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# Short-term memory for movement in photographs: A developmental study

Futterweit, Lorelle Ruth, Ph.D.

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300 N. Zeeb Rd.
Ann Arbor, MI 48106

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# SHORT-TERM MEMORY FOR MOVEMENT IN PHOTOGRAPHS: A DEVELOPMENTAL STUDY

by

LORELLE R. FUTTERWEIT

A dissertation submitted to the Graduate Faculty in Psychology in partial fulfillment of the requirements for the degree of Doctor of Philosophy, The City University of New York.

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Date

Chair of Examining Committee

April 26, 1990
Date

Herbert D. Saltzstein
Executive Officer

Sylvia Scribner

Dalen Muller Jr.

Supervisory Committee

The City University of New York

Abstract

SHORT-TERM MEMORY FOR MOVEMENT IN PHOTOGRAPHS:

A DEVELOPMENTAL STUDY

by

Lorelle R. Futterweit

Adviser: Professor Harry Beilin

A series of studies investigated a proposed picture-memory phenomenon reported by Freyd (1983), later termed "representational momentum" (Freyd & Finke, 1984), in which adults' short-term memory for movement in photographs is distorted slightly forward in the direction of the implied motion. In the present studies, a reaction time paradigm was used to determine whether children exhibit the same memory errors and whether there are developmental differences in short-term memory for movement in photographs. In Experiment 1, third grade, fifth grade, and graduate students were presented with a photograph of an action scene and asked to remember it. Subjects were then shown a second photograph that was either the "same as" or "different from" the first. Of the "different" photographs, half were photographs of the same scene but taken slightly later in time ("forward" order), while the other half were photographs taken slightly earlier in time ("backward" order). In addition to age, the present experiments assessed the effect of different directions of motion, interstimulus intervals, and pictorial movement cues on recognition memory. Repeated Measures ANOVAS were used to

analyze the reaction time and error rate data. Subjects took significantly longer to correctly determine that a second photograph was different from the first when photograph pairs were presented in "backward", rather than "forward", order, contrary to Freyd's (1983) finding. In Experiment 2, however, the picture-memory phenomenon was replicated when using a range of real-world time separations between photograph pairs. That is, subjects made the greatest number of errors on those photograph pairs separated by only one frame "forward", indicating that memory for the action in the first photograph was distorted in the direction of the implied movement. No forward memory errors occurred when "still" photographs were used in Experiment 3. Thus, the picture-memory phenomenon is specific to photographs that depict movement. The results are discussed in terms of their implications for the representational momentum hypothesis and theories of photographic comprehension.

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# INTRODUCTION

Research in developmental psychology often uses pictures (line drawings, photographs) as stimuli (e.g., DeLoache, 1987; Massey & Gelman, 1988). Assessment procedures do the same (Bayley Scales of Infant Development; Bayley, 1969). Yet, comprehensive developmental theories of pictorial representation, and in particular photographic representation, are rare. Scattered experiments in the developmental literature have documented that the ability to recognize objects in pictures develops early (Daehler, Perlmutter & Meyers, 1976) and that experience with pictures is not necessary (Hochberg & Brooks, 1962). Habituation studies with infants have shown that they can perceive the similarity between a face and a photograph of a face (Dirks & Gibson, 1977), and that they can recognize their mother's face in a photograph (Barrera & Maurer, 1981). Research with older children, however, has shown that there are developmental changes in the comprehension of photographs (Beilin, 1983). Thus, although it is evident that even very young children can recognize objects in pictures, the ability to comprehend the unique properties of photographs, their meaning, and their relation to reality, as well as the ability to comprehend more complex information in photographs, such as the representation of motion, develops over time and depends on both cognitive factors and experience with photographs (Beilin, 1983, 1988).

The present studies were designed to expand upon previous work on children's comprehension of motion in photographs (e.g., Futterweit & Beilin, 1987) by incorporating a task developed in the adult mental representation literature. In particular, the present experiments attempted not only to replicate and extend a picture-memory phenomenon reported by Freyd (1983), later termed "representational momentum" (Freyd & Finke, 1984), but also examined potential developmental differences in short- term memory for movement in photographs. Thus, the present studies were concerned specifically with how knowledge of photographic representations is acquired. They also addressed the current debate over whether information in photographs is directly perceived or whether the comprehension of photographic content entails cognitive factors.

The next section presents a general theoretical overview of pictorial representation, highlighting basic approaches as well as controversies in the field. The section after that discusses picture-memory research. The third section examines theories of photographic representation, outlining how they are both similar to and distinct from theories of pictorial representation. The last section focuses on the perception of motion in pictures, and the theoretical and empirical background of the approach adopted in the present studies.

## Theories of Pictorial Perception and Representation

Pictures are unique in that while they are objects in their own right (different from the objects and scenes they represent), they simultaneously (and more or less faithfully) represent those objects and events in the world. Further, pictures are often experienced as though they were the real world. This "paradox" has made the perception of pictures an important area of investigation for several reasons. To begin with, researchers have debated how objects and events are perceived and recognized in pictures, and whether picture perception is the same as or different from the perception of the real world. Second, psychologists, philosophers, and art historians have attempted to understand the relationship between pictures and the world they represent. Third, although theories of pictorial perception have been informed by theories of perception, at the same time, picture perception studies have had implications for general theories of perception. Fourth, given the remarkable ability adults have to remember thousands of pictures, although each is seen for only a few seconds (Shepard, 1967; Standing, 1973), pictorial representation is significant for theories of cognition and memory. Finally, since some imagery researchers (e.g., Kosslyn, 1980) claim that mental images are "like pictures in their mode of representation (and also in the way they're used or processed)" (Block, 1981, p. 3), the study of pictorial representation may lead to a greater understanding

of the nature of mental representation and imagery.

## Theories of Pictorial Representation

Analogous to the psychological literature on perception, there are two major, though antithetical, theories of pictorial perception: direct perception and cognitive theories. The major issue debated is whether pictures are perceived directly or whether the perception and comprehension of pictures entails cognitive processing. The direct perception tradition is represented by Gibson (1971), who initially argued that picture perception is the same as the perception of the 3-dimensional real world; namely the direct pick-up of informational invariants. "A picture is a surface so treated that a delineated optic array to a point of observation is made available that contains the same kind of information that is found in the ambient optic arrays of an ordinary environment" (1971, p. 31). Since a picture and the optic array provide viewers with the same information, when one views a picture, the information in the picture is perceived, picked up, and experienced "as if" one were perceiving the information in the world - that is, directly. Gibson, however, distinguished between the surface of objects and the surface of pictures. Although both surfaces are perceived directly, the essential property of picture surfaces is that they contain two kinds of information: information that specifies the picture as an object, and also information that specifies the object pictured. Since viewers are able to

perceive and distinguish between the two kinds of information (and even shift attention from one to the other) when looking at a picture, an image of an object is never mistaken for the object itself.

Since this theory was unable to account for all aspects of picture perception, Gibson (1980) later modified his view on the nature of pictorial perception and proposed that object surfaces and picture surfaces are not perceived in the same manner. In particular, while object surfaces are directly perceived, marks on representational objects were no longer believed to be perceived directly. Marks on representational objects have referential meanings, whereas marks on object surfaces do not. Thus, Gibson allowed a role for conventions and even learning in pictorial perception.

In accord with Gibson's position, research with infants (e.g., Dirks & Gibson, 1977), children (Hochberg & Brooks, 1962), people from cultures untrained in depiction (Kennedy, 1974), and even some animals (Cabe, 1980) provides evidence that there may be an innate, biologically given ability to perceive and <u>recognize</u> objects in pictures, and that past experience with pictures, or learning, may only be minimally required for picture perception and recognition.

Cognitive theorists, on the other hand, reject Gibson's notion that there is informational equivalence between pictures and the 3-dimensional world they represent. These theorists emphasize instead that pictures are more than

simply informational sources; pictures are artistic, representational objects. Since artists may utilize (relatively arbitrary, culturally determined) conventions of representation that render pictures ambiguous or unrealistic, the viewer must use past experience, world knowledge, or expectation (in addition to purely perceptual processes) in order to interpret and comprehend the meaning and communicative intent of a picture (Gombrich, 1969; Hochberg, 1972; Goodman, 1968).

Thus, cognitive theories emphasize the nature of the observer rather than the nature of the stimulus (as in direct perception theories). For example, Hochberg (1972) maintains that the perception and comprehension of both pictures and the world is constructed from the process of integrating information provided by directed, saccadic eye movements. This process results in schemas, which are useful in "deciding where to glance next, in putting together the successive fragments of information, and in terminating the elective perceptual inquiry..." (Hochberg, 1983, p. 17). Further, "we can fit schemas we have learned from the world to the patterns that are presented to the eye by the pictures themselves" (p. 17). Thus, "If the ability to perceive pictures is learned at all, it is learned simply by commerce with the world..." (p. 16).

The philosopher Nelson Goodman (1968) and the art historian Gombrich (1969) propose that pictorial representation is symbolic in nature. Rejecting resemblance

between picture and object as a basis for representation, Goodman argues instead that pictures represent objects or events because they are symbols for them. "The plain fact is that a picture, to represent an object, must be a symbol for it, stand for it, refer to it; and that no degree of resemblance is sufficient to establish the requisite relationship of reference" (1968, p. 5). Thus, pictures do not depict reality directly but indirectly through symbols. In order to "read" a picture a viewer must understand the nature of the symbolic code (which is learned through experience with pictures). Gombrich (1969) wrote of the "beholder's share" as an important contributing factor to picture comprehension and interpretation. Thus, expectation and past experience play a large role in understanding pictures. Acknowledging, however, the ease of recognition in picture perception, and in response to criticisms of subjectivity, Gombrich (1982) later modified his own views and now believes that pictorial codes are not wholly arbitrary or conventional, and that pictorial comprehension depends, at least in part, on innate properties of the visual system and the nature of perception. Therefore, only a minimum of learning is required for comprehension.

A few investigators propose that the development of pictorial comprehension occurs concurrently with cognitive development. Based on Piaget's theory, Sigel (1978) theorizes that the development of conservation enables children to conserve the meaning of objects in the face of

physical transformations that occur when objects are depicted in pictures. Incorporating the views of Piaget and Goodman, Gardner (1982) also proposes that children's production and comprehension of pictures, as well as other conventional symbols systems, is related to their cognitive development. Developmental theories, therefore, focus on the understanding of meaning implicit in pictures and its relationship to cognitive changes in the child.

More recently, theorists influenced by information processing theories have demonstrated that, contrary to direct perception theories, the ability to perceive and comprehend pictures consists of a sequence of complex perceptual and cognitive processes. Loftus (Loftus et al., 1988), for example, has proposed that there are a series of encoding processes that result in a picture's memory representation: "those that operate on perceptual information that is available while the picture is physically present, (those that operate on) perceptual information that is available during the presence of the icon that follows the picture's offset, and (those that operate on) information constituting some nonvisual, short-term representation of the picture that is constructed shortly after stimulus onset that can continue after the icon's termination. (The) processes that operate on the first two kinds of information (are) perceptual processes and (the) processes that operate on the third kind of information (are) conceptual processes" (p. 237). Potter

(1976) and Intraub (1980) have also proposed models of the early stages of picture processing. Their evidence (based on tachistoscopic presentation of pictures) suggests that a picture is rapidly understood and identified in approximately 100 msec. Once identified, the picture is held for a few hundred milliseconds in a short-term "conceptual buffer" or store. This representation, however, is unstable and requires additional processing. If a new picture is presented at this point, the memory for the first picture may be lost. This phenomenon has been referred to as "conceptual masking" and is thought to occur because the new picture disrupts processing of the previous picture (Potter, 1976). These studies demonstrate not only that successive eye fixations allow expectations to build up that serve to guide and facilitate perception (consistent with Hochberg, 1983) but also that information from scenes is encoded and understood even when exposure time allows for only one fixation or less.

The information processing-influenced theorists, while contributing to the picture perception literature, have been more interested in developing a model of the early stages of scene perception than in developing a theory of pictorial representation per se. Pictures or photographs are often used as substitutes for real world scenes (while their special properties are ignored) in an attempt to understand how information is picked up from eye fixations on real scenes. Tachistoscopic presentation is used, because it

mimics single fixations upon the world and simulates input from successive fixations. The information processing approach to picture perception has also generally neglected to study children, under the assumption that there are few developmental changes in these processes.

In sum, although the ability to perceive and comprehend pictures is a seemingly effortless activity, cognitive theorists argue that it consists of a complex combination of processes that occur over time. Integrating the available evidence, Beilin (1988) concludes that, "the perception of pictures is assumed to require the same processes as needed to perceive the real (physical) world. These processes are of two kinds: one involves the direct registration of pictorial information by the visual system; the second entails the integration and organization of information obtained in the visual (saccadic) scanning of pictorial detail. The result of both processes is the constitution of perceptual schemes that persist in memory and affect the later perception of pictures. Cognitive schemes also affect the perception and understanding of pictures. They are constructed developmentally as a function of commerce with the world and with pictures themselves. Cognitive pictorial schemes are subject to the same developmental processes that affect all cognitive acquisitions" (p. 2).

Picture Memory Research

The picture memory literature springs from two related findings: the remarkable ability that adults have to

remember pictures (Shepard, 1967; Standing, 1973) and the finding that pictures are remembered better than equivalent verbal stimuli such as words or sentences (Shepard, 1967). This later phenomenon, known as the "picture superiority effect", is thought to occur because of the greater amount of detailed information available in pictures as compared with verbal material (Bevan & Steger, 1971).

Recognition tests have been the most widely used measures for studying picture memory. Standing (1973), for example, found that adults recognized thousands of pictures in a recognition task, even though they had viewed each picture for only a few seconds 48 hours earlier. Standing hypothesized that the capacity for this kind of memory may be unlimited. However, it is now known that a variety of factors affect picture memory, including the nature of the distractor pictures used. Earlier studies, such as Standing's, typically used an "old-new" recognition task, whereby subjects are asked to discriminate previously seen (old) pictures from completely new distractor pictures. These tasks, therefore, test how well people can distinguish pictures they have seen before from those they have not. If, however, distractor pictures are used that are more similar to the old pictures, recognition memory is less accurate (Dallett, Wilcox & D'Andrea, 1968). Memory for pictures has also been found to increase with longer exposure durations (Potter, 1976; Tversky & Sherman, 1975) and with age (Dirks & Neisser, 1977; Hoffman & Dick, 1976).

A separate body of picture memory studies has been concerned with memory for specific pictorial information. In contrast to the "old-new" recognition paradigm, this research generally uses a "same-changed" recognition task, in which memory for a particular aspect or detail of a picture (rather than the entire picture) is tested by selecting distractors that are likely to mimic a possible memory error (for example, a deletion, addition, or distortion). Using this type of recognition task, researchers have recently found several interesting picture memory phenomena. Pezdek and Chen (1982), for example, found that when adult subjects were presented with simple and complex line drawings (in which the scenes were the same but the complex form contained extra details), and then tested with a same-changed recognition test (e.g., the "changed" pictures involved presenting previously viewed simple pictures as complex), recognition memory was significantly greater for pictures presented in the simple than complex form. Pezdek termed this the "asymmetric confusability effect" and recently replicated the phenomenon with 7 and 9-year old children (Pezdek, 1987). According to Pezdek, the effect occurs because subjects' memory for both simple and complex pictures is similar to the simple version of each picture. As a result, people can more easily recognize added than deleted details in pictures. Intraub and Richardson (1989) also reported a phenomenon in which there was a distortion in memory for picture boundaries. In

particular, adults remembered more information in photographs than was actually depicted (e.g., their memory included information that had not been present in the picture but that would have been likely to have existed just outside the picture's physical boundaries). These recent studies suggest that, contrary to the remarkable memory found for pictures using old-new recognition tests, memory for specific pictorial information is limited.

An attempt has been made by some researchers to specify how pictorial information is mentally represented. Pavio's (1971) dual-code theory has been amongst the most prominant explanations of picture memory effects. He proposes that pictures are encoded in two distinct formats: a sensory-spatial-analogue code and a semantic-thematic-abstract code. The visual details of a picture are stored at a sensory level, and the meaning of a picture is stored semantically. Paivio has been attacked by those who argue for a single, propositional form of representation (analagous to the imagery-propositional debate in cognitive psychology). The propositionalist camp claims that people do not remember exact visual details and their spatial relations, but rather a more abstract representation that captures the meaning of a picture (Pylyshyn, 1984). There have been, however, almost no picture memory studies undertaken to buttress their claim (with the exception of Anderson & Paulson, 1978). Further, as Anderson (1978) has argued, it is logically impossible to determine whether the form of mental

representation is analog or imaginal.

Although picture memory studies have become increasingly compatible with the information processing approach in theory and method, they have, to a greater extent, documented the importance and uniqueness of picture memory. In addition, there have been a number of developmental studies. Picture memory studies, however, often are concerned with broader issues than the nature of pictorial representation per se: they are also interested in explaining and understanding the encoding and storage of information about the visual environment.

Theories of Photographic Representation

Photographs are often presumed to capture and record reality more faithfully than other representational form. Yet, photographs, too, are different from the objects and events they represent (particularly black and white photographs). The questions that arise with regard to photographic representation are thus similar to those concerning pictorial representation (e.g., is the perception and comprehension of photographs the same as the real world). One additional question arises, however: what is the nature of the relationship between photographs and other forms of depiction (e.g., are photographs perceived and comprehended differently from drawings, paintings).

One argument that has been made historically is that photographs are more truthful copies of reality than other representational media. Barthes (1981) wrote that,

"Painting can feign reality without having seen it. Contrary to these imitations, in photography I can never deny that the thing has been there. There is a superimposition here: of reality and of the past. And since this constraint exists only for photography, we must consider it, by reduction, as the very essence, the noeme of photography" (p. 76). This "realist" view is also held, in part, by Arnheim (1974) who states that, "The photograph has an authenticity from which painting is barred" (p. 154). This approach implies that only the camera is involved in the construction of a photograph, and not the photographer. Viewing a photograph is considered the same as viewing the real world and no interpretive or cognitive processes are necessary (Gibson, 1971).

Others, however, have argued that photographs are neither objective nor accurate records of what exists in the world, but rather the products of both the camera and the intentions of the photographer (e.g., Gombrich, 1969, 1982). Gombrich states that a black and white photograph, in particular, is "not a replica of what is seen but a transformation which has to be re-translated to yield up the required information" (1982, p. 282). However, similar to his modifications with regard to pictorial representation, Gombrich adds that, "the fact that they are transformed does not entitle us to call them an arbitrary code" (p. 282). Arnheim (1974) also recognizes that "in order to make sense of photographs one must look at them as encounters between

physical reality and the creative mind of man" (p. 159). Thus, the "conventionalist" view appreciates the conventional elements of photography and the ability of the camera to distort reality. Viewers must understand these conventions (and the process by which photographs are made) in order to interpret the meaning of a photograph.

A more moderate position is taken by Beilin (1988) who concludes that, "Photographs have properties that are understood by resemblance to objects and scenes in the world, as in resemblance of form ... and so are understood as realistic on this basis alone. But they are also understood in a realist sense because of their causal relation to the objects depicted, by virtue of the manner in which they were made: that is, "they were there". But photographs also depict in ways that are not realistic, as any surreal photograph shows. Here the conventions of depiction must in some sense be known for the photograph to be understood" (p. 13).

A series of studies by Beilin and his colleagues (1983) demonstrate the importance of a developmental approach for attempting to resolve the realist-conventionalist debate. Acknowledging that there may be an innate ability to perceive and recognize objects and events in photographs, these studies emphasize that much of the information inherent in photographs is not immediately understood by young children. Contrary to Gibson, one study found that young children believed that photographs of various objects

possessed the properties of the objects themselves (e.g., a photograph of a rose was thought to smell like a rose). This confusion was termed "iconic realism" (Pearlman & Beilin, 1979). Another study showed young children believed in the fidelity of photographs to a greater extent than line drawings. This belief even extended to cases where photographs depicted an illogical event (O'Connor, Beilin & Kose, 1981). Finally, studies indicate that there is a developmental progression in the comprehension of different types of motion cues in photographs (e.g., from realistic to conventional), and that performance with motion cues varies depending on whether photographs or line drawings are viewed (Kose, Beilin & O'Connor, 1983; Futterweit & Beilin, 1987).

In sum, these studies demonstrate that young children only gradually learn about the properties of photographs and only gradually develop the ability to comprehend the more complex information in photographs, such as the representation of motion. These studies also suggest that photographs have unique properties that are understood differently from other representational media. Based on these findings, Beilin (1983) has theorized that in addition to cognitive development, increased knowledge of objects in the world and representational objects as well as increased understanding of the way photographs are constructed and used to represent reality are important factors in children's developing ability to comprehend the meaning of photographs. Thus, developmental studies must go beyond the

mere recording of children's recognition of objects and events in photographs to the assessment of their knowledge of the nature of photography, its unique properties, and its relation to reality.

The Perception of Motion in Pictures

Some perceptual psychologists have theorized that motion, or patterns of change in the environment, plays an important role in perception (Gibson, 1979; Johansson, 1975; Cutting, 1986). Within the pictorial representation literature, however, most studies have analyzed the perception of static objects and neglected the perception of "motion" in pictures. It has been proposed, however, that motion cues might be particularly useful for understanding photographic representation because, "even if one accepts that the ability to perceive and recognize objects is an essentially unlearned competence, the question is still open as to how everything else is understood, since most other information in photographs is relational or bears upon knowledge of the world and requires some inferential process to discern" (Beilin, 1983, p. 30). Since photography is unique in its ability to capture and manipulate the representation of motion in various ways, from more realistic to more conventional forms, researchers may attempt to determine whether photographic movement information is directly perceived or whether it requires the development of cognitive processes in order to be comprehended.

In one study, Friedman and Stevenson (1975) hypothesized that pictorial movement cues vary in the degree to which they correspond to the environment. To test if postural, cartoon, and multiple motion cues are equally effective, they had preschoolers, first graders, sixth graders and college students classify pictures of human figures as "moving" or "still". The results indicated that the younger subjects were only able to understand the postural and multiple image cues, whereas the older subjects were able to understand all of the cues. The ability to comprehend the cartoon cues improved with age, while the reliance on postural cues diminished. The authors theorized that the postural cues were easier to understand because they corresponded most to the real world, whereas the cartoon cues were less representative of the environment (they are arbitrary, conventional cues) and therefore needed to be learned by a process of association. Although multiple image cues are also abstract, the authors suggested that the younger subjects understood them because they relied on postural information. The older subjects utilized their knowledge of cartoon cues to interpret the pictures. Finally, the authors pointed out that the differential effectiveness of the movement indicators was contrary to predictions from the theories of Gibson, Gombrich and Goodman, which (while differing on the nature of the relation between pictures and the world) suggest that all types of pictorial information should be equally effective.

More recently, Friedman and Stevenson (1980) surveyed pictures from different historical and cultural periods and found that postural movement indicators have been the most frequently used, while metaphor and highly abstract cues have become used only recently. A review of the developmental and cross-cultural studies supported their earlier findings that postural indicators are effective cues for young children, and that the comprehension of multiple, metaphor and abstract cues improves with age and acculturation (e.g., Amen, 1941; Brooks, 1977).

Following Sigel's theory (1978), and in an attempt to determine if different cognitive levels affect the perception of motion in photographs, Bernard (1982) classified kindergarten and first grade children as preoperational, transitional, or concrete operational, and asked them to classify realistic photographs of a variety of events as either moving or still. He found that both age and developmental level were important factors in the development of pictorial motion perception. Bernard suggested that as children undergo changes in cognitive operational level, their understanding of the content and cue information in photographs changes as well. While the concrete operational children "conserved the real-life and implied motion indicators", the preoperational children may not have "realized the correspondence between explicit and implicit motion indicators" (p. 1274).

In order to examine the effectiveness of the various

motion indicators described by Friedman and Stevenson (1980), and in order to determine if photographs are understood differently from drawings, Futterweit and Beilin (1987) asked 3- and 5-year-old children to label either color photographs or equivalent line drawings as "moving" or "still". There were four types of movement indicators: postural, context, metaphor, and inherent movement indicators. In an attempt to determine the role of real world knowledge in pictorial comprehension, children were asked a series of questions to probe their knowledge of the distinction between animate and inanimate objects with regard to movement. The results indicated that young children were able to comprehend almost all of the movement indicators, and this skill improved with age. In accord with Beilin (1983), children's real world knowledge was related to their performance with photographs to a significantly greater degree than with line drawings. Contrary to Kose (Kose et al., 1983), photographs were easier for children to interpret than line drawings.

In sum, although photographs are static objects that only imply movement, viewers understand that an action or event was occurring when the photograph was taken. The limited research concerning children's (as well as adults') understanding of pictorial movement indicators suggests not only that a wide variety of indicators are understood at an early age, but also that there is a developmental progression in the comprehension of different types of

cues. In particular, while more realistic motion indicators are understood by very young children, and in the same manner as movement information in the environment, more conventional indicators, those that are particular to photography (such as blurring), require either increased cognitive development and/or experience with photography in order to be comprehended. Given both the ease of recognition and developmental differences, these studies suggest that an adequate theory of photographic representation must incorporate both realist and conventionalist, direct perception and cognitive theories. An adequate theory might also incorporate current theories of mental representation (and their methods) in order to clarify how pictures are mentally represented.

The Representational Momentum Viewpoint

A recent study, which combines both direct perception and cognitive perspectives, appears to offer an explanation of how pictorial movement information is mentally represented. Freyd (1983) found that adult subjects represent the motion implied in photographs in a particular manner. The materials for this experiment consisted of pairs of photographs created from frames of movie films of simple action sequences (e.g., a person walking). The photograph pairs were separated by small amounts (from 1 to 12 frames) in the film. Subjects were shown the first photograph in the pair for 250 msec. This was followed by a 250 msec interstimulus interval, and then the second

photograph was presented. The task for the subjects was to remember the first photograph and then to determine as quickly possible whether the second photograph was the "same as" or "different from" the first. There was an equal number of "same" and "different" pairs. Half of the "different" pairs, however, were shown in real world or "forward" order, (a photograph of a scene was followed by a photograph of the same scene but taken slightly later in time) while the other half were shown in reverse or "backward" order.

Freyd found that subjects' reaction time to correctly determine that the second photograph was different from the first was significantly longer when viewing pairs presented in a forward, rather than backward, order. Further, subjects made more errors when judging forward pairs, although the difference was not significant. Freyd concluded that the forward pairs took more time to judge because when subjects perceived the first photograph in the pair, they (automatically) mentally "unfroze" the implied action and continued it forward in time. As a result, their memory for the photograph was distorted slightly forward in the direction of the implied motion. Since the mental representation of the first photograph was more similar to the second photograph in the forward trials, more time was required to discriminate correctly between the two. However, since the memory representation was less similar to the second photograph in the backward trials, reaction time

decreased.

Follow-up studies by Freyd and her colleagues have found the phenomenon using nonpictorial stimuli, such as a sequence of static displays implying the rotation of a rectangle (Freyd & Finke, 1984) and dot patterns (Finke & Freyd, 1985). Similar to the photograph study, Freyd has found that the final rectangle, or dot pattern, in a sequence is remembered as slightly forward (e.g., rectangles that are displayed slightly forward of the final position are judged as "same" more often than equivalently rotated backward rectangles). Thus "the cognitive process in which visual memories are shifted forward by small amounts in the act of stopping the spontaneous extrapolation of implied motions (is) analogous to the way a physical object continues to move for a short distance before it can be brought to a complete stop" (Finke & Freyd, 1985). Since the process appears to resemble the physical momentum of a moving object, the phenomenon has been referred to as "representational momentum". Other experimental findings (e.g., that the memory shift increases with increases in implied velocity (Freyd & Finke, 1985) and retention interval (Freyd & Johnson, 1987) have been taken as further evidence that representational momentum corresponds to physical momentum in the world. Freyd has speculated that, as a natural tendency, "representational momentum" may be useful for anticipating the future position of moving objects, planning motor behavior when interacting with

moving objects, and perceiving and recognizing objects and events. Freyd's theory is similar to Gibson's in its emphasis on the perception of events and patterns of change in the environment. Rather than postulating an innate tendency, however, Gibson (1979) claims that humans use optical information in the environment (e.g., magnification, minification) to perceive events.

Since the representational momentum studies are related to Roger Shepard's mental rotation studies (e.g., Shepard & Metzler, 1971; Shepard & Cooper, 1982), the assumptions and implications of those studies will be discussed in this section.

Shepard's "mental rotation" studies are amongst the most important and widely cited lines of evidence for both the existence of mental images and an analog form of representation. Shepard and his colleagues used a chronometric technique to investigate the transformation of mental images (Shepard & Cooper, 1982). In the classic mental rotation study (Shepard & Metzler, 1971), adult subjects were asked to view pairs of drawings of three-dimensional abstract forms. For half of the trials, the two simultaneously presented forms were the same shape (although they differed in angular orientation), while for the remaining trials the forms were mirror-images of each other (although they too were separated by different degrees of rotation in space, from 0 to 180). It was found that the time required to compare and determine correctly whether the

two forms were identical in shape, or mirror images of each other, increased linearly with increasing angular disparity. The authors interpreted the linear function (and subjects' introspective reports) as evidence that the solution of the task had been mediated by mental rotation. That is, subjects mentally rotated an image of one of the objects into congruence with the other object in order to compare their shape and determine whether they were the "same" or "different". The greater the angular separation between the two objects, the longer it took to compare them because more time was required to imagine the object and its rotation into congruence with the other.

Mental rotation has also been demonstrated with successively presented alphanumeric characters (Cooper & Shepard, 1973), angular shapes (Cooper, 1975), drawings of right and left hands (Cooper & Shepard, 1975), and bends in a line, representing right or left turns on a map (Shepard & Hurwitz, 1984). Based on these findings, Shepard argues that mental rotation is an analog process precisely because, "the intermediate stages of the internal process have a demonstrable one-to-one relation to intermediate stages of the corresponding external process - if that external process were to take place" (Shepard & Cooper, 1982, p. 13). Further, Shepard assumes that the "internal representation upon which mental rotation operates is holistic in that the representation preserves the essential spatial structure of its corresponding external referent" (p. 185). The claim

is not, however, that there is a complete structural isomorphism between internal representations and external objects, but rather that there is a more abstract "second-order" isomorphism whereby "the brain is passing through an ordered series of states that (whatever their neurophysiological nature) have much in common with the perceptual states that would occur if the appropriate physical object were presented in successively more rotated orientations in the external world" (p. 14). Shepard believes that as a natural, spontaneous capacity, mental imagery (and mental rotation) is adaptive because it enables individuals not only to recognize objects and events in the world, but also to anticipate the consequences of external events (e.g., the rearrangement of furniture in a room) without having to experience them directly. Introspective reports by scientists and inventors (cited in Shepard & Cooper, 1982) also testify to the critical role of mental imagery in certain forms of abstract problem solving and creative thought.

More recently, Shepard has argued that "the external constraints that have been most invariant throughout evolution have become most deeply internalized ... (for example), those of kinematic geometry, which govern the relative motion of rigid objects" (Shepard, 1984, p. 422). Consequently, Shepard argues that such internalized constraints automatically guide both the perception and imagination of objects and their transformations. These

constraints are believed to have been "picked up genetically over an enormous history of evolutionary internalization" (p. 431). The constraints considered by Shepard are different from those considered by Keil (1981), who states that "It is extremely unlikely that there is any simple mapping between the structure of the environment and the structure of natural cognitive systems in humans. There are simply too many indeterminacies" (p. 218). Shepard's theory of internal representation is similar to Gibson's theory of direct perception in its emphasis on the mutuality between the environment and the animal. However, Shepard claims that "an appropriate match has evolved" because some of the most enduring external constraints (or invariants) have been internalized. Shepard believes that these genetically pre-wired constraints are highly adaptive, because it spares each animal from having to learn them through experience.

Pylyshyn (1981) has been the most vocal critic of the claim that a special (pictorial or analog) form of representation and type of process is necessary to explain the imagery findings. He has proposed that mental images are derived from underlying symbolically coded propositions. Mental images are thus epiphenomenal; mere products of more abstract processing of propositional representations. Further, contrary to Shepard, Pylyshyn argues that the imagery phenomena are not due to, or constrained by, some "intrinsic property of the representational medium", but rather to subjects' (largely unconscious) tacit knowledge of

physical principles and perceptual processes. Imagery, according to Pylyshyn, does not involve representations normally used in perception, but rather, the nature of the imagery tasks leads subjects to believe that they are to imagine the events as if they were actually seeing them.

The tacit knowledge account of imagery is related to Pylyshyn's distinction between psychological processes that are cognitively impenetrable (those that are part of the "functional architecture" and innately determined) and processes that are cognitively penetrable (those that operate on symbolically encoded representations such as beliefs and goals). Since Pylyshyn argues that mental imagery can be altered by changes in a subject's goals and beliefs, it is cognitively penetrable. Pylyshyn interprets the mental rotation findings, for example, as simply due to subjects' knowledge of how real transformations occur, rather than as evidence for internalized constraints on an imaginal medium.

Freyd's studies are clearly related to Shepard's in that both researchers have attempted to explain how mental images (although Freyd prefers to use perceptual or memorial representations) contribute to the recognition or comparison of objects that differ according to some transformation (e.g., rotation, orientation). Both have claimed that some internal processes resemble external physical processes, both have argued for an analog form of representation (Freyd & Johnson, 1987), and both have argued that these processes

are only abstractly related to physical laws of motion ((Kelly & Freyd, 1987). Further, on the basis of the representational momentum findings, and consistent with Shepard (1984), Freyd has theorized that "representational momentum originated as an internalization within the visual system of the principle of physical momentum" (Kelly & Freyd, 1987, p. 397). Consequently, such internalized principles automatically guide both the perception and representation of moving objects. Although Freyd (unlike Shepard) has not used the term "constraints", her view is consistent with a constraints perspective (Keil, 1981).

Freyd's perspective, however, has departed from Shepard's in two ways. First, whereas Shepard assumes that static images of objects are transformed, Freyd claims that at least some representations are themselves <u>dynamic</u> (Freyd, 1987). A dynamic representation is one "in which time is represented analogically or ... <u>intrinsically</u>. That means that time is represented with a representing dimension that has some of the same inherent structure that real-world time has ... (a dynamic representation is) also one in which time is necessarily represented. In other words the representing dimension for time could not be removed from the representation while still preserving any sort of useful representation" (Freyd, 1987, p. 430). Freyd claims that the representational momentum findings are consistent with the notion of dynamic mental representations, because they "suggest that under some conditions a directional,

continuous dimension of time seems to be necessarily represented " (p. 432). Second, Freyd argues that representational momentum may be an even better example of an analog process than Shepard's mental rotation studies because the effect is mandatory (although subjects are asked to remember the first picture or final position of an object, the memory is still transformed), and rapid (it occurs within a 250 msec retention interval). Since Fodor (1983) suggested that mandatory and rapid processes are characteristic of informationally encapsulated modular systems, Freyd has argued that representational momentum is modular and cognitively impenetrable. That is, it is due to the intrinsic nature of the perceptual system, rather than task demands, beliefs, or tacit knowledge of physical laws. The rapid and mandatory characteristics of representational momentum are also consistent with characteristics of direct perception (Cutting, 1986). Contrary to direct perception theories, however, Freyd believes that mental representations mediate perception.

Although not intended as a picture memory study, the phenomenon reported by Freyd (1983) is of interest from a pictorial representation perspective for several reasons. First, contrary to previous assumptions that picture memory in adults is remarkably good (Shepard, 1967; Standing, 1973), this study implies that memory for specific information in pictures is less accurate. Second, consistent with Hochberg (1983) and Beilin (1988), the study

implies that cognitive processes are involved in the picture perception process. Third, it is one of the few studies that has examined not only memory for movement in photographs but also memory for movement using a reaction time method.

Purpose

The first goal of the present study was to determine not only whether the original representational momentum finding could be replicated but also whether children would remember pictorial movement information in the same manner as the adults in Freyd's (1983) study. A replication study was important because representational momentum has begun to be referred to and incorporated into the mental imagery literature (e.g., Shepard, 1984; Kosslyn et al., 1988), even though it has not been replicated by independent researchers. Further, although Freyd never returned to the use of photographs, she cites the (1983) picture study as important evidence for the existence of dynamic mental representations (Freyd, 1987). Finally, since representational momentum is hypothesized to be an innate process that affects the perception of and memory for movement, a replication study that included a sample of children was necessary in order to determine when and whether children represent and interpret movement in the same fashion as adults.

The second goal of the present study was to test certain assumptions of the "representational momentum" perspective. This was done both by examining variables not

considered by Freyd (1983) (such as age, direction of movement, interstimulus interval, pictorial movement cues, and still pictures), and by incorporating a technique used by Freyd only in later representational momentum studies (i.e., using a range of distractor positions). A developmental design was critical, for if representational momentum is indeed a spontaneous and automatic process that arises because the visual system has internalized certain principles of physical motion, there should be few developmental changes. That is, children should demonstrate the same forward memory shifts as adults in Freyd's (1983) study (i.e., they should take longer to correctly discriminate and make more errors on the forward pairs). If developmental differences are found, however, then other factors may be responsible for the effect, such as changes in the nature of mental representation, changes in the early stages of picture processing, or changes in knowledge.

The third goal of the study was to add to the literature on children's comprehension of movement in photographs by incorporating both a reaction time paradigm from the cognitive psychology literature and a "same-changed" recognition paradigm from the picture memory literature. Although not acknowledged, Freyd's (1983) picture study used essentially a same-changed recognition paradigm, whereby the picture to be remembered was shown either in the "same" form in which it had originally been presented or in a "changed" form (e.g., forward or

backward). The study is therefore related to those picture memory studies that have used a same-changed recognition paradigm to assess memory for specific details in pictures (e.g., Intraub & Richardson, 1989; Pezdek & Chen, 1982). The use of a same-changed and reaction time technique in the present study allowed for a greater specification of how pictorial movement information is internally represented and recognized than the method of asking children to judge whether pictures are "moving" or "still". It also allowed for an examination of possible developmental changes in the early stages of pictorial information processing, an area that has been relatively neglected in the pictorial representation literature.

Finally, the present study was relevant to the debate over whether young children can employ mental imagery to represent spatial transformations. Some researchers (e.g., Marmor, 1975, 1977; Childs & Polich, 1979) have used Shepard's mental rotation paradigm to test Piaget and Inhelder's (1971) theory that preoperational children's imagery is static and that the onset of concrete operations is necessary in order to anticipate the effects of movement and change on objects and relations. These studies have found that young children imagine rotations in the same manner as adults (their reaction times increase linearly as a function of angular separation between stimuli) but at a slower rate. As the first developmental study of representational momentum, the present study supplemented

the few developmental studies of mental rotation by investigating whether children represent movement in imagery. As Mandler (1983) states, "It is clear that developmental work on imagery must incorporate the current sophisticated theory and experimental techniques and leave behind the simpler measures with which we are more familiar if the development of imagery is to be understood" (p. 442). Further, "Developmental studies of imagery may also help us resolve some major theoretical issues. For example, ... the role of experimenter demands and tacit knowledge of perception as an explanation for imagery findings. ... Developmental studies ... which find similar imagery phenomena in very young children decrease the likelihood that the use of tacit knowledge can explain imagery phenomena because these children are too young to be aware in a sophisticated way of their perceptual processing. This may be an arena in which developmental work can settle a general psychological issue - an all too rare phenomena" (p. 443).

In sum, the present experiments sought to replicate and extend a possible picture-memory phenomenon reported by Freyd (1983). At a methodological level, this investigation added to the literature by expanding the standard repertoire of methods used to examine children's comprehension of movement in photographs. At a theoretical level, the study added to the literature by examining developmental differences in very short-term memory for movement in

photographs.

## Experiment 1

Since there has been only one unpublished replication with adults, and none with children (Freyd, personal communication, 1988), the purpose of the first experiment was to determine whether the phenomenon reported by Freyd (1983) could be replicated with another sample of adults, and more importantly, with children. Second, the study sought to explore more fully this possible picture-memory phenomenon and its implications for a theory of pictorial representation. Therefore, the materials and procedures in the present experiment were similar to those used by Freyd (1983), with the exception of several important modifications which are discussed in detail below.

In addition to age, four factors not considered by Freyd (1983) were considered in the present study: direction of movement, interstimulus interval, rate of implied movement, and pictorial movement cue. Direction of movement in the photographs was examined for three reasons. First, some studies suggest that there may be a difference in the perception of right-left versus left-right (Corballis & Beale, 1976). Second, the representational momentum hypothesis predicts that forward memory errors will occur in the same direction as the implied motion, regardless of the direction. Third, later representational momentum studies

counterbalanced direction of implicit rotation of rectangles (clockwise and counterclockwise), but only across subjects, and found that there were no differences between the two directions (e.g., Finke & Freyd, 1985). The one study that examined direction of motion as a within subject factor, however, found that it weakened the effect (Finke & Shyi, 1988). This was the first study to examine three different directions of movement (left to right, right to left, and down) as a within subject factor. If "representational momentum" is affected by the direction of movement (i.e., if there are significant left-right differences, or more forward than backward errors only with some directions), it would be inconsistent with the representational momentum claim and would imply that cognitive mechanisms might be responsible for the effect.

The second factor examined in the present experiment was interstimulus interval (ISI). One study (Finke & Freyd, 1985) examined ISIs ranging from 100 msec to 2 sec (using an exposure duration of 250 msec) and still found the effect. This led Freyd to reject sensory processes (such as visual afterimages, icons, or illusions of apparent motion) as an explanation of the findings, because only very short ISIs would be vulnerable to these sensory effects. However, since only an ISI of 250 msec was used in the (1983) picture study, it remains possible that the memory representation of the first photograph was in an unstable form and thus vulnerable to conceptual masking (Potter, 1976). Further,

although recognition memory for pictures increases with increasing exposure duration (Tversky & Sherman, 1975), with short exposure times longer ISIs are important for the further processing and storage of pictorial information (Intraub, 1980). Finally, since afterimages or icons are thought to have a maximum duration of .5 seconds in adults (Haber, 1983), they may have influenced Freyd's (1983) study. Thus in addition to a 250 msec ISI, a 500 msec ISI was used in the present experiment in order to eliminate any possibility of masking or afterimages, to allow time for the further processing of pictorial details, and to examine the time course of the pictorial movement information over 750 msec. If the representational momentum effect is not due to masking or afterimages, it should still be present with an ISI of 500 msec.

Rate of implied movement was examined in order to test the representational momentum hypothesis that just as physical momentum increases with increasing velocity, so too does representational momentum. In one study Freyd and Finke (1985) varied the implied velocity of the displays (by varying the ISIs in between the presentation of a sequence of rectangles) and found that with increased implied velocity (shorter ISIs) there was an increase in the size of the memory shift. Although two different ISIs were examined, the present experiment also sought to determine whether, independently, there is an increase in the magnitude of the memory distortion depending on the rate of

movement implied in photographs.

Finally, different types of pictorial movement indicators were examined in order to determine which, if any, affect short-term memory for movement in photographs. In a previous study (Futterweit & Beilin, 1987), following the work of Friedman and Stevenson (1980), photographs were categorized as containing either postural, context, metaphor, or inherent movement indicators. However, since most photographs actually contain more than one movement cue, in this study photographs were categorized as those containing either one, two, or three movement indicators.

Based on Freyd's (1983) study, it was hypothesized that subjects should take significantly longer to correctly judge that a second photograph is different from the first when photograph pairs are shown in "forward" (real world) order as opposed to "backward" (reverse) order. Subjects should also make more errors ("same" responses) when judging forward pairs. Further, based on pilot data, and consistent with developmental studies of mental rotation (e.g., Kail, Pellegrino & Carter, 1980; Marmor, 1977), it was hypothesized that there would be developmental differences in speed of reaction time (response times would decrease with age), but not in number of errors.

## METHOD

### Subjects

Thirty-five subjects participated in this study. There were 11 3rd grade students whose mean age was 8 years-6 months (range = 9 months); 12 5th grade students whose mean age was 10 years-3 months (range = 10 months); and 12 graduate students whose mean age was 30 years-1 month (range = 243 months). Within the third grade, there were 6 males and 5 females; within the fifth grade, there were 8 males and 4 females; and within the graduate students, there were 3 males and 9 females. All subjects had normal or corrected to normal vision.

The children were recruited from two private elementary schools in New York City and were from middle to upper middle class families. The graduate students were recruited from the Graduate School of the City University of New York. All subjects completed the task.

Third and fifth grade children were chosen in order to be comparable with developmental studies of mental rotation (e.g., Childs & Polich, 1979; Kail, Pellegrino & Carter, 1980), and memory for pictures (e.g., Pezdek & Chen, 1982). Previous studies have reported that children across this age range differ in their recognition memory for details in pictures (Dirks & Neisser, 1977; G.S. Goodman, 1980). Further, a group of adults was included in order to be comparable with the representational momentum studies and the majority of the mental imagery and picture memory literature. Using subjects across a large age range allowed this study to test whether there are age differences in

short-term memory for movement in rapidly presented photographs.

Materials

Stimuli. The stimuli consisted of pairs of "before" and "after" color photographs. The pairs were made from frames of 35 mm movie film. The selected frames were spliced from the film and placed in slide mounts for carousel projection. The films were made by a graduate film student. This process yielded clearer images than those used by Freyd (1983), who filmed the sequences with a Super 8 movie camera and then photographed the desired frames.

Nine filmed action sequences were used: a person walking from left to right, the same person walking from right to left, a person jumping off a wall, a person tossing a ball, a person pouring water out of a cup onto the ground, a person running from left to right, the same person running from right to left, a person bouncing a ball, and a person swinging on a swing. The first five actions were the same as those reported by Freyd (1983), (although the direction of movement was not reported in her study). The last six sequences were selected in order to test not only a variety of simple, unambiguous actions but also the effects of direction of movement (left to right, right to left, and down). A list of photograph pairs by direction is presented in Table 1.

Table 1
Photograph Pairs and Direction of Movement
Experiment 1

| Left to Right | Right to Left | Down |
|---|---|---|
| Toss | Swing | Jump |
| Walk | Walk | Bounce |
| Run | Run | Pour |

Each action sequence was filmed from a single point of observation. Further, a reference point was provided in each sequence (e.g., there was a tree in the background in the walking and running sequences).

Five of the action sequences implied a fast rate of movement (the running in both directions, pouring, bouncing, and tossing sequences), while four of the sequences included a slower rate of implied movement (the walking in both directions, jumping, and swinging sequences).

Three of the filmed sequences contained one pictorial movement indicator (the walking in both directions (postural) and pouring (context) sequences). Three of the sequences included two cues (the running in both directions (postural and blur) and swinging (postural and context) sequences). Three of the sequences includes three movement cues (the bouncing, throwing and jumping sequences (postural, context and blur).

Two distinct pairs from each action sequence were made, for a total of 18 "different" pairs. There was an equal number of pairs from each action sequence, as opposed to a variable number in Freyd, 1983. Two distinct pairs (and

thus two distinct "memory" photographs) were used in order to ensure that the effect was not specific to one type of photograph. One of the two pairs from each sequence was shown in "forward" order, and the other in "reverse" order. This allowed for a direct test of whether there is a distortion in memory for pairs drawn from the same sequence and separated by an equal number of frames, but simply shown in different orders. Further, in order to test precisely the left-right and right-left difference in the running and walking sequence, the selected frames were those in which the position of the walker and runner (in both directions) was exactly the same.

Although Freyd (1983) did not analyze responses to "same" pairs, in the present experiment "same" pairs were considered a third type of trial. Thus, there was an equal number of same, forward, and backward pairs. One pair from each action sequence was made, for a total of 9 "same" pairs. The same pairs were made by selecting a frame from each action sequence (one that was not used in the "different" pairs), and then making two duplicates of that frame. The two duplicates of each same frame were presented (rather than the original frame and a duplicate) in order to eliminate any differences (such as color) between original and duplicate slides. Thus, there was a total of 27 experimental pairs.

There were also 8 practice pairs. Two same and two different pairs were made from "the person tossing a ball"

sequence (Freyd, 1983), and the other 2 same and different pairs were made from "the running sequence" (from left to right). These practice pairs were not used in the experimental trials.

The real world time separation between frames for the 2 "different" pairs from each action sequence was the same. The real world time separation between frames for the "different" pairs across action sequences, however, varied from 41 msec (1 frame) to 208 msec (5 frames). Specifically, the person walking pairs (in both directions) were separated by 208 msec; the person jumping by 125 msec; the person tossing a ball by 41 msec; the person pouring water out of a cup by 41 msec; the person running (in both directions) by 41 msec; the person bouncing a ball by 41 msec; and the person swinging on a swing by 125 msec. The real world time separations for the first six action sequences were the same as those used by Freyd (1983), while the remaining real world time separations were chosen on the basis of how fast the action was (e.g., since running is faster than walking, it was separated by a fewer number of frames).

Equipment. The equipment, and assistance in setting up the equipment, was provided by Professor David Swinney of the Linguistics Program of the Graduate School of the City University of New York.

The slides were projected onto a screen by means of 2 Kodak carousel projectors that operated in direct

succession. This procedure mimicked the standard tachistoscopic viewing used by Freyd (1983). Two projectors were necessary to test ISIs under 1 second, because it takes approximately 1 second for a slide to advance in a carousel. The two projectors were placed on a specially designed styrofoam board containing two mirrors placed at right angles. The two mirrors, and the properly placed projectors, allowed the 2 successively presented pictures to be projected onto the same place on the uniform medium grey projection screen. The pictures from both projectors were also displayed at the same luminance. This was necessary so that differences would not be attributed to differences in projected location or brightness, but rather to differences in the content of the two pictures. A schematic diagram of the equipment is presented in Figure 1 (p. 78).

The duration of exposure of the pictures was controlled by Gerbrands tachistoscopic shutters mounted in front of the projector lenses. The two carousels and the response key box were linked to a Commodore C64 computer. The computer, through a program written specifically for tachistoscopic presentation, controlled the exposure duration, the interstimulus interval time, as well as automatically recorded both reaction time (in milliseconds) and responses. The experimenter initiated the beginning of each trial by pressing the appropriate key on the computer.

## Procedure

*Pretraining task*. To ensure that children understood

the meaning of "same" and "different" (that same means not only the same object but also the same object in the same position), there was a pretraining phase. Children (but not adults) were shown pairs of line drawings of ice cream cones (2 same and 2 different), adapted from Marmor (1977). The "same" pairs were drawings of 2 identical cones with bites taken out of the same side. The "different" pairs depicted the same cones but with bites taken out of opposite sides. The pretraining pictures are presented in Figure 2 (p. 79).

The pictures were approximately 4 X 4 in. (10 cm X 10 cm) in size, and were mounted on 8 & 1/2 X 11 in. (22 cm X 28 cm) white ledger bond paper. The pairs were presented in random order, and the children were asked to verbally indicate whether the 2 simultaneously presented cones were the same or different. Feedback was provided, and children proceeded to the experimental task only when they responded correctly to all four pairs.

Practice task. All subjects were tested individually (children in a separate room at their school and adults in the developmental laboratory at the CUNY Graduate Center). The equipment was set up on a table. Each subject was seated 2 ft away from the front of the projection screen in a darkened room. The pictures were projected at eye level and at a visual angle of 9.4 degrees. The subject rested one hand on each of the two response keys (right, or dominant, hand on same; left, or nondominant, hand on different).

Following Freyd (1983), the first photograph in the pair was presented for 250 msec. A 250 msec exposure duration allowed for only one eye fixation (Intraub, 1980), and thus eliminated any possible developmental differences in visual scanning (Vurpillot, 1968). Following a blank interstimulus interval of 250 msec, the second photograph was presented for 3 seconds. Timing of reaction time began with onset of the second photograph. A blank ISI was used in order to ensure that the second photograph was compared with a memory representation of the first. Although Freyd allowed the second photograph to remain on the screen until the subject responded, she excluded reaction times over 2 seconds from all analyses. A schematic outline of the trials is presented in Figure 3 (p. 80).

For the 500 msec ISI block of trials, the procedure and exposure duration (250 msec) remained the same.

Instructions. The subjects were told that the task was to look at the first photograph, hold it in memory, and then decide as rapidly and as accurately as possible whether the second photograph was the "same" as or "different" from the first. Freyd's instructions stressed speed over accuracy. However since she did not analyze the speed-accuracy tradeoff, and since a proper speed-accuracy tradeoff analysis was beyond the scope of this experiment, both speed and accuracy were stressed. Subjects were told that the photographs in each pair were of the same scene, and that the difference between them, if any, was a small one.

"Movement" was not mentioned in the instructions. Finally, subjects were told that although there would be both same and different trials, there might be more of one kind of trial than the other.

The subjects were then given 8 practice trials with feedback (the experimenter orally indicated whether the response was correct or not). Half of the practice trials were presented with a 250 msec ISI, while the other half were shown with a 500 msec ISI. It was necessary to present two different ISI blocks, because the computer program was unable to randomly present different ISI trials successively. Thus an equal number of subjects within each grade were randomly assigned to receive either the 250 or 500 msec ISI block first. If subjects made any errors on the practice trials, they repeated the trials in a different order.

Experimental task. When subjects responded correctly to all the practice trials, they saw all 27 experimental pairs twice: once with an ISI of 250 msec and once with an ISI of 500 msec, for a total of 54 trials. An outline of the trials is presented in Table 2.

Table 2
Outline of experimental trials
Experiment 1

| 250 ISI | | | 500 ISI | | |
|---|---|---|---|---|---|
| Forward | Backward | Same | Forward | Backward | Same |
| 9 | 9 | 9 | 9 | 9 | 9 |

There was a two minute rest period between ISI blocks during which the experimenter reprogrammed the computer. For each subject, the order of the experimental ISI blocks received was the same as that used for the practice trials. The order of the 27 experimental pairs within each ISI block was randomized both within and across subjects. Of the 18 different pairs within each ISI block, 9 (one from each action sequence) were shown in real world order (forward), and 9 in reverse (backwards) order. Those pairs that were shown in forward order in the first ISI block were then shown in backward order with the second ISI block. Each trial began when the experimenter advanced the slides in the projectors and asked subjects to both keep their eyes still and to look at the appropriately marked area of the projection screen.

Variables

Grouping variables. Grade (3rd/5th/graduate students), sex (male/female), handedness (right/left), pretraining (pretraining pictures seen once/twice), practice (practice trials seen once/twice), vision (corrected/not corrected),

and ISI block (250/500 msec block presented first) were used as grouping variables in this study.

Within-subject variables. Interstimulus interval (250 msec, 500 msec), direction (left-right, right-left, down) and test (forward, backward, same) were used as within-subject variables.

Dependent variables. Reaction time and error rate were the dependent variables in this study.

## RESULTS

Both reaction time (in msecs) and error rate were recorded. Separate analyses of variance were conducted on correct reaction times and number of error responses. Reaction times longer than 3 secs were excluded from analyses (they were coded as missing data and were not entered as errors). These (reaction times longer than 3 secs) accounted for 1% of the trials for all subjects (third = 2%, fifth = 1%, graduate = < 1%). These grade differences were significantly different, = 12.52, $p < .01$.

All trials on which errors occurred were dropped from the reaction time analyses.

Pretraining trials. Four (36%) of the 11 third graders, but none of the fifth graders, saw the pretraining pictures twice. Preliminary analyses indicated that there were no differences between third graders who needed to see the pretraining pictures once versus twice in either mean

correct reaction time or error rate, so this variable was dropped from later analyses.

Practice trials. Nine (80%) of the third graders, two (16%) of the fifth graders, and three (25%) of the graduate students saw the practice pictures twice. Preliminary analyses indicated that there were no differences within each grade between subjects who saw the practice pictures once versus twice in either mean correct reaction time or error rate, so this variable was dropped from later analyses.

Reaction Time

Preliminary t-tests indicated that there were no differences between subjects in mean correct reaction time by handedness (right/left), vision (corrected/uncorrected), or which ISI block was received first (250/500 msec). There were also no sex differences, except within the third grade where there was a trend for males to have longer correct reaction times than females, $t(9) = 2.03$, $p < .08$. Since no significant effects due to these variables were found, they were dropped from further analyses.

The mean correct reaction times for each direction and test for subjects in each grade are presented in Tables 3 and 4.

Table 3
Mean Correct Reaction Times and Standard Deviations
By Direction (in msecs)
Experiment 1

| Age group | Left | Right | Down |
|---|---|---|---|
| Grade 3 | 1440 | 1327 | 1480 |
| | (484) | (445) | (543) |
| Grade 5 | 1006 | 967 | 1087 |
| | (375) | (339) | (447) |
| Graduate | 901 | 866 | 933 |
| | (389) | (304) | (377) |

Table 4
Mean Correct Reaction Times and Standard Deviations
by Test (in msecs)
Experiment 1

| Age Group | Forward | Backward | Same |
|---|---|---|---|
| Grade 3 | 1383 | 1504 | 1353 |
| | (475) | (499) | (492) |
| Grade 5 | 1043 | 1038 | 976 |
| | (433) | (316) | (400) |
| Graduate | 880 | 934 | 880 |
| | (301) | (369) | (389) |

The first major analysis performed, a 3 (grade) X 2 (ISI) X 3 (direction) X 3 (test) repeated measures ANOVA, indicated a highly significant effect for grade, $F(2,26) = 10.84$, $p < .001$, with mean correct reaction times decreasing with increasing age (third = 1410 msecs, fifth = 1016 msecs, and graduate = 898 msecs). Comparisons of means using the Tukey HSD procedure (Winer, 1962) showed that adults had faster response times than third grade children ($p < .05$) and that fifth grade children had quicker reaction times than third grade children ($p < .05$). The main effect of direction was also significant, $F(2,52) = 9.67$, $p < .01$. Repeated measures univariate F tests on the direction effect revealed that subjects took significantly longer on the down direction ($p < .01$), and left-right ($p < .01$), than right-left direction. A significant main effect of test was found, $F(2,52) = 4.10$, $p < .05$. Contrary to Freyd's (1983) picture study, subjects took significantly longer to respond correctly to the backward pairs than to the forward pairs ($p < .05$). Subjects also took significantly longer to respond correctly to the backward than same pairs ($p < .05$).

Although mean correct reaction time increased with the 500 msec ISI for all grades combined (ISI 250 = 1067 msecs; ISI 500 = 1117 msecs), and for each test separately, the main effect of ISI was not significant, $F(1,26) = 1.97$, $p > .2$.

Even though the main effect of ISI was not significant, separate analyses were conducted to determine the effect of

test within each ISI. The main effect of test was not significant with the 250 msec ISI (the one that Freyd (1983) used), $F(2,64) = 1.29$, $p > .3$. It was, however, significant with the 500 msec ISI, $F(2,64) = 6.65$, $p < .01$. Unlike Freyd's finding, this was due to subjects' significantly longer correct responses to the backward than forward ($p < .05$) or same pairs ($p < .05$).

There was a nonsignificant grade X ISI X test three-way interaction trend, $F(4,52) = 2.40$, $p < .08$. With the 250 msec ISI, the graduate students' correct reaction times were slightly longer to the forward than backward pairs, whereas with the 500 msec ISI the reverse was true. Conversely, with the 250 msec ISI the fifth graders had longer reaction times to the backward than forward pairs, however with the 500 the reverse was true. Finally, with both ISIs, the third graders' longest reaction times were to the backward pairs.

Separate repeated measures ANOVAS were then performed in order to examine in detail the effects of ISI, direction and test within each grade.

Grade three. A 2 (ISI) X 3 (direction) X 3 (test) repeated measures ANOVA on the third graders' correct reaction times revealed a significant main effect for test, $F(2,12) = 4.34$, $p < .05$. Third grade children were the only subjects who took significantly longer to respond correctly to the backward than forward ($p < .05$) or same tests ($p < .05$). There was also a significant main effect of

direction, $F(2,12) = 3.27$, $p < .05$, with children taking significantly longer to respond correctly to the down direction ($p < .05$) and left-right ($p < .05$) than right-left direction.

Grade five. Similar to the third grade children, there was a significant main effect of direction, $F(2,22) = 7.98$, $p < .01$. Fifth grade children took significantly longer to respond to the down than right-left direction ($p < .05$).

Graduate students. Although the main effect of direction was not significant, there was a trend for the down direction to be longer than the right-left ($p < .07$).

In order to determine the effect of rate of implied movement on memory for action in photographs, a separate 3 (grade) X 2 (rate of implied movement) X 3 (direction) X 3 (test) repeated measures ANOVA was performed. Grade, direction, and test were again significant, as was the effect of rate of implied movement, $F(1,23) = 39.83$, $p < .001$. Consistent with the representational momentum claim, subjects had significantly longer correct reaction times to those photographs implying a faster than slower rate of movement. Since those photographs that implied a faster rate of movement, however, were also those that were separated by the fewest number of frames, these two variables were confounded in this experiment. Thus, the results of this analysis also indicate that subjects took longer to judge correctly those pairs that were closest in real world time. The mean correct reaction times for each rate of implied

motion by subjects in each grade are presented in Table 5.

Table 5
Mean Correct Reaction Times and Standard Deviations by Rate of Implied Movement (in msecs)
Experiment 1

| Age Group | Faster Rate | Slower Rate |
|---|---|---|
| Grade 3 | 1521<br>(525) | 1307<br>(435) |
| Grade 5 | 1070<br>(417) | 966<br>(353) |
| Graduate | 960<br>(411) | 837<br>(281) |

Finally, a separate 3 (grade) X 3 (pictorial movement cue) X 3 (test) repeated measures ANOVA was performed in order to determine the effect of pictorial movement indicator. Once again, grade and test were significant, as was the effect of pictorial movement indicator, $F(2,64) = 4.56$, $p < .05$. Subjects took significantly longer to correctly respond to those pictures that contained 3 cues than to those that contained 1 ($p < .05$) or 2 cues ($p < .05$). The mean correct reaction times for each movement indicator by subjects in each grade are presented in Table 6.

Table 6
Mean Correct Reaction Times and Standard Deviations
by Pictorial Movement Indicator (in msecs)
Experiment 1

| Age Group | 1 Cue | 2 Cues | 3 Cues |
|---|---|---|---|
| Grade 3 | 1402 (510) | 1366 (467) | 1458 (495) |
| Grade 5 | 1017 (415) | 979 (337) | 1050 (405) |
| Graduate | 869 (349) | 910 (344) | 916 (377) |

In addition to the ANOVAS, an analysis was conducted to examine whether there were individual differences in reaction times for correctly rejecting the forward and backward pairs. Freyd (1983) reported that 93% of her subjects took longer to respond correctly to the forward than backward pairs. In the present experiment, however, there were individual differences. While only 1 of 11 (9%) third graders demonstrated longer correct reaction times to the forward than backward pairs, 6 of 12 (50%) 5th graders, and 4 of 12 (33%) graduate students had longer response latencies to the forward pairs.

In order to determine whether correct reaction times changed over the course of the experiment, the trials were split in half and a correlated t-test was performed. Mean correct response times decreased significantly during the second half of the trials for all subjects combined, $t(34) = 2.04$, $p < .05$, and for the fifth graders separately, $t(11) =$

2.23, $p < .05$, thus indicating a practice effect.

Separate correlated t-tests on mean correct response times for each test pair revealed that response times decreased significantly during the second half of the trials only with the forward pairs for all subjects combined, $t(34) = 2.33$, $p < .05$. Thus, the decrease in correct response times was specific to the forward, but not the backward or same, pairs.

Error Rate

Preliminary t-tests performed on the total number of errors made by each subject revealed no significant effects of sex, handedness, corrected or uncorrected vision, or whether subjects received the 250 or 500 msec ISI block first. Thus, each of these variables was dropped from further analyses.

The overall error rate was 20%. The percentage of errors made for each direction and test by subjects in each grade are given in Tables 7 and 8.

Table 7
Percentage of Errors by Direction
Experiment 1

| Age Group | Left | Right | Down |
|---|---|---|---|
| Grade 3 | 23 | 13 | 32 |
| Grade 5 | 20 | 11 | 28 |
| Graduate | 15 | 10 | 25 |

Table 8
Percentage of Errors by Test
Experiment 1

| Age Group | Forward | Backward | Same |
|---|---|---|---|
| Grade 3 | 20 | 29 | 18 |
| Grade 5 | 24 | 26 | 10 |
| Graduate | 22 | 17 | 11 |

A 3 (grade) X 2 (ISI) X 3 (direction) X 3 (test) repeated measures ANOVA performed on the number of error responses made by each subject demonstrated a significant main effect for direction, $F(2,64) = 33.94$, $p < .001$. Consistent with the results of the reaction time analysis, subjects made significantly more errors with the down direction ($p < .01$) and left-right ($p < .01$) than right-left direction. In addition, however, more errors were made with the down than left-right direction ($p < .01$). The main effect of test was also significant, $F(2,64) = 8.29$, $p < .01$. Subjects made significantly more errors on the forward ($p < .01$) and backward ($p < .01$) than same pairs. Together, the "different" pairs were significantly more difficult than the "same" pairs ($p < .01$.). Contrary to the representational momentum claim, but consistent with the reaction time data, subjects made a greater number of errors on the backward than forward pairs. This difference, however, was not significant, $t(34) = -.82$, $p > .4$.

A significant direction X test interaction, $F(4,128) = 11.37$, $p < .01$ reflected the fact, contrary to the representational momentum hypothesis, that the error rate on the forward pairs was significantly greater than the backward pairs only with the left-right direction. With the right-left and down directions, the greatest number of errors was made on the backward pairs. This interaction is presented in Figure 4 (p. 81).

Since there was a significant direction X test interaction, separate 3 (grade) x 3 (test) repeated measures ANOVAS were performed in order to assess the effect of test within each direction. The main effect of test was significant with the left-right direction, $F(2,64) = 13.47$, $p < .01$. Significantly more errors were made on the forward than backward ($p < .01$) or same trials ($p < .01$). The test effect was also significant with the down direction, $F(2,64) = 17.98$, $p < .01$. However, unlike the left direction, significantly more errors were made on the backward pairs than forward ($p < .05$) or same pairs ($p < .01$).

The error rate data also revealed two nonsignificant three-way interaction trends. One, consistent with the reaction time data, was a grade X ISI X test interaction trend, $F(4,64) = 2.22$, $p < .08$. With both the 250 and 500 msec ISIs, the graduate students made (nonsignificantly) more forward than backward errors, while the third graders made more backward errors. The fifth grade students, however, made slightly more forward errors with the 250 msec

ISI but more backward errors with the 500 msec ISI.

There was also a grade X direction X test 3-way interaction trend, $F(8,128) = 1.63$, $p < .10$, which reflected the fact that while the graduate students made more forward than backward errors with all directions (this was significant only with the left-right direction, $t(11) = 3$, $p < .01$), and the fifth graders made significantly more forward errors only with the left-right direction ($t(11) = 3.12$, $p < .01$), the third graders made more backward errors with all directions.

Although the younger subjects made more errors than the older subjects (third = 23%, fifth = 20%, graduate = 17%), these differences were not significant ($p > .3$). Similar to the reaction time results, although there was a small increase in the number of errors with the longer ISI for all grades separately and combined (18% versus 21%), and for each test separately, there was no main effect of ISI, $F(1,32) = 1.58$, $p > .2$.

Although the main effect of ISI was not significant, separate analyses were performed in order to determine the effect of test within each ISI. The main effect of test was nearly significant with the 250 msec ISI, $F(2,64) = 2.84$, $p < .07$. Similar to the reaction time results, the main effect of test was significant only with the 500 msec ISI, $F(2,64) = 8.53$, $p < .01$. This was due to subjects' greater number of errors on the forward ($p < .01$) and backward ($p < .01$) than same pairs.

In order to determine the effects of ISI, direction, and test within each age group, separate repeated measures ANOVAS were performed.

Grade three. A separate 2 (ISI) X 3 (direction) X 3 (test) repeated measures ANOVA on just the third graders' number of errors revealed a significant main effect of direction, $F(2,20) = 15.12$, $p < .01$, with children producing significantly more errors on the down ($p < .01$) and left-right ($p < .05$) than right-left direction. There were also significantly more errors on the down than left-right direction ($p < .05$). Although the main effect of test was not significant, there was a trend for there to be more backward than forward errors ($p < .10$)

Grade five. Another 3-factor repeated measures ANOVA revealed a significant main effect of direction, $F(2,22) = 8.58$, $p < .01$. Children made significantly more errors on the down ($p < .01$) and left-right ($p < .05$) than right-left direction. There was also a significant main effect of test, $F(2,22) = 11.69$, $p < .01$, with the forward pairs ($p < .01$) and backward ($p < .01$) significantly more difficult than the same pairs. Together, children made significantly more errors on the "different" than "same" trials ($p < .01$).

Graduate students. A significant main effect of direction was found, $F(2,22) = 12.55$, $p < .01$. The down direction produced significantly more errors than the left-right ($p < .05$) or right-left direction ($p < .01$).

A separate 3 (grade) X 2 (rate of implied movement) X 3

(direction) X 3 (test) repeated measures ANOVA was performed in order to determine the effect of rate of implied motion in the photographs. The direction and test effects were both significant again, as was the effect of rate of implied motion, $F(1,32) = 195.70$, $p < .001$. The number of errors, consistent with the reaction time data and the representational momentum claim, increased significantly with the faster rate of implied motion. Since those photographs that implied a faster rate of movement were also those separated by the fewest number of frames, this result also indicates that subjects had more difficulty with those pairs that were closest in real world time. The mean percentage of errors for each rate by subjects in each grade is presented in Table 9.

Table 9
Percentage of Errors by Rate of Implied Movevement
Experiment 1

| Age Group | Faster Rate | Slower Rate |
|---|---|---|
| Grade 3 | 33 | 10 |
| Grade 5 | 31 | 7 |
| Graduate | 25 | 6 |

Unlike the reaction time data, there was a significant rate of implied motion X test interaction, $F(2,64) = 40.29$, $p < .001$. With the faster rate of motion, subjects made an equal number of errors on the forward and backward trials

followed by the same trials. With the slower rate of motion the greatest number of errors was given to the same trials followed by the backward and then forward trials. This interaction is presented in Figure 5 (p. 82).

Finally, there was a nonsignificant grade X rate of implied motion X test interaction trend, $F(4,64) = 2.34$, $p < .07$. While the 3rd graders made more backward than forward errors with both rates, the fifth graders and graduate students made more forward than backward errors only with the faster rate of implied motion (this trend was nearly significant for the graduate students, $p < .10$).

In order to determine the effect of pictorial movement cue, the last ANOVA performed was a 3 (grade) X 3 (pictorial movement cue) X 3 (test) repeated measures ANOVA. Unlike the results of the reaction time analysis, the main effect of pictorial movement indicator was not significant. The mean percentage of errors for each cue by subjects in each grade is presented in Table 10.

Table 10
Percentage of Errors by Pictorial Movement Indicator
Experiment 1

| Age Group | 1 Cue | 2 Cues | 3 Cues |
|---|---|---|---|
| Grade 3 | 22 | 24 | 21 |
| Grade 5 | 20 | 22 | 18 |
| Graduate | 17 | 16 | 18 |

There was, however, a significant pictorial movement cue X test interaction, $F(4,128) = 3.90$, $p < .05$. With only one pictorial movement indicator, subjects made (nonsignificantly) more errors with the forward than backward trials. However, with 2 and 3 movement cues, more errors were given to the backward than forward trials. This interaction is presented in Figure 6 (p. 83).

In order to determine whether subjects' correct responses were above chance, the following equation was used: for subjects in each age group C is the mean number of correct trials

$$Z = \frac{\bar{C} - 27}{\sqrt{\frac{54/4}{N}}}$$

The results of these Z transformations indicate that subjects' responses were above chance and therefore not based on guessing (3rd grade, $Z = 13.88$, $p < .01$; 5th grade, $Z = 15.56$, $p < .01$; graduate students, $Z = 16.89$, $p < .01$).

Similar to the reaction time analysis, and contrary to Freyd's (1983) study, individual differences in forward versus backward error rates were found. While only 1 of 11 (9%) 3rd graders made more forward errors, 3 of 12 (25%) fifth graders, and 7 of 12 (58%) of graduate students made more errors on the forward than backward trials. Further,

unlike the reaction time data, these grade differences were significant, $\chi^2 = 6.77$, $p < .05$, indicating a strong developmental trend.

In order to determine whether there was a practice effect, a correlated t-test was performed on the number of errors made in the first and second half of the trials. There was a trend toward fewer errors in the second half of the trials for all subjects combined, $t(34) = 1.93$, $p < .07$. This trend was significant for the fifth graders separately, $t(11) = 2.35$, $p < .05$.

The decline in error rate during the second half of the experiment was due specifically to the decline in the number of errors made on the forward trials by the fifth graders, $t(11) = 2.45$, $p < .05$, and graduate students, $t(11) = 2.46$, $p < .05$. Similar to the reaction time data, but contrary to the representational momentum claim, the practice effect was specific to the forward pairs.

The main effect of test was significant in each half of the experiment: first half, $F(2,64) = 6.10$, $p < .01$; second half, $F(2,64) = 5.40$, $p < .01$. In both halves, the forward and backward pairs were not significantly different. Instead, subjects made significantly more errors on the forward ($p < .01$) and backward ($p < .01$) than same pairs (although during the second half of the experiment, the number of errors on the backward pairs was almost significantly greater than the forward pairs ($p < .10$), due to the significant decline in the number of forward errors

by the older subjects).

During the first half of the experiment, there was a trend for fifth graders ($p < .10$) and graduate students ($p < .10$) to make more forward errors than third graders, although this trend disappeared during the second half of the trials. Further, the graduate students were the only group that made nearly more forward than backward errors during the first half of the experiment ($p < .15$). During the second half of the experiment, the main effect of grade was nearly significant, $F(2,32) = 2.83$, $p < .08$, with the number of total errors decreasing with age. This was due to the significant practice effect shown by the fifth graders and graduate students, but not third graders.

A summary of the results of Experiment 1 is presented in Table 11.

Table 11
Summary of Results
Experiment 1

Significant Effects ($p < .05$)

| Independent Measures and Interactions | Dependent Measures: Reaction Time | Dependent Measures: Error Rate |
|---|---|---|
| Grade | Yes<br>3rd > Graduate<br>3rd > 5th | No |
| Direction | Yes<br>Down > Right<br>Left > Right | Yes<br>Down > Right<br>Left > Right<br>Down > Left |
| Test | Yes<br>Bkwd > Fwd<br>Bkwd > Same | Yes<br>Fwd > Same<br>Bkwd > Same |
| Direction X Test | No | Yes |
| Rate of Implied Movement | Yes<br>Fast > Slow | Yes<br>Fast > Slow |
| Rate of Movement X Test | No | Yes |
| Pictorial Movement Cue | Yes<br>3 > 1<br>3 > 2 | No |
| Movement Cue X Test | No | Yes |

# DISCUSSION

In general, the results of Experiment 1 provide only minimal support for the "representational momentum" claim and question the robustness of the phenomenon. Most tellingly, contrary to Freyd's (1983) picture study, the present experiment found that subjects took significantly longer to correctly judge photograph pairs presented in "backward", rather than "forward" order. Further, although not statistically significant, the error rate data were in the same direction. Beyond these overall main effects, however, the results of Experiment 1 reveal several subtle developmental differences that both support (although not strongly) and do not support the representational momentum claim. The graduate students, the group most comparable to Freyd's subjects, took (nonsignificantly) longer to respond to the backward than forward pairs). Consistent with Freyd, however, they were the only subjects that made (nonsignificantly) more forward errors. Thus, with regard to overall reaction time and error rate, the graduate students neither confirmed nor refuted the original representational momentum finding.

It is unclear why, in this experiment which attempted to replicate Freyd's (1983) study as closely as possible, the backward pairs took significantly longer to judge correctly than the forward pairs (particularly for the third graders). There are, however, two possible reasons why this

result might be expected to occur. Similar to Freyd's explanation, the first photograph in the pair might have created an expectation that the next scene would continue the action. However, when the next scene contradicted this expectation, longer object identification and decision time is consistent with studies that report longer processing time is required when objects occur in low-probability contexts (e.g., Biederman et al., 1973). A second explanation, consistent with Gibson (1979), is that information in events specifies a sequential order. If this does not occur, it is incoherent, an ecological contradiction, which might require more time, rather than less, to analyze.

Another possibility for the discrepant reaction time findings could be, as Freyd later claimed (Freyd & Finke, 1985), that reaction time is not as reliable a measure as error rate. Further, since children were less accurate than adults, their reaction time analyses included a smaller number of responses (only correct response times were included). Since the implications from the reaction time data may be less clear, the remainder of the discussion will focus on the error rate data.

Both children's and adults' memory for the photographs was better than exhibited by Freyd's adult subjects. This may have been due to the better quality photographs used in the present experiment. In any event, when errors did occur, they were just as likely to occur with the forward as

backward pairs. Thus, although short-term memory for photographs is not always accurate, the results of Experiment 1 do not support the essential representational momentum hypothesis that short-term memory for movement in photographs is distorted in a unidirectional (i.e., forward) direction.

Although the forward and backward pairs were not significantly different in error rate, the "different" pairs were significantly more difficult than the "same" pairs for all grades combined, and particularly for the fifth-grade students. This finding is consistent with other developmental studies that found, using brief exposure durations in which perceptual scanning is eliminated, children are less accurate on "different" than "same" judgments (e.g., Blake & Beilin, 1975). A signal detection analysis performed on the present data suggests that the fifth-grade children had a less strict criterion for "same" than the adults, and that this may have been responsible for their greater error rate on "different" pairs. Although it is unclear why, they may have had a bias to respond "same" when they were unsure. This analysis is tentative, however, since there was not an equal number of same and different trials nor an equal opportunity to make same and different errors.

The main effect of direction was statistically significant for reaction time and error rate. The finding that a greater number of errors was made on one direction

than another is not in itself contrary to the representational momentum hypothesis. Subjects' greatest difficulty with the down direction, for example, could have been due to the fact that the majority of those pairs were separated by the fewest number of frames, and thus could have been more difficult for this reason alone. What is inconsistent with the representational momentum claim, however, is the left-right difference and the finding that significantly more forward errors were made only with the left-right direction. The left-right difference is important because these two directions were never significantly different in any of the representational momentum studies. Although the graduate students in the present study did not exhibit significant left-right differences, consistent with Freyd's data, they did not exhibit a significant test effect either. The one study that tested both left and right directions as a within-subject factor found that it weakened, but did not eliminate the effect (Finke & Shyi, 1988). The finding that significantly more forward than backward errors were made only with the left-right direction is even more damaging, because according to the representational momentum hypothesis, more forward errors should occur regardless of direction. Although adults made more forward errors with all directions, it was only significant with the left-right.

The task became more difficult with the longer ISI, as indicated both by increased error rate and reaction time.

The main effect of ISI, however, was not statistically significant. This result, consistent with Freyd's data, tends to rule out such sensory effects as afterimages, apparent motion, or conceptual masking as an explanation of the results, because these effects would decrease in strength over time. Thus, the representational momentum effect probably has a cognitive as opposed to a sensory basis. Freyd and Johnson (1987), however, recently reported that the representational momentum effect peaks at approximately a 250 msec delay and diminishes after that. This did not occur in the present experiment, however. Nor were there more forward errors with the 250 ISI, which would also be predicted by the representational momentum hypothesis, due to the increase in velocity (speed of presentation). Although the graduate students (and fifth graders) did make more forward than backward errors with the 250 msec ISI, this was not significant.

With the longer delay interval, graduate students were the only subjects whose number of errors increased the least. This could be the result of age-related differences in rehearsal strategies or the time information remains available in short-term memory. There is evidence that adults retain information from scenes for longer periods of time than do children (G.S. Goodman, 1980), and that children are not as capable of maintaining or rehearsing visual information (Blake & Vingilis, 1977; Morrison, Holmes & Haith, 1974).

The one effect that appeared to support the representational momentum hypothesis was rate of implied motion in the photographs. With the faster rate of implied motion, there were significantly more errors and longer reaction times. To be completely consistent with the representational momentum hypothesis, however, there should have been more errors specifically on the forward pairs, since according to the representational momentum hyothesis, amount of momentum increases as implied velocity or rate increases. This was not the case, here, however. Instead, with the faster rate, there was an equal number of forward and backward errors. Thus, once again, the effect did not occur in a specific (forward) direction. The older subjects (fifth graders and graduate students), however, did make more forward than backward errors only with the faster rate (and this trend was nearly significant for the graduate students).

The pictorial movement effect was the least clear. While children made the fewest errors on the photographs that contained 3 movement cues, graduate students made the most errors on photographs with 3 cues. Photographs containing only 1 cue were the only ones that received (nonsignificantly) more forward errors. This finding suggests that something about the photographs themselves, and the manner in which the information is depicted, has an effect on memory for pictures.

Contrary to Freyd's findings, the present results

suggest that there is a great deal of individual variability in response to forward and backward distractors. Although Freyd reports that almost all of her adult subjects demonstrate forward memory errors (show the effect), very few of the children in the present study demonstrated a greater number of forward than backward errors. By graduate school age, however, over half (but not all) of the subjects made more errors on the forward pairs, and this developmental trend was significant.

Only the adults made a (nonsignificantly) greater number of errors on the forward pairs, more forward errors with each direction (this was significant only with the left), and (nonsignificantly) more forward errors with both ISIs. Conversely, the third graders consistently made more backward errors. The fifth graders were a transition group, making more forward errors under some conditions (with the 250 ISI, the left direction (significantly), and the faster rate of implied movement), similar to the adults, but more backward errors with others. Thus although the grade differences in overall error rate were not statistically significant, which would be consistent with the representational momentum hypothesis, these more subtle differences suggest a developmental trend (toward more forward errors with age). Further, the effect may not be innate or automatic but result from some types of learning or experiential processes.

As predicted, the only significant developmental

difference was in speed of reaction time, which is a robust developmental finding. The decrease in reaction time with age could reflect the development of more efficient strategies for approaching the task, or increased automatization (Case, 1985). Although adults were faster and more accurate in this picture recognition memory task, the differences were of a quantitative not qualitative nature. Given the paucity of data on children's short-term memory for pictures, it is of interest that they performed nearly as well as adults.

The practice effect found for both reaction time and error rate specifically and exclusively on the forward pairs suggests, contrary to Freyd's claim, not only that representational momentum is influenced by practice, but also that the underlying assumptions of the representational momentum hypothesis that the effect is modular, mandatory, cognitively impenetrable, and an analogic process that stems from the nature of the perceptual system, may be incorrect. This finding is particularly important since there was a significant practice effect with a much smaller number of trials than in the representational momentum studies. At the same time, however, it suggests that there may be something special about response to the forward pairs initially but that the effect diminishes with practice. Once again, however, the practice effect was significant only for the graduate students and fifth graders.

The results of the present experiment lead to questions

concerning the robustness of the representational momentum claim, in finding that subjects took significantly longer on the backward than forward pairs, the error rate was in the same direction, there were individual differences, a practice effect, and, lastly, a developmental trend.

In sum, although there was no clear representational momentum effect, one possibility is that the test positions used in this experiment were not sensitive enough to capture the effect, since the real world time separation between frames varied. Experiment 2 was undertaken to test for the effect of real-world time separation by utilizing a technique developed by Freyd and Finke (1985).

Figure 1.

**THE EQUIPMENT**

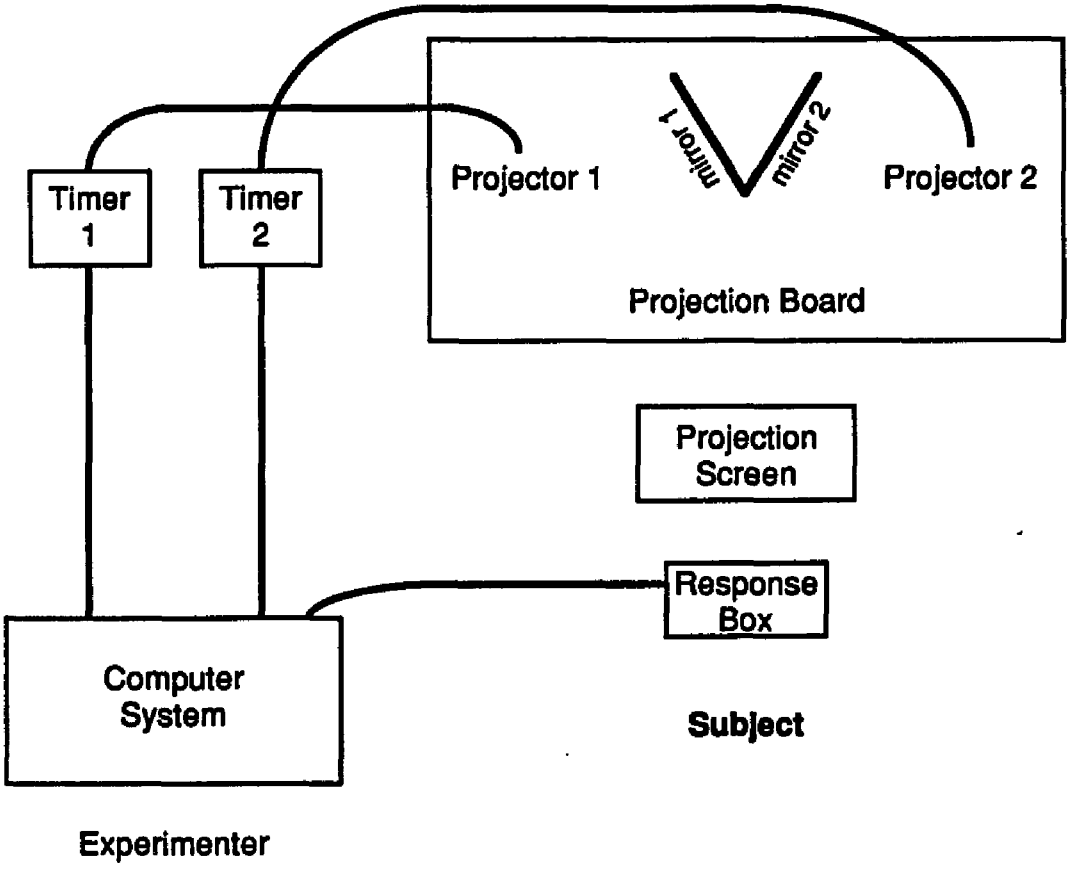
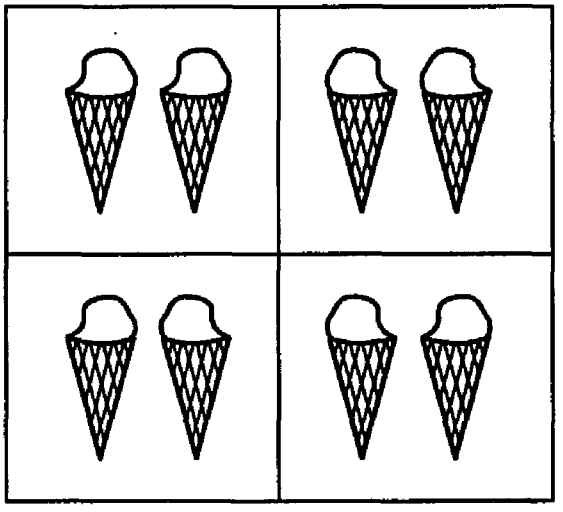


Figure 2.

**Stimulus pairs for pretraining phase**



Note: A = Same Pair; B = Same Pair; C = Different Pair; D = Different Pair.

Figure 3.

**Schematic diagram of sequence of photograph pairs**

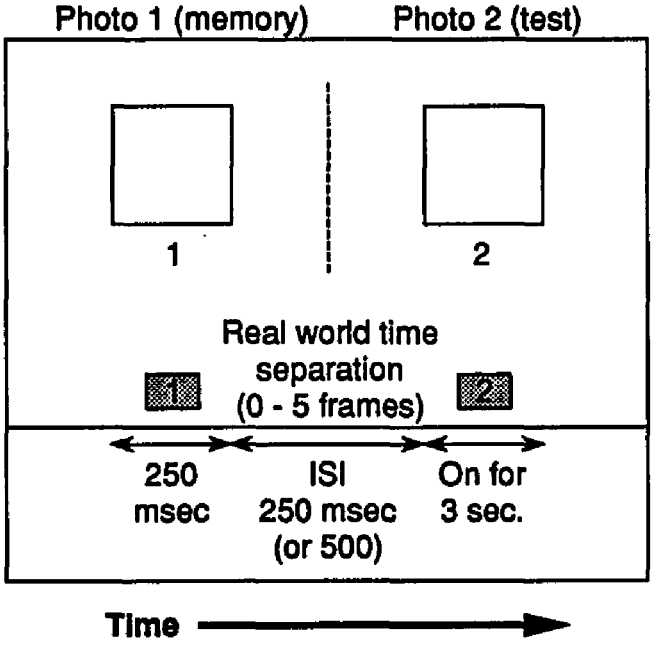


Figure 4

Direction by test interaction (Error rate)

Experiment 1

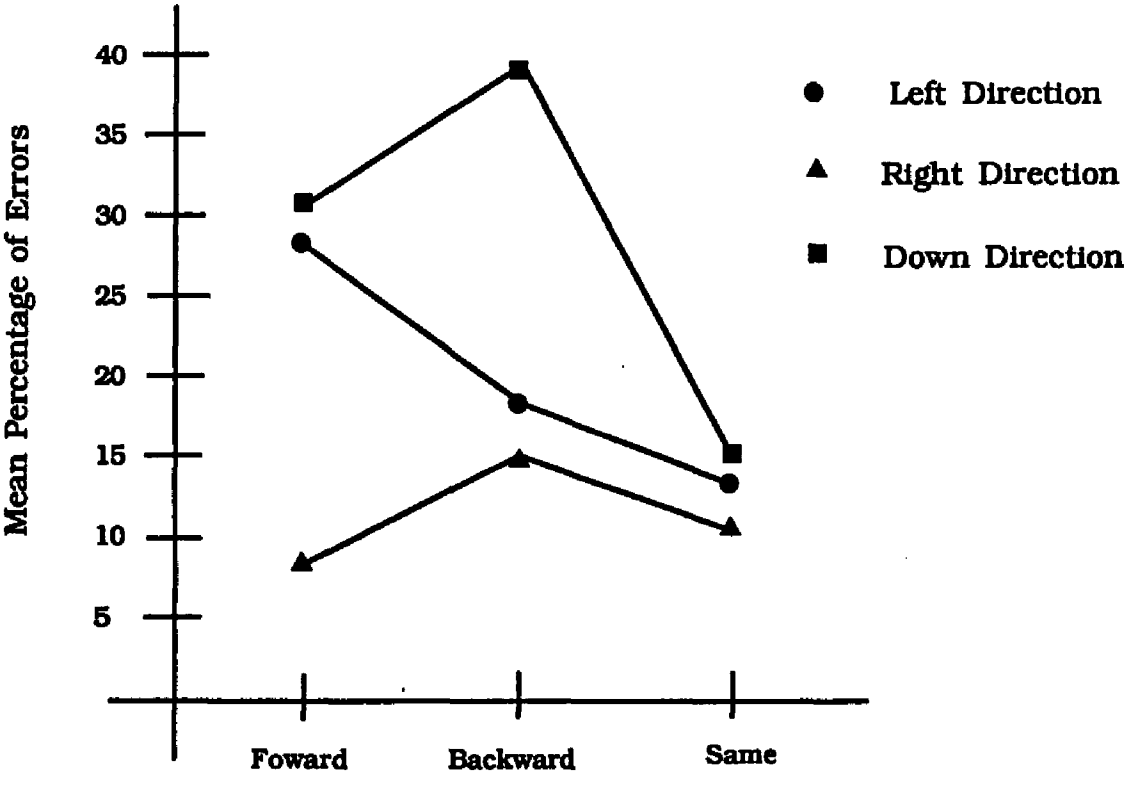


Figure 5

Rate of implied movement by test interaction (Error rate)

Experiment 1

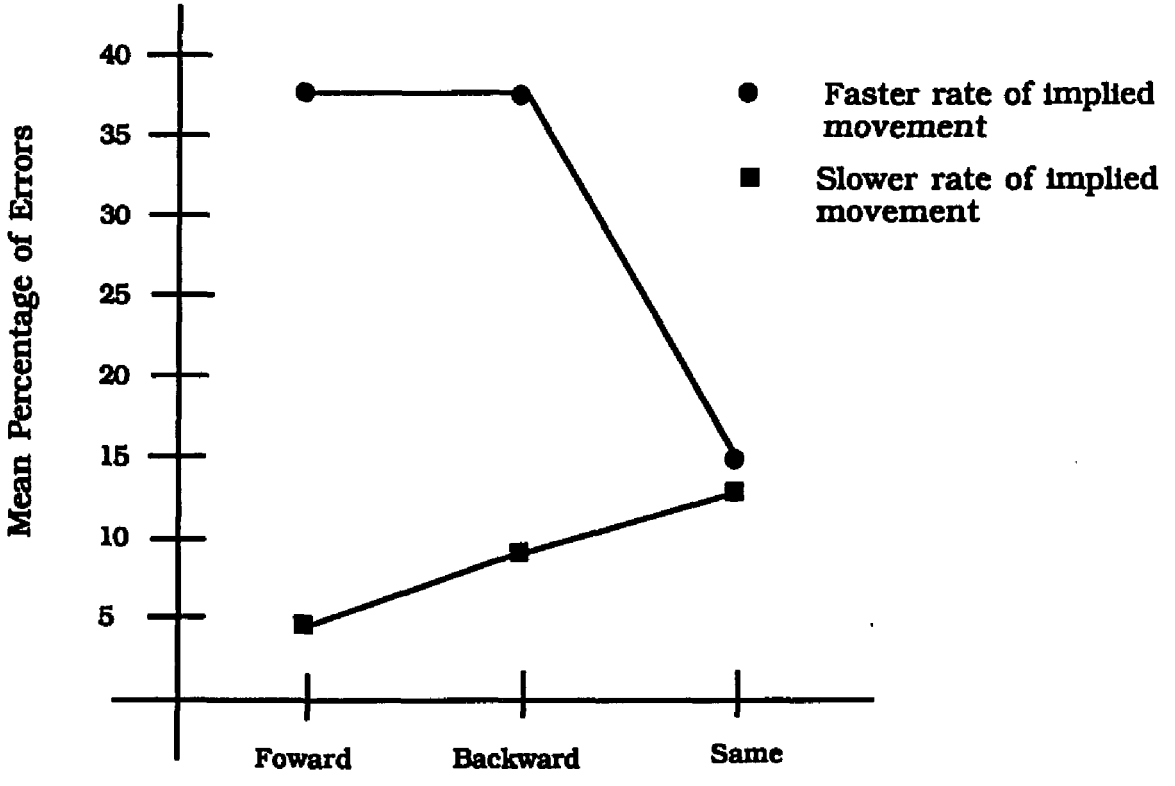
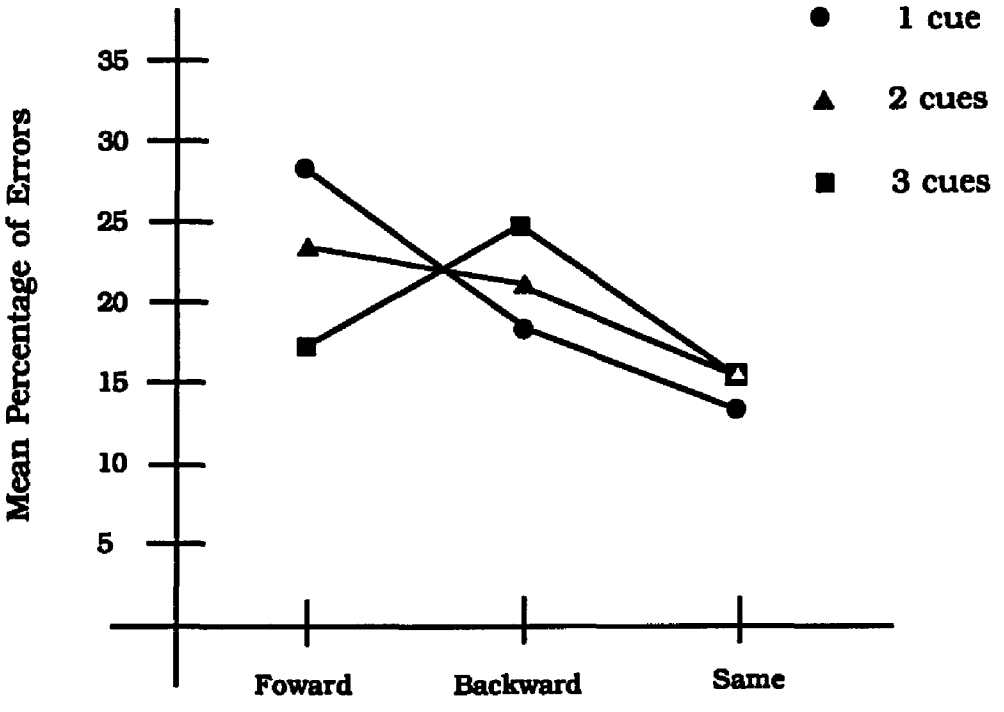


Figure 6

Pictorial movement indicator by test interaction (Error rate)

Experiment 1



## Experiment 2

Since the amount of real world time separation (number of frames) between photograph pairs varied across the different action sequences in Experiment 1 (in order to be consistent with Freyd, 1983), and since the effect of the different separations was not considered but may have affected the results (i.e., it may have weakened the effect), the purpose of the second experiment was to determine whether the "representational momentum" effect would be obtained if a range of real world time separations was presented to subjects. The separation to which the greatest number of errors or longest reaction times is given to is, presumably, the one most similar to the memory representation and thus the one most representative of how far the memory has "shifted".

More recent representational momentum studies have used a range of 9 (rather than simply 3) test patterns (1 "same", 4 "forward", and 4 "backwards" by small amounts from the "same" pattern). Using rectangles as stimuli, for example, Freyd and Finke (1985) found that subjects gave the greatest number of "same" responses not to the actual "same" rectangle, but to the one that was presented only slightly forward from the "true" same. The distribution of error responses across the test patterns was then used to estimate how far the memory had shifted forward.

Although never attempted with photographs, it was

hypothesized that this more precise technique might reveal the effect described by Freyd (1983) more strongly than in Experiment 1. Based on the later representational momentum studies, it was hypothesized not only that more errors would occur with the forward, rather than equivalently displaced backward, trials but also that the greatest number of errors would occur with the smallest real world time separation (i.e., 1 frame forward).

## METHOD

### Subjects

Thirty-six subjects participated in this study. There were 12 3rd grade children whose mean age was 8 years-9 months (range = 8 months); 12 5th grade children whose mean age was 10 years-9 months (range = 6 months); and 12 graduate students whose mean age was 32 years-10 months (range = 249 months). The third grade group included 6 males and 6 females, the fifth grade children included 4 males and 8 females, and the graduate students included 4 males and 8 females. All of the subjects had normal or corrected to normal vision and all completed the task. None of the subjects had participated in Experiment 1.

### Materials

The photograph pairs were drawn from the same nine filmed action sequences from Experiment 1, except that for this experiment 7 pairs were drawn from each action

sequence: one "same" and 6 "different". In the interest of reducing the number of necessary trials for children, it was decided that 7 test positions (rather than 9) would be used in the present experiment: 1 "same", 3 forward (by 1, 3 and 5 frames), and 3 backward (by 1, 3 and 5 frames). The photograph pairs were made by selecting one "same" frame from each filmed action sequence, and then taking the 1st, 3rd and 5th frames from the "same" frames in both directions (forward and backward).

Thus, unlike Experiment 1 where there was a different "memory" or first photograph in each pair, each pair (from the same action sequence) now contained the identical "memory" photograph. Since it was necessary to present the one "same" photograph with each "different" photograph, duplicates were made of all the slides so that they would be of the same color and brightness.

Further, unlike Experiment 1, there were 63 experimental trials (9 action sequences X 7 pairs for each). Since the main effect of ISI was not significant in Experiment 1, and since the majority of the representational momentum studies used a 250 msec ISI, only a 250 msec ISI was used in the present experiment.

Finally, there were now 14 practice pairs (7 from the tossing and 7 from the running sequences), so that subjects would have an opportunity to see each type of pair twice.

Equipment and Procedure

The equipment and procedure was the same as Experiment

1.

## RESULTS

The data were organized in the same manner as Experiment 1. All trials on which reaction times were greater than 3000 msecs were excluded from all analyses. These occured on fewer than 1% of all trials for all grades combined and separately. Thus, unlike Experiment 1, there were no significant grade differences on number of trials greater than 3 seconds.

Pretraining Trials. None of the third or fifth graders needed to see the pretraining pictures more than once.

Practice Trials. Four (33%) of the 12 third graders, four (33%) of the 5th graders, but none of the graduate students saw the practice pairs twice. Preliminary analyses indicated that there were no differences between those subjects who viewed the practice pairs once or twice in either correct reaction time or error rate.

### Reaction Time

Preliminary t-tests indicated that there were no differences in mean correct reaction times by handedness or corrected or uncorrected vision. Similar to Experiment 1, however, there was a trend in the third grade for males to have longer mean correct reaction times than females, $t(8) = 1.87$, $p < .10$. Within the fifth grade, however, there was a trend for females to have longer reaction times than males,

$t(5) = -2.28$, $p < .07$.

The mean correct reaction times for each direction and test by subjects in each grade are presented in Tables 12 and 13.

Table 12
Mean Correct Reaction Times and Standard Deviations by Direction (in msecs)
Experiment 2

| Age Group | Left | Right | Down |
|---|---|---|---|
| Grade 3 | 1151 (387) | 1177 (411) | 1311 (481) |
| Grade 5 | 741 (299) | 789 (328) | 891 (377) |
| Graduate | 742 (338) | 748 (299) | 834 (351) |

Table 13
Mean Correct Reaction Times and Standard Deviations by Test Position (in msecs)
Experiment 2

| Age Group | -5 | -3 | -1 | 0 | +1 | +3 | +5 |
|---|---|---|---|---|---|---|---|
| Grade 3 | 1147 (399) | 1194 (375) | 1381 (502) | 1242 (410) | 1332 (548) | 1146 (377) | 1126 (419) |
| Grade 5 | 769 (296) | 799 (304) | 879 (361) | 867 (323) | 808 (475) | 767 (298) | 764 (338) |
| Graduate | 701 (231) | 735 (287) | 839 (337) | 822 (370) | 864 (420) | 790 (370) | 719 (302) |

A 3 (grade) x 3 (direction) x 7 (test position) repeated measures ANOVA performed on correct reaction times

revealed, consistent with Experiment 1, a significant main effect of grade, $F(2,20) = 6.54$, $p < .01$, with mean correct reaction times decreasing with increasing age (third = 1209 msecs; fifth = 804 msecs; graduate = 772 msecs). Comparisons of means using the Tukey HSD procedure showed, similar to Experiment 1, that graduate students had significantly faster reaction times than third grade children ($p < .05$), and that fifth grade children responded more quickly than the third grade children ($p < .05$). Consistent with Experiment 1, the main effect of direction was also significant, $F(2,40) = 14.82$, $p < .01$. Repeated measures univariate F tests revealed that subjects took significantly longer on the down than 1-r ($p < .01$) or r-1 direction ($p < .01$). Further, subjects took significantly longer on the r-1 than 1-r direction ($p < .05$). A significant main effect of test was found, $F(6,120) = 7.69$, $p < .01$. This effect was due to the quadratic distribution ($p < .01$), or curvilinear nature of the data. Consistent with Freyd's data, subjects' correct reaction times were fastest at the end points and became longer as the test positions became more similar to the "same" test (that is, as the discriminations became more difficult). There was also a nonsignificant trend for subjects to respond more quickly to the "same" than the -1 trials ($p < .07$). Contrary to the representational momentum hypothesis, subjects took longer to respond to the -1 (backward) than +1 (forward) trials. This difference was not statistically significant

however, $F(1,33) = .23$, $p > .6$.

Unlike Experiment 1, there was a significant grade X test interaction, $F(12,120) = 2.39$, $p < .05$. While the third and fifth graders took (nonsignificantly) longer on the -1 than +1 trials, the graduate students took (nonsignificantly) longer on the +1 than -1 trials. This interaction is presented in Figure 7 (p. 108).

Separate analyses were then conducted in order to assess the effects of direction and test within each grade.

Grade three. A separate 3 (direction) X 7 (test) repeated measures ANOVA revealed a significant main effect of test, $F(6,48) = 3.60$, $p < .05$, which was due to the quadratic trend ($p < .01$). Reaction times in response to the "same" position were also significantly faster than to the -1 position ($p < .05$). The main effect of direction was also significant, $F(2,18) = 4.31$, $p < .05$, with students taking significantly longer to respond correctly to the down than r-l ($p < .01$) or l-r direction ($p < .01$).

Grade five. There was a significant main effect of direction, $F(2,18) = 8.10$, $p < .05$, with students taking significantly longer to judge correctly the down than r-l ($p < .01$) or l-r direction ($p < .01$). The right-left direction also took significantly longer for the students to judge than the left-right ($p < .05$).

Graduate students. There was a significant main effect of direction, $F(2,18) = 6.63$, $p < .05$, with students taking significantly longer to respond to the down direction than

the r-l ($p < .05$) or l-r direction ($p < .05$). There was also a significant main effect of test, $F(6,48) = 2.77$, $p < .05$, which was due to the quadratic trend ($p < .01$).

Rate of implied movement in the photographs was analyzed using a 3 (grade) X 2 (rate of implied motion) X 7 (test) repeated measures ANOVA. Unlike Experiment 1, rate of implied movement was not significant (faster rate = 917 msecs; slower rate = 938 msecs). The mean correct reaction times for each rate by subjects in each grade are presented in Table 14.

Table 14
Mean Correct Reaction Times and Standard Deviations by Rate of Implied Movement (in msecs) Experiment 2

| Age Group | Faster Rate | Slower Rate |
|---|---|---|
| Grade 3 | 1197 (448) | 1223 (410) |
| Grade 5 | 797 (350) | 812 (329) |
| Graduate | 762 (320) | 784 (346) |

Another 3 (grade) X 3 (pictorial movement cue) X 7 (test) repeated measures ANOVA was performed in order to determine the effect of pictorial movement indicator. Once again grade and test were significant, as was the effect of movement cue, $F(2,26) = 23.49$, $p < .01$. Significantly longer reaction times were given to those photographs

containing only 1 movement cue than those with 2 ($p < .01$) or 3 cues ($p < .05$). In addition, similar to Experiment 1, those photographs with 3 cues took significantly longer to judge correctly than those with 2 cues ($p < .01$). The mean correct response latencies for each movement cue by grade are presented in Table 15.

Table 15
Mean Correct Reaction Times and Standard Deviations by Pictorial Movement Indicator (in msecs) Experiment 2

| Age Group | 1 Cue | 2 Cues | 3 Cues |
|---|---|---|---|
| Grade 3 | 1291 (469) | 1114 (405) | 1226 (400) |
| Grade 5 | 825 (332) | 732 (312) | 854 (362) |
| Graduate | 857 (428) | 698 (238) | 768 (292) |

Unlike Experiment 1, there was a significant grade X cue interaction, $F(4,26) = 4.11$, $p < .05$. While the third graders and graduate students took longest with those photographs containing 1 cue followed by 3 and then 2 cues, the fifth graders took longest with those photographs containing 3 cues followed by 1 and then 2 cues. This interaction is presented in Figure 8 (p. 109).

As in Experiment 1, there were individual differences in mean correct reaction times to the forward and backward pairs. Unlike Experiment 1, however, a greater number of

students in each age group took longer to respond correctly to the forward than backward pairs (that is, showed the representational momentum "effect"). While 6 (50%) of the third graders had longer reaction times to the +1 than -1 trials, 7 (58%) of the fifth graders and 7 (58%) of the graduate students had longer mean correct reaction times to the +1 trials.

Consistent with Experiment 1, correct reaction times decreased over the second half of the experiment for all grades combined, $t(35) = 3.0$, $p < .05$, and for the fifth graders separately, $t(11) = 3.46$, $p < .01$, thus indicating a practice effect. Unlike Experiment 1, however, reaction times decreased specifically on the -1 (rather than +1) trials for the fifth graders, $t(11) = 2.44$, $p < .05$ and graduate students, $t(11) = 3.10$, $p < .01$.

Error Rate

The overall error rate was 16%. The percentage of errors made across each direction and test by subjects in each grade is given in Tables 16 and 17.

Table 16
Percentage of Errors by Direction
Experiment 2

| Age Group | Left | Right | Down |
|---|---|---|---|
| Grade 3 | 12 | 16 | 24 |
| Grade 5 | 10 | 14 | 18 |
| Graduate | 11 | 19 | 24 |

Table 17
Percentage of Errors by Test Position
Experiment 2

| Age Group | -5 | -3 | -1 | 0 | +1 | +3 | +5 |
|---|---|---|---|---|---|---|---|
| Grade 3 | 4 | 7 | 34 | 8 | 51 | 12 | 7 |
| Grade 5 | 4 | 7 | 25 | 13 | 38 | 8 | 1 |
| Graduate | 8 | 8 | 34 | 13 | 49 | 10 | 3 |

A 3 (grade) X 3 (direction) X 7 (test) repeated measures ANOVA revealed, consistent with the reaction time data, a significant effect of direction, $F(2,66) = 21.88$, $p < .01$. Repeated measures univariate F tests revealed that subjects made a significantly greater number of errors with the down than left-right ($p < .01$) or right-left directions ($p < .01$). Subjects also made a significantly greater number of errors on the right-left than left-right direction ($p < .01$). The main effect of test was also significant, $F(6,198) = 65.64$, $p < .001$. Consistent with the representational momentum hypothesis, and unlike Experiment 1, subjects made a significantly greater number of errors on the +1 than -1 test positions ($p < .01$). Further, a greater number of errors was made on the +1 trials ($p < .01$) and -1 ($p < .01$) than "same" trials. The test results also yielded, consistent with the reaction time data, a quadratic trend ($p < .01$), with errors decreasing as the test positions became more dissimilar from the "same" position.

Consistent with Experiment 1, there was a significant

direction X test interaction, $F(12,396) = 5.94$, $p < .05$. Unlike Experiment 1, however, there were more +1 than -1 errors with each of the directions (although this was significant only with the 1-r and r-1 directions). With the down direction, there was almost an equal number of forward and backward errors. This interaction is presented in Figure 9 (p. 110).

Since there was a significant direction X test interaction, separate ANOVAS were performed in order to determine the effect of test within each direction. The results revealed that the test effect was significant within each; 1-r direction, $F(6,210) = 20.35$, $p < .01$, r-1, $F(6,210) = 58.33$, $p < .01$, and down, $F(6,210) = 19.89$, $p < .01$. With the r-1 and 1-r directions, there were significantly more +1 than -1 errors ($p < .01$); more +1 ($p < .01$) and -1 than "same" errors ($p < .01$); and quadratic trends ($p < .01$). With the down direction, however, only the +1 ($p < .01$) and -1 trials ($p < .01$) were more difficult than the "same" trials.

Similar to Experiment 1, there were no grade differences in error rate, although in this experiment the graduate students made even slightly more errors than the fifth and third graders (18%, 14% and 17%, respectively).

Separate analyses were then conducted within each grade.

Grade three. A 3 (direction) X 7 (test) repeated measures ANOVA revealed a significant main effect of

direction, $F(2,22) = 6.57$, $p < .01$, with students making more errors on the down than 1-r direction ($p < .01$). The effect of test was also significant, $F(6,66) = 28.38$, $p < .01$, with the data yielding a quadratic trend ($p < .01$). Students made significantly more errors on the +1 than -1 trials ($p < .01$), and on the +1 ($p < .01$) and -1 ($p < .01$) than "same" trials.

Grade five. There was a significant main effect of direction, $F(2,22) = 5.28$, $p < .05$, with the down direction more difficult than the 1-r ($p < .01$). The effect of test was also significant, $F(6,66) = 13.30$, $p < .01$. Students made significantly more errors on the +1 than the -1 trials ($p < .05$), and on the +1 ($p < .01$) than "same" trials. The error data also yielded a quadratic trend ($p < .01$).

Graduate students. There was a significant main effect of direction, $F(2,22) = 11.85$, $p < .01$, with students making significantly more errors on the down ($p < .01$) and the r-1 ($p < .05$) than the 1-r direction. The test effect was significant, $F(6,66) = 27.72$, $p < .01$. Students made significantly more errors on the +1 than -1 trials ($p < .01$). The +1 ($p < .01$) and -1 trials ($p < .01$) were also more difficult than the "same" trials. There was also a significant quadratic trend ($p < .01$).

A 3 (grade) X 2 (rate of implied movement) X 7 (test position) repeated measures ANOVA was performed in order to determine the effect of rate of implied movement in the photographs. Consistent with the reaction time data, and

unlike Experiment 1, the main effect of rate of implied motion was not significant (mean percentage of errors for the faster rate = 16%; slower rate = 17%). The percentage of errors for each rate by subjects in each grade is presented in Table 18.

Table 18
Percentage of Errors by Rate of Implied Movement
Experiment 2

| Age Group | Faster Rate | Slower Rate |
|---|---|---|
| Grade 3 | 17 | 17 |
| Grade 5 | 15 | 13 |
| Graduate | 16 | 19 |

Finally, another 3 (grade) X 3 (pictorial movement indicator) X 7 (test position) repeated measures ANOVA was performed in order to determine the effect of pictorial movement indicator. It revealed, in addition to test, a significant main effect of movement cue, $F(2,66) = 44.10$, $p < .01$. Unlike Experiment 1, but consistent with the reaction time data, a significantly greater number of errors was made on those photographs containing one cue than those with 2 ($p < .01$) or 3 movement cues ($p < .01$). The percentage of errors for each movement cue by grade is presented in Table 19.

Table 19
Percentage of Errors by Pictorial Movement Indicator
Experiment 2

| Age Group | 1 Cue | 2 Cues | 3 Cues |
|---|---|---|---|
| Grade 3 | 23 | 11 | 17 |
| Grade 5 | 23 | 10 | 8 |
| Graduate | 26 | 13 | 14 |

Similar to Experiment 1, the movement cue X test position interaction was also significant, $F(12,396) = 2.38$, $p < .05$. With those photographs containing 1 and 3 cues, subjects made significantly ($p < .01$) more errors on the +1 than -1 trials. With those photographs containing 2 cues, however, subjects made almost an equal number of +1 and -1 errors. This interaction is presented in Figure 10 (p. 110).

As in Experiment 1, Z transformations revealed that subjects' responses were above chance. For third graders, $Z = 18.42$, $p < .01$; fifth graders, $Z = 19.29$, $p < .01$; and for graduate students, $Z = 17.47$, $p < .01$.

Similar to Experiment 1, there were individual differences in the number of errors on the +1 and -1 pairs. Unlike Experiment 1, however, a much higher percentage students (nine (75%) of 12 in each grade) made a greater number of errors on the +1 than -1 test positions. Further, the grade differences were not significant.

Consistent with Experiment 1, the number of errors

decreased significantly during the second half of the experiment for all grades separately and combined, $t(35) = 3.11$, $p < .01$, thus indicating a practice effect. Further, the decline in the number of +1 errors was nearly significant for all subjects combined, $t(35) = 1.86$, $p < .07$, and for the graduate students, $t(11) = 1.88$, $p < .08$. Unlike Experiment 1, but consistent with the reaction time data, there was also a significant decline in the number of -1 errors for the fifth graders, $t(11) = 5.74$, $p < .01$, and graduate students, $t(11) = 6.17$, $p < .01$.

The +1/-1 error difference was not significant in the first half of the experiment, $t(35) = .95$, $p > .2$. Only in the second half of the experiment were there significantly more +1 than -1 errors for the fifth graders, $t(11) = 4.75$, $p < .01$, and graduate students, $t(11) = 4.68$, $p < .01$. This was probably due to the significant decline in the number of -1 errors made during the second half of the experiment.

A summary of the results of Experiment 2 is presented in Table 20.

Table 20
Summary of Results
Experiment 2

| Independent Measures and Interactions | Significant Effects ($p < .05$) Dependent Measures: Reaction Time | Error Rate |
|---|---|---|
| Grade | Yes<br>3rd > Graduate<br>3rd > 5th | No |
| Direction | Yes<br>Down > Left<br>Down > Right<br>Right > Left | Yes<br>Down > Left<br>Down > Right<br>Right > Left |
| Test | Yes<br>Quadratic | Yes<br>Quadratic<br>+1 > -1<br>+1 > Same<br>-1 > Same |
| Grade X Test | Yes | No |
| Direction X Test | No | Yes |
| Pictorial Movement Cue | Yes<br>1 > 2<br>1 > 3<br>3 > 2 | Yes<br>1 > 2<br>1 > 3 |
| Grade X Movement Cue | Yes | No |
| Movement Cue X Test | No | Yes |

# DISCUSSION

Unlike Experiment 1, in this experiment, using a range of real world time separations, and consistent with the representational momentum findings using nonpictorial stimuli, a significantly greater number of errors was made by students in all grades specifically to the +1 (forward) than -1 (backward) test positions. That is, subjects more often chose the photograph separated by one frame forward, rather than one frame backward, as the photograph they had seen first. This finding is consistent with the representational momentum hypothesis that subjects represent movement when viewing photographs that depict motion. Since the "effect" occurred with only the smallest forward real world time separation, it remains possible that the technique used in Experiment 1 was not precise enough to capture this "forward memory distortion". The memory distortion is thus so small, that in order to capture it very similar distractor photographs must be presented. Similarly, the results suggest that the effect is not due to a general bias to regard all forward distractors as equal to the memory photograph. Rather, only the smallest forward transformation of the memory photograph is judged as same.

The presence of the forward memory distortion in this experiment, as opposed to Experiment 1, may have been due to other subtle differences in the techniques used in the two experiments. In this experiment, for example, using a range

of test positions, the first (memory) photograph was necessarily identical in each trial (from the same action sequence), rather than varied as in Experiment 1. Repeated presentation of the same photograph to be remembered may bias the results in a particular (forward) direction.

It is of interest that the effect was captured with photographs, not only because photographs were never used before with this technique, but also because of differences between the present study and the representational momentum studies. In the representational momentum studies, for example, a sequence of static displays (e.g., rectangles, dots) were used to induce the effect, whereas in the present experiment only two displays were presented (both of which depicted movement).

Consistent with recent representational momentum studies which claim that error rate is the more reliable measure (Freyd & Finke, 1985), the +1/-1 difference was only evident with the error rate, but not with the reaction time data. The curvilinear relationship amongst the test positions, however, such that judgments became more difficult as distractor similarity increased, was evident for both the reaction time and error rate data. Similar to Experiment 1, judgments on the "same" trials were significantly more accurate than on the +1 or -1 trials for all grades.

The reason that reaction time data were not used in the representational momentum studies was due to the

extraordinarily high error rates found (particularly with the +1 positions). Consequently, an insufficient number of correct responses were available to calculate a reliable reaction time. In the present experiment (as well as Experiment 1), much lower error rates were found. (The error rate in the present experiment was even lower than in Experiment 1, possibly due to presentation of the same "memory" photograph.) This could be due to several reasons. First, contrary to Freyd's claim, the nature of the instructions given to subjects might make a difference. In most representational momentum studies, speed is stressed over accuracy, whereas in the present experiment speed and accuracy were equally stressed. Increased accuracy may occur when subjects are not under as much time pressure to respond. Further, whereas response times greater than 2 sec were eliminated in their studies, response times greater than 3 sec were eliminated here. Second, the nature of the stimuli used may make a difference. Photographs of real world scenes provide more cues and context than line drawings of rectangles and dots. Further, photographs of people in action (involving changes in leg and arm positions), provide more information than an object (e.g., rectangle) that remains unchanged. Thus, real world knowledge may have been involved in this study to a greater extent than in the representational momentum studies with abstract stimuli.

Although the results of the present experiment are

generally consistent with the representational momentum findings, two inconsistencies stand out. One, the present study did not find a "recorded shift" (e.g., Freyd & Finke, 1985), whereby the number of "same" responses given to the +1 trials is even greater than to the actual "true" same trials. Instead, only a forward shift was found, such that a greater number of same responses were given to the +1 than the -1 test positions. It may only be possible to obtain a "recorded shift" with abstract stimuli, where distractor positions may be created with very small distinctions. Second, although the representational momentum studies find that a greater number of errors is given to each of the forward than corresponding backward test positions, this was not the case with the pairs separated by 5 frames in the present study.

Consistent with Experiment 1, the direction effect was significant, as evident with both reaction time and error rate. As in Experiment 1, the down direction was the most difficult. Again, this in itself is not problematic for the representational momentum hypothesis. As in Experiment 1, however, there were left-right differences (the r-l direction was significantly more difficult than the l-r in this experiment). Further, unlike Experiment 1, even the graduate students demonstrated this difference. Consistent with the representational momentum claim, however, there were more +1 than -1 errors with all directions, and this was significant for both the l-r and r-l directions (unlike

Experiment 1 where it was only significant for the left-right). Thus, the effect was more robust in the present experiment than in Experiment 1, and was even obtained using different directions as a within-subject factor.

Given the strong effect of rate of implied motion found in Experiment 1, it is surprising that the effect was not significant in Experiment 2. Since the effect of real world time separation was examined separately in this experiment, but confounded with rate of implied movement in Experiment 1, most likely the effect in Experiment 1 was due to the smaller frame separation rather than implied rate per se. Even so, according to the representational momentum account, there should have been some interaction between rate and test position in the present experiment, such that most errors occurred on the +1 test position with the faster rate of implied motion.

The results of the pictorial movement cue effect were more consistent in this experiment than in Experiment 1. As evident for both reaction time and error rate, subjects had significantly more difficulty with those photographs that contained only 1 cue. With 2 and 3 cues, however, the differences were negligible. Further, similar to Experiment 1, with 1 cue (as well as 3 cues), subjects made significantly more errors on the +1 than -1 test positions. Thus, there appears to be something special about the photographs with only 1 motion cue, such that subjects are more likely to demonstrate a forward memory distortion.

As in Experiment 1, there were no grade differences in error rate. Unlike Experiment 1, however, there were no apparent developmental trends. The number of students in each grade demonstrating more +1 than -1 errors was the same, unlike Experiment 1, where there was a significant trend toward more forward errors with age. Thus, consistent with the representational momentum hypothesis, the effect was much stronger in the present experiment and certainly evident by third grade (although it is unclear whether it would be evident earlier). The only developmental trend in the present experiment was that only the graduate students had, consistent with the representational momentum claim, (nonsignificantly) longer response times to the +1 than -1 trials. As in Experiment 1, the only significant developmental difference was in speed of response time.

Even stronger than in Experiment 1, subjects in every grade demonstrated a significant practice effect in this experiment. In particular, similar to Experiment 1, there was a trend toward fewer errors on the +1 pairs. Unlike Experiment 1, however, there was also a significant practice effect on the -1 pairs. Although subjects made slightly more forward than backward errors during the first half of the experiment, this trend became significant only during the second half of the experiment, due to the significant decrease in the number of -1 errors. Thus, unlike Experiment 1, but consistent with the representational momentum hypothesis, the forward distortion was more robust

and resilient to practice. The discrepant findings between Experiments 1 and 2 could be due to the fact that in Experiment 1, the practice effect took into account forward and backward errors (which subsumed 1, 3, and 5 frames). In the present experiment, only the +1 and -1 errors were examined, because that was where most errors were made and where the significant forward/backward error difference occurred. Further, unlike Experiment 1, there was not an equal number of different test positions in each half of the experiment: there was only one block of trials in the present experiment and test positions were randomized within that one block.

In sum, subjects in this experiment made significantly more +1 than -1 errors, thereby demonstrating a specific forward memory distortion for movement in photographs. It is still not clear, however, what underlying process is responsible for the effect. The task clearly became more difficult as test positions became more similar. Yet it is not evident why more errors were made specifically on the +1 trials. Experiment 3 was designed to discover why by eliminating one possibility; the possibility that the forward errors may have been due to a more general phenomenon, one that might have nothing to do with the representation of implied movement.

Figure 7

Grade by pictorial movement indicator interaction

(Reaction time)

Experiment 2

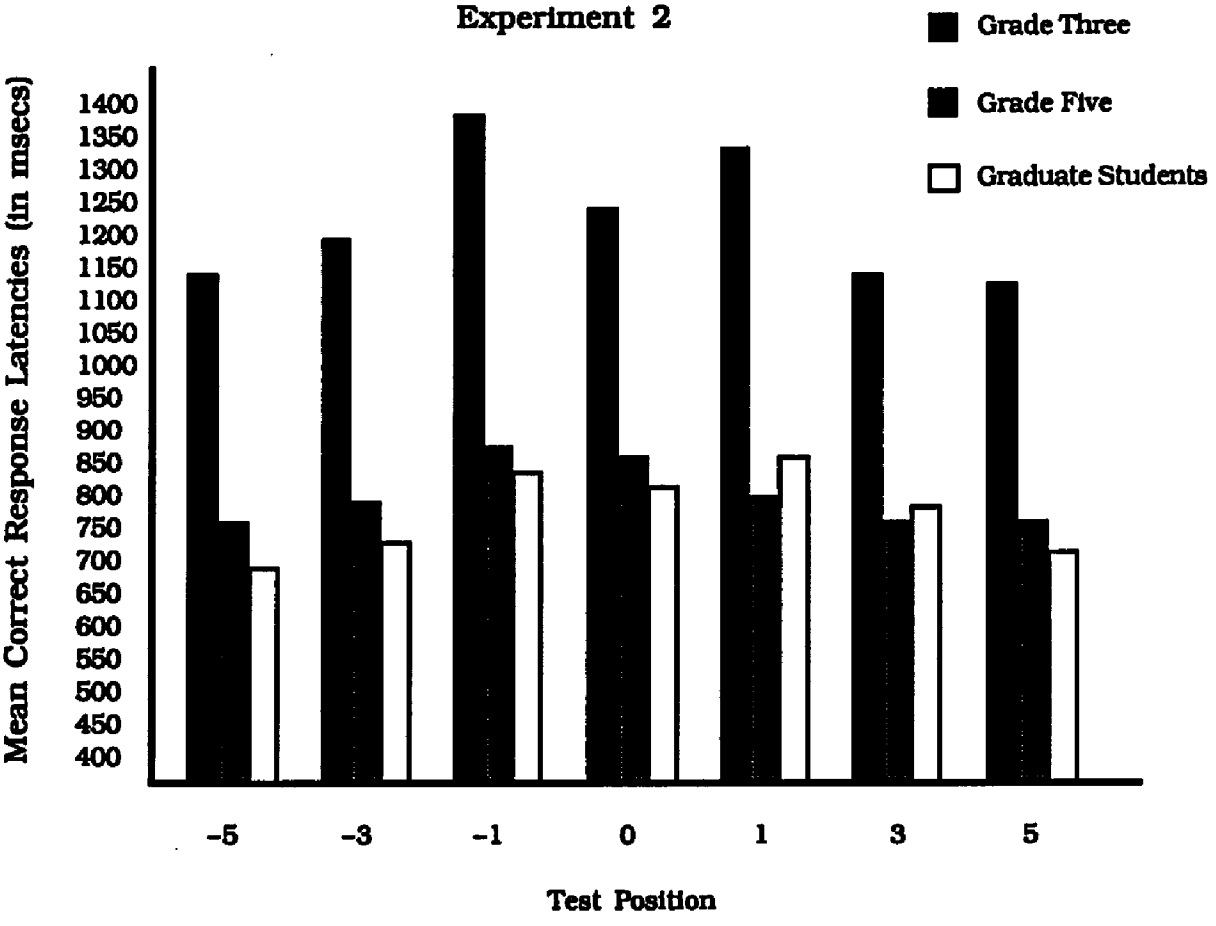


Figure 8

Grade by pictorial movement indicator interaction

(Reaction time)

Experiment 2

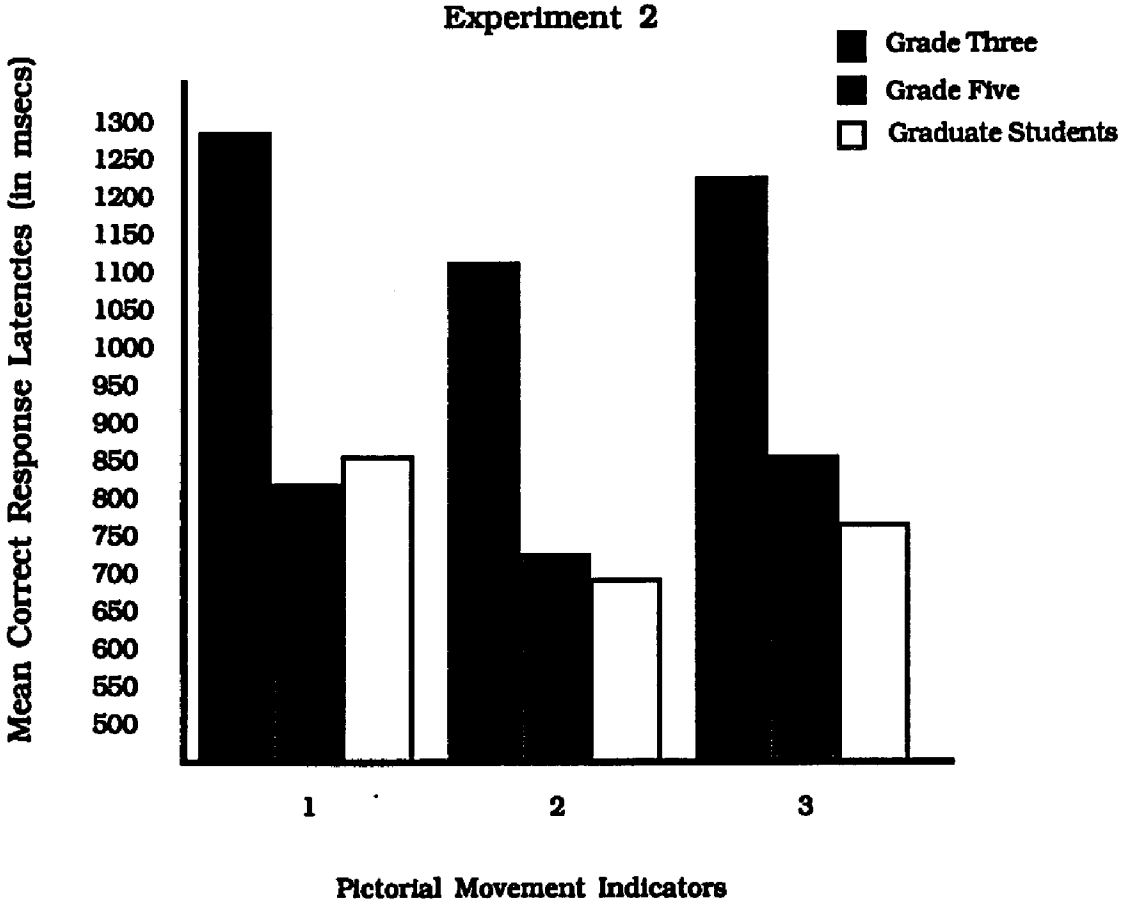


Figure 9

Direction by test position interaction (Error rate)

Experiment 2

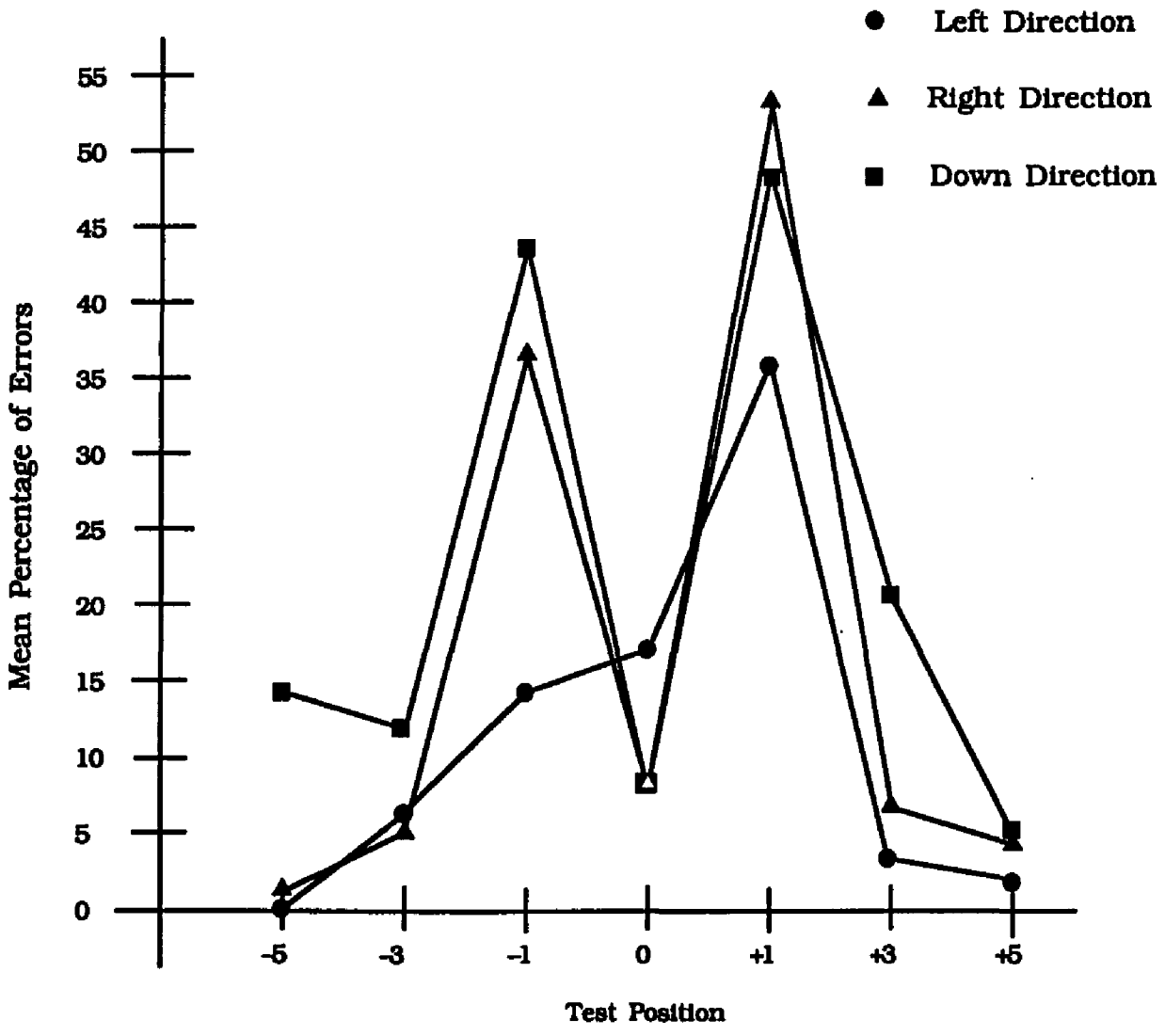
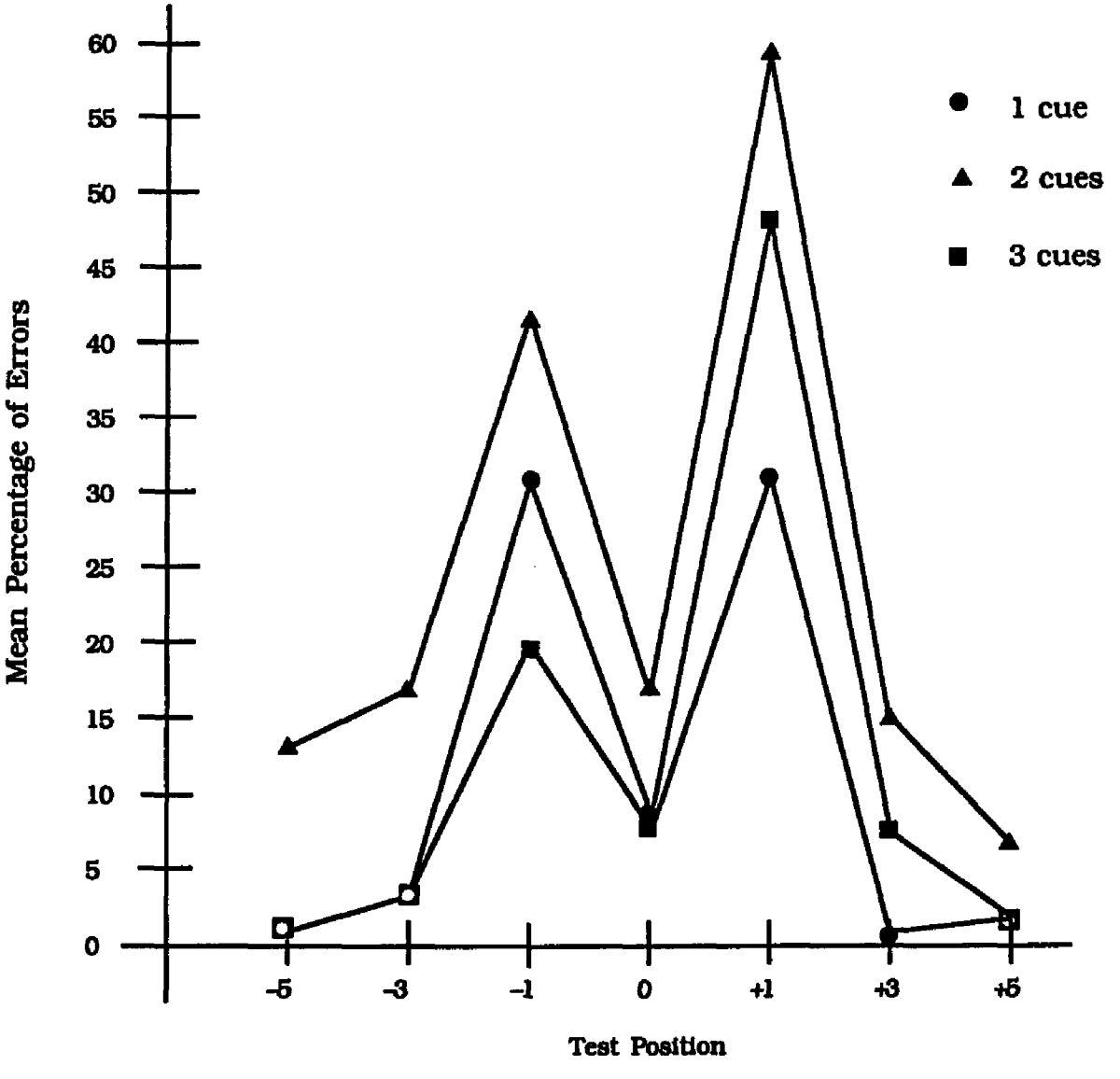


Figure 10

Pictorial movement indicator by test position interaction (Error rate)

Experiment 2



## Experiment 3

The results of Experiment 2, while supporting the representational momentum hypothesis, are unclear with regard to the basis of the forward memory errors. Freyd and Finke (1984) found that the representational momentum effect does not occur when a sequence of rectangles does not imply a consistent forward motion (e.g., one forward, followed by one backward, followed by one forward rectangle). The effect also does not occur when one of the rectangles in a sequence is a different shape from the others (Kelly & Freyd, 1987). While demonstrating that forward memory errors disappear under some conditions, these studies have not established unequivocally that movement, or implied movement, rather than some concomitant of movement, is the critical factor underlying representational momentum.

In order to ensure that the forward memory errors observed in Experiment 2 result exclusively from photographs that depict motion, and in order to eliminate the possibility that the effect stems simply from a more general preference to remember an object in a forward direction (independent of "representational momentum"), "still" photographs were employed in this final experiment. Further, since photographs that capture people and objects at different times during an action sequence necessarily involve a change in spatial location, these two factors were disentangled.

In order to accomplish this, photographs of a person standing in a still, sideways position were used. In order to be consistent with Experiment 2, however, the person was photographed in 7 "still" positions (one "same" position, three "forward" (by one, two and three steps) from the starting position, and three "backward" (by one, two and three steps) from the starting position).

As in Experiment 2, there were "same" and "different" pairs. Unlike Experiment 2, however, the different pairs in this experiment did not imply movement (no action was depicted in the individual photographs). Instead, the photograph pairs implied only a change in spatial position. Since no movement was implied, according to the representational momentum account, no movement should be represented and no significant forward memory errors should occur.

## METHOD

### Subjects

Thirty-six subjects participated in this experiment. There were 12 3rd grade students whose mean age was 8 years-10 months (range = 6 months); 12 5th grade students whose mean age was 10 years-1 month (range = 7 months); and 12 graduate students whose mean age was 32 years-11 months (range = 245 months). The third graders consisted of 9 males and 3 females; the fifth graders of 5 males and 7

females, and the graduate students of 4 males and 8 females. All subjects had normal or corrected to normal vision. None had participated in any other experiment.

## Materials

Stimuli. The stimuli were color photographs made with a Nikon camera. The person was photographed in front of a brick wall with a small black box in the center as a reference point.

In this experiment, there were 56 experimental pairs. Twenty-four of the "different" pairs showed the person in a "starting" ("same") position and then one of three "forward" positions (separated by 1, 2, and 3 steps from the starting position), while the other 24 pairs showed the person in the starting position and then one of the three "backward" positions (separated by 1, 2, and 3 steps). The 8 "same" pairs showed the person in the starting position followed by the identical photograph. As in Experiment 2, there were 14 practice pairs.

In order to investigate the effects of direction of movement, half (28) of the photographs depicted the person in a right-left orientation, while the remaining 28 trials showed the person in a left-right orientation. Unlike Experiments 1 and 2, there was no "down" direction.

## Equipment and Procedure

The equipment and procedure were the same as in Experiments 1 and 2.

## RESULTS

The data were organized and analyzed in the same manner as Experiment 2. Reaction times longer than 3 seconds were excluded from all analyses and accounted for less than 1% of all trials for all grades separately and combined. As in Experiment 2, there were no grade differences in number of trials longer than 3 seconds.

Pretraining trials. None of the third or fifth grade children needed to see the pretraining pictures more than once.

Practice trials. Two (16%) of the 12 third graders, none of the fifth graders, and 5 (41%) of the graduate students needed to see the practice pictures twice. Preliminary analyses indicated that there were no differences between those subjects who viewed the practice trials once or twice in either mean correct reaction time or number of errors.

### Reaction time

Preliminary t-tests indicated that there were no differences in mean correct reaction time by gender, corrected or uncorrected vision, or handedness.

The mean correct reaction times and standard deviations for each direction and test position by subjects in each grade are presented in Tables 21 and 22.

Table 21
Mean Correct Reaction Times and Standard Deviations by Direction (in msecs)
Experiment 3

| Age Group | Left | Right |
|---|---|---|
| Grade 3 | 927 (415) | 881 (372) |
| Grade 5 | 750 (231) | 750 (254) |
| Graduate | 632 (250) | 609 (256) |

Table 22
Mean Correct Reaction Times and Standard Deviations by Test Position (in msecs)
Experiment 3

| Age Group | -3 | -2 | -1 | 0 | +1 | +2 | +3 |
|---|---|---|---|---|---|---|---|
| Grade 3 | 831 (364) | 830 (404) | 959 (447) | 1014 (362) | 950 (358) | 919 (430) | 843 (358) |
| Grade 5 | 714 (223) | 706 (199) | 781 (286) | 838 (297) | 779 (223) | 740 (218) | 708 (224) |
| Graduate | 569 (244) | 553 (165) | 635 (230) | 764 (309) | 701 (340) | 596 (220) | 553 (155) |

A 3 (grade) X 3 (direction) X 7 (test) repeated measures ANOVA indicated, consistent with the other two experiments, a significant main effect for grade, $F(2,32) = 7.48$, $p < .01$, with mean correct reaction times decreasing with increasing age (third grade = 904 msecs; fifth grade = 750 msecs; and graduate students = 621 msecs). Comparison of means using the Tukey HSD procedure revealed that only

the graduate students had significantly faster reaction times than the third grade students in this experiment ($p < .05$). The main effect of test was also significant, $F(6,192) = 16.50$, $p < .01$. Contrary to Experiment 2, subjects took significantly longer on the "same" pairs than the +1 ($p < .05$) or -1 pairs ($p < .01$). Similar to Experiment 2, however, there was a quadratic distribution ($p < .01$), with correct reaction times decreasing as test similarity decreased (for both forward and backward pairs). Unlike Experiment 2, but consistent with the representational momentum hypothesis, subjects took longer to respond correctly to the +1 than -1 trials. However, these differences were not significant, $t(35) = .77$, $p > .4$.

There was, unlike Experiments 1 and 2, a significant grade X direction X test interaction, $F(12,192) = 2.65$, $p < .05$. The third and fifth grade subjects were similar in that, on one of the two directions, their reaction times to the -1 trials were longer than to the +1. The graduate students, however, took (nonsignificantly) longer to respond to the +1 than -1 trials with both directions.

Although the mean correct reaction time to the left-right direction was greater than to the right-left direction (769 and 746 msecs, respectively), unlike Experiments 1 and 2, this difference was not significant.

Separate analyses were then conducted in order to examine the effects of direction and test within each grade.

Grade three. A separate 2 (direction) X 7 (test)

repeated measures ANOVA revealed a significant main effect of test, $F(6,66) = 4.60$, $p < .05$, which was due to the quadratic trend ($p < .01$).

Grade five. The main effect of test was significant for the fifth graders, $F(6,66) = 3.78$, $p < .05$, and yielded a quadratic trend ($p < .01$).

Graduate. There was a significant main effect of test, $F(6,66) = 9.81$, $p < .01$, with students' response times to the "same" trials significantly longer than to the -1 trials ($p < .05$). The data also yielded a quadratic trend ($p < .01$). Finally, similar to Experiment 2 and unlike the other age groups, there was a trend toward longer response times to the +1 than -1 trials, $t(11) = 1.55$, $p < .15$.

Consistent with the other two experiments, there were individual differences in forward versus backward correct reaction times. Seven of 12 (58%) third graders, 5 of 12 (41%) fifth graders, and 7 of 12 (58%) of graduate students had longer reaction times to the +1 than -1 test positions. This is approximately the same percentage as in Experiment 2.

As in Experiments 1 and 2, correct reaction times decreased across the second half of the trials for each grade separately and combined, $t(35) = 6.02$, $p < .01$, indicating a strong practice effect. Similar to Experiment 2, reaction time decreased specifically on the -1 trials for each grade separately and combined, $t(35) = 3.87$, $p < .01$. Unlike Experiment 2, reaction time also decreased on the +1

trials for the fifth graders, $t(11) = 2.17$, $p < .05$, and was nearly significant for the graduate students, $t(11) = 1.99$, $p < .07$.

Error Rate

Preliminary analyses indicated that there was no difference in overall number of errors by gender, handedness, or corrected/uncorrected vision.

The percentage of errors for each direction and test position by subjects in each grade are given in Tables 23 and 24.

Table 23
Percentage of Errors by Direction
Experiment 3

| Age Group | Left | Right |
|---|---|---|
| Grade 3 | 6 | 5 |
| Grade 5 | 5 | 5 |
| Graduate | 5 | 5 |

Table 24
Percentage of Errors by Test Position
Experiment 3

| Age Group | -3 | -2 | -1 | 0 | +1 | +2 | +3 |
|---|---|---|---|---|---|---|---|
| Grade 3 | 1 | 5 | 6 | 15 | 4 | 7 | 1 |
| Grade 5 | 0 | 1 | 7 | 15 | 7 | 3 | 0 |
| Graduate | 0 | 2 | 4 | 15 | 8 | 4 | 0 |

The overall error rate was much lower than in Experiments 1 and 2, 5%. A 3 (grade) X 2 (direction) X 7 (test) repeated measures ANOVA performed on the number of error responses revealed a significant main effect for test, $F(6,198) = 9.74$, $p < .01$. Consistent with Experiment 2, there was a significant quadratic trend ($p < .01$), with the number of errors decreasing as test similarity decreased. Unlike Experiment 2, but consistent with the reaction time data, subjects also made significantly more errors on the "same" than the -1 ($p < .05$) or +1 trials ($p < .05$). Most importantly, although there were (consistent with the reaction time data) slightly more errors on the +1 than -1 trials, unlike Experiment 2, these differences were not significant, $t(35) = .44$, $p > .6$. Thus, without action photographs, the significant forward errors observed in Experiment 2 were eliminated. Unfortunately, a direct statistical comparison between Experiments 2 and 3 was impossible due to the different number of directions and experimental trials in each experiment. The percentage of +1/-1 errors made by subjects in all grades for Experiments 2 and 3 is presented in Figure 11 (p. 128).

The direction X test interaction was nearly significant, $F(6,198) = 1.84$, $p < .10$, similar to Experiments 1 and 2. This interaction reflected the fact that (nonsignificantly) more +1 than -1 errors were made only with the left-right direction, while with the right-left direction the reverse was true.

Although the third grade subjects made slightly more errors than the older subjects (third=6%, fifth=5%, graduate=5%), as in Experiments 1 and 2, these differences were not significant. Consistent with the reaction time analysis, but unlike Experiments 1 and 2, there was no main effect of direction (the mean percentage of errors for the left-right and right-left direction was 5%).

Separate repeated measures ANOVAS were then performed within each grade.

Grade three. The error rate data for the third grade subjects revealed a significant main effect of test, $F(6,66) = 2.94$, $p < .05$, which was due to the quadratic trend ($p < .01$).

Grade five. There was a significant main effect of test, $F(6,66) = 3.83$, $p < .01$, due to the quadratic distribution of errors ($p < .01$).

Graduate students. There was a significant main effect of test, $F(6,66) = 3.66$, $p < .01$, due to the quadratic trend ($p < .01$). Unlike the other two age groups, but similar to the reaction time data, the graduate students demonstrated a trend toward more errors on the +1 than -1 trials, $t(11) = 1.55$, $p < .15$.

Similar to the other two experiments, the Z transformations revealed that subjects' responses were above chance (third graders, $Z = 22.99$, $p < .01$; fifth graders, $Z = 23.42$, $p < .01$; and graduate students, $Z = 23.42$, $p < .01$).

As in the other two experiments, there were individual differences in the preponderance of forward as opposed to backward errors. A smaller number of students in this experiment, however, made more errors on the +1 than -1 test positions. While only 1 (8%) of 12 third graders and 1 of 12 fifth graders made more forward than backward errors, 3 (25%) of the graduate students did so. Consistent with Experiment 2, but unlike Experiment 1, these grade differences were not significant.

Finally, unlike Experiments 1 and 2, the number of errors did not decrease significantly during the second half of the experiment for any grade separately or combined, $\underline{t}(35) = 1.59$, $\underline{p} > .13$, thereby providing no evidence of a practice effect. Nor was there any decline in the number of +1 or -1 errors in the second half of the experiment, unlike Experiment 2. This may have been due to the low percentage of errors overall in this experiment as compared to the other two experiments. Further, the percentage of +1/-1 errors was approximately the same during both halves of the experiments.

A summary of the results of Experiment 3 is presented in Table 25.

Table 25
Summary of Results
Experiment 3

| Significant Effects ($p < .05$) | | |
|---|---|---|
| Independent Measures and Interactions | Dependent Measures | |
| | Reaction Time | Error Rate |
| Grade | Yes | No |
| | 3rd > Graduate | |
| Direction | No | No |
| Test | Yes | Yes |
| | Same > +1<br>Same > -1<br>Quadratic | Same > +1<br>Same > -1<br>Quadratic |
| Grade X Direction X Test | Yes | No |

## DISCUSSION

The results of the final experiment indicate that the significant forward memory errors observed in Experiment 2 were eliminated when "still" photographs were presented. In particular, subjects did not make significantly more errors on the +1 than -1 trials. These findings suggest that significant forward memory errors arise only when viewing action photographs, when there is an initial representation of movement. This experiment also eliminated the possibility that subjects simply misremembered objects in a

forward direction, independent of the perception of movement in photographs.

Consistent with Experiment 2, however, the data exhibited a quadratic trend, such that error rate and reaction time diminished as similarity between test positions decreased. Thus, with or without movement information, the task became more difficult as discriminations become more difficult. Although it is unclear why, unlike the other two experiments, the "same" trials were the most difficult for all grades as indicated by both reaction time and error rate.

Unlike the other two experiments, there was no significant difference between the right and left directions. Similar to the other experiments, however, subjects made (nonsignificantly) more +1 than -1 errors only with the left-right direction. These findings suggest that there may be a learning component involved, such that people learn that movement in the world and pictures occurs in particular ways.

As in the other experiments, there were no developmental differences in error rate, but significant developmental differences in speed of reaction time. Although not statistically significant, there was a developmental trend such that only the graduate students, consistent with the representational momentum hypothesis, had longer reaction times to the +1 than -1 trials (similar to Experiment 2), longer reaction times to the +1 trials

with both directions (similar to Experiment 1), and more errors with the +1 than - 1 trials (also similar to Experiment 1). Thus, even without movement in the initial photographs, adults were more sensitive to the implied motion between the photograph pairs than children. The finding that adults, who have had extensive exposure to principles governing physical motion, appear to exhibit the "momentum" effect more strongly suggests that the effect may depend, contrary to Freyd, at least in part, on learning.

This experiment yielded both the smallest percentage of errors and the shortest correct reaction times of all the experiments, indicating that the task was easier without implied movement. This may have occurred for several reasons. One, the distractor positions selected may not have been similar enough, so the task may have been easier for this reason alone. Second, and more likely, the "still" photographs contained less information than the action photographs; they lacked the rich detail and background information of the photographs of real world scenes used in the previous experiments. Thus, less attention and processing was probably needed to encode all of the relevant information in such a short amount of time. The simplicity of the pictures may have also highlighted the reference point provided. As a result, subjects may have been able to rely on the position of the person with regard to the reference point in order to make their judgments.

It is important to emphasize that the only difference

between Experiments 2 and 3 was whether or not movement was depicted in the photographs. With "still" photographs, however, this experiment was actually similar to the representational momentum studies that used a sequence of stationary objects, displayed at different positions, in order to induce the effect. Thus, it may not be unexpected that the error rate and reaction time data, while small and nonsignificant, were in the direction predicted by the representational momentum account. The important point is that significant forward memory errors occurred only in Experiment 2 when action photographs were employed, but not here. Without the movement in the initial photograph, there was no inducement of a mental representation that included movement. Instead, subjects in this experiment represented a person in a stable, as opposed to moving, position.

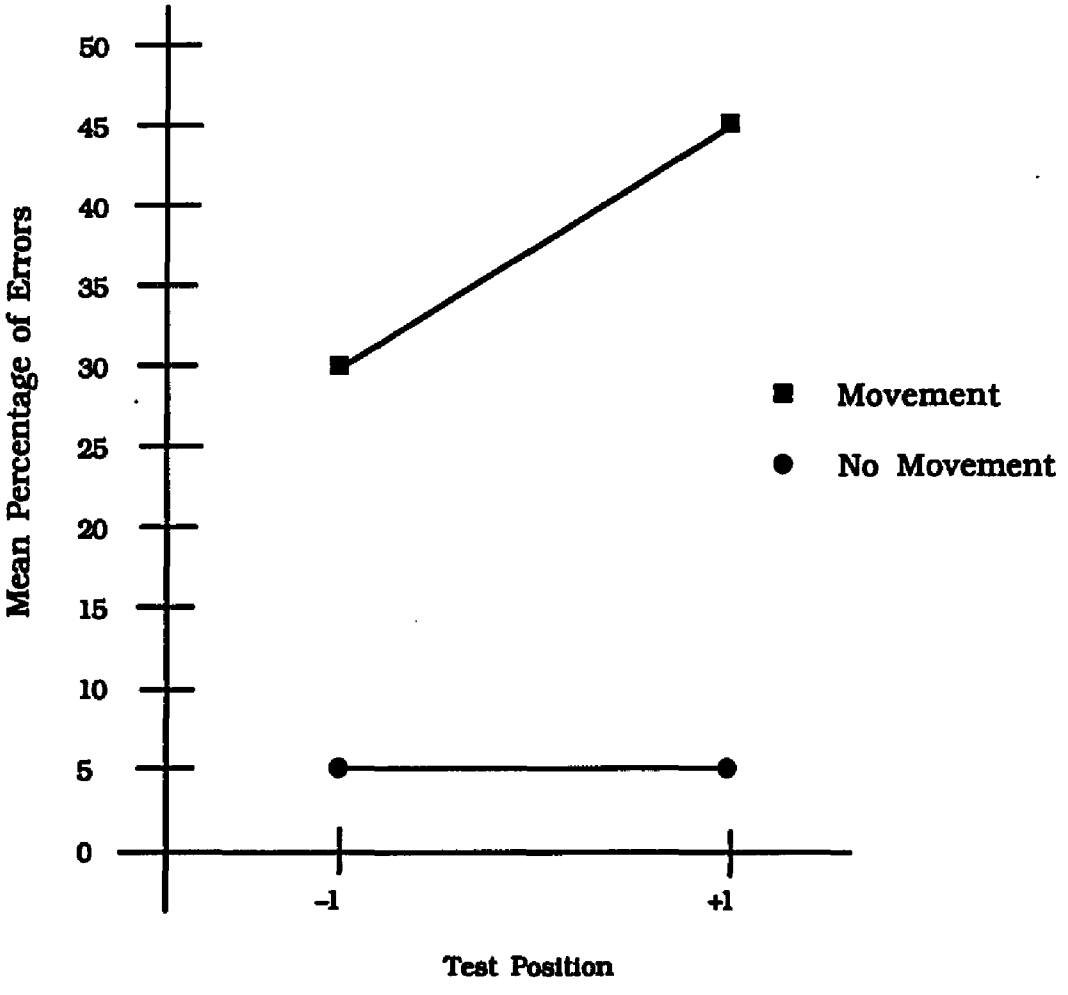
This experiment in particular, as well as all of the representational momentum studies, may be criticized for being dependent upon the perception of "apparent motion", similar to Michotte's (1946) apparent movement experiments. Michotte, for example, discovered the "tunnel phenomenon", in which an observer perceives an object as moving even during the interval between going in and out of a tunnel. He attributed this effect to a tendency for perception to be completed across a gap, similar to the gestalt principles of "good continuation". Although apparent motion, or good continuation, may be contributing factors to the forward memory errors, several observations suggest that they are

not the only factors. Although not tested in the present experiment, Freyd (1983) claimed that her results were not dependent upon apparent movement, because no apparent motion could be seen with her photographs unless the first photograph in the pair was presented for approximately 1000 msec (as opposed to 250 msec). Finke and Freyd (1985) also found the momentum effect using a 2 sec interstimulus interval, which is beyond the point at which apparent motion is experienced. Kelly and Freyd (1987) argue that good continuation cannot fully account for the momentum effect, because the effect does not occur when the test position is intentionally created to be the next logical step in a sequence of displays (which would be predicted by the good continuation account). Instead, the effect only occurs when the test position is only slightly forward of the memory display. Finally, if apparent motion was responsible for the forward memory errors in Experiment 2, the effect should have occurred in the present experiment as well, since the only difference between the two experiments was that "still" photographs were used here.

In sum, this experiment suggests that the forward memory errors observed in Experiment 2 depend upon an initial perception and representation of movement in photographs. Thus, there is something distinctive about photographs that depict movement.

Figure 11

Error rates for –1 and +1 positions from Experiment 2 (Movement) and Experiment 3 (No Movement)



# GENERAL DISCUSSION

The present experiments were designed in an attempt not only to replicate and extend a possible picture-memory phenomenon reported by Freyd (1983), later termed "representational momentum" (Freyd & Finke, 1984), but also to examine developmental differences in short-term memory for movement in photographs. As compared with all of the representational momentum studies, and the majority of the picture-memory studies, a special feature of the present experiments was their potential to yield comparison data between children and adults. The overall results of the three experiments support some aspects of the proposed representational momentum process, but at the same time suggest modifications of the original formulation, since such factors as age, direction of movement, and practice influenced the phenomenon in complex ways.

Specifically, this study had four goals. The first was to attempt to replicate the original momentum finding (Freyd, 1983), and to determine whether children remember pictorial movement information in the same manner. The second was to test certain basic assumptions of the representational momentum claim. The third was to expand upon previous work on children's comprehension of movement in photographs. The fourth was to relate the present findings to more recent developmental studies that utilize the "mental rotation" technique to explore the nature of

children's mental imagery. Results pertaining to each of these goals will be discussed in turn.

1. Was the original representational momentum finding replicated, and were basic claims of the momentum hypothesis supported?

Evaluating the findings with respect to replication is difficult. First, there were conflicting results between the first and second experiments. Second, there were developmental trends and significant interactions between variables. Third, whereas some predictions were supported, others were not. Considering these difficulties, the task will be one of identifying patterns in the results.

The first experiment did not replicate the phenomenon, which is troubling because that experiment was designed to be as close as possible to Freyd's (1983) photograph study. A closer examination of Experiment 1 data, however, revealed that the results neither confirmed nor refuted the original finding when only the graduate students' data were inspected (the group most comparable to Freyd's subjects). The second experiment, employing a technique used by Freyd only in later momentum studies, replicated the phenomenon (but only with regard to error rate), with subjects in all age groups making significantly more +1 (forward) than -1 (backward) errors. This experiment demonstrated that the effect is so subtle that only very similar distractor positions are sensitive enough to reveal it. Experiment 3, a control experiment, demonstrated that the forward memory errors

observed in Experiment 2 were due to the initial perception of movement in photographs.

Developmental trends. Since Freyd claims that knowledge of the principles governing physical motion has been internalized such that the visual system automatically extrapolates future positions of moving objects, there should be no age differences in the phenomenon. Subjects should therefore take significantly longer to correctly judge that a second photograph is different from the first when photograph pairs are shown in "forward" order as opposed to "backward" order. Subjects should also make more errors ("same" responses) when judging forward pairs. Adults' and children's error rates were remarkably similar in the present experiments, which appears to support that prediction. There were, however, more subtle developmental trends in the data. In Experiment 1, for example, individuals made significantly more forward than backward errors with age, and more errors with age in ways predicted by the momentum hypothesis (e.g., only adults made more forward errors with each direction). In Experiment 2, only the graduate students took longer to correctly judge the +1 (forward) than -1 (backward) test positions. In Experiment 3, using "still" photographs, only the graduate students demonstrated a trend toward more errors and longer response times to the +1 than -1 test positions. This suggests that adults may be more sensitive to implied motion even without an initial perception of motion in photographs. While these

developmental trends are highly suggestive and need to be explained, they are not necessarily strong evidence against the representational momentum or, specifically, a modularity claim.

One explanation for the developmental trends that would not be inconsistent with the momentum account is perceptual learning. "Perceptual learning (is) most appropriately thought of as a process of differentiation, of perceiving progressively more deeply embedded structure and more encompassing superordinate invariant relations... As differentiation occurs, perception increases in specificity. Diversity and detail, fine structure, invariant relations and affordances of a greater subtlety are detected" (Gibson & Spelke, 1983, p. 59). At a microdevelopmental level, this is supported by the fact that only the adults and older children benefitted from practice, such that their errors decreased even over the course of the experiment. In particular, only the older subjects made significantly fewer errors on the forward pairs in Experiment 1, and fewer errors on the +1 and -1 test positions in Experiment 2 (the most difficult pairs). At a macrodevelopmental level, however, how would perceptual learning account for more forward errors with age? "Along with this increase in sensitivity to information about the world goes a trend toward increasing economy. Perceiving becomes more efficient as exploratory skills increase and as the critical, minimal information for guiding action is

detected" (Gibson & Spelke, 1983, p. 59). Thus, even if representational momentum is operative in young children (consistent with evidence by von Hofsten (1980) that even infants reach predictively and accurately for a moving target), adults may have become so efficient at picking up movement information for guiding behavior in the real world that they automatically make more forward errors on a laboratory task such as this.

Ross-Kossak and Turkewitz's (1986) research on the processing of facial information suggests, similar to a perceptual learning view, that processing proceeds "from relatively simple to highly complex with shifts in processing mode associated with transitions in the direction of hemispheric advantage" (p. 127). In particular, "in its initial stages processing is relatively undifferentiated and performed better in the right than the left hemisphere. Following this, there is an analytic stage in which distinctive features are identified and used for making discriminations; this is posited as a left-hemisphere function. Finally, a stage is reached in which material is processed in an integrated mode that is best served by the right hemisphere" (p. 127). These proposed shifts occur as a function of increasing familiarity and experience with the material. The practice effects found for older subjects in the present experiments may, therefore, reflect either increased familiarity with the photographs and/or development of a strategy for recognizing photographs under

tachistoscopic presentation.

Another explanation of the developmental trends that would not be inconsistent with the momentum account is increasing accessibility of knowledge (e.g., Brown et al., 1983; Rozin, 1976). In this account, differences between younger and older children and adults are believed to reside in their ability to access and flexibly use competencies they already possess. Increasing access to knowledge of principles of physical motion may have simultaneously helped older subjects solve the tasks in the present experiments and make more forward errors.

Direction effect. In addition to age, the direction effect yielded some unexpected trends. The representational momentum view predicts that there should be no left-right differences and that forward memory errors should occur in the same direction as the implied motion, regardless of the direction. Yet, in Experiments 1 and 2, there were direction effects. First, there were significant left-right differences. In particular, children made significantly more errors with the l-r direction than the r-l direction in Experiment 1, while in Experiment 2, adults made significantly more errors with the r-l direction than the l-r direction. Second, there was a trend such that more forward than backward errors occurred most consistently with the left direction. For example, there were significantly more forward errors only with the l-r direction in Experiment 1, and a trend toward more forward errors only

with l-r direction in Experiment 3. Consistent with the momentum hypothesis, however, there were significantly more forward errors with both the l-r and r-l directions in Experiment 2. These findings are not easy to explain.

For one, the photographs were not mirror images of each other, which is a difficult discrimination for children (and even adults) to make (Vogel, 1979). Instead, the photographs simply differed with regard to whether the person was traveling from a left to right or right to left direction (between, not within, photograph pairs). The findings, therefore, suggest that, even though there is no consistent left-right bias in the world with regard to motion (which is presumably why the momentum hypothesis predicts there should be no left-right differences), through experience and the learning of conventions, particularly reading and writing English (which involves a consistent left to right direction), individuals develop a directional preference. Thus, adults made more errors on those photograph pairs that depicted a right to left direction, while children (who have had less experience with reading and writing) made more errors on those pairs that depicted a left to right direction.

These results are similar to two early studies (Mishkin & Forgays, 1952; Orbach, 1952) that found that English words presented tachistoscopically are better recognized to the right of a fixation point, while Hebrew words (read from right to left) are recognized better in the left visual

field. The differences were attributed to "early visual training which contributes to the perceptual organization of maturity" (Orbach, 1952, p. 562). It is also possible, although there is no experimental evidence for this, that this directional preference may transfer to pictures, such that action in photographs "looks better" if captured in a left to right direction. This would be similar to studies in which adults and children judge drawings of geometric shapes to be upright in some positions but nonupright in others with a high degree of consistency (Schaller & Harris, 1975; Braine, 1972). As with the developmental trends, then, the direction effect suggests that the momentum phenomenon cannot be due strictly to basic perceptual mechanisms, but rather must involve cognitive mechanisms affected by experience.

Practice effects. While the developmental trends and direction effects are highly suggestive, the practice effects observed in Experiments 1 and 2 represent the greatest challenge to the representational momentum, and specifically, modularity claim. Freyd claims that representational momentum is impervious to practice (Kelly & Freyd, 1987) and therefore mandatory, cognitively impenetrable, and, in short, modular. However, only one study (Finke & Freyd, 1985) reported no practice effect, and in that case error rates were averaged across blocks of trials rather than for each test position separately. Therefore, it is impossible to determine whether there were

specific practice effects. Experiment 1 demonstrated a significant practice effect for older subjects, specifically and exclusively on the forward pairs. This was unexpected given the relatively small number of trials in that experiment as compared with representational momentum experiments, which often involve more than three times as many trials. This finding suggests that, while there may be something special about forward trials, individuals can learn to compensate for the effect even in a limited amount of time. Similar to Experiment 1, the practice effect on the +1 (forward) test position was nearly significant for the graduate students in Experiment 2. However, there was also a significant practice effect on the -1 test position by the older subjects. Experiment 2 was not as fair an assessment of the practice effect as Experiment 1, however, because there was not an equal number of +1/-1 trials in each half of the experiment. The practice effects found in the present experiments are reminiscent of the practice effect found in performance on the embedded figures task (Chance & Goldstein, 1971; Goldstein & Chance, 1965), which led to questioning the use of that task as a measure of field dependency (a supposedly stable dimension of perceptual and cognitive functioning).

Individual differences. The individual differences found in the present experiments also represent a challenge to the automatic processing, modularity claim. Although Freyd reports that nearly 100% of her subjects demonstrate

the effect, the highest percentage found in the present experiments was 75% (Experiment 2). In addition, there was a trend toward more forward than backward errors with age in Experiment 1 (where it was significant) and in Experiment 3.

The developmental trends, direction effects, practice effects, and individual differences found in the present experiments mount a substantial challenge to the representational momentum hypothesis. These results suggest that learning is, at least in part, responsible for the effect and that knowledge of principles of motion is modified by experience. A more complete model of representational momentum, therefore, requires an adequate explanation and incorporation of these trends. However, with the possible exception of the practice effects and individual differences, these findings are not necessarily evidence against one of the more recent and major assumptions of the momentum claim, namely modularity. As previously discussed, the momentum account can, with some difficulty, accommodate evidence of learning through a perceptual learning explanation of the differentiation type (i.e., E. Gibson's). The only evidence against modularity, however, would be a demonstration of cognitive penetrability, where knowledge or belief influences ongoing perceptual processing. Unfortunately, the present experiments could not directly test cognitive penetrability because of the nature of the stimuli used - photographs of real world scenes, which necessarily invoke real world

knowledge. This is why later momentum studies used abstract stimuli.

There are two pieces of evidence, however, that suggest the phenomenon may be cognitively penetrable. In one study, Hubbard and Bharucha (1988), using an apparent motion paradigm, similar to momentum studies with dots (e.g., Finke & Freyd, 1985), found that knowledge of future positions of a dot (ball) influenced memory errors. In particular, when the ball proceeded along a consistent (forward) path of motion, similar to the momentum studies, forward memory errors occurred. However, when the ball proceeded along a consistent path of motion, but then "bounced off a wall" (implying a future position in the direction opposite to the original path of motion), subjects' knowledge and anticipation of the future position led to backward (rather than forward) memory errors. The authors concluded that the memory errors could not be due solely to an informationally encapsulated modular mechanism (in which case memory errors would only occur in the same direction as the current path of motion) but rather must be due to a cognitive mechanism that predicts behavior of moving objects on the basis of knowledge or belief about past and future behavior.

In a second piece of evidence, McCloskey and his colleagues (Kaiser, Profitt & McCloskey, 1986; McCloskey, 1983) demonstrated that, as opposed to accurate internalization of principles governing physical motion, many people have misconceptions about fundamental properties

of motion. In their most illustrative example, when asked to predict the path of a ball exiting a curved tube, many college students (as well as children) respond that the ball will continue along a curved (rather than straight) path. McCloskey explains such erroneous predictions as evidence that, when people are asked to reason abstractly about motion, their "intuitive" models of motion (developed from encounters with moving objects in daily life) frequently resemble a medieval impetus theory rather than a Newtonian model. Either through everyday experience or formal physics instruction, some people (although not all) reformulate their earlier model and eventually attain a more accurate theory of motion.

In sum, the present results suggest that the representational momentum, and resulting picture-memory phenomenon, is replicable, but only under certain conditions. The findings further suggest that the forward memory errors observed in Experiment 2 cannot be accounted for solely by basic perceptual mechanisms. Instead, at least with photographs, consistent with the theories of Beilin (1988) and Hochberg (1983), the effect appears to be, at least partially, dependent upon cognitive processes.

2. How do the present studies relate to previous studies of the comprehension of motion in photographs, and what are the implications of these studies for a theory of photographic representation?

The present studies not only expanded upon the standard

repertoire of methods used to investigate children's comprehension of movement in photographs but also examined the very early stages of pictorial perception. The results of Experiment 2, for example, may explain why even young children are easily able to label photographs as "moving" or "still" (Friedman & Stevenson, 1975; Futterweit & Beilin, 1987). They may also explain why pictorial movement has been described as "compelling" and able to "transmit a sense of movement" (Friedman & Stevenson, 1980, p. 226).

The attempt to determine which pictorial movement indicators might influence short-term memory yielded only one finding: that more forward than backward errors were made most consistently with those photographs containing only one movement cue. In Experiment 1, for example, there were (nonsignificantly) more forward than backward errors only with one movement cue, while in Experiment 2, there were significantly more +1 than -1 errors with one cue. In addition, subjects in Experiment 2 made most errors on those photographs containing only one cue. Photographs containing only one movement cue may provide the viewer with less information than those with two and three movement cues. Thus, contrary to the momentum hypothesis, the effect may be influenced by the content of photographs.

The present experiments are most similar conceptually and methodologically to those picture-memory studies that have examined memory for specific details using a "same-changed" recognition paradigm (e.g., Intraub & Richardson,

1989; Pezdek, 1987). Similar to those studies, but contrary to previous reports (e.g., Shepard, 1967; Standing, 1973), the present results suggest that memory for pictures is not unlimited. However, considering the striking similarity of the distractor positions and short exposure duration, adults' and children's memory for movement was remarkably good. The important point, however, is not that recognition memory for pictures is not veridical but that the pattern of errors observed is sometimes asymmetrical (consistent with the work of Intraub, Pezdek). In Experiment 2, subjects' memory for photographs appears to have contained additional information (they incorrectly thought they had seen photographs that contained information that would have been immediately beyond the "memory" photograph). This suggests, consistent with the representational momentum hypothesis, that viewers comprehend action photographs through expectation or anticipation of continuation of the action.

When viewed in this context, the results of Experiment 2 are also consistent with schema theory, which emphasizes the role of <u>expectations</u> for event sequences. Mandler and Parker (1976) define a schema as "an internal structure, developed through experience with the world, which organizes incoming information relative to previous experience" (p. 39). Schema theory is also consistent with the view that the perceptual process, even in its earliest stages, is influenced by knowledge and expectations (Biederman, 1981).

Some theorists have proposed that schemas are used not

only to encode and represent information presented in scenes but also in pictures (Friedman, 1979; Mandler & Parker, 1976; Pezdek, 1987). Scene schemas "govern what we expect to see upon looking at or entering a particular scene" (Mandler, 1983, p. 453). At the same time schemas may distort, such that "much of what we think we have actually seen, we have only inferred" (Mandler, 1983, p. 454). Thus there is a reconstructive aspect to memory for scenes, similar to that for prose (e.g., Bartlett, 1932; Bransford & Franks, 1971). With regard to pictures, schemas affect how rapidly and accurately items are identified (Biederman et al., 1973), scanned (Friedman, 1979), and recognized (Friedman, 1979; G.S. Goodman, 1980). In one study, Friedman (1979) found that subjects are more likely to recognize changes in unexpected, rather than expected, objects in pictures. She hypothesized that objects in pictures that are "schema- relevant" require less visual analysis for identification than unexpected objects; consequently, transformations of expected items are less well-noticed. This is consistent with the finding that the "forward" (+1) pairs in Experiment 2 ("expected") were more often judged as "same" than the backward (-1) pairs (which transformed the memory photograph in an unexpected way).

One distinction between schema theory and the momentum hypothesis is that schemas refer to cognitive processes that influence comprehension of and memory for events, while momentum refers to basic, innate, automatic, modular

perceptual processes. Momentum research, as compared with most of the schema research, is concerned with very short-term perceptual expectations involving dynamic events created in the laboratory. Thus, the momentum effect refers to highly specific memory errors (those that occur only to a slightly forward stimulus) that occur within a very brief retention period, as opposed to more global memory processes, such as elaboration or reorganization, that occur over a longer retention period (e.g., Bransford & Franks, 1971; Neisser, 1982).

With regard to pictorial representation, the present results are consistent with the theories of Gombrich (1969, 1982) and Hochberg (1983), in which expectations (derived from past experience) contribute to pictorial comprehension. In Hochberg's (1983) proposal, information from both the world and pictures is derived from the integration of saccadic eye movements. This process results in the construction of schemas, which then, in addition to expectations, further guide perception and direct eye movements. Contrary to Freyd, however, "schemas do not obey the constraints of the physical world" (Hochberg, 1983, p. 18).

In a related issue, although Freyd rejects eye movement explanations for the momentum effect (Finke & Freyd, 1985), eye movements may have contributed to the present results. Mental imagery theories, particularly those that present subjects with simultaneous patterns to compare (as do many

mental rotation studies) are vulnerable to the possibility that eye movements are responsible for the findings (Finke, 1985). In the present experiments, photograph pairs were presented successively and the short exposure duration of the first photograph (but not the second) prevented visual scanning. However, eye movements were not specifically controlled for in these, nor any of the momentum, studies other than to ask subjects to maintain constant eye fixation. Further, the use of reference points in the background of the photographs may have allowed subjects to track movements. Thus, judgments might have been based, in part, on changes in eye position.

How do the present experiments contribute to the realist-conventionalist debate in pictorial representation? The present results appear to support a realist interpretation inasmuch as the forward errors in Experiment 2 seemed to occur automatically, thus implicating the nature of the visual system. At the same time, however, a realist account is inadequate because subjects did not respond veridically to the information in the photographs. Was this due to knowledge of conventions of photography? Both knowledge of photography as well as knowledge of real world events most likely played a role (Beilin, 1983). Since photographs were understood within 250 msec of exposure, however, it is clear that pictorial codes cannot be wholly arbitrary and that comprehension depends, at least in part, on the nature of the visual system (Gombrich, 1982). The

present results, therefore, support a moderate position, one consistent with Beilin (1988). In this view, photographic comprehension involves both the nature of the visual system and cognitive processes. "Acquiring knowledge and meaning from photographs is ... the product of processes of cognitive development that build upon genetically given competences that are basic to perceiving the natural world. Knowledge of the world, as well as knowledge of photographs of that world, accrues according to processes of scheme construction, defined by the registration and integration of perceptual information through visual information processing, and by the construction of schemes of a cognitive nature"
(p. 49).

In sum, the present experiments suggest that the study of the early stages of picture processing may be fruitful for gaining a better understanding of the comprehension of motion in photographs. The momentum effect is an intriguing picture-memory phenomenon that, while previously overlooked by researchers, should be further examined and incorporated into a theory of photographic representation. Finally, the present studies are consistent with the view that perceptual and cognitive processes interact even in the early stages of picture perception.

3. How do the present studies relate to developmental studies of "mental rotation"?

Developmental studies of "mental rotation" have been

undertaken to determine whether children can employ mental imagery to represent spatial transformations (e.g., Marmor, 1975, 1977). Their goal is mainly to test (and refute) Piaget and Inhelder's (1971) claim that anticipatory or kinetic imagery (imagery representing movement) does not emerge until approximately 7 or 8 years of age with the onset of concrete operations. Prior to that imagery is conceptualized as static. Shepard's mental rotation task has been employed because it is presumed to tap the ability to imagine (anticipate) what an object will look like when rotated in space. Further, it is presumed to capture kinetic imagery more directly and precisely than Piaget's measures (e.g., drawings).

In general, the developmental studies of mental rotation have found that children's reaction times, similar to adults', increase linearly as angular discrepancy between stimuli increases (Childs & Polich, 1979; Kail, Pellegrino & Carter, 1980; Marmor, 1977). Thus, it is concluded that children use not only mental rotation but also kinetic imagery to solve these tasks. These findings, contrary to the theories of Bruner (Bruner et al., 1966) and Piaget and Inhelder (1971), are in accord with recent theories that claim there are no qualitative shifts in the nature of representation (Mandler, 1983). Instead, the major developmental change proposed is increasing access of domain-specific knowledge (Mandler, 1983).

There are several problems with the developmental

studies of mental rotation, however. First, similar to Shepard, the results are based on reaction time, which is a measure used to infer something about a psychological process correctly executed. However, since children do not always perform as well as adults, the implications from their reaction time data are less clear. Second, different stimuli have been used with children and adults (e.g., drawings of panda bears versus geometric forms). Third, some researchers have "trained" children to mentally rotate (e.g., Marmor, 1975), while Shepard never offered any particular solution strategy to subjects. Fourth, these studies assume that imagery, rather than some other strategy, was used to solve the task (e.g., eye movements, tacit knowledge). Finally, the lack of developmental differences may be due to use of children as subjects over the age of 8 years. Studies of younger children are contradictory (e.g., Marmor, 1975; Dean & Harvey, 1979). Given the procedural and methodological problems, it is difficult not only to assess possible changes that may occur with age in "mental rotation" but also to conclude that the nature of representation may not change.

The one finding, however, that is consistent in the developmental studies is that rate of mental rotation (the speed with which a rotation is imagined) increases with age. A robust developmental finding is that children need more time to execute cognitive processes than adults (e.g., Bisanz, Danner & Resnick, 1979). Kail (1988) offers the

following list of potential explanations for age differences in processing speed. One, the differences may reflect acquisition of task-specific skills that are then generalized to other domains (Chi, 1977). Two, they may reflect changes in metacognitive processes (e.g., selecting efficient strategies, allocating effort, monitoring task performance). Three, they may be due to the quantity of processing resources available to execute cognitive processes (Kail, 1988). This is similar to Case's (1985) proposal, in which the quantity of processing resources increases with age, either because of maturation of the nervous system or practice. Although not considered by Kail, changes in rate of processing may also reflect improved speed-accuracy monitoring and regulation (Brewer & Smith, 1989). Unfortunately, the conventional reaction time method used by Shepard (and Freyd) is inadequate to determine which component(s) may be responsible for age differences, because this measure reflects the combination of several complex processing components (encoding, retrieval, decision, and response preparation). Only more sophisticated speed- accuracy methods are able to examine the intermediate components of reaction time performance and the relations among them (e.g., Meyer et al., 1988).

In general, the studies reported here are consistent with the developmental studies of mental rotation. In particular, the present studies found developmental differences in speed of processing, but not accuracy (as in

Childs & Polich, 1979: Kail et al., 1980). Thus, it appears that children above the age of 8 and adults use the same process to solve these recognition problems. Further, since representational momentum involves the representation of physical motion, it appears that children aged 8 and older use kinetic imagery. The present studies of representational momentum may be an even better demonstration of kinetic imagery than the developmental studies of mental rotation, however, for the following reasons. First, unlike developmental studies of mental rotation, the present studies did not ask (train) subjects to transform objects but simply to remember them veridically. Second, the present studies utilized the same stimuli and procedure with children as the representational momentum studies used with adults. Third, the present studies relied more on error rate than reaction time data.

Unlike mental rotation, representational momentum involves or iconic memory (Neisser, 1967). Iconic memory refers to a very brief, precategorical visual representation that remains perceptually available for a few hundred msecs after a stimulus is turned off. The lack of developmental differences in error rate found in the present studies is consistent with several developmental studies of iconic memory (Blake, 1974; Haith et al., 1970). These studies conclude that development consists of the acquisition of increasingly efficient strategies for encoding and rehearsing information with little change in the nature

(structure) of iconic memory itself (Morrison, Holmes & Haith, 1974). The slight increase in accuracy with age in the present studies may have been due to age related changes in strategy use, or in the ability to selectively attend to the (limited) portion of the display necessary to make the judgments (Haith et al., 1970). The present studies do not indicate on what kind of strategy subjects relied. The lack of significant developmental differences in accuracy, however, suggests that there was no major change in strategy use.

Since the present investigation was the first developmental study of "representational momentum", several follow-up investigations are possible. One extension would be to test younger children (since even 8-year-old children were quite capable of performing the task). Such a study might reveal significant developmental differences (instead of trends). It would also test whether young (preoperational) children can use kinetic imagery. Future research might also use abstract stimuli (similar to the later representational momentum studies) to determine whether there are differences in short-term memory for motion in photographs and other types of motion. Future studies could vigorously test the modularity and cognitive impenetrability claim. This could be done by assessing the effect of different instructions or beliefs (knowledge) on memory errors (similar to Hubbard & Bharucha, 1988). It might also be done by assessing whether individuals could

learn to compensate for the momentum effect (either through extended practice or feedback). In order to relate these studies to other picture-memory studies, future research might test whether longer exposure durations would improve performance, since memory for pictures increases with increasing exposure duration (Tversky & Sherman, 1975). Finally, research might assess whether long-term memory is affected in the same way as short-term memory.

In conclusion, the present study used the representational momentum technique to determine whether there are developmental differences in short-term memory for movement in photographs. This study has both theoretical and methodological implications. On a theoretical level, the representational momentum phenomenon is an intriguing picture-memory finding that needs to be investigated further and, if replicated, incorporated into a theory of photographic representation. Methodologically, the assessment of short-term memory with this technique allows for exploration of the nature of developmental differences in the early stages of photograph processing. This method also provides a means for attempting to understand the interaction of perceptual and cognitive processes in the early stages of picture processing.

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