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Temporal integration in 17- and 20-month old infants as assessed by elicited imitation

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TEMPORAL INTEGRATION IN 17- AND 20-MONTH-OLD INFANTS AS ASSESSED BY ELICITED IMITATION.

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TEMPORAL INTEGRATION IN 17- AND 20-MONTH-OLD INFANTS AS ASSESSED BY ELICITED IMITATION.

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University of Nebraska, 1998

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The present study used a unique task derived from the elicited imitation paradigm to assess temporal integration in 17- and 20-month-old infants. Experiment 1 implemented a simpler task than has previously been used in order to tap temporal integration ability in 17-month-olds. The results indicated that the performance of 17-month-olds did not improve over that of previous research (de Haan & Bauer 1997). Experiment 2 added storage and processing demands to the de Haan and Bauer task in order to assess the robustness of temporal integration ability in 20-month-olds. The results indicated that the performance of 20-month-olds did not suffer with the added demands of the task. Implications of the findings in regards to the structure and development of working memory are discussed.

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Temporal Integration in 17- and 20-month-old Infants as Assessed by Elicited Imitation.

Temporal integration refers to the ability to put together bits of information presented over time in order to form a coherent representation of an event. Temporal integration is presumed to provide a test of working memory ability because a person must be able to maintain activation of material in memory while simultaneously processing new information and putting the separate relevant pieces of information together. The present research was aimed at assessing temporal integration in very young children using a unique technique derived from the elicited imitation paradigm. To understand the concept of temporal integration, a model of working memory will first be discussed, along with several theories concerning the development of working memory. Next, a discussion of methods used to test different aspects of working memory in both adults and children will lead the reader to the task implemented in the present experiments.

Working Memory: Structure and Development

The term "working memory" has been developed as a way to conceptualize a system that is more active than the system traditionally referred to as "short-term memory" (Baddeley 1981). Short-term memory has been delegated to refer to a passive storage system only, that is, short-term memory is the system involved in traditional span tests in which a set of items is presented and immediate recall of the items is required (Case, Kurland, & Goldberg 1982; Halford, Maybery, O'Hare, & Grant 1994). In contrast, working memory is used to refer to a system involving not only the passive storage of information, but also the simultaneous manipulation or processing of the same or other information (Daneman & Carpenter 1980; Swanson 1996). Thus, any task that simply measures immediate recall of presented items is a measure of short-term span, which is the storage aspect of working memory in isolation. However, a task that measures the storage of items when the simultaneous manipulation or processing of the same or other information is required during presentation is a measure of working memory.

To understand the concept of temporal integration, a model of working memory must first be explained. The most prominent model of working memory currently in the literature is the one devised by Baddeley and Hitch (1974). In their model, Baddeley and Hitch suggested that working memory can be broken down into three components; the central executive, the articulatory loop, and the visuo-spatial scratch pad. The three subsystems of working memory were assumed to play various roles in the processing and storage of information (Baddeley 1981; Baddeley & Hitch 1974).

Baddeley and Hitch (1974; Baddeley 1981) referred to the core of the working memory system as the central executive and described it as a "work space" with a limited capacity that can be allotted to either the processing or the storage of information. The central executive was proposed to be the subsystem of working memory in which the direction of attention and other resources takes place. It is also the component involved in reasoning and in other information processing tasks. Storage demands can be offloaded onto two proposed slave systems; the articulatory loop and the visuo-spatial scratch pad.

The articulatory loop was proposed as a separate component of working memory devoted to the storage of verbal material by means of rehearsal. Any chunks of information that can be articulated can be maintained in the articulatory loop without affecting the processing taking place in the central executive, provided the storage capacity of the articulatory loop is not overloaded. When the articulatory loop becomes overloaded, somewhere between three and six items, it begins to drain resources from the central executive to help with storage demands. Since some of the limited capacity of the central executive would then be used for storage, an overloading of the articulatory loop leads to a decrement in processing performance in the central executive (Baddeley 1981; Baddeley & Hitch 1974).

The third component in the working memory model proposed by Baddeley and Hitch (1974) was the visuo-spatial scratch pad. This slave system is analogous to the articulatory loop but rather than verbal information, the visuo-spatial scratch pad maintains visual or spatial information (Baddeley 1981; Baddeley & Hitch 1974).

Thus, the limited capacity model of working memory proposed by Baddeley and Hitch (1974) suggests a trade-off between processing and storage when presented with a demanding task. Support for the trade-off concept has been found in studies indicating that a memory preload or a concurrent memory load of six items both produce lower verbal reasoning and comprehension performance than without the memory load (Baddeley & Hitch 1974).

Theories regarding the structure of working memory can perhaps be better understood in terms of how short-term span (the storage aspect of working memory) develops. Research has made it clear that short-term span increases with age (e.g. Huttenlocher & Burke 1976; Diamond 1985; Alp 1994). More specifically, when auditory digit span was tested in groups of children averaging 4 ½, 7, 9, and 11 years of age, Huttenlocher and Burke found an overall increase in span with age (the average digit span across conditions increased by approximately one digit with each increase in age group). Likewise, evidence for increases in short-term span with age was apparent in Diamond's findings that the delay necessary to cause the A not B reaching error increases by approximately two seconds per month between the ages of 7 ½ to 12 months.

Research by Alp (1994) also indicated linear increases in short-term span with increasing age. The measurement of short-term span was provided by the Imitation Sorting Task (IST). To perform the task, a child first watched the experimenter sort various objects into two containers, and then the child attempted to imitate the sorting of the objects. The highest number of objects the child successfully sorted was taken as the child's score. The significant finding in Alp's study was that the IST scores of children increased steadily, averaging one unit every six months, from 12 to 36 months of age. Thus, several different methods have clearly demonstrated that short-term span increases with age. The next logical question concerning the structure and development of working memory is how does short-term span increase with age?

Following from Baddeley's model of working memory, it has been argued that short-term span increases with development due to an increase in the speed of rehearsal (which presumably provides one measure of processing speed). That is, because the articulatory loop can store information for only a short time, the speed at which a person can rehearse information directly affects the amount of information that can be stored in the articulatory loop before the approximately two second decay time elapses (Halford, Maybery, O'Hare, & Grant 1994). This argument, referred to as a decay and rehearsal hypothesis, suggests that in a working memory system composed of at least partially distinct components, a faster processing speed will allow more information to be stored in a slave system without affecting the resources of the central executive. Faster processing in the articulatory loop as a mechanism for span development has been supported by findings such as those of Cohen and Heath (1990) in their research demonstrating a correlation between articulation speed and span.

A similar theory in explaining the development of short-term span also focuses on the role of increased processing efficiency. Case, Kurland, & Goldberg (1982) posit a more direct and complete trade-off between storage space and processing space within one limited pool of total processing space (operating space plus storage space). Case et al. argue that total processing space does not increase with age, rather, operations become more efficient, taking up less attentional resources, and therefore leaving those resources to be used for storage of information. This conclusion was supported by a series of experiments that not only demonstrated strong relationships between operational efficiency (speed of processing) and span, but also found that when different age groups are equated in processing speed, their spans no longer differ.

Thus, the theories of span development which fall out of Baddeley' s model and that of Case et al. claim that increases in span are due to increases in processing efficiency. The difference between the two models is in the breakdown of the structure of working memory. While Baddeley's model holds that the faster processing rate allows more information to be held in the articulatory loop without affecting the central executive, Case et al.'s model states that working memory consists of only one pool of resources leading to a direct trade-off between storage and processing demands. In addition, Baddeley's model makes no claims that total processing space stays constant with age, as processing and storage demands do not compete for a singular pool of resources. Case et al. argue that total processing space does stay constant while processing becomes more efficient leaving more resources available for storage (Halford, Maybery, O'Hare, & Grant 1994).

A third explanation concerning the development of short-term span argues that the increase in span is not due to increased processing efficiency, but reflects an increase in total processing space. Swanson (1996) came to this conclusion after comparing different age groups of children (approximately seven to 13 years of age) on three measures of working memory. First, children performed a working memory task with no assistance, determining their initial scores. The second measure, called a gain score, was defined as the highest score available with probes or cues provided to the children. Finally, a third measure, the maintenance score, was determined by the stability of the gain scores after the removal of all probes. The theory behind using these three measures was that if age-related differences in working memory are due to differences in processing efficiency, then the performance of younger children should be improved to reach that of older children when cues are provided. If, however, age-related differences in working memory are due to differences in total processing space, cues would not improve younger children's scores up to the level of the older children's scores and differences would still be apparent between the gain scores and maintenance scores of different age groups. Therefore, Swanson predicted that the differences between the age groups would be greater for the gain scores and the maintenance scores than for the initial scores.

Swanson's (1996) predictions were supported by the finding that the best predictor of age-related differences in performance was the maintenance condition, accounting for approximately 50% of the variance. In other words, performance on the condition requiring the highest storage demands (this was the maintenance condition because it included both the stimuli involved in the initial task as well as added stimuli which had been brought to attention by the use of probes and cues to form the gain scores) was more predictive of age differences than was performance on the initial task involving no assistance. Since the inferior working memory performance of the younger children could not be compensated for by memory probes, Swanson concluded that younger children simply cannot store as much information as older children. Thus, improvements in working memory with age were presumed to be due to increases in total processing space (a similar conclusion was drawn by de Jonge and de Jong (1996) discussed later).

Adult Studies

In order to assess the structure and development of working memory, it is necessary to tap both the processing and storage aspects of working memory. Unlike traditional measures of short term span, such as digit span tests, which only tap storage functions, other methods have been implemented which attempt to tax both the storage and processing systems of working memory (Daneman & Carpenter 1980; Masson & Miller 1983; de Jonge & de Jong 1996; Shah & Miyake 1996). In order to assess the trade-off of processing and storage space in working memory, Daneman and Carpenter devised the reading span test. In the reading span test, subjects are presented with a series of sentences that they are required to read aloud and attempt to remember the last word in each sentence. Following each trial (consisting of the presentation of three sets of either two, three, four, five, or six sentences), the subjects were asked to recall the last word of each sentence in the given set in the correct order. Subjects were presented with increasingly larger sets of sentences until they failed all three span tests at a given level. The highest level at which the subject was correct in recall for two out of the three sets was interpreted as his/her reading span. Daneman and Carpenter used reading span as a measure of working memory capacity.

Although previous research had found no correlation between traditional measures of short term span, specifically digit span, and reading comprehension (i.e. Guyer & Friedman 1975), Daneman and Carpenter (1980) found that reading span correlated significantly with reading comprehension in college students. Thus, the authors concluded that better readers were more efficient in processing the sentences than were poor readers, leaving a greater amount of working memory capacity to be used for storage. Similar results were reported for a listening span task, providing further support for the trade-off between processing and storage in working memory.

Research by Masson and Miller (1983) has provided findings similar to those of Daneman and Carpenter (1980). Masson and Miller also employed a reading span test and again found a high correlation between reading span and reading comprehension. In addition, the authors also found that reading span was highly correlated with the ability to integrate information from different parts of a reading passage and to use the integrated information to draw inferences not explicitly stated in the text. An implication of the research was that normal reading comprehension ability depends not only on storage of information in working memory, but also on processing operations which form coherent relations among propositions and encode the information into long-term memory. Thus, the reading span test provides a measure of the ability to store and process information in adult working memory.

Thus far, the discussion of tasks that assess both the storage and processing functions of working memory has been limited to verbal tasks. Other examples of research focusing on the role of working memory in reading comprehension can be found in the literature [for example, the model of text comprehension proposed by Kintsch and van Dijk (1978) and studies lending support to that model (i.e. Fletcher 1981)]. However, work has also been performed assessing spatial working memory with a 'spatial span task' (Shah & Miyake 1996).

Shah and Miyake (1996) developed a spatial span task analogous to the reading span test devised by Daneman and Carpenter (1980). The spatial span task requires simultaneous storage and processing of spatial information by having the participant remember the original orientation of each letter in a set of letters presented one at a time in varying orientations. In addition to the storage aspect of the task, the participant has to decide whether each letter is presented normally or as a mirror image by rotating the letter mentally. A person's spatial span score is defined as the highest level at which correct recall of spatial orientations was obtained for at least three out of the five presented sets of letters.

Shah and Miyake (1996) found that spatial span was significantly correlated with measures of spatial ability. In other words, participants with high spatial span scores also achieved high performance levels on tasks that reflected processes of spatial ability, such as mental rotation. These results were analogous to those of Daneman and Carpenter (1980), indicating that the spatial span task provides another measure that can concurrently assess the storage and processing functions of working memory.

Child Studies

Up to this point in the discussion, the studies assessing working memory have all been performed with adult subjects. It would also be of interest to assess simultaneously both the storage and processing functions of working memory in children and in infants in order to better understand the structure and development of working memory. Complex span tasks have been administered to children, but conflicting results have been obtained. Some of these findings were consistent with the findings from the adult studies (Siegal & Ryan 1989), and others were not the same as those in the adult studies (de Jonge & de Jong 1996).

Siegal and Ryan (1989) administered a task similar to that of Daneman and Carpenter's (1980) reading span test to children ranging from seven to 13 years of age.

In the working memory sentence task implemented by Siegal and Ryan, a child was presented with a series of sentences (either two, three, four, or five) and was asked to supply the final word for each sentence (e.g. "In summer it is very _____."). After the series of sentences was presented, the child was to repeat all of the missing words from the sentence set. The test continued until the child failed all of the items at a given level. The resulting score was analogous to Daneman and Carpenter's reading span.

Like Daneman and Carpenter (1980), Siegal and Ryan (1989) also found that the reading span scores of children were related to reading ability. Specifically, the results of the Siegal and Ryan study indicated that normally achieving readers had significantly higher scores on the working memory sentence task than did reading disabled children. This study suggests that complex span tasks can be used to assess simultaneously both the processing and storage aspects of working memory in school-age children. However, when complex span tests were administered to 10- to 12-year-old children, de Jonge and de Jong (1996) reported that performance on complex span tests (reading or computation span tests) correlated as much with performance on simple span tests (word or digit span) as with one another. In addition, complex and simple span tests were equally correlated with reading comprehension. The authors concluded that complex span tests only assess storage capacity in children, not the simultaneous processing of information as in adults. Because these complex span tests do not seem to be reliable measures of working memory in children, new tasks will need to be devised in order to gain a more complete measure of children's working memory. The same is true for measuring working memory in infants, as past research concerning the working memory of infants has often focused on the storage aspect in isolation.

Short-term span (storage only) and working memory (storage and processing) have been assessed in human infants with tasks such as the delayed nonmatch-to-sample (DNMS) (Overman, Bachevalier, Turner, & Peuster 1992; Overman, Bachevalier, Sewell, & Drew 1993), the A not B task (Diamond 1985; see Wellman, Cross, & Bartsch 1986 for a meta-analysis), and the oculomotor delayed response task (Gilmore & Johnson 1995). All three of these tasks tap some aspect of working memory in that the infant is required to hold a piece of information in temporary storage over a short delay in order to complete the task successfully.

The delayed nonmatch-to-sample (DNMS) task was applied to human infants (12-32 months old) in a study by Overman et al. (1992). Each trial in the DNMS task involved two steps. First, a tray with three food wells was placed in front of the child with a sample object concealing a food reward in the center well. The child removed the object to obtain the reward (training to do so had been provided prior to the task), and the tray and object were concealed from the child's view. Following a 10-second delay, the second step in the trial involved presentation of the tray with the original and a novel object covering the lateral food wells. At this point in the trial, the food reward was located under the novel object. This procedure ensured that in order for the child to complete the task successfully, that is, to obtain the food reward in the second step of the trial, s/he was required to retain the memory of the original object over the 10 second delay interval between steps one and two (Overman et al. 1992).

Successful performance on the DNMS task requires lengthy training to reach criterion performance (Overman et al. 1992). For example, the results in the Overman et al. study indicated that the 18-20-month age group did not reach criterion performance (87% correct on 15 trials/day for two consecutive days) until a mean of 48 days of testing. The youngest group, 12-15-months, did not reach criterion for an average of 123 days. In addition to requiring extensive training, the authors concluded that human infants need to reach a certain unspecified level in their cognitive or maturational development before they can perform the DNMS task successfully. The minimum age for this to occur seems to be in the range of 19 plus or minus three months (Overman et al. 1992). Because the DNMS task requires several cognitive abilities, not only recognition memory but also formation of a generalized rule over the trials, it is not clear which ability delays the learning of the DNMS task (Overman et al. 1992). Therefore it is difficult to assess early working memory ability with the DNMS task alone.

Another task which taps working memory ability in young infants is Piaget's A not B task. In the A not B task, the infant is presented with two wells and watches as the experimenter hides a reward in one of the wells, well (A) (Diamond 1985). After a delay, the infant reaches for the well and reveals the reward. From approximately eight months of age, the infant is able to successfully reach for the location in which the reward is hidden on the first trial and on subsequent trials when the reward is repeatedly hidden in location A. However, on one critical trial, the reward is hidden under the other well, well (B). Given a certain delay, the infant tends to reach for the original A location even though s/he watched the experimenter hide the reward in the B well. This action is known as the A not B error (Diamond 1985).

Similar to the DNMS task, the A not B task involves a reward hidden in one of two or three wells, which the infant must reach for. In order to reach successfully during the second part of each task, the infant must maintain some type of representation in memory of information gained previously. In the DNMS task it is the representation of the previously seen object which the child is required to recognize, while in the A not B task, the child must remember the location in which the reward was hidden. Thus, the storage aspect of working memory is necessary for successful performance on the A not B task because the child must continually maintain the mental representation of the reward's location over a delay (Diamond 1985).

Diamond's (1985) findings demonstrated increased short-term span with increasing age in that the delay interval necessary to cause the A not B error increased by an average of two seconds per month from 7 1/2 months to 12 months of age. In other words, 12-month-old infants were able to remember where the object was located over a delay of 10 or more seconds and successfully retrieve the object on the critical B trial (Diamond 1985). However, short-term recall is not sufficient for successful performance on the A not B task, as is demonstrated by the fact that the infant reaches successfully to A, when the reward is hidden in A, with the same delay which causes an error when the reward is hidden in B (Diamond 1985). Because the A not B task requires the inhibition of a competing response, in addition to short-term recall, it may be considered a test of working memory.

A task that has been designed specifically to test working memory in nonverbal subjects is the oculomotor delayed response (ODR) task (Gilmore & Johnson 1995). One version of the ODR task involves three computer screens that display a series of stimuli over time. First, a fixation stimulus is presented on the center screen. Next, one of two cue stimuli appears on the center screen briefly, and then the original fixation stimuli returns. A delay ranging from 3-5 seconds is imposed before a target stimulus appears on either the right or left screen depending on which cue stimulus was presented. Once a contingency between cue and side of target presentation has been learned, the subject's eye movements toward the correct side before the target appears demonstrates evidence of working memory (Gilmore & Johnson 1995). In other words, the infant must maintain the cue representation in memory over a delay in order to predict the location of the target stimulus. Therefore, evidence of working memory (at least the storage aspect) can be inferred from predictive eye movements.

The ODR task has been implemented to assess working memory in 6-month-old infants (Gilmore & Johnson 1995). The results indicated that the infants demonstrated a strong preference for the cued location. Thus, 6-month-old infants are able to maintain information about spatial location in working memory for delays of up to 5 seconds (Gilmore & Johnson 1995).

Although the DNMS, A not B, and ODR tasks all assess working memory in very young infants, these tasks have limitations. As mentioned previously, the DNMS and A not B tasks clearly require additional cognitive components such as learning a generalized trial-to-trial rule in the DNMS task (Overman et al. 1992), and response inhibition in the A not B task (Diamond 1985). In addition to working memory, the ODR task requires learning a contingency between cue stimuli and target location. It is not clear whether these additional cognitive components could be considered to involve the processing aspect of working memory, or if they require other cognitive resources (i.e. long-term memory). Another limitation inherent in these tasks is the training necessary for performance. The training is especially lengthy in the DNMS task (Overman et al. 1992). Another issue with the DNMS, A not B, and ODR tasks is that none of them have much ecological validity. A task is needed that taps working memory in pre-verbal infants in a more ecologically valid manner than previous tasks. A task which can meet these criteria, as well as assessing both the storage and processing aspects of working memory simultaneously in infants can be found within the elicited imitation paradigm.

Elicited imitation is a task that has been used to assess immediate and long-term memory in infants and pre-verbal children (Meltzoff 1995; see Bauer 1997 for review). Elicited imitation involves using props to perform event sequences made up of a series of distinct steps. For example, the sequence "make a rattle" involves a plastic base with handle, a wooden block, and a cup that attaches onto the base when inverted. The required steps are: placing the block onto the base, covering the block with the cup, and shaking the rattle.

The basic elicited imitation procedure begins with the experimenter giving the props necessary for one event sequence to the child for a baseline measure of performance. Next, the experimenter models the event sequence two times in succession, with narration. The props are then returned to the child who is encouraged to imitate the experimenter's actions. This portion of the task assesses immediate recall. To assess delayed recall, or long-term memory, the child is returned to the lab after a certain delay has been imposed. The child is again provided with the props in the same manner as during the original baseline phase. If a greater number of target actions are produced during this phase than were produced during baseline, long-term memory is inferred (Bauer 1995). The number of pairs of target actions performed in the correct order is also measured as a dependent variable to assess memory for the temporal order of events. In that the child is required to remember individual actions, as well as the temporal order of actions in a sequence, the task clearly taps the storage aspect of memory (either short- or long-term). Elicited imitation has been used to assess short- and long-term memory in children as young as 9 months (e.g. Carver & Bauer, in press; Meltzoff, 1988) and as old as 30 months (Bauer & Fivush, 1992).

Present Task

The elicited imitation task can also be adapted to assess working memory in young children by adding a distinct concurrent processing requirement to the basic task. Elicited imitation can be used to tap temporal integration ability by presenting the steps of several event sequences intermingled with one another. For example, the experimenter can model the first step of one sequence, followed by the first step of another sequence, and the first step of a third sequence, then return to the first sequence and model its second step and so on until all event sequences have been modeled completely. This method will accomplish several objectives. First, in its requirement that children maintain different concurrent streams of information, the task will simultaneously assess both the storage and processing components in working memory. Thus, the new temporal integration task will provide a more complete measure of working memory than any of the infant tasks discussed previously. The task is analogous to the complex span tasks discussed previously in that the child is required to store each step in working memory while simultaneously processing the presentation of the next steps. Processing will also be required for the segregation and integration of the various steps into their respective sequences. Second, the task will have greater ecological validity than have previous tasks measuring working memory in infants. In this task, children are seeing a series of events over time, similar to events experienced in real life. The intermingling of steps involved in various events is also ecologically valid. For example, a child may watch as a parent alternates between the steps involved in baking cookies and doing laundry. Finally, because it is a non-verbal task, the present task may provide a measure of working memory performance across the entire period of transition from infancy to early childhood.

A study performed in the Bauer lab (de Haan & Bauer 1997) used elicited imitation to tap temporal integration ability in 17- and 20-month-old infants. The authors chose to examine 17- and 20-month-olds because past research had suggested that some type of cognitive transition occurs somewhere around 19 months of age. For example, Alp (1994) reported a transition around 19 months of age in children's ability to imitate sorting of objects into two canisters. Likewise, Overman et al. (1991) concluded that the minimum age for successful performance on the DNMS task seems to be approximately 19 months. The method implemented in the de Haan and Bauer study consisted of two conditions: a 3-sequence/3-step/1-repetition condition, and a 3-sequence/3-step/3-repetition condition. The two conditions both involved three 3-step sequences modeled by the experimenter in the following manner: A1 (sequence A, step 1), B1, C1, A2, B2, C2, A3, B3, C3. The only difference between the two conditions was that in the one-repetition condition each step was only modeled one time, while in the three-repetition condition each step was modeled three times in succession. After modeling, for each sequence in turn, the necessary props were provided to the child, who was verbally encouraged to perform the sequence with a statement such as: "Now it's your turn. Show me what you can do with this stuff".

The analysis of the de Haan and Bauer (1997) study indicated that both age and step repetition had effects on the number of target actions and pairs of target actions in the correct order produced by the infants. Specifically, 20-month-olds performed better than 17-month-olds [the effect was marginal for target actions ($\underline{p} < .07$), but significant for pairs ($\underline{p} = .02$)], and performance was better with three repetitions than with only one repetition of each step during modeling (target actions $\underline{p} < .05$, pairs $\underline{p} < .04$). In addition, a marginal Age X Gender X Repetition interaction was found for pairs ($\underline{p} = .053$). The interaction indicated that the number of repetitions did not have an effect for either 17-month-old males or 20-month-old females, but did have an effect for the other two groups with 17-month-old females and 20-month-old males performing better with three repetitions than with only one repetition.

The authors concluded that while 17-month-olds had difficulty with the task, 20-month-olds displayed temporal integration ability with the present methodology (de Haan

& Bauer 1997). One indication of the discrepancy between the two age groups was evident in the means. Specifically, 17-month-olds in the three repetition condition performed fewer target actions and pairs than did 20-month-olds in the one repetition condition. Thus, the results of the de Haan and Bauer experiment provided two important pieces of information regarding the working memory abilities of children in these age groups. First, working memory clearly undergoes development between the ages of 17 and 20 months: Relative to 17-month-olds, 20-month-olds were more successful at bridging the gaps between steps of the event sequences and integrating the steps correctly. Second, at both ages, temporal integration was aided by multiple presentations of each step in the sequences. It appears that even though repeated presentations added a time strain on working memory, they compensated for it by strengthening the memory traces for each step. This information was taken into account in the present experiments where the goals were to test the limits of temporal integration ability in 17- and 20-month-olds, thus assessing the robustness of the de Haan and Bauer findings under varying conditions.

Present Experiments

The present experiments were designed to further examine temporal integration in 17- and 20-month-old infants using the elicited imitation paradigm. Experiment 1 attempted to tap temporal integration ability in 17-month-old infants by providing a task that is simpler than the one used in the de Haan and Bauer study. Specifically, along with a replication of the 3-sequence/3-step/3-repetition condition used previously, a 3-sequence/2-step condition was added to attempt to provide a more sensitive measure that would demonstrate temporal integration ability in 17-month-olds. In addition, a 1-sequence/3-step/delay condition was added in order to assess whether the poor performance in the previous study was due to the length of time between modeling of successive steps in a particular sequence, or due to the interference of the modeling of other sequences in between modeling of successive steps. It was hypothesized that 17-month-old infants would demonstrate more temporal integration ability under these simpler conditions, due to fewer storage and processing strains on working memory.

The second experiment was an attempt to assess the robustness of temporal integration ability in 20-month-old infants by making the task more difficult. The task was made more ecologically valid than the de Haan and Bauer study by adding two modifications. Like the de Haan and Bauer study, Experiment 2 involved presentations of three 3-step event sequences for each condition. The first condition was a replication of the 3-sequence/3-step/1-repetition condition from the de Haan and Bauer study. The second condition involved a longer delay between each modeled step, thus further tapping the capacity of working memory. Finally, the third condition added environmental distraction during the modeling presentation. The hypothesis was that 20-month-old children would demonstrate less temporal integration ability than in the de Haan and Bauer study due to the difficulty of the task. The difficulty was increased by raising the storage (longer intervals) or processing (attentional resources drained by distraction) requirements of the task.

In addition, the present research included control conditions in which additional sequences were presented in the traditional elicited imitation format as discussed previously. It was predicted that the temporal integration tasks would result in lower performance, in terms of both target actions and pairs produced for both ages, than in the control conditions. This was expected because the temporal integration tasks were presumed to require both the storage and processing functions of working memory while the traditional elicited imitation task relies primarily on the storage of information. That is, successful performance on the temporal integration tasks requires not only the storage of information, but also the simultaneous processing of concurrent information, making it a test of working memory. Lower performance on the temporal integration tasks were expected because if some or all of the resources of the central executive are required for processing functions in the temporal integration task, less capacity will be available for storage, resulting in lower performance.

Experiment 1

Method

Participants. Participants consisted of 14 healthy, full-term, 17-month-old (+/- 2 weeks) infants. Seven of the participants were females and 7 were males. Participants were recruited from a pool of parents who had indicated an interest at the time of their child's birth. All children were from a large midwestern city and most were from white, middle-class families. Parental consent was obtained for all participants and each child received a small toy as a reward for taking part in the study.

Apparatus. For the warm-up period, props consisted of large plastic beads, a plastic bucket, a slinky, and a soft ball. Testing procedures utilized the parts involved in the following 2- and 3-step sequences: doll, car, gong, dump truck, frog, tools, strawberries, rattle, and merry-go-round (see Appendix for complete descriptions). Additional materials consisted of see-and-say toys, soft plastic books, a stuffed elephant, and plastic rings. A video camera, a cardboard box to hide props, and a timer were also used during testing.

Procedure. The same female experimenter tested all children individually. The session began with a short warm-up period in which the experimenter played with the child on the floor while the parent read and signed the consent form. The experimenter also briefly explained the procedure to the parent at this time. Warm-up play consisted of the experimenter demonstrating putting plastic beads into a bucket and the child imitating this action. The child was then seated in a booster seat at an adult-size table across from the experimenter and next to the parent. The parent remained present throughout testing but was asked to refrain from providing any guidance to the child. Warm-up at the table consisted of rolling a ball and placing it in a slinky. Both warm-up activities were imitation exercises to prepare the child for the general testing format. When the experimenter felt that the child was ready, testing began with the demonstration of the first step in the first sequence. All children were exposed to all three conditions: The 3-sequence/3-step condition, the 3-sequence/2-step condition, and the 1-sequence/3-step/delay condition.

In the 3-sequence/3-step condition, the experimenter demonstrated the steps in the following order: A1 (sequence A, step 1), B1, C1, A2, B2, C2, A3, B3, C3. Each step was repeated three times in succession (A1, A1, A1, B1, B1, B1...) and the actions were verbalized simultaneously. A see-and-say toy was presented between each step in order to keep the child's interest and to keep the timing between the demonstrations consistent. Following the presentation of all of the steps involved in the three sequences, the props necessary for each sequence were placed in front of the child, one sequence at a time. The experimenter encouraged the child to perform the target sequence by saying "Now show me what you can do with all of this stuff". The props were taken away from the child when he or she had performed the target sequence two times or when he or she became disinterested in the props (i.e. pushed the props toward the experimenter).

The 3-sequence/2-step condition was identical to the 3-sequence/3-step condition except that three 2-step sequences were used. The steps were presented as follows: A1 (sequence A, step 1), B1, C1, A2, B2, C2, again with three repetitions of each step.

The 1-sequence/3-step/delay condition involved only one sequence. In this condition, each of the three steps was presented to the child, again with three repetitions and verbalizations, and was followed by a 70 second delay interval (A1...A2...A3). The delay was 70 seconds long because this was the average span of time between the presentation of consecutive steps in one sequence (e.g. steps A1 and A2) in the 3-sequence/3-step condition. During the delay, the child was kept occupied with books or with a stuffed elephant and plastic stacking rings. Following presentation of all of the steps, the child was again provided with the props and encouraged to play with them. All four 3-step sequences used in the 3-sequence/3-step and 1-sequence/3-step/delay conditions were counterbalanced across children so that each sequence was presented in each position an approximately equal number of times. In addition, the 2-step sequences used in the 3-sequence/2-step condition were also counterbalanced across children. The order of the three conditions was counterbalanced across children, so that each possible order was presented to at least two of the children.

As a control, an additional new 3-step sequence was presented twice in its entirety and then given to the child to imitate at the end of the 3-sequence/3-step condition. Likewise, a new 2-step sequence was presented in the same manner immediately following the 3-sequence/2-step condition. These two sequences ensured that the participants were proficient at imitating sequences presented in the original elicited imitation format as had been previously demonstrated in children in the same age group (Bauer & Hertsgaard 1993; Bauer & Dow 1994).

After all conditions had been presented, the child received a toy to take home. The entire session lasted approximately 35-45 minutes.

Scoring. One experienced rater, trained in behavioral coding, coded videotapes of the sessions for number of target actions produced and number of pairs of target actions performed in the correct order. For the number of individual target actions produced, the maximum score was 3.0 for the 3-sequence/3-step condition (averaged over the three sequences), 2.0 for the 3-sequence/2-step condition, and 3.0 for the 1-sequence/3-step/delay condition. For pairs, the maximum score was 2.0 for the 3-sequence/3-step condition, 1.0 for the 3-sequence/2-step condition, and 2.0 for the 1-sequence/3-step/delay condition. A second trained rater coded 20% of the participants in order to assess inter-rater reliability. Overall agreement between the two raters (the number of agreed upon target behaviors divided by the total number of target behaviors recorded) ranged from 89% to 100% (mean 95%). In calculating the number of correct pairs of actions produced in the target order, only the first occurrence of each target action was considered. For example, if a child produced the target actions in the target order (1-2-3), s/he received credit for three individual target actions and two pairs of actions in the target order (1-2 and 2-3). If a child produced the target actions in a string of 3-2-1-2, however, s/he was credited with all three individual target actions but no correctly ordered pairs of actions. S/he was not credited with the pair 1-2, because action 2 first occurred in the string 3-2-1. As a final example, a child producing the first occurrences of the target actions in the string 1-3-2 received credit for all three individual actions but only one correctly ordered pair of actions (1-3). This method of scoring reduced the likelihood that children received credit for production of a correct sequence by chance or by trial and error.

Results & Discussion

Descriptive statistics, including means and standard deviations, were calculated for number of target actions (components) produced and number of pairs of target actions produced in the correct order for each condition. These data are presented in Table 1 as both raw scores and proportions.

To test for the effects of gender and condition on the proportions of possible target actions produced, a 2(Gender: Male, Female) X 3(Condition: 3-sequence/3-step, 3-sequence/2-step, 1-sequence/3-step/delay) mixed design ANOVA was conducted with gender as the between subjects factor and condition as the within subjects factor. No significant effects were found for gender, $\underline{F}(1, 12) = .72$, $\underline{p} > .05$, condition, $\underline{F}(2, 24) = .44$, $\underline{p} > .05$ (see Figure 1), or the Gender X Condition interaction, $\underline{F}(2,24) = 1.20$, $\underline{p} > .05$.

Likewise, a 2(Gender) X 3(Condition) ANOVA was conducted to test for the effects of gender and condition on the proportion of pairs of target actions produced in the correct order. Again, no significant effects were found for gender, $\underline{F}(1, 12) = 1.62$, $\underline{p} > .05$, condition, $\underline{F}(2, 24) = .83$, $\underline{p} > .05$ (see Figure 1), or the interaction, $\underline{F}(2, 24) = 2.04$, $\underline{p} > .05$.

In other words, contrary to what was predicted, 17-month-old children did not perform significantly more target actions or pairs in the 3-sequence/2-step and the 1-sequence/3-step/delay conditions than in the 3-sequence/3-step condition (see Figure 1). The findings suggest that the new conditions implemented in Experiment 1 were not simpler for 17-month-old children than the conditions used by de Haan and Bauer (1997). The fewer storage and processing demands required by the new tasks did not significantly increase performance.

Despite these conclusions, it is possible that performance did increase over the de Haan and Bauer (1997) results in the present experiment. Evidence for improved performance can be found when comparing means for the two studies. In identical tasks (the 3-sequence/3-step/3-repetition condition in the de Haan and Bauer study and the 3-sequence/3-step condition in the present experiment) the means for both components and pairs were higher in the present study (components $\underline{M} = 2.24$, pairs $\underline{M} = 1.05$) than in the de Haan and Bauer study (components $\underline{M} = 1.92$, pairs $\underline{M} = .67$). Because both the present experiment and the de Haan and Bauer experiment utilized within subject designs, the overall difficulty level of the session may have been lower for the present experiment, allowing 17-month-old infants to display greater ability in temporal integration than had been displayed in the past. For example, it is possible that the most difficult condition in the de Haan and Bauer study, the 3-sequence/3-step/1-repetition condition, may have caused fatigue in the 17-month-olds. The conditions in the present study were presumably less taxing.

In order to compare performance on the 3-step/control sequence with performance in the 3-sequence/3-step temporal integration condition, two 2(Gender) X 2(Condition: 3-step/control, 3-sequence/3-step) mixed design ANOVAs were conducted, one on number of target actions produced and one on number of pairs produced in the correct order. The main effect for gender was significant for components, $\underline{F}(1, 12) = 4.67$, $\underline{p} = .05$, and for pairs, $\underline{F}(1, 12) = 4.74$, $\underline{p} = .05$, with females performing higher (producing more target actions and pairs) than males. No significant effects were found for the main effect of condition (see Figure 2), or for the interaction.

Likewise, two 2(Gender) X 2(Condition: 2-step/control, 3-sequence/2-step) ANOVAs were conducted to compare performance on the 2-step/control sequence with performance in the 3-sequence/2-step temporal integration condition. No significant effects were found for main effect of gender, main effect of condition (see Figure 3), or for the Gender X Condition interaction.

In other words, contrary to what was predicted, 17-month-old infants did not perform significantly more target actions or pairs in the control conditions than in the temporal integration conditions (see Figures 2 & 3). This finding, along with the lack of differences between conditions, suggests that the present tasks did not measure the processing aspect of working memory for the 17-month-olds. Rather, it seems that the tasks reflected only the storage aspect of working memory, similar to the span tests used by de Jonge and de Jong (1996). A probable conclusion is that 17-month-olds are incapable of storing enough information to cause a competition for resources between the storage and processing functions within working memory (see General Discussion).

The two dependent variables, target actions and pairs of target actions in the correct order, are clearly correlated with each other. It is necessary for two target actions to be performed for any given pair of target actions to occur. In order to evaluate whether or not the pairs variable provides any additional information in the present research, analyses against chance were performed for all conditions. That is, based on chance alone, one half of all pairs of target actions would be in the correct order. Therefore, within-subjects t-tests (one-tailed) were calculated for each condition to see if the numbers of pairs of target actions in the correct order were greater than would be expected by chance alone. All of the t-tests were significant (see Table 2), indicating that the children were not simply remembering single target actions, but were remembering them in the correct sequential order.

Experiment 2

Method.

Participants. Participants consisted of 14 healthy, full-term, 20-month-old infants who did not participate in experiment 1. Infants were selected in the same manner as those in the first experiment.

Apparatus. Additional props for Experiment 2 consisted of the items involved in the 3-step sequences car, gong, spaghetti, dump truck, and doll (see Appendix). This experiment also involved items used in distracter tasks: a stuffed elephant and plastic rings, several pop-up books, an object made up of a long, flat, piece of plastic with two cylindrical plastic shapes standing at either end, a piece of elastic spanning the two cylinders, and a nerf ball and ornament used to roll down the elastic "bridge". In addition, a video was made of a stuffed pig making noise, a stuffed dog making noise, and the stuffed pig in a car.

Procedure. Testing took place in the same lab as Experiment 1 and had the same general format. The only differences in procedure were in the specific conditions. All conditions involved 3-step sequences and each step was demonstrated only one time. The first condition, the 3-sequence/3-step was the same as the 3-sequence/3-step condition in experiment 1, except that each step was only presented one time. The 3-sequence/3-step/delay condition was also the same as the 3-sequence/3-step condition except that longer delays were imposed between step presentations. The interval between each step was extended to 45 seconds rather than the average of 24 seconds as in the 3-sequence/3-step condition. During the delay intervals the children were occupied with one of three tasks: putting plastic beads on a stuffed elephant, looking at pop-up books, or rolling a ball or ornament down an elastic “bridge”. Finally, in the 3-sequence/3-step/distraction condition, a video was playing behind and to the right of the experimenter, in the child’s view. Conditions and sequence order were counterbalanced across children.

Scoring. Scoring was the same as for Experiment 1. The maximum number of target actions for each condition was 3.0, and the maximum number of pairs of actions in target order was 2.0. Overall agreement between the two raters ranged from 86% to 97% (mean 90%). The dependent variables were derived in the same manner as in Experiment 1.

Results & Discussion

Descriptive statistics, including means and standard deviations, for number of target actions (components) and pairs produced are presented in Table 3 as both raw scores and proportions.

To test for the effects of gender and condition on number of target actions produced, a 2(Gender) X 3(Condition: 3-sequence/3-step, 3-sequence/3-step/delay, 3-sequence/3-step/distraction) mixed design ANOVA was conducted with gender as the between subjects factor and condition as the within subjects factor. No significant effects were found for gender, $F(1, 12) = 1.32$, $p > .05$, condition, $F(2, 24) = .11$, $p > .05$ (see Figure 4), or the Gender X Condition interaction, $F(2, 24) = 1.93$, $p > .05$.

Similarly, a 2(Gender) X 3(Condition) ANOVA was conducted to test for the effects of gender and condition on number of pairs of target actions produced in the correct order. Again, no significant effects were found for gender, $F(1, 12) = .58$, $p > .05$, condition, $F(2, 24) = .39$, $p > .05$ (see Figure 4), or the interaction, $F(2, 24) = .53$, $p > .05$.

The analyses indicated that 20-month-old children performed equally well in all conditions (see Figure 4). Therefore, the hypothesis that 20-month-olds would perform better, in terms of more target actions and pairs produced, on the 3-sequence/3-step condition than on either the 3-sequence/3-step/delay or the 3-sequence/3-step/distraction conditions was not supported. The results demonstrated that 20-month-old infants displayed temporal integration ability in spite of added storage and processing demands required by the present tasks.

As in the first experiment, two 2(Gender) X 2(Condition: 3-step/control, 3-sequence/3-step) ANOVAs were conducted in order to compare performance on the 3-step control sequence with performance in the 3-sequence/3-step condition. Significant effects for condition were found with higher performances in the control condition than in the 3-sequence/3-step condition as measured both by components, $\underline{F}(1, 12) = 21.54$, $\underline{p} = .001$, and by pairs, $\underline{F}(1, 12) = 19.93$, $\underline{p} = .001$ (see Figure 5). No other effects were significant in these analyses.

Thus, as predicted, the temporal integration task resulted in lower performance than in the control condition, presumably due to the added processing demands required in the temporal integration task.

As in Experiment 1, analyses against chance were performed for each condition in order to evaluate whether or not more pairs of target actions were produced in the correct order than would be expected by chance. Again, all t-tests were significant (see Table 4), indicating that the target actions that were performed were in the correct order.

General Discussion

The present research was aimed at assessing temporal integration in 17- and 20-month-old infants. Specifically, a modified elicited imitation task was used to provide a measure of working memory, taking into account both the storage and processing functions of working memory. The purpose of Experiment 1 was to examine further temporal integration ability in 17-month-olds by simplifying the methods used previously by de Haan and Bauer (1997). Experiment 2 employed more difficult versions of the tasks used previously in order to assess the robustness of temporal integration ability in 20-month-old infants.

The hypotheses of Experiment 1, that 17-month-olds would produce more target actions and pairs of target actions in the correct order in the 3-sequence/2-step condition and in the 1-sequence/3-step/delay condition than in the 3-sequence/3-step condition and that performance would be better in the control conditions (control/2-step and control/3-step) than in the temporal integration conditions (3-sequence/2-step and 3-sequence/3-step respectively), were not supported by the data. No differences were found in performance for any of the conditions presented to 17-month-old infants in Experiment 1.

In light of the similar levels of performance displayed by 17-month-olds in the three conditions presented in Experiment 1, it can be concluded that the fewer storage and processing strains on working memory involved in the two "simpler" conditions (3-sequence/2-step and 1-sequence/3-step/delay) did not lead to higher levels of performance than did the 3-sequence/3-step condition as was hypothesized. In addition, the lack of performance differences between the temporal integration conditions and their respective control conditions suggests that the additional processing and storage demands involved in the temporal integration conditions did not hinder performance in 17-month-olds.

The best possible arguments that can be made based on the present data, under the assumption that the intended manipulations were indeed successful, are as follows in next few paragraphs. The fact that additional processing demands did not lead to lower performance in 17-month-olds disputes the trade-off theory of working memory development argued by Case et al. (1982) which posits that there is a complete trade-off between processing and storage space within a limited capacity system. Specifically, as processing demands were added to the present task, storage did not suffer, as would be predicted by the theory of Case et al. The present findings also do not lend direct support to Baddeley's (Baddeley & Hitch 1974; Baddeley 1981) model as discussed in the introduction. Specifically, additional processing demands did not lead to a decrement in storage in 17-month-olds in the present research. However, because Baddeley's model involves distinct components within the working memory system, a likely explanation for the present findings is that the performance of the 17-month-olds is at a level too low to cause competition for resources between processing and storage demands. In other words, the 17-month-olds are apparently incapable of storing enough information to fill up the slave system and make use of additional storage resources from the central executive.

The evidence indicates that the conditions presented to 17-month-olds in Experiment 1 are not measuring the processing functions of working memory at all. First, the finding that performance did not improve in the 1-sequence/3-step/delay condition as compared to the 3-sequence/3-step condition suggests that it is the time delay between presentation of steps that causes difficulty for 17-month-olds, not the interference caused by presentation of intervening steps from other sequences. This finding supports a conclusion made by de Jonge and de Jong (1996) that "the additional processing requirements in complex span tests lead only to longer intervals between the material...that has to be remembered." (p. 1017). However, the present conclusion must be taken cautiously. Another possible explanation concerning the lack of difference between performance in the 1-sequence/3-step/delay condition and the 3-sequence/3-step condition is that the processing manipulation was not strong enough. That is, it is possible that the processing requirements in the 1-sequence/3-step/delay were not significantly decreased from those of the 3-sequence/3-step condition. Although cautious, it is likely that the more monotonous and repetitive filler tasks did require less processing than the highly novel presentation of intervening steps from other event sequences.

A second source of evidence indicating that the present methodology did not measure the processing aspect of working memory in 17-month-olds is the lack of higher performance on the control conditions as compared to the temporal integration conditions. The additional processing requirements involved in the temporal integration conditions did not lower performance in 17-month-olds. These findings suggest that performance on the temporal integration tasks used in the present research appear to be analogous to the performance of the 10-12-year-olds on the complex span tests used by de Jonge and de Jong (1996). That is, the temporal integration tasks seem only to reflect the storage aspect of working memory in 17-month-olds, rather than the simultaneous measurement of both storage and processing functions. The present results lead to the same conclusion that de Jonge and de Jong made, that the development of working memory seems to be caused by a general increase in capacity (total processing space) rather than by increased processing efficiency. These results are analogous to Swanson's

(1996) finding that tasks involving high storage demands are the most predictive of age-related differences in working memory capacity. That is, it seems that 17-month-olds are simply unable to store as much information as 20-month-olds, suggesting a general capacity increase in working memory between these ages. The lack of differences between the control and temporal integration conditions, taken together with the lack of differences between the 1sequence/3-step/delay condition and the 3-sequence/3-step condition, provide evidence that the most likely conclusion concerning the present methodology is that it did not measure processing in 17-month-olds.

The first hypothesis of Experiment 2, that 20-month-olds would produce fewer target actions and pairs of target actions in the correct order in the 3-sequence/3-step/delay and the 3-sequence/3-step/distraction conditions than in the 3-sequence/3-step condition, was not supported by the data. The second hypothesis, that the temporal integration task would result in lower performance than the control task, was supported as indicated by a higher level of performance, as measured by target actions and pairs, in the control condition (3-step/control) than in the 3-sequence/3-step condition.

Given that the additional storage and processing demands involved in the 3-sequence/3-step/delay and the 3-sequence/3-step/distraction conditions did not lower performance of 20-month-olds as compared to the 3-sequence/3-step condition, it can be concluded that temporal integration ability in 20-month-olds is more robust than demonstrated previously in de Haan and Bauer (1997), to the extent that the present manipulations were successful. That is, despite additional storage (longer intervals in the delay condition) or processing (draining of attentional resources in distraction condition) requirements, 20-month-olds were still performing at the high levels displayed in the de Haan and Bauer research. Because additional storage and processing demands did not lower temporal integration performance in 20-month-olds, Case et al.'s (1982) trade-off theory of working memory can again be ruled out as a model to fit the present data. However, processing demands did play a key role in the performance of the 20-month-olds in Experiment 2, as indicated by the comparison of the temporal integration task to the control task. As predicted, 20-month-olds demonstrated higher levels of performance in the 3-step/control condition than in the 3-sequence/3-step condition. Thus, it is possible that the additional processing requirements involved in the temporal integration task led to decrements in storage as compared to the control task.

Another possible explanation for higher levels of performance in the 3-step/control condition than in the 3-sequence/3-step condition is that in the 3-sequence/3-step condition children had already experienced some forgetting before recall could be tested. That is, a much longer delay occurred between demonstration of the steps in the 3-sequence/3-step condition and recall testing than between demonstration and testing of the steps involved in the 3-step/control condition, thus providing ample time for forgetting to occur. This explanation seems likely given research performed by Bauer, Dunisch, and de Haan (1998) which found that 20-month-old children perform better on an immediate recall task (the same as the 3-step/control task presented here) than on a delayed presentation task involving a 3-step sequence presented with a 10-second delay preceding and following each step. It is unclear at this point how much of the differences between the control task and the temporal integration tasks in the present experiment were due to added processing requirements and how much were due to added delay time. It would be beneficial to test 20-month-olds on the 1-sequence/3-step/delay condition used in Experiment 1 to try to tease out the effects of added processing and added delay. If it turns out that the delay is indeed the greatest factor in lowering performance, further evaluation will be required to better understand the ways in which working memory and long-term memory mediate performance in 20-month-olds.

Together, the findings of Experiment 2 suggest that the working memory systems of 20-month-olds are made up of at least partially distinct components, as suggested by Baddeley and Hitch's model (Baddeley 1981; Baddeley & Hitch 1974). Performance was highest on the control/3-step condition, which measured only storage capacity, presumably because extra resources from the central executive were available to be used for storage of information. But when additional processing requirements were introduced with the temporal integration task (3-sequence/3-step), performance declined presumably because at least some of the resources of the central executive were necessary for the processing of information and were therefore not available for storage, as they were in the control task. Additional processing requirements involved in the other temporal integration tasks (3-sequence/3-step/delay, and 3-sequence/3-step/distraction) seemingly did not affect storage capacity, suggesting that the storage took place only in the slave systems (again, this conclusion must be taken cautiously as it assumes that the manipulations were successful). In other words, the resources of the central executive were utilized for processing, rather than storage. Presumably, more efficient processing would allow more resources to be allotted to storage. Future research should use the present temporal integration tasks with progressively older children in order to assess this question. In addition, attempts should be made to increase the differences among the three temporal integration conditions in order to rule out the possibility that the manipulations that were implemented in Experiment 2 (3-sequence/3-step/delay and 3-sequence/3-step/distraction) were simply not strong enough to lead to significant differences in performance.

Another possible line of research would be to investigate whether children performing the present task store the information verbally (in the articulatory loop), visually (in the visuo-spatial scratch pad), or in both slave systems. Previous research has demonstrated a greater dependence on visual working memory than on verbal working memory in young children (Hitch, Halliday, Schaafstal, & Schraagen 1988). Such research would aid in better understanding the development of the working memory system.

It seems that while the traditional elicited imitation task (control/3-step) assesses the storage aspect of working memory, the present research provides tentative evidence that the temporal integration tasks assess both the storage and processing functions of working memory, analogous to the complex span tasks used in previous working memory research (Daneman & Carpenter 1980; Masson & Miller 1983; de Jonge & de Jong 1996; Shah & Miyake 1996). Thus, the temporal integration tasks may be used to provide a more complete measure of working memory capacity (at least in 20-month-olds) than have previous working memory tasks such as the delayed nonmatch-to-sample task (Overman et al. 1992).

In conclusion, the present research indicated that a modified form of elicited imitation, the temporal integration tasks, might be used as a measure of working memory in 20-month-olds, accessing both the storage and processing aspects of working memory. The temporal integration tasks appear to be analogous to complex span tests which have been used to test working memory in adults, and which have been demonstrated to correlate highly with reading comprehension (Daneman & Carpenter 1980). Future research should study possible correlations between performance on the temporal integration tasks at 20 months of age and future reading ability. In addition, attempts should be made to devise a method with which to study the relationship between storage and processing in the working memory systems of 17-month-olds and even younger children. Such a method may possibly be obtained by varying the processing and storage demands of the present temporal integration tasks (i.e. varying the number of different sequences presented and the amount of filled and unfilled time between steps of the sequences).

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Appendix

Here are provided descriptions of all of the 3-step and 2-step sequences used in the present experiments. The materials involved in each sequence are in parentheses, followed by descriptions of the required steps for each sequence.

3-step sequences:

1. Frog. - (a wooden triangle base, a long, flat piece of wood to use as platform, and a plastic frog) The required steps were: placing the platform on the base, placing the frog on the platform, and hitting the platform causing the frog to jump.
2. Tools. - (a wooden base with sides that raise, wooden top with holes holding wooden nail, hammer) The required steps were: opening the sides of the base, placing the top on, and hammering the nail.
3. Strawberries. - (a plastic box with top, plastic strawberries, and a plastic spoon) The required steps were: removing the top from the box, putting the strawberries into the box, and stirring the strawberries with the spoon.
4. Rattle. - (a plastic base with handle, wooden block, and a cup which Velcros onto the base when inverted) The required steps were: placing the block onto the base, covering the block with the cup, and shaking the rattle.
5. Merry-go-round. - (a wooden stand, wooden circle which opens and closes, and wooden horses hanging from the circle) The required steps were: closing the circle, placing it on the base, and spinning it.
6. Car. - (a plastic base, folding ramp, wooden car) The required steps were: unfolding ramp, placing ramp on base, and making the car go down the ramp.

7. Doll. - (a plastic stand with long pole with Velcro on top, cover for pole, dancing doll) The required steps were: taking off cover, Velcroing doll to top of pole, and pulling the string to make it dance.

8. Spaghetti. - (a ball of play-doh, plastic play-doh spaghetti maker, plastic knife) The required steps were: putting play-doh in spaghetti maker, pressing down to make playdoh come out spaghetti holes in maker, cutting spaghetti with knife.

9. Gong. - (a base with two sides holding moveable horizontal bar, metal square, and hammer) The required steps were: putting bar into place, hanging metal square from bar, and ringing the metal with the hammer.

10. Dump Truck. - (a toy dump truck with cover Velcroed on and plastic blocks) The required steps were: removing the cover, putting the blocks into the dump truck, and dumping them out.

2-step sequences:

1. Doll. - (a plastic stand with long pole with Velcro on top, dancing doll) The required steps were: Velcroing doll to top of pole, and pulling string to make it dance.

2. Car. - (a plastic base, plastic ramp, matchbox car) The required steps were: placing ramp on base, and making the car go down the ramp.

3. Gong. - (a base with two sides holding a horizontal bar, metal square, and hammer) The required steps were: hanging the metal square from the bar, and ringing the metal with the hammer.

4. Dump Truck. - (a toy dump truck and plastic blocks) The required steps were: putting the blocks into the dump truck and dumping them out.

Table 1.

Mean Number of Target Actions (Components) and Target Pairs Produced in the Correct Order in Experiment 1.

	Raw Scores		Proportions	
Condition	M	SD	M	SD
3-sequence/3-step				
Components	2.24	.48	.75	.16
Pairs	1.05	.39	.52	.19
3-sequence/2-step				
Components	1.45	.36	.73	.18
Pairs	.52	.25	.52	.25
1-sequence/3-step/delay				
Components	2.00	.88	.66	.29
Pairs	.79	.80	.39	.40
Control/2-step				
Components	1.57	.65	.79	.32
Pairs	.64	.50	.64	.50
Control/3-step				
Components	2.00	1.04	.66	.35
Pairs	1.07	.92	.53	.46

Note. Maximum raw scores for 3-step sequences: Components = 3.0, pairs = 2.0.

Maximum raw scores for 2-step sequences: Components = 2.0, pairs = 1.0.

Table 2.

Analyses Against Chance for Number of Pairs of Target Actions in the Correct Order in Experiment 1.

Condition	total pairs	correct pairs	t-test
3-sequence/3-step	54	44	2.68**
3-sequence/2-step	23	22	3.95***
1-sequence/3-step/delay	14	11	1.93*
Control/2-step	9	9	18.18****
Control/3-step	15	15	2.97**

*p < .05. **p < .01. ***p < .005. ****p < .0005.

Table 3.

Mean Number of Target Actions (Components) and Target Pairs Produced in the Correct Order in Experiment 2.

	Raw Scores		Proportions	
Condition	M	SD	M	SD
3-sequence/3-step				
Components	1.91	.58	.64	.19
Pairs	.88	.50	.44	.25
3-sequence/3-step/delay				
Components	2.00	.45	.67	.15
Pairs	.88	.48	.44	.24
3-sequence/3-step/distraction				
Components	1.93	.73	.64	.24
Pairs	1.02	.50	.51	.25
Control/3-step				
Components	2.86	.36	.95	.12
Pairs	1.71	.47	.86	.24

Note. Maximum: Components = 30, pairs = 2.0.

Table 4.

Analyses Against Chance for Number of Pairs of Target Actions in the Correct Order in Experiment 2.

Condition	total pairs	correct pairs	t-test
3-sequence/3-step	42	36	2.82**
3-sequence/3-step/delay	43	35	2.46*
3-sequence/3-step/distraction	45	42	3.23***
Control/3-step	26	24	3.25***

*p < .025. **p < .01. ***p < .005.

Figure Captions

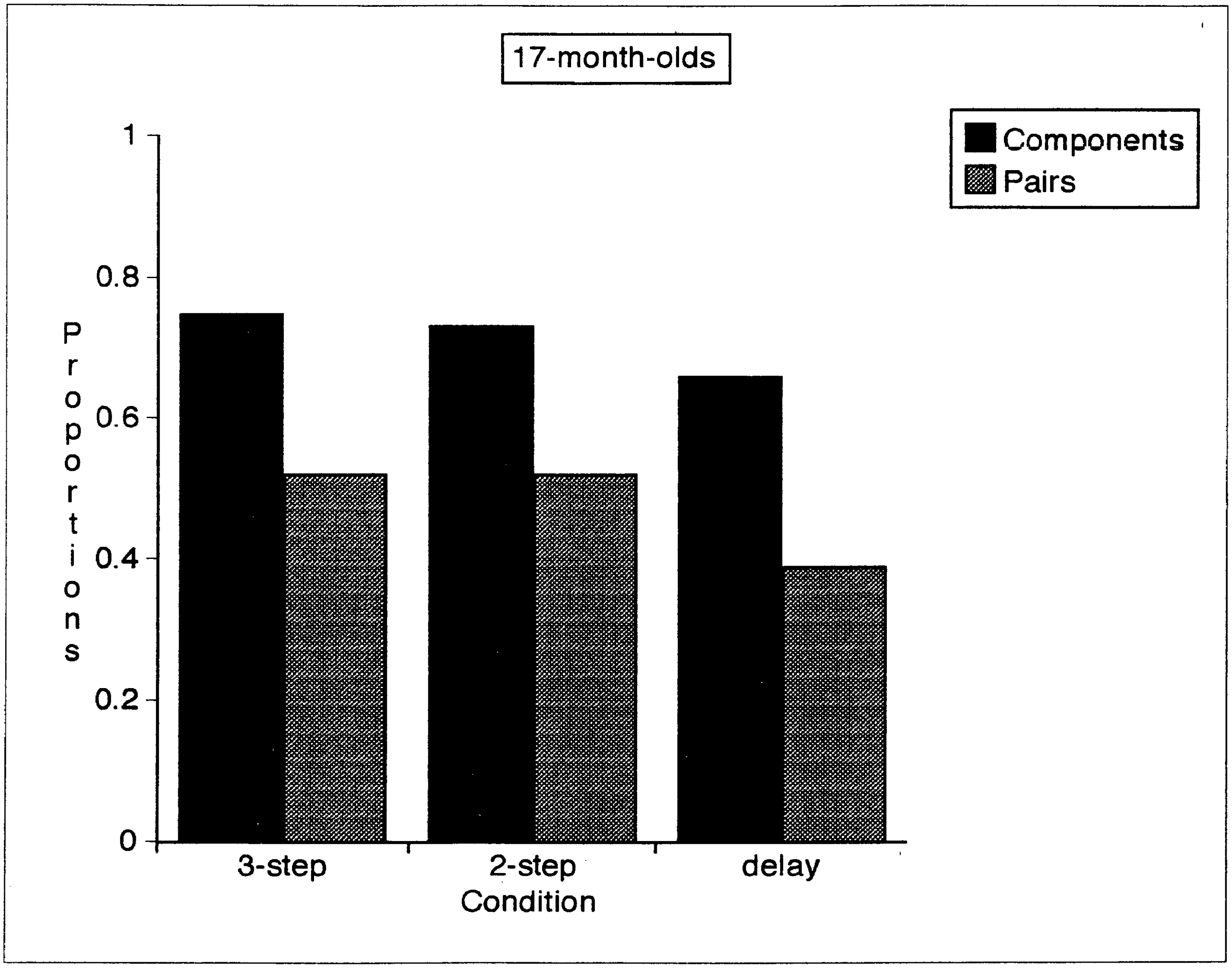
Figure 1. Proportions of possible target actions (components) and pairs of target actions in the correct order performed by 17-month-olds in Experiment 1, by condition.

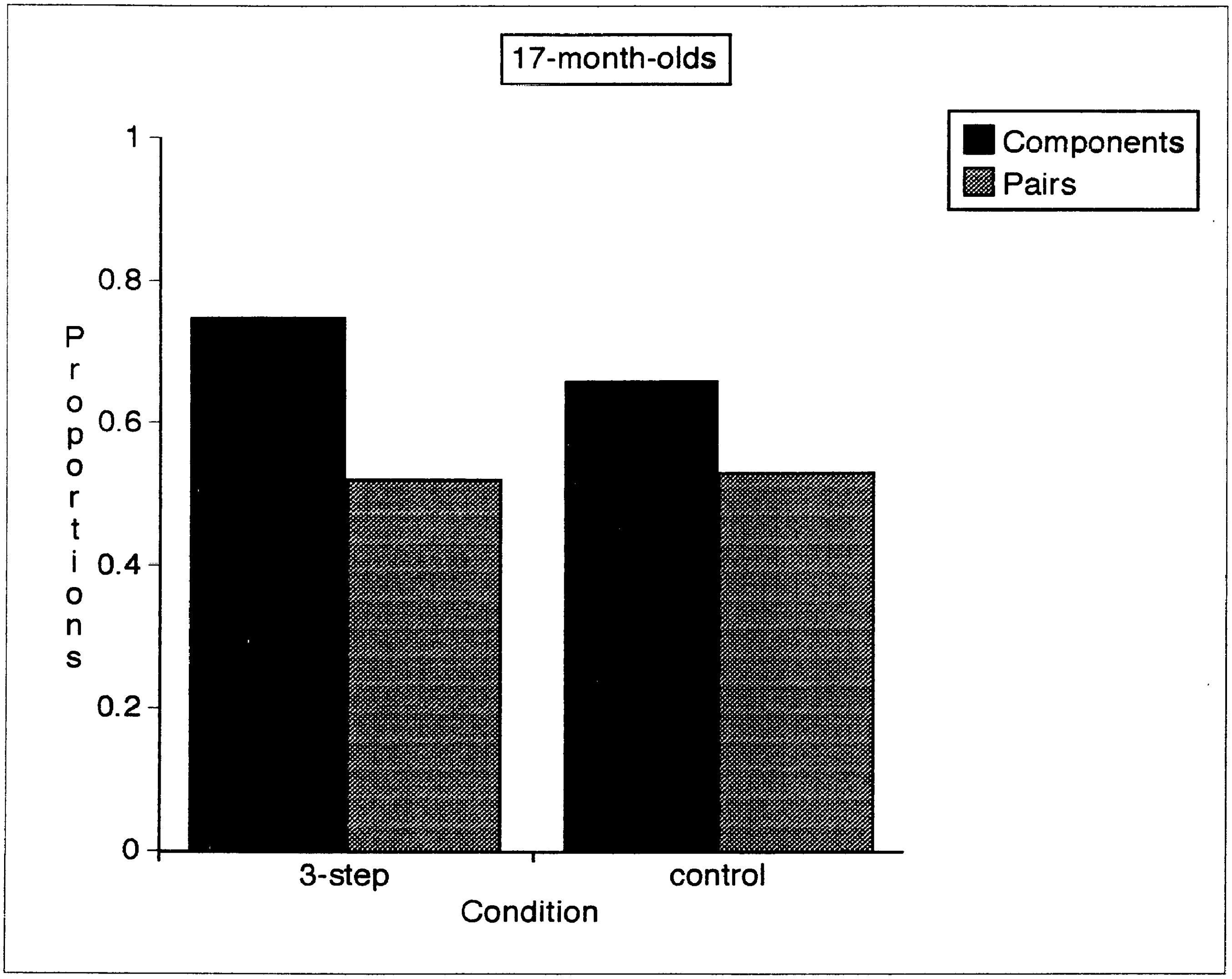
Figure 2. Proportions of possible target actions and pairs of target actions in the correct order performed by 17-month-olds in the 3-sequence/3-step and control/3-step conditions in Experiment 1.

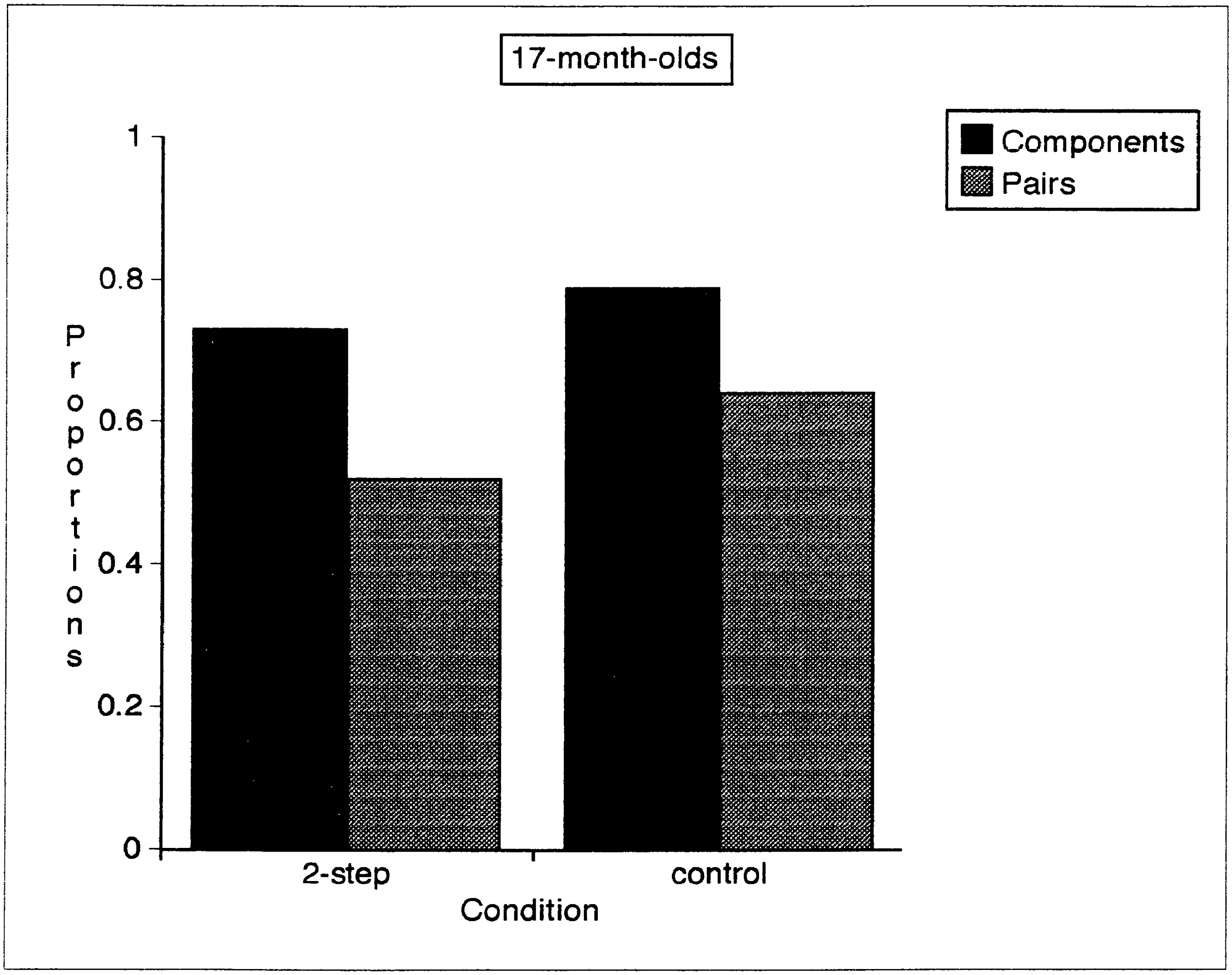
Figure 3. Proportions of possible target actions and pairs of target actions in the correct order performed b y 17-month-olds in the 3-sequence/2-step and control/2-step conditions in Experiment 1.

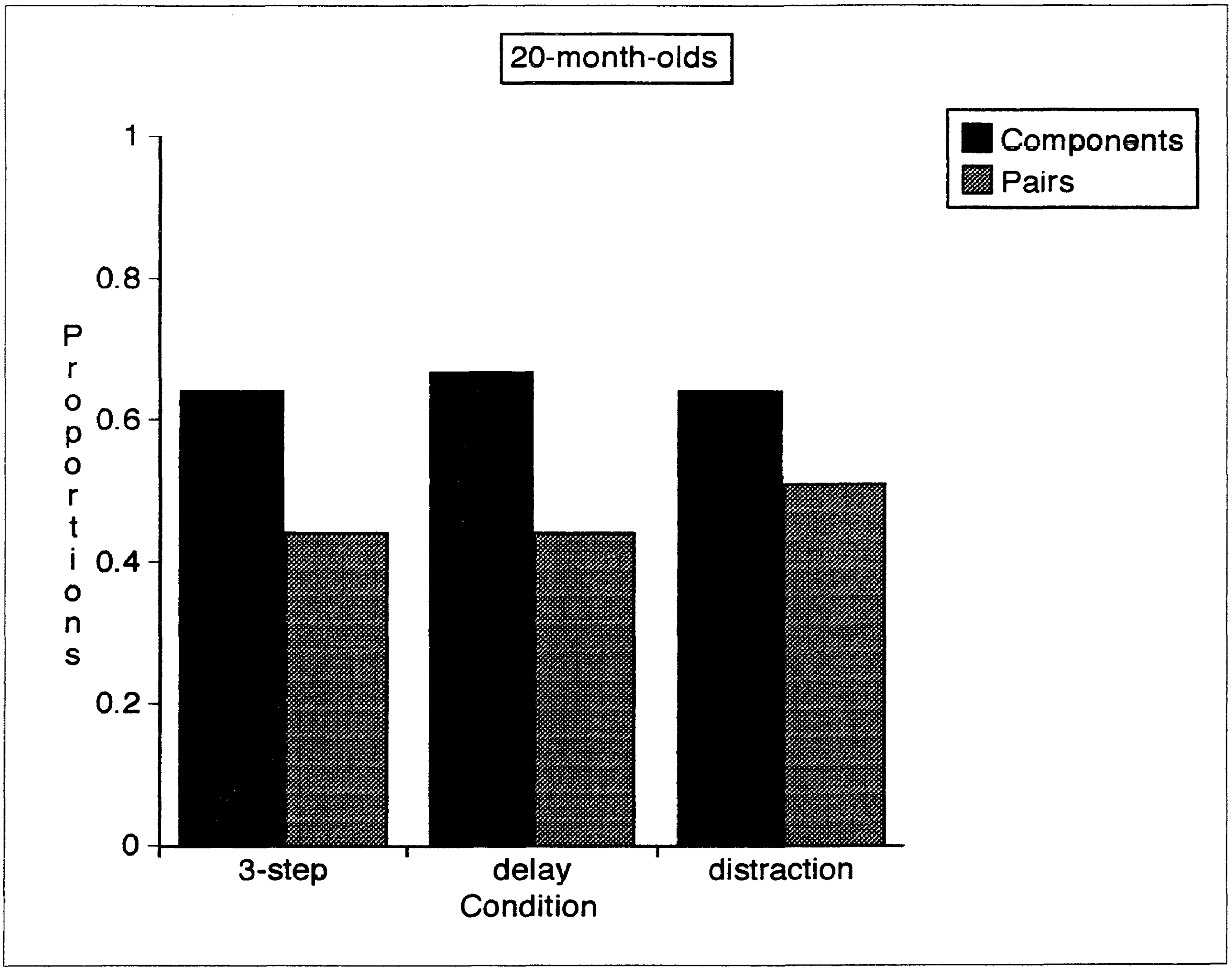
Figure 4. Number of target actions (components) and pairs of target actions in the correct order performed by 20-month-olds in Experiment 2, by condition.

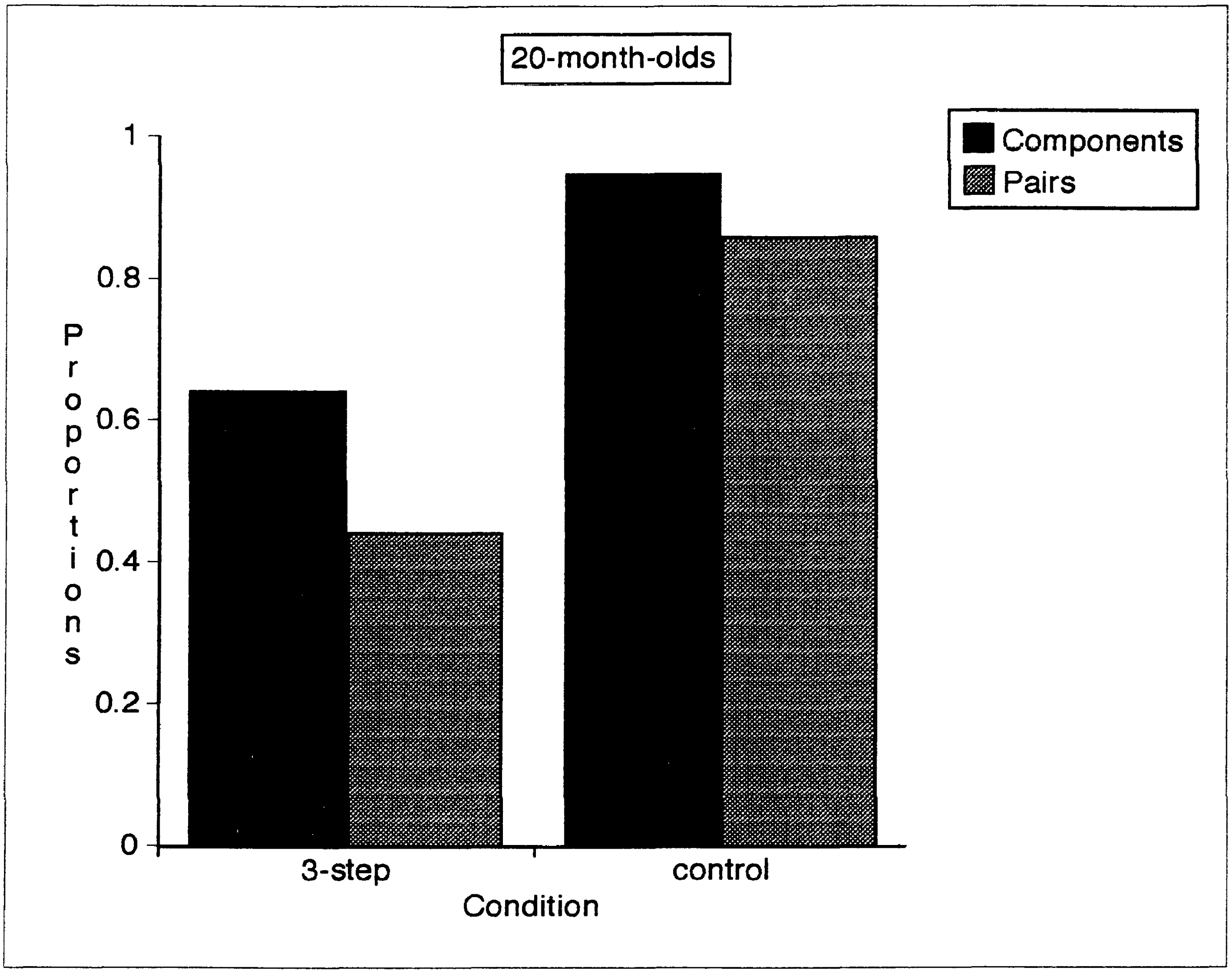
Figure 5. Number of target actions and pairs of target actions in the correct order performed by 20-month-olds in the 3-sequence/3-step and control/3-step conditions in Experiment 2.


17-month-olds
Components
Pairs
Proportions
1
0.8
0.6
0.4
0.2
0
3-step
2-step
delay
Condition


17-month-olds
Components
Pairs
Proportions
1
0.8
0.6
0.4
0.2
0
3-step
control
Condition


17-month-olds
Components
Pairs
1
0.8
0.6
0.4
0.2
0
Proportions
2-step
control
Condition


20-month-olds
Components
Pairs
1
0.8
0.6
0.4
0.2
0
Proportions
3-step
delay
distraction
Condition



20-month-olds
Components
Pairs
Proportions
1
0.8
0.6
0.4
0.2
0
3-step
control
Condition