Research Report

APPARENT MOTION OF THE HUMAN BODY

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Abstract—*Observers viewed pairs of alternating photographs of a human body in different positions. Shortest-path motion solutions were pitted against anatomically possible movements. With short stimulus onset asynchronies (SOAs), observers tended to report the shortest path despite violations of anatomical constraints. However, with longer SOAs observers became increasingly likely to report the anatomically possible, but longer, paths. This finding, in conjunction with those from a second study, challenges the accepted wisdom that apparent motion paths are independent of the object. Instead, our findings suggest that when given enough time and appropriate stimuli, the visual system prefers at least some object-appropriate apparent motion paths.*

In classic demonstrations of apparent motion, two spatially separated objects are sequentially presented within a certain temporal range. The visual system interprets this pattern as arising from a single moving point. Although there are an infinite number of possible paths of apparent motion between these two points, observers typically report seeing only the single shortest possible path. How does the visual system determine the path of apparent motion? Does the object influence path choice?

Early studies of apparent motion demonstrate that the perceptual construction of motion is critically dependent upon the temporal and spatial separation of the two stimuli (Korte, 1915; Wertheimer, 1912). These early studies often used pairs of identical objects as stimuli. As a result, the classic view of apparent motion was as a process dependent solely upon factors of time and distance. Other possible factors, such as shape, solidity, occlusion, or symmetry, were little considered.

Kolers and Pomerantz (1971) first systematically addressed the influence of stimulus structure on the perception of apparent motion. In their first experiment, they found that if clearly different objects were flashed within a certain range of temporal and spatial values, subjects reported seeing a single moving object smoothly deforming while translating back and forth. For example, if a display consisted of a flashed triangle followed by a flashed circle, observers would experience a triangle continuously changing into a circle as it moved. This suggested that the visual system ignores shape when constructing apparent motion, instead of preserving the independence and rigidity of two differently shaped objects, the visual system interprets the display as a single non-rigid contour translating across the shortest two dimensional path.

Further evidence in favor of the independence of stimulus shape and experienced path of motion was reported in an influential set of experiments by Burt and Sperling (1981). Using an experimental procedure in which subjects rated the relative strength of apparent motion paths, these researchers found "no measurable preference for motion between figurally similar elements over dissimilar elements" (p. 172). Many researchers have concluded from this result, in combination with Kolers and Pomerantz's (1971) first experiment, that object shape has no influence on perceptions of apparent motion. As a result, the generally accepted wisdom has been that stimulus structure is independent of path choice. As Shepard (1984) eloquently states this position:

> There evidently is little or no effect of the particular object presented. The motion we involuntarily experience when a picture of an object is presented first in one place and then in another, whether the picture is of a leaf or of a cat, is neither a fluttering drift nor a pounce, it is, in both cases, the same simplest rigid displacement. (p. 426)

Our research began by questioning this widely accepted wisdom. Consider biological motion.[1] Outside of the laboratory the ability to correctly interpret biological motion can have direct ecological consequences for an observer. Yet biological motion often violates a shortest-path constraint. Given the importance of biological motion, it seems reasonable to propose that observers might be sensitive to characteristic paths of biological motion. We do know from research using point-light displays that human adults are sensitive perceivers of biomechanical motion (Johansson, 1975) as are human infants (Bertenthal, Proffitt, & Cutting, 1984). Most apparent motion research has used highly abstract, geometric stimuli that may not engage object-specific knowledge in the visual system. These considerations lead us to the hypothesis that under the right conditions, perceivers may construct a motion path that violates the general abstract constraints traditionally thought to dominate interpretations of motion. In particular, we hypothesized that with high-quality photographs of the human body in different poses, and with sufficient processing time, the interpolated motion paths might be consistent with anatomically possible motion even if that motion is not the simplest, or shortest, displacement.

Our hypothesis invokes the notion of sufficient processing time (see also, Shepard, 1984). This proposed temporal boundary is supported by the many apparent motion studies that demonstrate the dependency of interpolated motion on stimulus onset asynchrony (SOA). During short SOAs, apparent motion

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[1] The idea of using the human body as a test case for the generality of apparent motion constraints emerged in conversations between Shepard and Freyd in Ithaca, New York in 1984 and 1985.

paths satisfy local shortest path constraints However during long SOAs, the constructed paths are more likely to be consistent with global or "higher level" constraints, such as maintaining figural rigidity and integrity over time (Anstis & Ramachandran, 1985, Berbaum, Lenel, & Rosenbaum, 1981, Braddick, 1980, Gerbino, 1984, Kolers & Pomerantz, 1971, Experiment 2; Pantle & Petersik, 1980) Therefore, the independence of stimulus structure and apparent motion path found in some earlier studies may be the result of the small temporal range from which measurements were made For example, the longest SOA used in the Burt and Sperling (1981) experiment was always less than 75 ms Thus, previous research does not rule out the possibility that structural information about an object could constrain the possible paths of apparent motion over long temporal separations

EXPERIMENT 1

In this first experiment we asked whether the tendency to see the shortest possible path of apparent motion would be overruled by knowledge of object-appropriate transformations, given compelling stimuli. Taking advantage of the fact that perceptual knowledge of biomechanical motion is presumably highly adaptive, and observers are highly familiar with human motion in particular, the stimuli we selected were high-quality photographs of the human body in different poses.

Two movement limitations of the human body were chosen for study First, as with any solid object, the human body cannot move through itself For example, one can not move an arm through a head. Therefore, the motions of the human body are constrained by solidity—the fact that solids can not pass through one another. While some previous research on the apparent motion of points of light has not produced evidence supportive of a solidity constraint (Berbaum & Lenel, 1983), there is suggestive evidence that observers will experience objects moving in depth around an occlusion when the displays convey some solidity (Kolers, 1972).

Second, the human body also contains a number of joints that limit the range of possible movements For example, one can rotate the right arm about the elbow toward the body, but not away from the body Therefore, the possible motions of the human body are also limited by joints While the solidity constraint is applicable to all solid objects, the joint constraint is only applicable to animals and some machinery (and not rocks or trees) The joint constraint is thus more specific to our hypothesis about apparent biological motion, one could imagine that the greater the range of a constraint's application, the greater its influence in image interpretation

We used a competition strategy to evaluate the influence of constraints on path choice Stimuli were created by choosing motions of the human body in which the shortest path was physically or anatomically impossible If the visual system is likely to be guided by higher order constraints when given sufficient time, then subjects should report seeing longer, anatomically possible motions at longer SOAs

Method

Subjects

Nine Cornell undergraduates were paid for their participation in this experiment All subjects were naive about the hypothesis being tested

Apparatus and stimuli

Stimuli were displayed with a Gerbrands four field tachistoscope, controlled by an IBM PC/XT Pairs of full-color photographs of a human body in different positions were created by photographing a model who remained stationary except for the movement of one or two limbs. The 15 pairs of stimuli were classified into two different types Five pairs involved movement about one of the model's joints (joint constraint stimuli); 10 pairs involved movement of a limb on two sides of some part of the model's body (solidity constraint stimuli) The five joint constraint stimuli included rotation of the right arm about the elbow, rotation of the fingers of the right hand about the wrist, rotation of the entirely visible right hand about the wrist, rotation of the head about the neck, and rotation of the entire right arm about the shoulder. The ten solidity constraint stimuli involved motion of the right foot about the left foot, motion of a closed fist about the head, motion of a closed fist about the torso, motion of the right hand about the left, motion of the first finger about the middle finger of the same hand, motion of an open hand about the torso, lateral motion of an open hand about the head, dorsal-ventral motion of an open hand about the head, motion of one arm about the other arm, and dorsal-ventral motion of one leg about the other leg An example of a joint constraint pair and a solidity constraint pair are shown in Figure 1 The individual photos were mounted on cards designed to fit into the tachistoscope

Procedure

Each subject sat in front of the tachistoscope with his or her forehead resting on a visor Subjects were told that they would observe some rapidly flashing pictures showing a model in different poses, and that sometimes during this flashing they might observe a kind of motion Subjects were told to indicate the path of this motion using the diagrams on the answer sheet They were also told that sometimes the path of the motion would be very clear to them while other times they might see multiple paths of motion, or even no motion at all

The subjects observed each of the 15 pairs of photos at seven different SOA levels during one sitting The order of presentation for the pairs of photos was randomized between subjects For all but two of the pairs of photos, the shortest SOA was 150 ms, consisting of 100 ms stimulus duration (SD) and 50 ms inter-stimulus interval (ISI). The remaining six SOA levels were constructed simply by adding 50 ms to each SD and to ISI at each level. Thus, for 13 of 15 pairs of photos, the longest SOA was 750 ms. The SOAs of the remaining two pairs also increased in 100 ms steps (SD step = ISI step = 50 ms) but differed in their starting values The joint constraint pair involving the rotating motion of the head began with a stimulus duration of 100 ms and ISI of 20 ms. The solidity constraint pair, involving the motion of one foot about the other, began with a 150 ms SD and a 100 ms ISI. These SOA values yielded the best apparent motion across different observers in a pilot study. Five

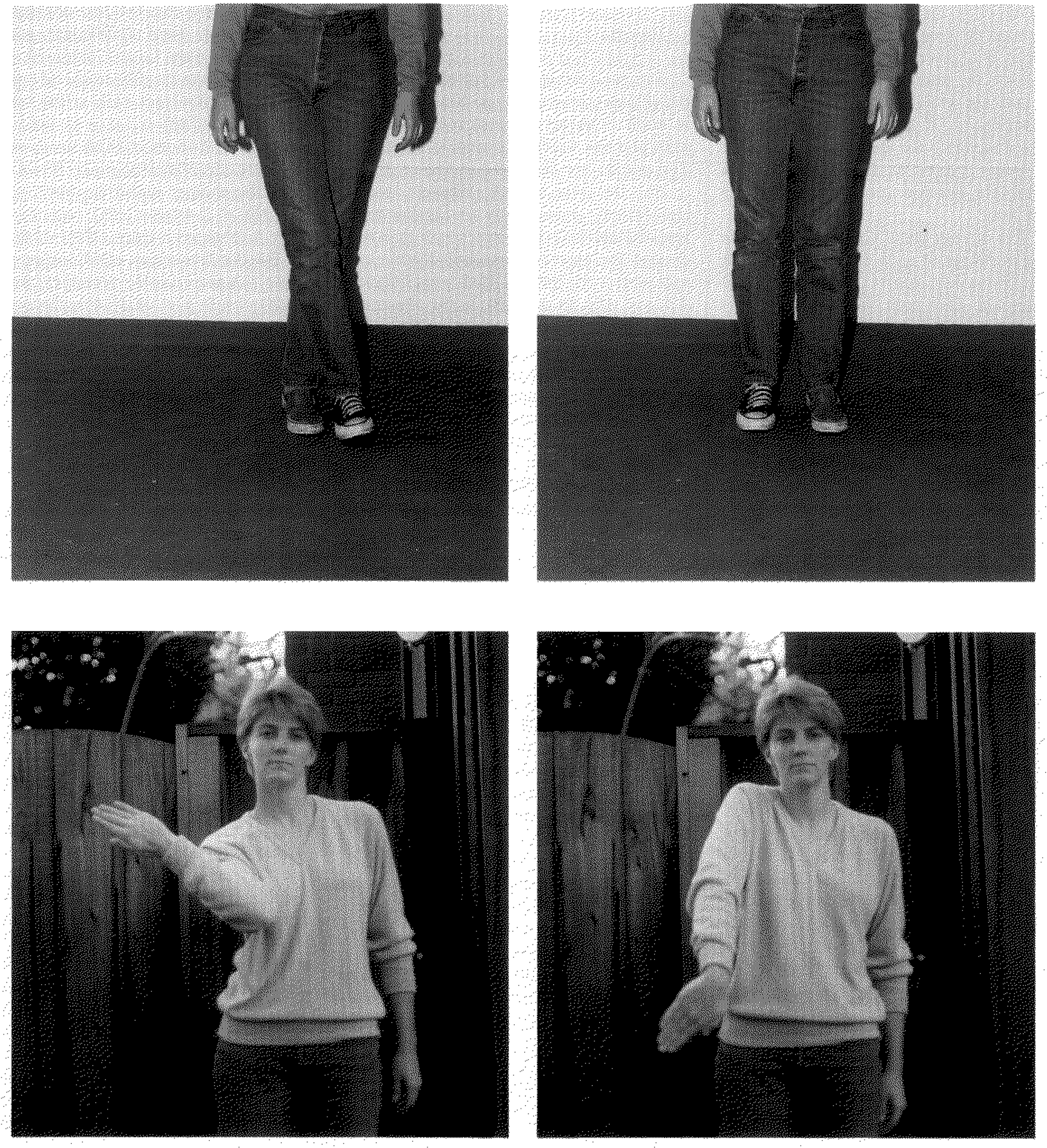

Fig. 1. Two pair of stimuli used in Experiment 1. On the top is an example of solidity constraint stimuli, and the bottom is an example of joint constraint stimuli.

subjects observed each of the photo pairs at SOAs of increasing magnitude while the remaining four subjects observed all of the photos at SOA levels of decreasing magnitude. At each of the seven SOA levels, subjects were asked to view the alternating photos and then to indicate which path(s) of motion they experienced, if any. Subjects were allowed to watch the alternating photos for as many cycles as they desired. The complete session took approximately one hour.

The answer sheet consisted of simple line drawings of each of the stimuli with two possible paths of motion diagrammed. One path, labeled "A," was always the shortest possible path and physically impossible given the solidity and/or joint constraints of the human body. The other longer path was physically possible and was always labeled "B." To the right of each line drawing was a set of possible answers. Subjects were able to choose from "A," "B," "A&B," or "other." This set of possible answers was presented seven times, once for each observed SOA level.

Results

For each subject we tallied the number of times a particular path was chosen at each SOA level (separately for the joint and the solidity constraint stimuli). The results are displayed in Figure 2.

For the joint stimuli, subjects were significantly more likely to choose the longer, anatomically correct path than to choose the shorter, anatomically incorrect path at the longest SOA level [$t(8) < 2.3, p < .05$]. In contrast, at the shortest SOA level subjects were significantly more likely to choose the shorter path than the longer path [$t(8) < 2.3, p < .05$]. An ANOVA revealed a main effect for SOA level for frequency of choosing the longer, anatomically correct path [$F(6,48) < 4.7, p < .001$]. A regression analysis, in which SOA level (coded as 1–7) predicted frequency of choosing the anatomically correct path, produced a significant linear trend [$F(1,61) < 20.1, p < .0001$].

Similarly, for the solidity constraint stimuli subjects were significantly more likely to choose the longer, anatomically correct path than to choose the shorter, anatomically incorrect path at the longest SOA levels [$t(8) < 3.8, p < .005$]. In contrast, at the shortest SOA level, subjects were significantly more likely to choose the shorter path than the longer path [$t(8) < 2.4, p < .05$]. Again, an ANOVA revealed a main effect of SOA level for the frequency of choosing the longer, anatomically correct path [$F(6,48) < 5.5, p < .001$]. Finally, a regression analysis in which SOA level was used to predict the frequency of choosing the anatomically correct path produced a significant linear trend [$F(1,61) < 18.1, p < .0001$].

Discussion

Previous investigators have demon-

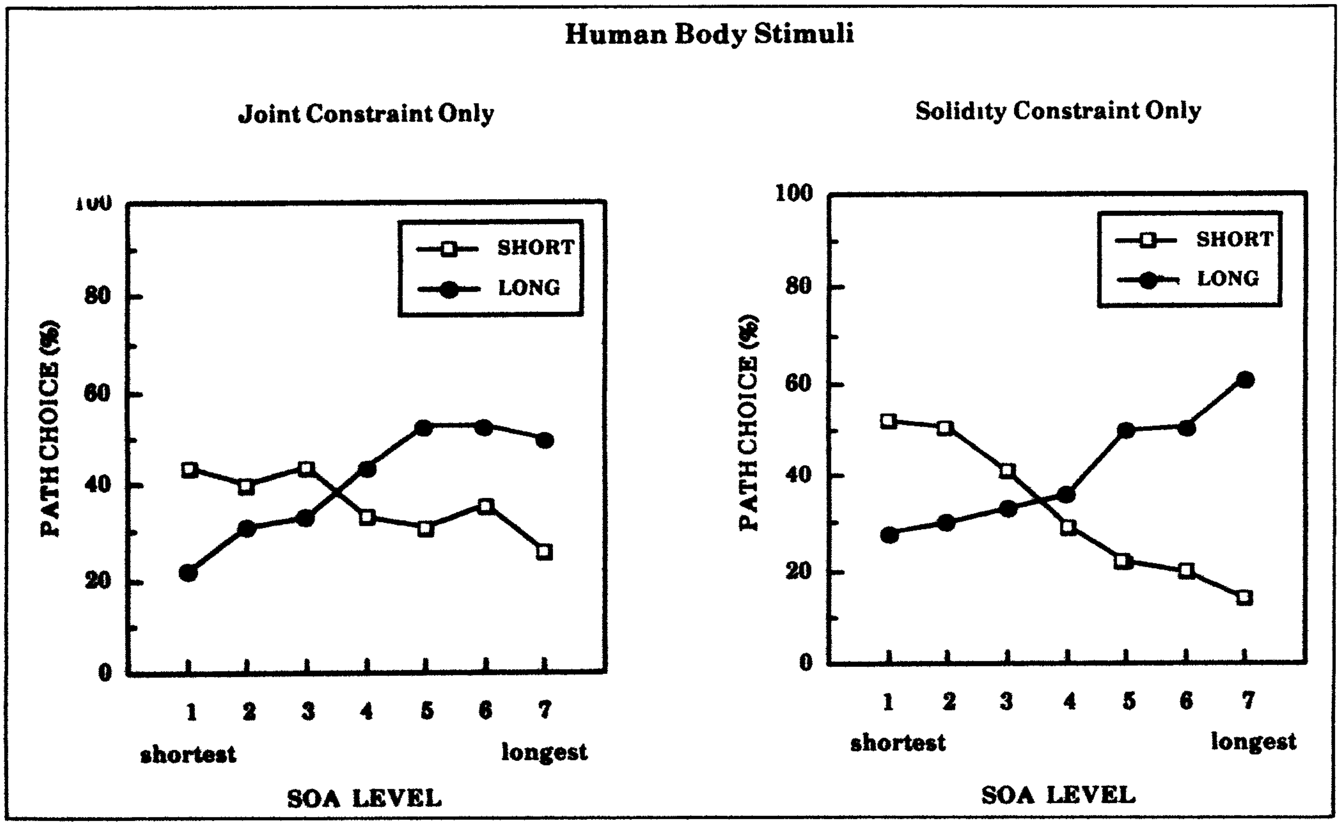

Fig. 2. Results from Experiment 1 divided according to stimulus type. On the left are the results from the five pairs of joint constraint stimuli. On the right are those from the ten pairs of solidity constraint stimuli.

strated that path choice is influenced by the constraints of object permanence (Gerbino, 1984), rigidity (Berbaum et al., 1981; Farrell & Shepard, 1981; Kolers & Pomerantz, 1971), and occlusion (Anstis & Ramachandran, 1985). Our results suggest that constraints of still greater specificity are accessible to the visual system for path choice. The solidity constraint clearly influences the experienced path of apparent motion (see also Kolers, 1972); at longer time intervals subjects were more likely to report seeing limbs move around a body rather than through it. Our result of even greater interest is that although the movement limitations imposed by joints are quite specific, the joint constraint also influences apparent motion: During long temporal separations subjects were more likely to report seeing paths of motion consistent with the specific directional limitations of each joint tested rather than the physically impossible paths of motion.

One possible explanation of the SOA effect for Experiment 1 is that the longer SOAs we used just happened to fall within a range of natural velocities of human motion given the pairs of photographs we used. Perhaps at the short times the motion is unnaturally fast, thus the path experienced is anatomically unnatural. This account does not explain why the shortest path is chosen at the shortest SOAs, and it does not question the result that anatomical constraints guide experienced motion paths. In addition, recently collected pilot data indicate that when the human body stimuli are observed for only a half-cycle, the long, anatomically possible paths of apparent motion are seen even for short SOAs.[2] Most likely the half-cycle presentations (which have extensive "blank" time before and after the two photographs) offer more processing time to the visual system than what is available when the photographs alternate in succession.

There is another possible interpretation of our results. In all of the cases we tested, the anatomically possible path of motion was always the longer path of motion. Perhaps our results reflect a preference for a particular velocity of motion, independent of object-appropriate transformations, so that when given extra processing time the visual system constructs a longer path merely to maintain that preferred velocity. This alternative explanation might be generalized from Korte's third law which states that the direct distance between two points should increase as the time interval increases (Kolers, 1972).

One piece of evidence which argues against a simple notion that given longer time a longer distance will necessarily be constructed, is the type of paths reported by our subjects. At longer SOAs, subjects reported seeing a specific class of paths and not just any one of the infinite number of longer paths. Nonetheless, we conducted Experiment 2 to test the possibility that a longer path will be constructed, independent of object-specific movement constraints, simply because more time is given.

EXPERIMENT 2

In Experiment 2 we examined path choice for objects not normally constrained by joint or solidity limitations. Would long paths be constructed for such stimuli merely because more time was allowed? Based roughly on the joint constraint stimuli of Experiment 1, we used photographs of a clock because the hands of the clock can rotate to either the left or the right. Based roughly on the solidity constraint stimuli of Experiment 1, we used line drawings of two dimensional rectangles that did not strongly convey solidity. The line drawn stimuli were two rectangles such that the shortest path between the two displays would require one rectangle to pass through the other, while a likely longer path would be the rotation of one rectangle about the other. For both these groups of stimuli, we predicted that the shortest, or most direct path of motion should be seen across all temporal and spatial separations.

Method

Subjects

Ten University of Oregon students participated in this study for credit toward completion of a class requirement. All of the subjects were naive about the hypothesis under examination.

Apparatus and stimuli

The apparatus was the same as used in the first experiment. The stimuli in this experiment were photographs of a clock showing different times and line drawings of rectangles. There were six pairs of clock stimuli and four of the line drawn block stimuli. The pairs of clock photos differed in the separation between the hour hands: 2, 3, 4, or 5 hours. These photos were mounted on cards which were used in the tachistoscope. Each line drawn stimulus consisted of a large obliquely oriented rectangle and a second smaller rectangle. The location of the smaller rectangle differed for the two stimulus cards. The line drawn stimuli were drawn directly onto the cards used in the tachistoscope. A sample of each type of stimulus is shown in Figure 3.

Procedure

All of these stimuli were shown at each of four different SOA levels. The shortest SOA was 150 ms (100 ms SD and 50 ms ISI). The remaining three SOA levels were created by the incremental addition of 100 ms to both the SD and ISI. The order of picture presentation with each stimulus type was randomized between subjects. All of the subjects saw the line drawn stimuli before the clock stimuli. Five subjects saw the stimuli with SOAs in ascending order; five observed them in descending order. Subjects watched the display for as long as required to make a response. Subjects recorded their responses onto answer sheets containing pictures of clocks and rectangles with possible paths of motion diagrammed. The format of the answer sheet was identical to that of the previous experiment. Subjects observed all 10 pairs of stimuli at each of four different SOA levels during one 45 minute setting.

Results and Discussion

The results from this second experiment, shown in Figure 4, demonstrate an independence between SOA and experienced motion path. For each subject we tallied the number of times a particular path was chosen at each SOA level for the clock stimuli. At the shortest SOA

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[2] This phenomenon was discovered by Asher Cohen during a visit to our laboratory.

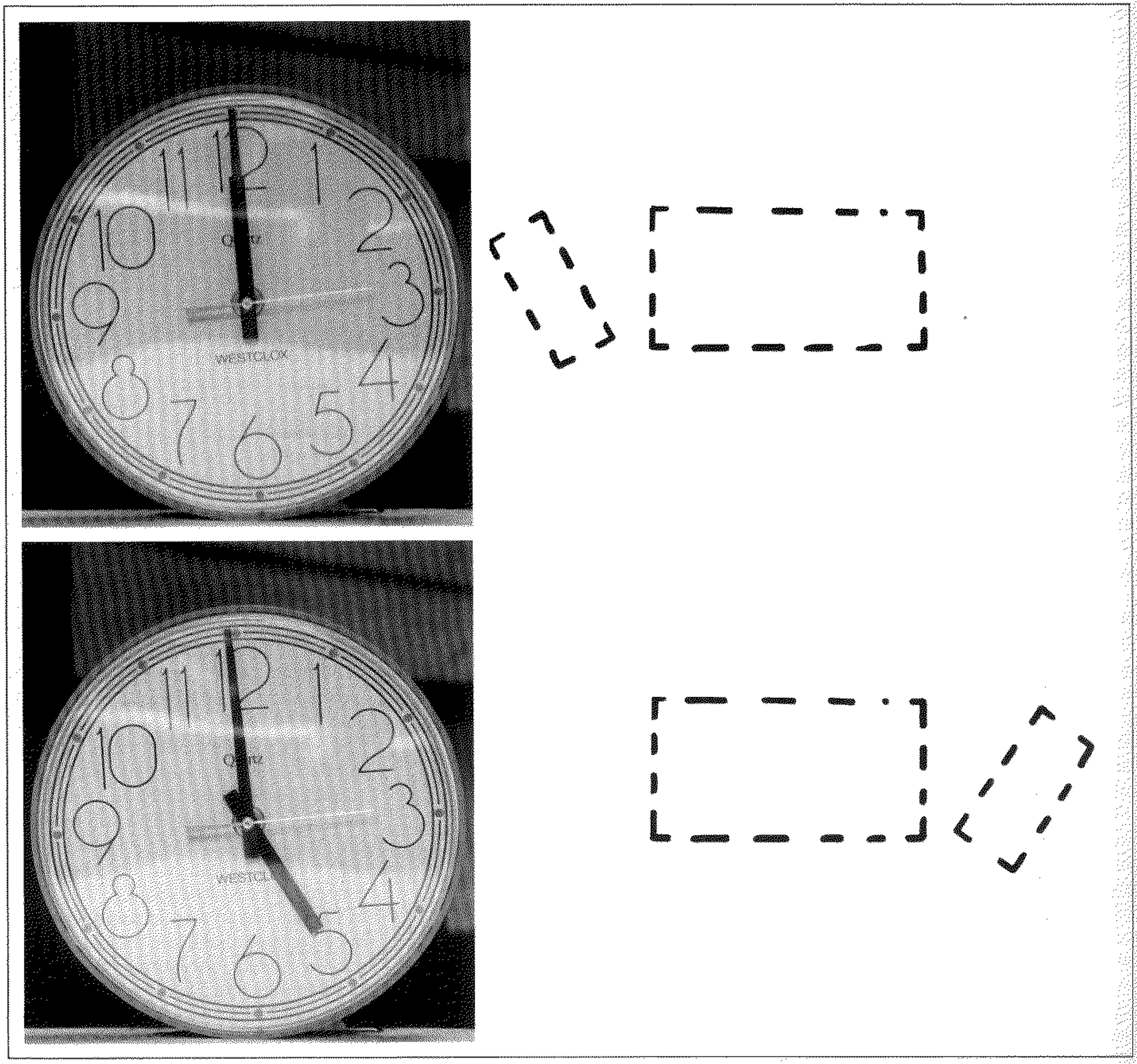

Fig. 3. Schematic depictions of the stimuli used in Experiment 2. Schematic example clocks are on the left (in the experiment full-color photographs of clocks were used); example line drawn rectangles are on the right.

level, subjects were significantly more likely to choose the short path of motion [$t(4) < 11.52$; $p < .0001$]. However, unlike the first experiment, subjects were also significantly more likely to choose the short path during the longest SOA level [$t(4) < 14.28$; $p < .0001$]. No significant main effect for SOA level on path choice nor significant linear trend was found.

We also tallied the number of times a particular path was chosen for each of the line drawn stimuli. Subjects tended to choose the short path during the shortest SOA, although not significantly so [$t(4) < 2.19$; $p < .065$]. Subjects also chose the short path for the longest SOA as well [$t(4) < 2.19$; $p < .065$]. The regression analyses and a main effect of SOA again proved not to be significant.

When constructing paths of apparent motion between freely movable objects, the visual system tends to default to the shortest possible path. The use of realistic or more complex stimuli does not by itself force the perception of long paths of apparent motion during long temporal intervals. Thus, we can conclude that the long paths of apparent motion seen with the human body photographs arose from

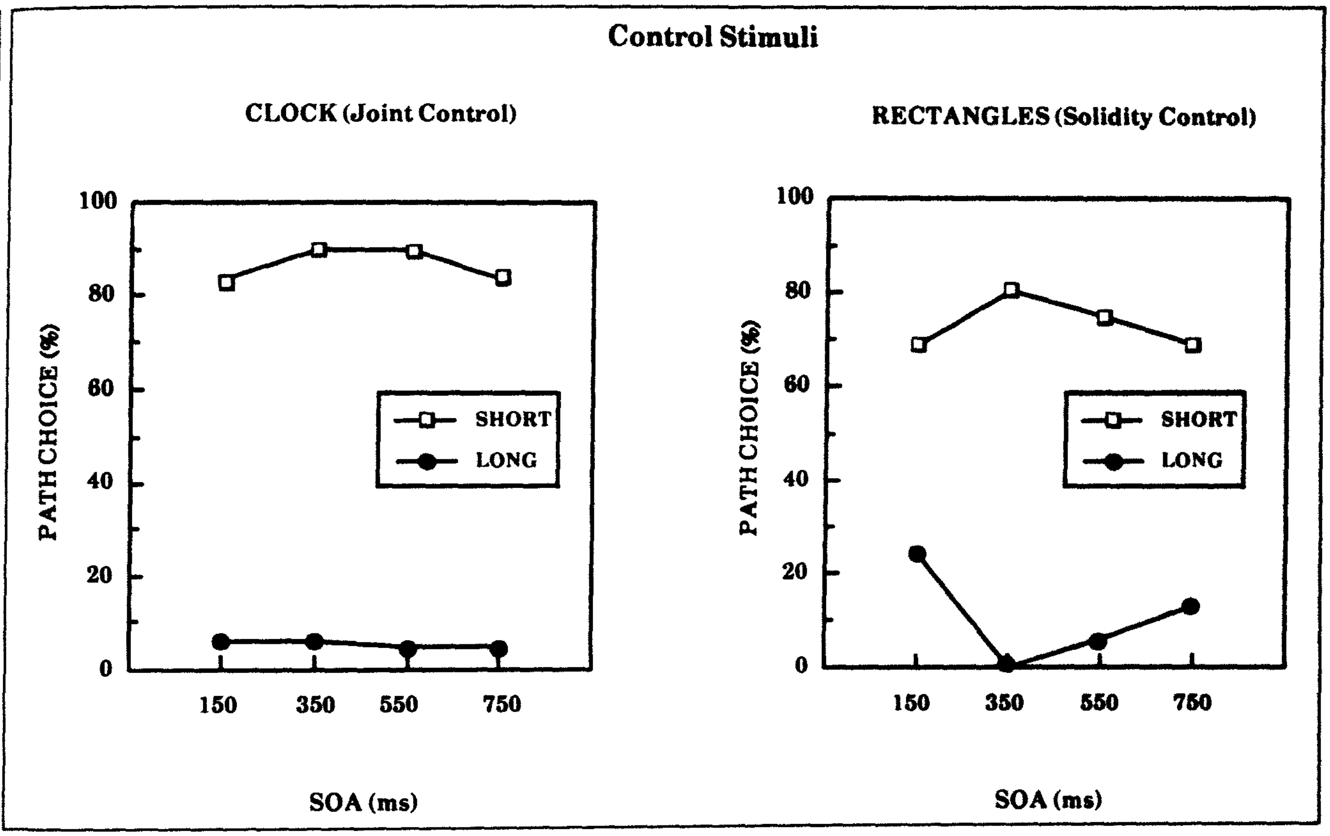

Fig. 4. Results from Experiment 2 The results from the clock stimuli are shown on the left and those from the line drawn stimuli are on the right

knowledge of structurally determined motion limitations (based on object solidity and joint limitations)

GENERAL DISCUSSION

When subjects watched photographs of a human body in different positions, their reports of apparent motion paths changed with SOA. At short SOAs, they tended to see the shortest, most direct path. With increasing SOA, they were increasingly likely to see longer paths that were consistent with the normal movements of the human body. These longer paths always preserved the human body's solidity and joint limitations. Conversely, when viewing pictures of clocks or line drawn rectangles, subjects experienced the shortest path of apparent motion across all temporal separations. This combination of results supports the hypothesis that, when given enough time, the visual system constructs paths of apparent motion that are consistent with the structural limitations of the observed objects

Various theories have been advanced to account for the influence of SOA on higher order constraints applying in apparent motion One theory invokes a dichotomy between low-level and high-level processing in apparent motion (Braddick, 1980), intelligent high-level processes take more time, perhaps because accessing the high-level information takes time An alternative theory, generalized from Shepard (1984), is that the visual system will attempt to construct a motion path that is as globally consistent as possible, that this solution sometimes requires longer paths (for instance three-dimensional paths that preserve object constancy), and that interpolating longer paths takes more time. With Experiment 2 we rejected the hypotheses that the visual system creates long paths merely because the SOA is longer, but it remains possible that the SOA effect in Experiment 1, and most previously reported results showing the dependence of higher order paths on SOA, depend on the fact that the higher order paths were longer than the alternative paths. Generalizations of both Braddick's (1980) and Shepard's (1984) explanations for SOA effects are consistent with our results.

In summary, our research suggests that the perceptual system does have at least some knowledge of object-specific transformations. Physical objects have physical limitations which clearly restrict the possible paths and types of motion they might undergo. Instead of considering all possible paths of motion, the visual system limits the number of potential paths by eliminating those alternatives inconsistent with its assumptions about the world. However, just as the perceptual system needs sufficiently long SOAs to reveal its preference for simple, rigid transformations, it is quite possible that sufficiently rich and compelling stimuli are needed to reveal its preference for object-appropriate transformations

Freyd (1987) has proposed that dynamic information is an intrinsic component of mental representations of objects and events "The 'necessary' criterion" for dynamic mental representations is met when dynamic information is inseparable from the mental representation Our results may reflect the inseparability of dynamic information (object-appropriate transformations) from the mental representation formed when viewing photographs of the human body

Many additional questions remain for future research Does the perceptual system have knowledge of other object-appropriate transformations or is biological motion "special"? How life-like do stimuli need to be in order to tap object-specific knowledge? Does the SOA effect depend on time needed to access knowledge or time needed to construct longer paths? Is perceptual knowledge of object-appropriate transformations learned? Is the experienced motion cognitively penetrable?

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