes, in that the same basic principles account for performance in all of those tasks.

According to SIMPLE, serial position functions occur when stimuli can be sensibly ordered along a dimension. In the typical episodic case – with sensory, short-term, working, or long-term memory – the dimension is relative time, but depending on the particular task, the dimension can vary, and can include perceptual dimensions (Neath, Brown, McCormack, Chater, & Freeman, 2006). In semantic memory tasks, the dimension can be position (Neath & Brown, 2006), but can also be something that corresponds historical importance (Neath, 2010; Neath & Saint-Aubin, 2011). What is the same in all of these cases is that an item is well remembered to the extent that it is distinct relative to its close neighbors on the dimensions of interest, the so-called relative distinctiveness principle (Surprenant & Neath, 2009a). There is no need for and no advantage to positing separate memory systems.

What the Brown-Peterson task, operation span, and the continual distractor task all have in common is that there is a distractor task that spreads the items out in time. According to SIMPLE, what is critically important is whether the distribution results in some items having more or fewer close neighbors. In that sense, the three tasks are the same.

Initially, distractor tasks were used to prevent rehearsal. SIMPLE does not dispense with the notion of rehearsal, but it does view it in a way perhaps different from other models. In SIMPLE, rehearsal of an item is like a re-presentation of the item but at a different temporal location. Ordinarily, item 4 in a 20 item list for free recall will not be well remembered. However, if it is rehearsed just a few seconds prior to test, it may functionally become item 18 or item 19, and thus be well recalled. Indeed, SIMPLE nicely fits the data obtained when subjects are asked to rehearse out loud and instead of using time of presentation to construct the main dimension, time of last rehearsal is used instead (Rundus, 1971; Tan & Ward, 2000; see Brown et al., 2007, p. 548).

SIMPLE, as described above, assumes that the distractor activity does not interfere with memory for the to-be-remembered items. For the modeling that has been done here and elsewhere, that is an appropriate assumption because the experimenters chose distractor tasks that would not be likely to interfere (e.g., counting backwards and recalling consonants). It is, of course, possible to use distractor tasks that do interfere. Nonetheless, it is possible to use distractor tasks that do interfere with the to-be-remembered items. This does not pose a problem for SIMPLE, in principle. For example, if a distractor activity were sufficiently similar to the to-be-remembered items, it could not only spread the to-be-remembered items out in time, but could also enter into calculations of distinctiveness along the interfering dimension. Similarly, most modeling has focused on verbal stimuli, but not only are temporal distinctiveness effects readily seen with, for example, spatial information (Guérard et al., 2010), but SIMPLE has also been fit to data where the stimuli – digitized photographs of snowflakes – were chosen precisely because verbal labels could not be used (see Neath & Brown, 2006, for the fit of data from Neath, 1993).

It should be noted that SIMPLE does not address one important aspect of complex span tasks: It does not say why these sorts of tasks are good predictors of a wide range of cognitive abilities, including fluid intelligence. To the extent that it views complex span tasks as being similar to both Brown-Peterson and continual distractor tasks, however, it does predict that both of those other tasks should have similar predictive qualities as complex span. There is some evidence for this. Unsworth and Spillers (2010) found that although performance on a continual distractor task correlated with performance on a standard operation span task, the correlation was smaller than the correlation between OSPAN and reading span (0.29 vs. 0.64). Moreover, performance on the continual distractor task was not as good a predictor on a range of tasks as OSPAN. However, there are a number of factors that may have minimized the predictive ability of the continual distractor task. In particular, there were only 3 lists in the continual distractor task compared to 15 on the operation span task. One possibility is that with more observations, the continual distractor task might become a better predictor.

Why do complex span and simple span tasks differ in their ability to predict performance on complex cognitive tasks? While SIMPLE does not directly address this, we think that the key is that in complex span tasks (and Brown-Peterson and continual distractor tasks), the subject is asked to do multiple things at the same time (e.g., remembering and solving distracting questions). Put another way, performance on complex span tasks is a better predictor than performance on simple span tasks when the target task is also complex because simple span tasks involve only one component, serial recall, whereas complex span tasks have multiple components.

The results of this and other modeling support the idea of a single memory system rather than multiple memory systems. Using relative time as the main dimension, SIMPLE can explain results from tasks thought to tap different memory systems. It is important the dimension is relative and not absolute time because the means that the there is nothing special about the duration over which an item must be remembered. In addition, because the relative distinctiveness principle applies when other dimensions are used, it means there is nothing special about time *per se*. In particular, because temporal cues can function like non-temporal cues (e.g., perceptual cues such as frequency, length, or weight), it suggests that temporal phenomena are not a proper basis for dividing up a memory system.[3]

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Correspondence may be addressed to Ian Neath at ineath@mun.ca.

Footnotes

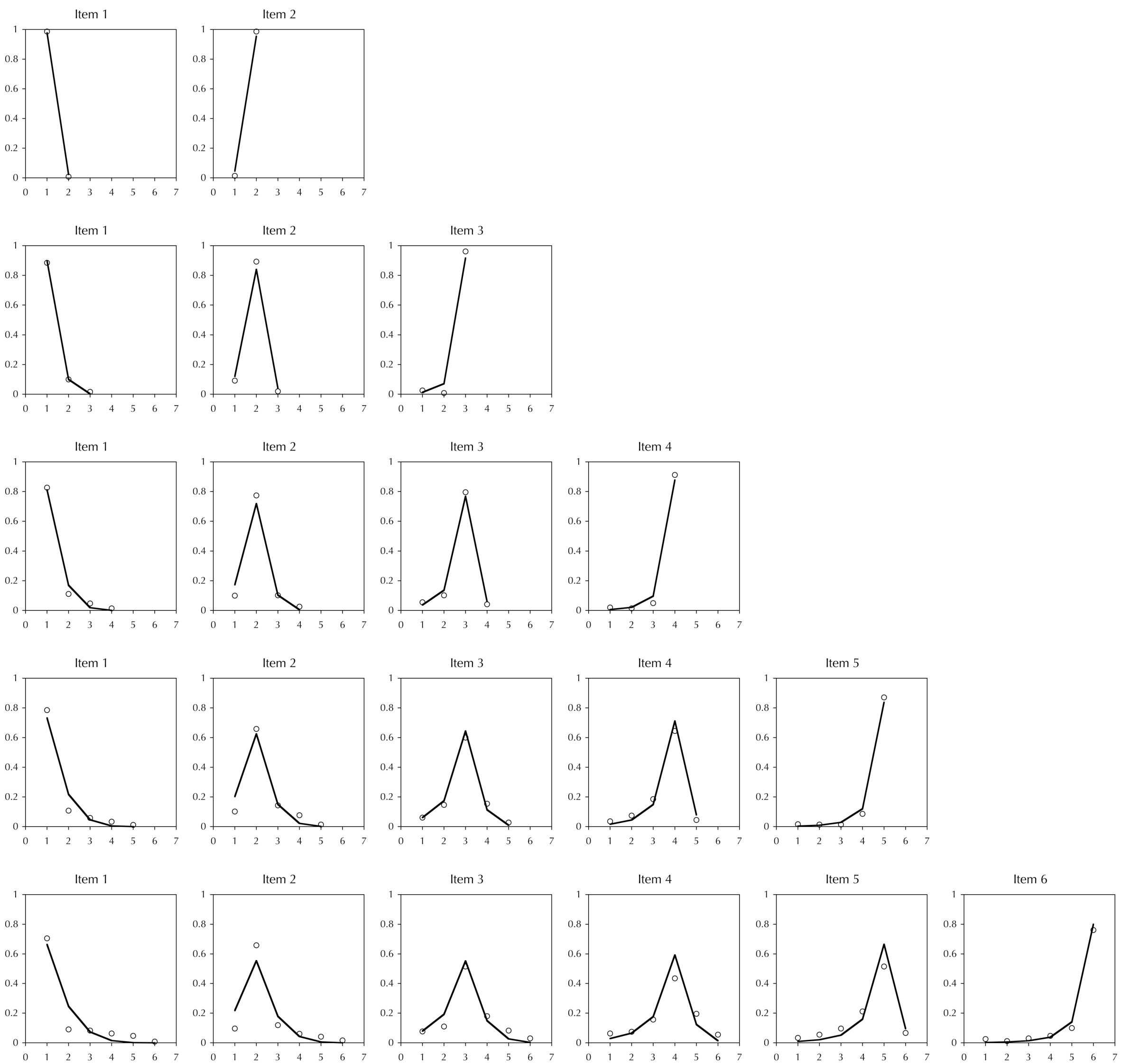
1. MATLAB code illustrating how SIMPLE fits data from the Brown-Peterson and other paradigms is available at http://memory.psych.mun.ca/models/ or from the first author.

2. A web-based implementation of this version of SIMPLE is available at http://memory.psych.mun.ca/models/simple/js/ospan/

3. We thank a reviewer for noting this succinct rationale.

Figure Caption

Figure 1. The proportion of times each item was recalled in each position as a function of list length in Experiment 1. Open circles show the data, and the lines show the fit of SIMPLE (see text for details).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