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Can semantic knowledge influence motion correspondence?

Karen Yu
Department of Psychology, University of the South, 735 University Avenue, Sewanee, TN 37383-1000, USA; e-mail: kyu@sewanee.edu
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Abstract. Semantic factors are presumed to have little influence on motion perception. Two experiments examined the effects of an object's semantic identity on motion correspondence using the Ternus paradigm. Motion correspondence was not influenced by whether the object depicted is typically moving or stationary, but it was influenced by the way(s) in which an object's components typically move relative to one another: perceived correspondence differed depending on whether the motion tokens constituted the feet of a person walking or the wheels of a car. Apparently, semantic knowledge can influence motion correspondence, although such influence is weak and may be restricted to certain types of semantic information. The adaptive significance of such restricted influences is considered.

1 Introduction

Phenomenologically, we consciously experience motion of meaningful, identifiable objects every day. These objects often display characteristic motions: relative to the earth's surface, a bicycle tends to move horizontally, whereas a rocket tends to move vertically at take-off; the wheels of a car translate in tandem, whereas the feet of a person walking move semi-independently. Such object-specific motions constitute semantic knowledge in that the nature of the motion is linked with the identity, or meaning, of the object.(1) Semantic knowledge, if accurate, could presumably contribute to the efficiency of visual processing by providing additional constraints on perceived motion. Does knowledge of object-specific motions contribute to motion perception? By and large, the idea that semantic information might influence motion perception is considered unlikely (Farah 1990; Poggio et al 1985; Ramachandran 1990; Shepard 1984).

Nearly all research on motion perception, however, has employed relatively simple stimuli such as dots and bars that do little to engage our prior knowledge about the objects undergoing motion. Given that such knowledge is in principle available during everyday visual perception, its potential contributions to perceptual processing are worth careful examination. The present experiments investigate the role of semantic knowledge in a specific aspect of motion processing: motion correspondence.

1.1 *Why motion correspondence?*

Motion correspondence, the process by which a portion of the changing visual scene is identified as a single object in motion or in change, is a requisite early step in motion analysis. Indeed, implicit in the very perception of motion is the determination that an object in the current visual scene and an object located elsewhere in an earlier scene constitute *different* glimpses of the *same* object.

The so-called 'correspondence problem' is particularly salient in the context of apparent motion (AM) displays with more than one object in each frame. Because AM is produced by the sequential presentation of static images, it contains no physically

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(1) Semantic identity can be distinguished from structural identity. For example, two objects may be structurally different yet semantically identical (ie they may differ physically but mean the same thing); conversely, two objects may be semantically different but structurally identical (ie they may differ in meaning yet be physically identical).

continuous motion (ie objects are first in one location and then in another); thus, the challenge of determining which object in the current scene corresponds to a given object from an earlier scene is highlighted.

Many researchers contend that correspondence is a low-level, data-driven process that, while sensitive to basic stimulus properties, cannot be influenced by higher-level information. For example, Dawson (1991) argues that correspondence "is a primitive component of perceptual processing and is insensitive to representational contents" (page 586). Given such views, any effects of semantic knowledge on motion correspondence would be particularly intriguing.

Motion correspondence can be effectively investigated with AM competition displays in which at least two correspondences are theoretically possible (eg Ullman 1979, 1980). Using competition paradigms, researchers have identified a number of structural factors that influence motion correspondence. For example, all other things being equal, motion is perceived across the shortest distance (eg Burt and Sperling 1981; Kolers 1972; Shechter et al 1988; Ullman 1979). Other factors that affect correspondence include spatial frequency (Green 1986; Ramachandran et al 1983; Watson 1986; although see Baro and Levinson 1988), orientation (Green 1986; Ullman 1980), figural characteristics (Kolers and Pomerantz 1971; Mack et al 1989; Orlansky 1940; Shechter et al 1988; but see Navon 1976), topological characteristics (Chen 1985; Prazdny 1986; although see Dawson 1989), and disparity (Green and Odom 1986).

So motion correspondence is influenced by a number of fairly basic stimulus characteristics. Whether it is influenced by what the stimuli represent—ie by semantic information—is much less clear. The observation that "wide deviations from the laboratory conditions required for apparent motion are found in motion pictures without seriously impairing the motion perception" (Oldfield 1948, as cited by Kolers 1972, page 43) certainly suggests that meaningful stimuli may function differently than the relatively meaningless dots and bars typically used to study motion perception. Other studies argue that semantic knowledge influences characteristics of perceived motion such as its quality (Blug 1932, as cited by Toch and Ittelson 1956; DeSilva 1926; Jones and Bruner 1954; Krolik 1935, as cited by Toch and Ittelson 1956; Neff 1926) and the particular trajectories that objects appear to take (Jones and Bruner 1954; Shiffrar and Freyd 1990).

Few studies, however, address the effects of such knowledge on correspondence per se. Toch and Ittelson (1956) found that, when presented with an ambiguous display where different correspondences were possible, participants tended to report downward motion of bombs but upward motion of airplanes. However, because the bombs always pointed downward and the planes upward, Toch and Ittelson's study does not reveal whether the directional biases were due to the identity of the objects or to the particular direction in which they pointed. McBeath et al (1992) found that people tend to solve the correspondence problem such that an object appears to move in the direction it faces; interestingly, McBeath et al's results also argue that object identity plays a role in this effect.

The intriguing findings mentioned above coupled with the important theoretical implications of any influences of semantic knowledge on motion correspondence argue for further investigation of this issue. The following experiments sought to do just that. Experiment 1 asked whether an object's general tendency to move influences motion correspondence, and experiment 2 examined whether the typical motions of an object's components influence motion correspondence.

1.2 *Methodological issues*

These questions pose some particular methodological challenges. For one, varying the semantic identity of an object generally involves varying its physical structure as well:

physical structure generally provides substantial information for object identification. Thus, care must be taken to disentangle effects of semantics from those of physical structure. The approach employed in the present experiments involves objects constructed to be highly similar in structure (experiment 1) and structurally identical objects whose semantic identities are manipulated by altering the surrounding context (experiment 2).

Response bias is also a critical issue when clearly meaningful stimuli are employed. It would not be difficult for participants to guess the purpose of the present experiments, and it is well-established that participants' hypotheses about an experiment can influence—consciously or not—their responses (eg Orne 1962). Response bias was assessed in the present experiments by varying the interstimulus interval (ISI), a stimulus parameter with known effects on correspondence (eg Pantle and Picciano 1976), in addition to varying semantic identity. Because ISI varied randomly from trial to trial, participants could not predict its particular value on any given trial. Moreover, participants were generally unaware of the known effect of ISI on correspondence, rendering response bias accounts less likely if ISI has its expected effects.

Finally, it is worth noting that in the present experiments a somewhat less conventional display has been used to study motion correspondence: a variant of the Ternus display (Ternus 1926/1938; see figure 1). In this display, two identical tokens, arrayed in a row, are displaced from frame 1 to frame 2. The amount of displacement equals the distance separating the individual tokens, with the result that one token location is identical in frames 1 and 2. The Ternus display is a competition display in that multiple correspondences are possible: observers usually perceive either 'element motion', in which the endmost token is seen as moving back and forth while the middle token remains stationary, or 'group motion', in which both tokens appear to translate in the same direction.

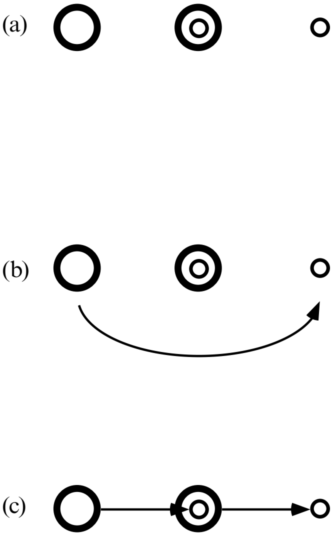

Figure 1. Schematic illustration of the two-token variant of the Ternus display used in the present experiments. (a) Large circles with heavy borders represent frame 1 tokens (time t_1); small circles with thinner borders represent frame 2 tokens (time t_2). (b) Element-motion percept. (c) Group-motion percept.

Although the Ternus display is not used as often as some other competition displays in studying motion correspondence, the perception of element versus group motion hinges on the correspondence process. Moreover, in most other competition displays, different correspondences are linked with different directions of motion, and perceptual anisotropies can thus pose added complications (see, eg, Yu 1995). With the Ternus display, different correspondences are linked with different trajectories in the *same* direction of motion, thus minimizing such complications.

2 Experiment 1

In this experiment, a two-frame, two-token variant of the Ternus display (see figure 1) was used to investigate whether the likelihood of motion associated with a particular object influences motion correspondence. Two mutually exclusive percepts are possible:(2) 'element motion', where the left token in frame 1 moves to the rightmost position in frame 2 while the other token remains stationary; or 'group motion', where the two tokens in frame 1 move rightward in tandem.

Does the semantic identity of the motion tokens influence the perception of element versus group motion? In particular, is element motion more likely when the overlapping token is a typically stationary object (eg a building) as opposed to a typically moving object (eg a bus)?

2.1 *Method*

2.1.1 *Participants.* Fifteen Vanderbilt University undergraduate and graduate students were paid for their participation in this experiment. All participants had normal or corrected-to-normal vision and were unaware of the hypothesis under test.

2.1.2 *Apparatus.* Stimuli were displayed on a 19-inch Radius monitor with Precision Color Interface Card (1152 × 882 pixels, 82 dpi, 72 Hz vertical scan rate) from a viewing distance of 57 cm. Luminances were linearized with a Precision Color calibrator and software. Presentation and timing of stimuli, as well as recording of responses, were under the control of a Macintosh II computer with a DayStar 030 40 MHz accelerator. Image presentation was synchronized with the monitor's vertical retrace.

2.1.3 *Stimuli.* The same basic motion display (see figure 1) was used across conditions. This particular experiment necessitated a typically stationary object and a typically moving object with minimal structural differences, because differences in token size and shape can influence perception of the Ternus display (eg Casco 1990; Petersik 1984). The objects chosen were schematic depictions of a bus and a building (see figure 2). Both the bus and the building shared the same basic structure—a rectangular outline with smaller rectangles representing a door and windows. To this common framework were added 'wheels' in the case of the bus, and 'shrubs' in the case of the building.

Each motion display consisted of two frames. Frame 1 contained two buildings, two buses, or one building and one bus (both possible arrangements); these four conditions are shown in figure 2. Frame 2 always consisted of two ambiguous bus/buildings (ie the shared basic structure of the bus and building, without the 'shrubs' or 'wheels'; see figure 2). A neutral condition, involving two outline rectangles in both frames of the motion sequence, was also included.

Use of the ambiguous bus/building in frame 2 was necessary in order to examine pure effects of semantic identity. To illustrate, suppose we were to compare the motion sequence bus – building in frame 1 and building – bus in frame 2 with the sequence bus – bus in frame 1 and bus – bus in frame 2. We should expect to find more element motion in the first scenario based simply on the *physical* characteristics of the tokens (see Casco 1990). Element motion in the first scenario allows each token to maintain its physical identity, whereas group motion essentially requires a building to turn into a bus and vice versa; in the second scenario, both element motion and group motion allow the tokens to maintain their physical identities. Thus, if unambiguous objects were used in frame 2 (as described in the above scenarios), a bias towards element motion when the building is the overlapping token could not be definitively ascribed to semantic knowledge per se.

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(2) A third percept, one of simultaneity, can also be evoked with very brief frame durations and ISIs (Dawson and Wright 1994).

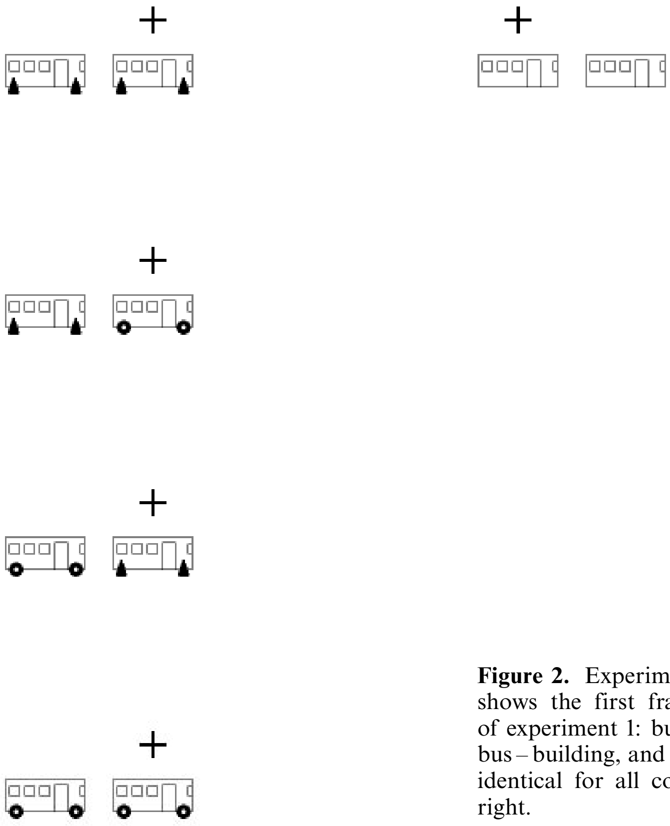

Figure 2. Experiment 1 stimuli. The left column shows the first frame for the various conditions of experiment 1: building – building, building – bus, bus – building, and bus – bus. The second frame was identical for all conditions, and is shown on the right.

Rendering the identities of the objects in frame 2 ambiguous also prevents individuals from basing responses solely on the identities of the tokens in frames 1 and 2 (eg "There was a bus on the left and a building on the right in frame 1, and in frame 2 the bus was still to the left of the building, so they must have both moved together ... group motion").

The unambiguous bus and building each subtended 1.46 deg × 0.71 deg. The ambiguous bus/building (no 'wheels' or 'shrubs') subtended 1.46 deg × 0.59 deg. The center-to-center distance between objects was 1.98 deg. A fixation cross was located 2.17 deg directly above the center of the overlapping object. All stimuli were displayed within a 7.75 deg × 3.10 deg rectangular aperture.

2.1.4 *Procedure.* Participants initiated each trial by a keypress. To facilitate object identification, each trial began with a 1 s presentation of the first frame of the motion sequence for that trial. This 'object preview' was followed by a 1 s ISI during which only the fixation cross appeared. Then the two-frame test sequence was presented. Frame duration was 194 ms. ISIs of 0, 28, 42, 56, 69, 83, and 97 ms were used.

After each test display, participants indicated by a keypress whether they had perceived element motion or group motion. All five object-arrangement conditions (building – building, bus – bus, bus – building, building – bus, and rectangle – rectangle) and seven ISIs were randomly intermixed within a block of trials. Each participant completed two sessions of 350 trials each over two days.

Prior to beginning the experiment proper, the distinction between element motion and group motion was explained and shown to each participant. As practice, each participant completed 21 trials of the rectangle – rectangle condition (3 trials at each of the 7 ISIs). Participants were also shown the schematic bus and building, and told what they were intended to represent. Participants were instructed to maintain fixation on the fixation cross.

2.2 *Results and discussion.*

The percentage of group-motion responses for each condition was determined for each participant. Data from two participants were excluded because of their highly biased responses for both the bus – building condition and the bus – bus condition (ie responses for these participants in these conditions did not vary with ISI: these two participants virtually always responded 'element motion' in the bus – building condition, and 'group motion' in the bus – bus condition). Figure 3 shows the mean percentage of group-motion responses for each condition as a function of ISI; each point is the mean of data from 13 participants.

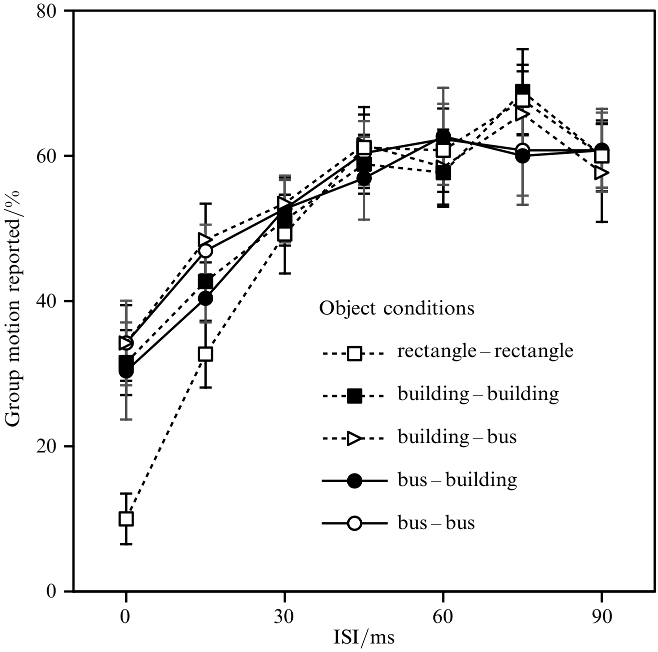

Figure 3. Results of experiment 1. The percentage of trials for which group motion was perceived as a function of ISI for the various object conditions. These conditions are explained in the text. Shown are the mean data for 13 participants. Error bars represent ±1 SE of the mean.

A randomized-block factorial analysis of variance (ANOVA) with ISI and object arrangement as factors showed a significant main effect of ISI ($F_{6,72} = 17.15$, $p < 0.0001$): consistent with previous work, the percentage of group-motion responses increased with ISI. Object arrangement did not affect the percentage of group-motion responses ($F_{4,48} = 1.09$, ns). The object arrangement × ISI interaction, however, was significant ($F_{24,288} = 2.66$, $p < 0.0001$). As suggested in figure 3, the linear component of the effect of ISI on group-motion responses differed for the rectangle – rectangle condition compared with the other four conditions ($F_{1,288} = 34.68$, $p < 0.0001$), accounting for roughly 54.4% of the omnibus interaction variance.

The greater incidence of element motion at smaller ISIs for the rectangle – rectangle condition likely arises because in this condition the motion tokens were identical across frames. Recall that, for all other conditions, frame 2 consisted of ambiguous bus/buildings, which differed from the bus(es) and/or building(s) in frame 1. Evidence suggests that element motion is more sensitive to spatial detail and position, whereas group motion is more tolerant of changes in the spatial structure of the stimulus (Pantle and Petersik 1980; Petersik 1984). The present results are consistent with these findings: element motion was less likely in those conditions where the motion tokens differed from frame 1 to frame 2 (ie all conditions save the rectangle – rectangle condition).

3 Experiment 2

In this experiment, a two-token variant of the Ternus display was used to examine whether semantic constraints operate for moving components *within* a given object, as opposed to the object as a whole. Semantic identity of the motion tokens was altered by manipulating the surrounding context, allowing physically identical tokens to assume different semantic identities.

Suppose the motion tokens in a Ternus display (see figure 1) represent a person's feet, and the context depicts a person walking. This context favors element motion. (Consider the manner in which a person's feet move relative to one another as he or she walks: one foot remains stationary on the ground while the other steps from behind to in front.) Now suppose the motion tokens represent the wheels of a car or bicycle, which typically move as a unit. In this case, group motion is implied. Using such displays, then, we can examine whether the tendency to see element or group motion depends on the semantic identity of the motion tokens.

3.1 *Method*

3.1.1 *Participants.* Seventeen adults (sixteen undergraduates and one graduate student) from the Vanderbilt community and three students from the University of the South participated in this experiment. Students participated in partial fulfillment of a course requirement or were paid for their participation. All participants had normal or corrected-to-normal vision and were naive as to the hypothesis under test.

3.1.2 *Apparatus.* The apparatus was identical to that of experiment 1.

3.1.3 *Stimuli.* The basic motion display consisted of a two-frame sequence in which the two motion tokens protrude from behind a rectangular occluder. The tokens were ellipses, each with major axis of 0.74 deg and minor axis of 0.59 deg when unoccluded; the occluder subtended 5.95 deg × 2.54 deg and covered the top half of each token. Center-to-center distance between the tokens was 1.86 deg. A fixation cross was located 0.90 deg directly above the overlapping token. All images were presented within a rectangular aperture subtending 10.08 deg × 4.65 deg.

Four context conditions were used. In the person context, the motion tokens represented the feet of a person walking. In the car context, the tokens represented the wheels of a car. Two control conditions—no context and tokens-alone context—were also used.

The motion display differed slightly across conditions. In the person condition, the top part of a person's head could be seen above the occluder. In the car condition, the top portion of a cab could be seen above the occluder. Each test display was preceded by a 'context preview' frame showing the entire object to which the tokens belonged. The object appeared to the left of the occluder, as if approaching it. The four context previews—no context preview, tokens-alone preview, car preview, and person preview—and their corresponding motion sequences are shown in figure 4.

3.1.4 *Procedure.* Participants initiated each trial by a keypress. The context preview display was presented for 1 s, followed by a 1 s ISI during which only the rectangular occluder appeared. Then the two-frame test sequence was presented. Frame duration was 97 ms. Six ISIs were used: 0, 14, 28, 42, 56, and 69 ms.

After each test display, participants indicated by a keypress whether they had perceived element motion or group motion. All four context conditions and six ISIs were randomly intermixed within a block of trials. Each participant completed four blocks of 240 trials over four days.

Prior to beginning the experiment proper, the distinction between element motion and group motion was explained and shown to each participant. As practice, each participant completed 60 trials of the no context condition (10 trials at each of the 6 ISIs) and 24 trials in which all conditions were intermixed.

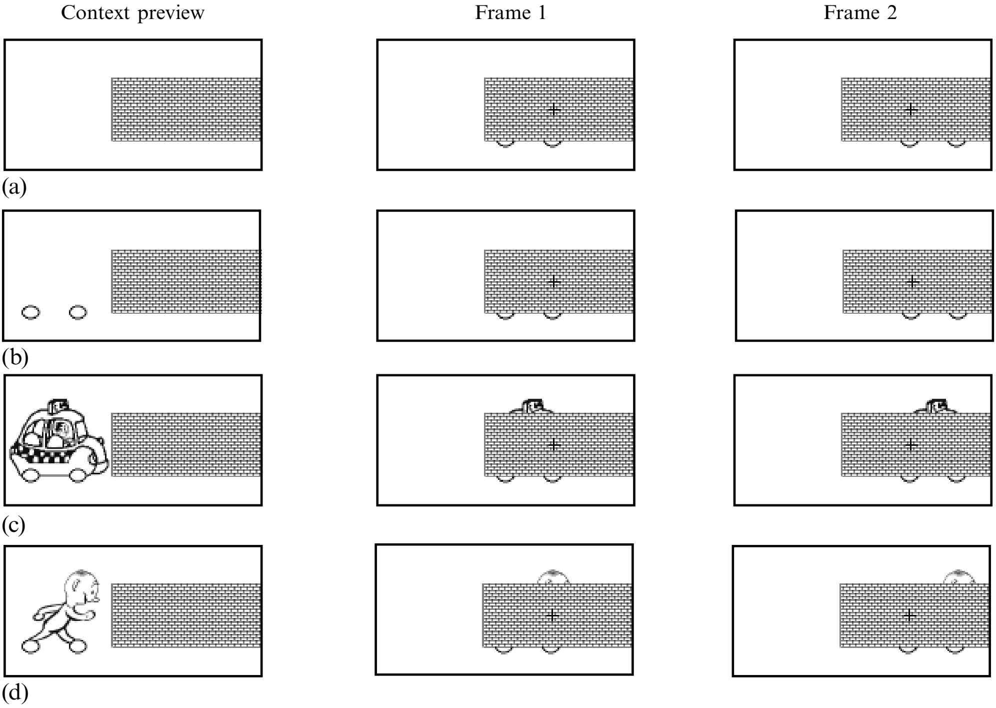

Figure 4. Context previews and two-frame Ternus sequences for the four conditions of experiment 2. From top to bottom, these are (a) the no-context condition, (b) the tokens-alone condition, (c) the car condition, and (d) the person condition.

Participants were instructed to maintain fixation on the fixation cross during each trial; while maintaining fixation, they directed their attention to the left side of the display at the beginning of each trial, noted the object (if any) that appeared there, and then directed their attention to the test display.

3.2 *Results and discussion*

Figure 5 shows the mean data from 20 participants, with the percentage of group-motion responses plotted as a function of ISI. A randomized-block factorial ANOVA with ISI and context as factors showed a significant main effect of ISI ($F_{5,95} = 110.96$, $p < 0.0001$) and a significant main effect of context ($F_{3,57} = 3.60$, $p < 0.02$). The ISI × context interaction also was significant ($F_{15,285} = 1.77$, $p < 0.05$).

Figure 5 shows that as ISI increased, so did the proportion of group-motion responses. This relationship between ISI and the perception of element versus group motion is well-documented (eg Breitmeyer et al 1988; Pantle and Picciano 1976; Petersik and Pantle 1979).

The significant ISI × context interaction appears to be primarily due to a floor effect on the percentage of group-motion responses for the 0 ms ISI and a near-ceiling effect for the longest ISI (see figure 5). At an ISI of 0 ms, the center token remains stationary and is reliably perceived as such: thus, all other things being equal, element motion is seen regardless of context condition. As ISI increases, the status of the center token (stationary versus moving) becomes more ambiguous, and hence effects of other variables are more likely to manifest themselves at non-zero ISIs.

Most interesting is the significant effect of context. Participants were more apt to see element motion when the motion tokens constituted the feet of a walking person than when they represented the wheels of a car. Comparing results from the person context with the mean of the other three context conditions indicates a significant

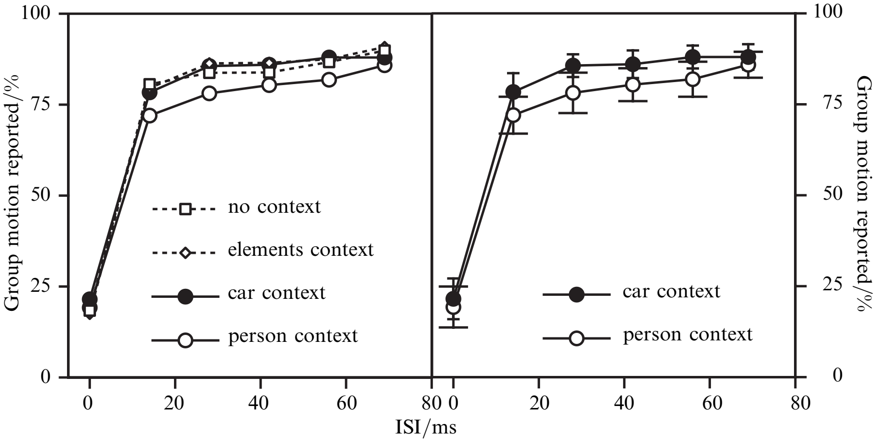

Figure 5. Results of experiment 2. The percentage of trials for which group motion was perceived as a function of ISI for each of the four context conditions. Context conditions are explained in the text. Data from the car-context condition and the person-context condition are re-plotted in the right panel for clarity. Shown are the mean data for 20 participants. Error bars represent ±1 SE of the mean.

difference ($F_{1,57} = 10.60$, $p < 0.01$) that accounts for roughly 98.1% of the variance attributable to the main effect of context.

4 General discussion

Experiment 1 found no influence of an object's likelihood of motion on the correspondence process. Element motion was not any more likely when the overlapping element was a typically stationary object than when it was a typically moving object. However, experiment 2 indicates that motion correspondence is sensitive to semantic knowledge about the way in which components of an object move relative to one another: element motion was more likely when motion tokens constituted the feet of a person walking than when they constituted the wheels of a car.

4.1 *Methodological concerns*

One might argue that the failure to find semantic effects in experiment 1 was due not to a lack of such effects per se, but rather to inappropriate methodological conditions. Perhaps the present experiments failed to provide sufficient processing time for knowledge-based effects to manifest themselves (eg Shiffrar and Freyd 1990, 1993; see also Ullman 1979). However, experiment 2 *did* reveal semantic effects with similar stimuli and even briefer presentation times than those employed in experiment 1.

Long stimulus durations help to ensure sufficient processing time, but they also have disadvantages. Relatively short stimulus durations were employed in the present experiments for several important reasons. First, longer stimulus onset asynchronies (SOAs) noticeably compromised the quality of perceived motion. Thus, somewhat shorter SOAs were used to avoid conditions in which motion might be inferred, rather than perceived. Second, brief displays minimize the influence of eye movements and attentional fluctuations on motion perception.

Another methodological consideration concerns the degree of realism in the displays. Detailed and realistic stimuli may gain readier access to object-specific knowledge, and thus one might question the cartoonish nature of the present displays. Clearly, there is a tradeoff here. While more realistic stimuli increase the likelihood of semantic influences, they also tend to introduce other confounding factors (eg structural differences) that complicate interpretation of the results. More ambiguous stimuli help eliminate these confounding factors, but tend to render semantic information less salient. While realism of both stimuli and situation may very well be an important issue in such experiments, the object-specific effects observed in experiment 2 argue against wholesale dismissal of the stimuli used here as insufficiently realistic (perhaps arguing, in fact, that the knowledge is abstract and flexible, given that the effects do not depend on the displays being absolutely true to the previous experience). This is an issue deserving more careful investigation.

Another issue worth further consideration is the possibility that offsets and/or contrast polarity changes in the displays might have affected the results of experiment 1.(3) What this really boils down to is the components that represent the wheels and the shrubs: these are present in frame 1 but disappear in frame 2. Moreover, these components have different contrast polarities—the wheels are both white and black, whereas the shrubs are entirely black. Given that offsets and contrast polarity have been shown to influence perception of the Ternus display (eg Breitmeyer et al 1988; Dawson et al 1994), these factors may have contributed to the null results of experiment 1, although previous findings do not suggest an obvious prediction about the expected effects for the experiment 1 displays.

4.2 *Implications*

How can we make sense of these results? Perception itself serves to facilitate our interactions in and with the world, by building a reliable representation of this world. Perception cannot fulfill this role if it is malleable by all sorts of knowledge. Thus, it is critical that perception be independent of knowledge at some level, precisely because of the kind of information that we depend on perception to provide. Yet, by embodying *reliable* relationships in the world, perceptual processes can gain greater efficiency with minimal cost.

Given the above reasoning, perhaps a critical determinant of whether a given type of knowledge will influence perception is the reliability of that knowledge. The generality of the knowledge is also likely to be an important factor. Knowledge that can be applied across vast domains is likely to be less costly for the organism in terms of both storage and retrieval.

The criteria for reliability and generality may vary with the perceptual process in question. In particular, the more important a given aspect of perception is to an organism's survival, the more stringent the criteria for reliability are likely to be. Whether a given type of knowledge is sufficiently reliable and/or general to be incorporated by a given perceptual process is ultimately an empirical question. Nevertheless, careful consideration of various types of knowledge may provide useful insights.

Consider the distinction between structural knowledge and semantic knowledge. Structural knowledge embodies properties that apply in general: opaque objects occlude one another; the size of an object's retinal image changes with its distance from the perceiver; two objects cannot occupy the same spatiotemporal locale; these are extremely general and fundamental characteristics of the physical world in which we live and hence are unlikely to be violated. By its nature, then, structural knowledge is unlikely to lead to error, and incorporating such knowledge about enduring, pervasive physical properties of the world would be highly advantageous. Indeed, structural knowledge seems to possess the qualities that any perceptual system would desire in a knowledge source: high reliability (thus little chance for error) and extensive generality (thus wide applicability). Much work is consistent with an extensive role of structural knowledge in perception (He and Ooi 1999; Nakayama and Shimojo 1990; Shiffrar and Freyd 1990; Shimojo and Nakayama 1990a; Shimojo and Nakayama 1990b; Sigman and Rock 1974).

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(3) Thanks to an anonymous reviewer for noting this possibility.

Semantic knowledge, however, embodies characteristics of particular objects or categories of objects in the world, and so is inherently less general than structural knowledge. Semantic knowledge varies in generality. For example, that animals have joints that tend to move in constrained directions, and that the human foot moves in particular constrained ways relative to the knee both constitute semantic knowledge, but the first statement is more general. Furthermore, this sort of knowledge is more variable in its reliability than is structural knowledge. For example, buildings may tend not to move at all, but on occasion, they do move owing to external forces. With greater variability in both reliability and generality, the utility of incorporating *semantic* knowledge into some perceptual process is itself more variable. Perhaps we should not be surprised, then, if semantic knowledge proves to play a much smaller role in perception than structural knowledge. [Compare, for example, the large effects of structural knowledge on the Ternus display demonstrated by He and Ooi (1999) with the very small effect of semantic knowledge found in the present experiment 2.]

With this perspective in mind, consider the present findings. In experiment 2, constraints on the relative motions of components within a given object affected perception. This is object-specific knowledge in that the relative motions of components differ from object to object. Whether these results reflect constraints particular to biological motion or more general constraints regarding component motions remains to be seen. Note that in experiment 2 it was essentially the results of the person context that differed from the other three contexts. Other evidence indicates that the visual system incorporates constraints associated with biological motion (eg Shiffrar and Freyd 1990), so the possibility that the present results are restricted to biological motion deserves consideration.

Because it is object-centered, such knowledge about relative component motions will generally be a more reliable predictor than observer-centered or environment-centered constraints; it is more likely that an object's components will move in a given manner relative to its own frame of reference than that the object will move in a particular manner relative to a perceiver's frame of reference.

Consider now the results of experiment 1: an object's tendency toward motion did not affect correspondence. Rather than incorporating specific knowledge about the motion tendencies of particular objects, the motion system may depend on more general constraints that can be applied across objects—a more flexible and reliable approach. Indeed, as Shepard has noted, "the objects that have been important to us evolutionarily have been informationally complex ... and, furthermore, have changed over the eons" (1984, page 441). Especially when considering the motion of objects in their entirety, outside forces can move virtually any object in virtually any direction. It would be advantageous to be able to accurately perceive this motion.

How might the semantic effect observed in experiment 2 be implemented? In part, this is a question about the cognitive penetrability of motion processing (see Fodor 1983; Pylyshyn 1984; Wright and Dawson 1994). One broad possibility is that knowledge operates on motion processing mechanisms themselves—ie that knowledge has a *direct* influence on motion processing. Such a direct influence could arise through unmediated interactions between knowledge and motion-processing mechanisms, or from knowledge that is actually built into the motion-processing system itself. Knowledge could also influence motion processing *indirectly*, eg via eye movements, representational momentum, and/or attention. These possibilities are considered independently; they need not, however, be mutually exclusive.

The effects of eye movements on motion perception are well-documented (eg Kowler and Steinman 1979a, 1979b, 1981), but seem rather unlikely to account for the present results for the following reasons. First, the potential role of eye movements in these experiments was minimized by using brief stimulus durations and by instructing participants to fixate on a highly visible fixation cross. Even if participants did not comply with these instructions, given average saccade and pursuit latencies, it is unlikely that eye movements initiated at stimulus onset could have exerted much influence with such brief stimulus presentations. Second, object-specific effects were observed in experiment 2 but not in experiment 1. Participants' knowledge about object-typical motions can provide a basis for the formation of expectations about an object's motion.(4) Yet if anticipatory eye movements driven by such expectations are to explain the present results, they must address the fact that object-specific effects were only observed in experiment 2. A remaining possibility is that the conditions of experiment 2 induced stronger expectancies (with associated eye movements), whereas the conditions of experiment 1 produced weak expectancies, if any.

Although eye movements per se are unlikely to explain the present results, the influence of expectations on eye movements and the possible influence of eye movements on motion perception do suggest an interesting possibility. Namely, we might observe stronger influences of semantic information when eye movements are *not* constrained. It is well documented that expectations, attention, and cognitive strategies can have a great impact on eye movements. Perhaps under less constrained conditions, semantic information does affect motion perception by inducing expectancies about the direction of motion that influence eye movements.

Another possible mechanism for an indirect influence of knowledge on motion perception is representational momentum (eg Freyd 1983, 1987; Freyd and Finke 1984)—a characteristic tendency of observers to extrapolate an object's motion beyond its last observed position. Representational momentum can be affected by an object's anticipated, as well as its actual, direction of motion (Hubbard and Bharucha 1988; Reed and Vinson 1996; Verfaillie and d'Ydewalle 1991). When the perceptual system cannot directly perceive change over time, it may seek out implicit evidence of change. Indeed, static scenes can convey motion information in a variety of ways (Friedman and Stevenson 1980).

With regard to the present experiments, knowledge of object-typical motions might induce a mental representation of the first frame that continues the implied motion, thus resulting in a shorter representational distance for the expected motion and hence—given the general correspondence bias toward shorter distances (eg Burt and Sperling 1981)—a bias towards the expected path. Moreover, Reed and Vinson (1996) demonstrated that representational momentum is greater in an object's typical direction of motion. A representational-momentum account, like an eye-movement account, would need to explain why the semantic effects were restricted to experiment 2, perhaps by appealing to the different types of semantic knowledge examined in experiments 1 and 2.

Attention represents yet another possible indirect mechanism by which semantic knowledge could affect motion perception. A number of models incorporate interactions between attention and motion processing (eg Dawson 1991). Moreover, various studies indicate that attention can influence motion perception (eg Cavanagh 1992; Hikosaka et al 1993; Stelmach et al 1994). For example, observers are more sensitive to motion when they know what direction and/or speed of motion to expect (eg Ball and Sekuler 1980, 1981; Sekuler and Ball 1977). Directing attention to a particular stimulus has an effect similar to presenting the attended stimulus slightly before the unattended stimulus, increasing the likelihood of perceiving motion from the attended toward the unattended stimulus (Hikosaka et al 1993; Stelmach et al 1994).

(4) Anticipatory eye movements could serve as a useful measure of the degree to which people expect certain objects to move in particular directions. An eye-movement indicator would have certain advantages over the subjective ratings. For one, anticipatory eye movements would permit measurements of expectations that might not be consciously accessible. They might also be particularly useful for studying expectations in children and animals (Kowler and Steinman 1979b).

Perhaps semantic knowledge influences motion perception via attention: since attention can be controlled by cognitive states, it may furnish a channel through which cognitive processes can affect perception. Although participants in the present experiments were instructed to distribute their attention over the entire display, it is possible that attention was differentially allocated. Such differential allocation of attention might account for the effects observed in experiment 2.

In experiment 2, semantic context influenced the tendency of participants to see group or element motion. As mentioned above, there is an increased tendency to see motion originating from an attended object or location. Perhaps attention to the left token of frame 1 (the rear foot of the walking person) reduces the likelihood of seeing motion of the other token, thus endowing greater correspondence strength to a match between the left token of frame 1 and the right token of frame 2. What about the car context? It seems an attentional account of the present results would need to assume that attention was distributed more evenly across the two frame 1 tokens in this condition, thus increasing the likelihood that both tokens would be seen as moving.

The mechanisms discussed above are not intended as an exhaustive list of possible routes via which semantic knowledge might influence motion perception, but rather some possible alternatives. Clearly, the mechanisms responsible for the semantic effect observed in experiment 2 require further examination. Yet regardless of precisely *how* semantic context exerts its influence, the present findings suggest that any complete account of motion correspondence—at least in the Ternus configuration—must incorporate semantic influences of the type illustrated here.

Although the present study leaves a number of questions unanswered, it provides a useful point of reference for future studies examining the role of knowledge in perception. Distinguishing different types of knowledge and different aspects of perception is critical in this endeavor. Moreover, we should not focus so closely on perception per se that we lose sight of the active organism that perception is presumably designed to serve. With this in mind, considering sources of knowledge in terms of their reliability and generality may prove particularly useful in determining which sorts of knowledge might influence perception, and in understanding why it is that certain types of knowledge play the role that they do.

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