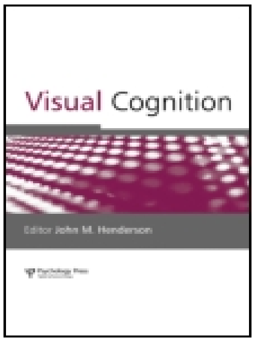

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The effect of body and part-based motion on the recognition of unfamiliar objects

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We investigated the role of global (body) and local (parts) motion on the recognition of unfamiliar objects. Participants were trained to categorise moving objects and were then tested on their recognition of static images of these targets using a priming paradigm. Each static target shape was primed by a moving object that comprised either the same body and parts motion; same body, different parts motion; different body, same part motion as the learned target or was non-moving. Only the same body but not the same part motion facilitated shape recognition (Experiment 1), even when either motion was diagnostic of object identity (Experiment 2). When parts motion was more related to the object's body motion then it facilitated the recognition of the static target (Experiment 3). Our results suggest that global and local motions are independently accessed during object recognition and have important implications for how objects are represented in memory.

Keywords: Object recognition; Object motion; Global local motion; Object causality; Characteristic motion.

INTRODUCTION

It was traditionally thought that object recognition depended on the separate and independent contribution of motion and form information. Yet the

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phenomenological experience of our world is one in which motion and form produce a coherent percept of a dynamic object suggesting that motion and form are integrated. However, our understanding of how dynamic information affects object recognition is currently a matter of some debate. In particular, our knowledge of what type of motion information is integrated into object memory, whether global information, local information or both, is relatively unknown. In the series of experiments described here, we investigated the role of different motion information on the recognition of novel objects.

In general, there are three possible ways in which object motion can affect recognition. First, motion may be an independent or alternative source of information to object identity. If so, then the recognition of both moving and static versions of an object should be equally accurate, provided sufficient spatial information is available in both versions. Moreover, a change of dynamic information should not have any effect on recognition accuracy if the original spatial information is fully available in the image and remains intact. Second, motion may complement and subsequently improve shape recognition since movement can reveal information about the spatial properties of an object resulting in a richer representation of the objects structure in memory. Accordingly, recognition performance may be facilitated through what has been referred to as the 'representational enhancement hypothesis' (O'Toole, Roark, & Abdi, 2002). This type of motion information is argued to be short-term and linked to the guidance of actions (Kourtzi & Nakayama, 2002). Finally, motion information may be integrated with an object's spatial structure to offer a unique, spatiotemporal signature of the object in long-term memory. In this case, motion can enhance object recognition through what is referred to as the 'supplemental information hypothesis' (O'Toole et al., 2002). A change to any aspect of that object's familiar motion characteristics, therefore, should disrupt recognition irrespective of the availability of spatial information.

Many studies have demonstrated that object identification can be achieved from dynamic information when spatial information is impoverished or unavailable (e.g., Johansson, 1973), suggesting that motion analysis can be a sufficient, or indeed alternative, cue to shape information for object recognition. For example, complex decisions such as the sex or familiarity of a person can be made from point-light displays of walkers (Kozlowski & Cutting, 1977; Cutting, Proffitt, & Kozlowski, 1978) and of faces (Hill & Johnson, 2001). Motion has also been shown to play a role in determining the sex of a walker, even when body shape is available, although motion is not as dominant as shape information in this task (e.g., Johnson & Tassinary, 2005). Relatively subtle information can also be determined from biological motion, such as the affect of the subject (Dittrich, Troscianko, Lea, & Morgan, 1996) or how attractive the subject is perceived (e.g., Johnson & Tassinary, 2007). Likewise, when spatial information about faces is impoverished then identification can be achieved on the basis of motion cues (Christie & Bruce 1998; Knight & Johnston 1997; Lander, Christie, & Bruce, 1999). Collectively, these studies suggest that motion can be a sufficient, alternative source of information for object perception when shape information is unreliable or compromised. Moreover, some argue that global motion, rather than part motion, seems to play an important role in biological motion recognition. For example, Kuhlmann and Lappe (2006) used degraded images of a person moving or performing actions and found that the recognition of the movement is good when global motion is preserved, even if local motion cues are degraded.

Although these previous studies suggest that motion information is sufficient for perceiving persons and faces, several other studies report that dynamic information is not an independent information source for object identification but that form and motion are integrated early on in visual processing for the purpose of object perception (see e.g., Giese, 1999 for a review). Evidence from neurophysiology and neuroimaging studies of both the monkey and human brain suggests that form and motion signals are not processed independently and that areas of the brain once thought functionally distinct for motion or shape processing can show some sensitivity to the other cue. In particular, an increasing number of reported findings challenge the idea that area MT/MTS or V5 is selective for motion processing only but instead suggest that this area may show some selectivity to static object form when motion is implied (Jellema & Perrett, 2003; Kourtzi & Kanwisher, 2000; Kourtzi, Bülthoff, Erb, & Grodd, 2002; Krekelberg, Dannenberg, Hoffman, Bremmer, & Ross, 2003). Conversely, an area of the brain known to be selective to object form, namely the lateral occipital complex (LOC) (Malach et al., 1995), is activated when object form has to be determined from motion cues (Yin, Shimojo, Moore, & Engel, 2002; Beauchamp, Lee, Haxby, & Martin, 2002).

Consistent with the idea of spatiotemporal integration, many behavioural studies have shown that object recognition performance is sensitive to motion information even when shape information is fully available (Liu & Cooper, 2003; Newell, Wallraven, & Huber, 2004; Stone, 1998, 1999; Vuong & Tarr, 2004; Vuong & Tarr, 2006). Liu and Cooper (2003), for example, found that the recognition of novel, distinct objects was best when the object was presented in a familiar sequence of rotation in depth rather than in a reverse sequence. Using more varied motion patterns, Newell et al. (2004) reported that object categorisation was best to novel objects presented in a familiar dynamic pattern rather than a novel dynamic pattern. This result was particularly surprising since both object form and colour information were diagnostic of object identity and were fully available in all object images. Conversely, motion has also been shown to affect the perception of form (Wallis & Bülthoff, 2001; Yantis & Nakama, 1998). Wallis and Bülthoff found that different views of different faces presented in an ordered motion sequence were integrated into the representation of a single face whereas views of different faces presented in a random sequence were not. These findings add support to the idea that objects are represented in terms of their integrated, spatiotemporal signatures (Stone, 1998).

Studies investigating the role of motion on visual object recognition, however, have mainly used global motion patterns and it is not known to what extent local or part-based motion affects the recognition of objects. In the real world, objects move both in terms of their global position and in terms of the local parts. For example, a rabbit can jump from one position to the next (body motion) but the movement of its local parts, such as its legs or twitching nose can differ to its global motion. Similarly the global motion of a car is generally a translation from one to another point but movement of its local parts, such as the wheels, is often defined by a different type of motion, i.e., rotation. Local motion has also been shown to be important for resolving socially relevant information such as the perception of the attractiveness of human walkers (Johnson & Tassinary, 2007) and the recognition of faces (Knight & Johnson, 1997; Lander et al., 1999; Lander & Bruce, 2000; Thornton & Kourtzi, 2002). Local, non-rigid motion may benefit face recognition when it is unique to that face because it supplements the spatial representation of the face in memory (O'Toole et al., 2002).

It is argued that the processing of the global motion of an object and the local motion of its components is underpinned by distinct perceptual and neural mechanisms. For example, there is some support from the linguistic or developmental literatures for the idea of independent processing of global and local motion for object perception (e.g., Kersten, 1998; Mandler, 1992; Rakison & Oakes, 2003) suggesting that these motion types may have a differential effect on object processing. Attention can be allocated to either the global or local motion in a display in order to resolve any ambiguity in incoherent motion information (Bulakowski, Bressler, & Whitney, 2007), suggesting that these motions are perceived as distinct. Moreover, evidence from neurophysiology suggests that the processing of local and global motion corresponds to two stages of motion processing in extrastriate cortex, with areas MT and MST devoted to processing of local and global motion (Born & Tootell, 1992; see Vaina, 1998, for a review). The neural units devoted to local motion perception have small receptive fields so they can detect the movement of small portions of the object, however they can only render the movement of the whole object if all its parts move coherently. Global motion units, on the other hand, have larger receptive fields (Burr, Morrone, & Vaina, 1998; Morrone, Burr, & Vaina, 1995) and can thus integrate the movement of the whole object even if its components do not all move in the same way.

Global motion can therefore be defined as the integration of local motion information from different spatial and temporal locations so that the direction of movement of the whole pattern is perceived. As such, a moving global shape can be perceived in a dot pattern, even if the local motion (i.e., motion of each dot) is different for each component. Evidence for the idea that global and local motion involve different neural mechanisms is also supported from neuropsychology (e.g., Bearsdley & Vaina, 2006) and from studies on psychiatric disorders such as schizophrenia (Chen, Nakayama, Levy, Matthysse, & Holzman, 2003).

In terms of higher level perception, local motion of parts, or non-rigid motion, may only be important for biological motion or in stimuli offering socially relevant cues such as faces (Puce, Allison, Bentin, Gore, & McCarthy, 1998; Haxby, Hoffman, & Gobinni, 2002; O'Toole et al., 2002). For example, attending to local features such as the direction of eye gaze or to the movement of lips may be important for perceiving the intentions of others (e.g., Langton, Watt, & Bruce, 2000) and for understanding other social signals such as speech (Calvert, Brammer, & Iversen, 1998). On the other hand, such analysis of object parts rarely has this type of significance. For example, the rotation pattern of the wheels of a car may not help recognise the car. Furthermore, it is argued that faces are a special class of object: there is evidence for dedicated cortical areas involved in processing facial information (Tsao, Freiwald, Tootell, & Livingstone, 2006) and, albeit more controversial, there is some evidence for behavioural effects which are true for faces but not necessarily other types of objects such as inversion and distinctiveness (e.g., Valentine, 1991). Faces represent an important set of highly similar stimuli in terms of spatial properties and it may be the case that local motion cues may be useful for distinguishing between such stimuli since the degree of similarity in spatial information may render it unreliable for robust recognition. In sum, it is not clear to what extent the literature on non-rigid or part-based motion in faces is relevant to other non-biological stimuli such as objects, or whether global or local motion information is processed separately for object recognition.

In the following experiments we tested the role of motion in object recognition when objects were defined by unique structural descriptions in all experiments. In particular, we were interested in determining whether global motion and local, part-based motion are equally represented in object memory. In the first experiment, objects were each defined by a unique combination of global and local motion patterns, therefore neither the global nor local motion patterns alone were unique to each target object. In Experiment 2 we changed this so that both the global and local motion patterns were unique to any one target. In the final experiment, the local motion was more associated with the global motion of the object. We trained our participants to identify a set of moving object shapes and subsequently tested their recognition of static versions of these target object shapes when primed by moving object shapes. We predicted that the integration of motion is mandatory for object recognition, even when spatial cues are more than sufficient for recognition. We explored whether global and local motion cues contribute to the spatiotemporal representation of the object in an independent manner.

EXPERIMENT 1

In the following experiments we investigated the role of motion on object recognition using a priming paradigm. In particular, we were interested in whether global or local motion affected recognition of object shapes or whether both types of motion were equally accessible for recognition. Unlike many previous studies on the role of object motion, we used novel object stimuli that were identifiable by a unique configuration of basic parts (Biederman & Gerhardstein, 1993). Previous studies investigating the role of motion on object recognition generally used highly similar exemplar objects (see e.g., Stone, 1998, 1999) or spatially homogenous stimuli such as faces (e.g., Knappmeyer, Thornton, & Bülthoff, 2003). Our objects were similar to those used by Kourtzi and Shiffrar (1999) in that each object was constructed as a large single part, or geon, to which three smaller parts (different in shape to the main body) were attached. The configuration of these parts was unique to each target object, although the individual parts themselves were not unique to the objects (although each shape did not appear more than twice across all objects).

During learning, each target object was presented moving both globally and locally. By global motion we mean motion of the entire object. For example, the object could be seen translating from left to right, rotating around its vertical axis or 'jumping' up and down (all movements produced a very small displacement, thus we assumed that they were perceived as global object motion and not object path or trajectory). By local motion we mean motion of the parts of the object, for example, the small object parts could translate up and down along the main object part, or swivelling around their own axes.

We predicted that object motion would affect subsequent recognition of the static object shape (previously learned as a moving object) in that motion information would prime the recognition of the static target object more than a non-moving prime. Furthermore, we expected that since both global and local object motion were important for object identity, both would facilitate recognition, with no particular advantage of one over the other.

METHOD

Participants

18 undergraduate students (5 males and 13 females) from the University of Bologna volunteered to take part in this experiment without pay. Their mean age was 26 years. All participants reported normal or corrected-to-normal vision. All participants provided written consent to partake in this study (as did all participants in the subsequent studies reported here).

Stimuli and Materials

Four target objects were designed for the purpose of our experiment (see Figure 1) along with two non-target objects. For each stimulus the object body and component parts were drawn using 3D Studio Max and imported into a custom-designed animation program. This program allowed us to

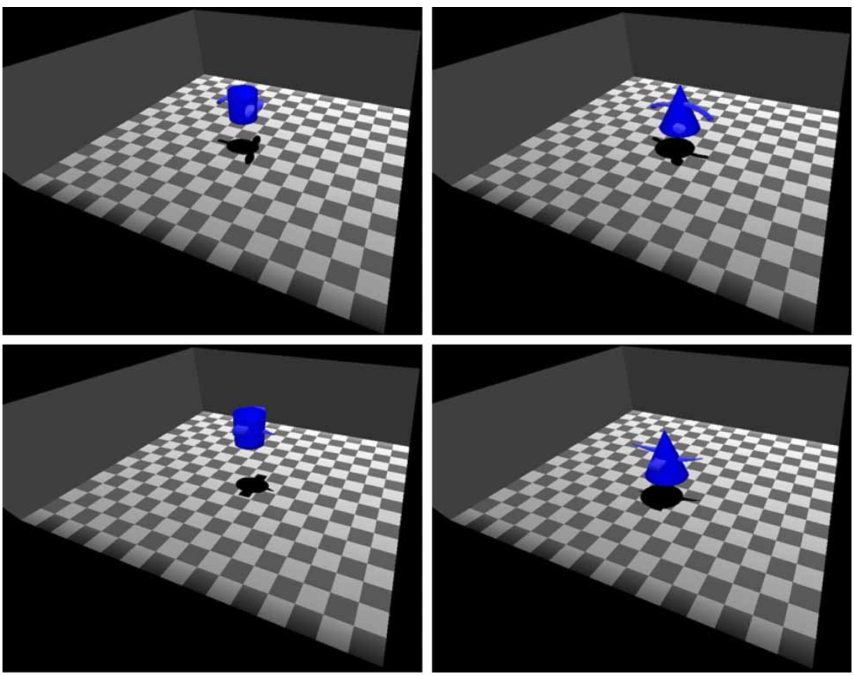

Figure 1. An illustration of the target stimuli used in all Experiment. The stimuli were presented against a chequerboard virtual room in order for the motion of the objects to be better viewed. For each target, both the parts of the object (either two or all three, depending on the experiment) and the whole object moved. To view this figure in colour, please visit the online version of this journal.

construct 3D object shapes with component parts and to allocate a unique motion pattern to the object parts and to the overall object. Each of the target objects was composed of a large basic shape to which three smaller parts were attached. For each target object two parts had the same shape and one was different and, for simplicity, only the two same-shaped parts moved. Two of the target objects were composed of a cylindrical basic shape to which 3 parts were added and the other two targets were composed of a conical basic shape to which the parts were added. Object parts were positioned at different heights relative to the main body axis. The combination of an object's body shape and the shape of the parts was unique for each object. The combination of global and local movement was different for each object but none of the individual features was unique to an object.

Two different non-target objects were also created and comprised novel configurations the object shapes used to create the target objects. Thus, these objects had a different shape to a target and were either moving (i.e., a different motion to a target) or were static.

All objects were presented inside an image of a 3D chequer-board room to allow the observer to see the motion of the object better. We further enhanced the perception of motion by projecting a cast shadow of the object onto the floor of the room which acted as an additional motion cue (Kersten, Knill, Mamassian, & Bülthoff, 1996). The approximate size of the objects subtented a visual angle of 4°.

The range of motions used for body motion comprised simple translations back and forth along either the x, y, or z axes, simple rotations around the x or y axes, or a combination of both translations and rotations (e.g., rotate y, translate z). The rotations comprised of either a complete rotation 360° (with the appearance that the object 'tumbled') or were partial rotations of 45° back and forth around the y-axis (with the appearance that the object 'wiggled'). For any of these motions, the maximum displacement of the object from fixation was on a radius of less than 6° visual angle. The range of motions used for parts motion comprised simple back and forth translations on either the x, y or z axes, complete rotations around the x or y axes or partial rotations of 45° around the z axis (with the appearance that the part 'flapped'). The motions themselves also differed in direction, speed and distance. Body- and part-based motions within the same object always differed in either motion type (e.g. rotation or translation) or in one motion parameter, e.g., direction. Thus the global and local motion vectors never coincided within the same object.

During the experiment, objects were presented as moving during training and as static images during the recognition test. For the static images, 4 different viewpoints of the object (with all parts visible) per target object were constructed in order to avoid repeated exposure to the same images within a trial.

The experiment was run on a DELL PC computer using DMDX (copyright Forster, K.I., & Forster, J.C. University of Arizona) software for presentation of the stimuli and response recording. The stimuli were presented on an Acer 77e monitor, with the dimensions of 1080/1024 pixels and a refresh rate of 75 Hz.

Design

There were two main sessions in the experiment: a training session followed by an object shape recognition task. Participants were presented with moving target objects during the training session and static images of the shapes of these target objects during the recognition test. During recognition task, the task for the participant was to identify the target object based on their shape only. Each object was primed by a moving object whose motion was related to the learned motion of the target object. As such, during the recognition test the prime could include either 'same Body motion' and 'same Parts motion' as the target object learned during training. As the target object did not move during the recognition task, this task essentially involved recognising the target object by its spatial characteristics alone. We use the term 'target objects' to refer to the static images of the learned objects, otherwise they are described as 'moving target objects'.

The experiment was based on a one-way, repeated measures paradigm with priming condition as the main factor with four levels. Thus, as described above, the priming conditions were as follows: same Body motion and same Parts motion (sBm/sPm); same Body motion and different Parts motion (sBm/dPm); different Body motion and same Parts motion (dBm/sPm); static Body and Parts but different viewpoint to target image (Static).

The four target objects were presented in each of the priming conditions, leading to 16 prime-target pairs. Each target was also paired with both a different moving and different static unrelated-prime object, leading to an extra 8 unrelated-prime pairs. These prime and unrelated-prime target pairs (a total of 24 pairs) were each repeated 4 times in random order during the experiment. Thus, 96 primes followed by static object image constituted the test trials, two thirds of which were primed trials and one third of which were unrelated-primed trials. The unrelated-primed trials ensured that the target was not always predictable from the prime. Furthermore, by including a different shaped prime to the target we could assess the effect of shape cues only on the recognition of the target object and isolate these from the benefit of motion primes.

Procedure

Participants were first seated in front of a computer screen at a distance of about 57 cm. The four moving target objects were first demonstrated to the participants, one at a time and in random order, for 2 seconds each. Within these 2 seconds participants were exposed to at least 1 complete cycle of body motion (e.g., translation on the x axis from the start point to the end point and back) and at least 2 complete cycles of parts motion (e.g., translation on the y axis from the start point to the end point and back). The experiment then consisted of two phases, a training and a recognition test phase.

Training phase. During training a trial consisted of the following sequence of events: a fixation cross appeared for 700 msec followed by a moving target object for 500 msec and then a blank screen appeared until a response was provided (or a time limit of 3000 ms had elapsed). For our object and part motions, 500 msec was a sufficient duration to perceive an optimal sample of the body motion and one cycle of the part-based motion whilst minimising any interference from, e.g., adopting a cognitive strategy. Participants were instructed to categorise each of the four target object by pressing one of 4 keys on the computer keyboard ('v', 'b', 'n', 'm') accordingly. Participants were not explicitly instructed on what object attributes they should use to categorise the objects in order to avoid inducing any bias towards attending to either the motion or shape cues. Feedback was presented on both the accuracy and timing of each response and participants were required to learn to categorise each moving target object as fast and as accurately as possible. As a basic minimum number of trials, the four moving target objects were presented 20 times each. If at the end of the 80 trials the performance criteria of 90% correct (response time out was set at 3000 ms) was not reached then participants automatically repeated the training block until they these criteria were met. Trials were presented in a random order for each repetition of the training block. In the training phase the average number of repetitions was 2.4, and the mode was 3.

Test phase. At the beginning of the test, participants were informed that after the fixation cross, they would see a prime object followed by a static target object. They were instructed to view but not to respond to the first object but to categorise the target according to its shape, by pressing the learned corresponding key, as fast and as accurately as possible. A trial began with a fixation cross for 700 msec, followed by the prime for 500 msec, which was then followed by the target image for 250 msec. The relatively long prime display was used in order to allow participants to perceive the different types of motion in the different conditions. A response was required within 2500 msec otherwise the next trial began.

RESULTS

In order to account for anticipatory or unusually slow response times, response times $\pm$ 2.5 standard deviations from the mean were removed from each participant's data set. This resulted in a removal of 3.8% of the data (all of which were excessively slow responses and none of which were anticipatory responses). Subsequent analyses of the response times included those to the correct (i.e., hit) trials only.

The mean response times across each of the priming conditions are shown in Figure 2. We conducted a one-way ANOVA on the response times across the four priming conditions. We found a main effect of priming condition by subjects [$F(3, 51) = 6.73$, $MSE = 2985$, $p < .001$] and by items [$F(3, 60) = 5.04$, $MSE = 4254$, $p < .01$]. Post-hoc Newman Keuls analysis revealed that response times to the sBm/dPm (mean = 676, SD = 177) condition were significantly faster than to the dBm/sPm (mean = 748, SD = 171) and Static conditions (mean = 731, SD = 183) for both the subjects and items analyses. Response times to the sBm/sPm (mean = 692, SD = 171) condition were

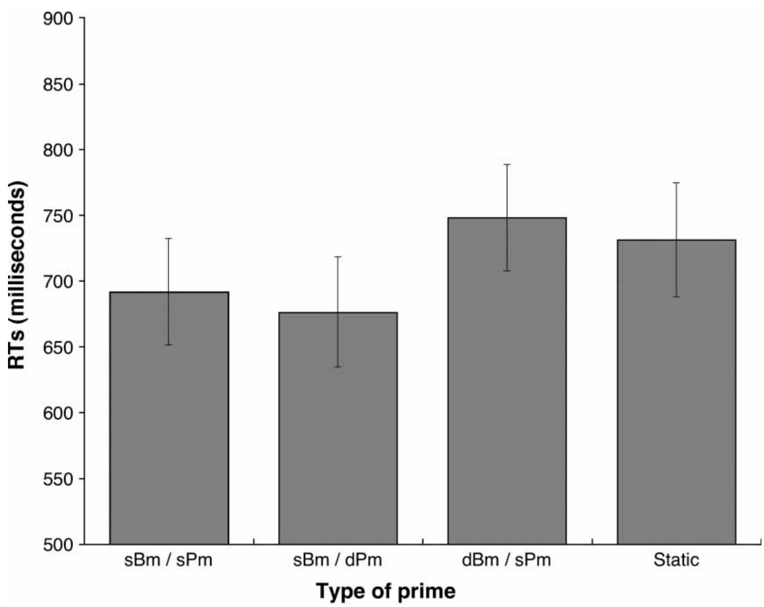

Figure 2. Plot showing the mean response times to the target object across the four different priming conditions in Experiment 1. Error bars represent the standard error of the mean.

significantly faster than to the Static condition and to the dBm/sPm condition in the item analysis (but not the subject analysis).

In order to establish whether facilitation occurred to the same shaped object primes, we compared response times across the prime and unrelated-prime conditions. Response times to the different moving unrelated-prime (mean = 833 ms, SD = 100 ms) differed from all the moving same-shaped primes (sBm/sPm, dBm/sPm, and sBm/dPm) [$t = 4.91$, $p < .001$; $t = 3.3$, $p < .01$, $t = 5.5$, $p < .001$ respectively]. Response times to the different static unrelated-prime (mean = 869, SD = 135) differed from the static same-shaped prime (mean = 731, SD = 183) [$t = 4.6$, $p < .001$].

The mean error rates across each of the priming conditions were as follows: sBm/sPm, 9%; sBm/dPm, 10%; dBm/sPm, 12%; and Static, 12%. Error rates across the main priming conditions were subjected to a one-way ANOVA which revealed no effect of priming condition on error rates, neither by subjects [$F(3, 51) < 1$] nor by items [$F(3, 60) < 1$].

DISCUSSION

First we found that primed objects with the same shape as the targets facilitated target recognition more than different shaped objects, demonstrating that object form was an important cue for recognition. More specifically, however, for the same shaped object primes, the time to recognise the shape of the target objects was fastest when the prime contained either the same global-body and part motion as the learned target, or when the prime contained only the same body motion. Thus the same body motion in the prime as the learned target was sufficient to further facilitate recognition performance, even though the target object was not shown moving during the recognition task. In contrast, a change to the original local part motion incurred no cost on recognition performance relative to a change in body motion. Therefore global object body motion seemed more important for object recognition than local, part-based motion.

Even when the body motion was not unique to the object, it was still important for recognition. In this experiment, neither global nor local object motion alone were diagnostic of target identity, rather a combination of both was unique to each target. Therefore it is surprising that global motion was processed independently from local motion. It is possible that global motion only was combined with shape to result in a unique spatiotemporal representation of the object. On the other hand, given that each object was defined by a combination of shapes and motion, rather than unique features, it is possible that local motion did not affect recognition because of stimulus complexity and consequent demands on working memory. In the following experiment, we explore this possibility by rendering all motion cues, but not shape cues, unique to each target object.

EXPERIMENT 2

Local part motion did not have any effect on object recognition when objects were defined by a unique combination of shape and motion cues. Here we used the same shaped objects as in Experiment 1 but made a change to the motion pattern of each target object learned during training. Each target moved in a unique manner both globally and in terms of their local parts. Thus, either type of motion information was sufficient to recognise the target object. Moreover, all small parts of the object moved in this experiment in order to increase the saliency of local part motion relative to global motion. The question we addressed here, therefore, was whether both global body and part-based motion cues could be used in object recognition when both were equally diagnostic of object identity and local motion was rendered more salient than in Experiment 1. As in the previous experiment, the recognition task involved recognising a non-moving version of the target object (i.e., shape only) which was primed by a moving object.

METHOD

Participants

18 undergraduate students (7 males and 11 females) from Trinity College Dublin took part in the experiment in exchange for either course credit or a small payment. Their mean age was 22 years. All participants reported normal or corrected-to-normal vision and none took part in Experiment 1. Both Experiments 2 and 3 were approved by the Trinity College, School of Psychology Research Ethics Committee.

Stimuli and apparatus

We used the same structural shapes as described in Experiment 1 and created new object motions so that each of the four moving target objects was unique based on either their global motion pattern (e.g., sway) or the local part motion (e.g., up/down translation). To further increase the saliency of the part-based motion, all three small parts of an object moved together in the same manner. The experiment was presented on a DELL PC with a monitor dimension of 1080/1024 and a refresh rate of 75 Hz.

Design and procedure

With one exception, we used the same design and procedures as described in Experiment 1. In this experiment the 'different shape' primes consisted of one of the other target objects rather than a novel object as was used previously. We decided to use the shape of the target objects as primes in all conditions in order that all primes remained the same in the experiment (i.e. across both same and different shape conditions) and that all primes had an associated potential response in order to increase the relevance of the different shape primes for the task. A further reason for using the same shape primes as targets was to ensure that any facilitation for the same shape objects relative to the different shape objects was not simply due to the relatively larger number of trials with same target shape primes then different shaped primes as was used in Experiment 1.

RESULTS

Data from two participants were removed from analyses due to the high error rate during the test phase (i.e., more than 25%), thus leaving a final sample of 16 participants. Before analysing the data, response times ± 2.5 standard deviations from the mean were excluded from each participant's data set. This resulted in a removal of 3.6% of the data (all outliers were slow responses and none were anticipatory). Response times to the correct trials only (hits) were analysed.

The mean response times to the experimental priming conditions are shown in Figure 3. We conducted one-way, subject- and item-based ANOVAs across the priming conditions and found a main effect of object prime [$F1(3, 45) = 3.06$, $MSE = 2994$, $p < .05$] for the subject analysis. A post-hoc Newman Keuls analysis on this effect revealed that response times to the sBm/dPm condition were significantly faster (mean = 750, SD = 129) than to the either the dBm/sPm (mean = 802, SD = 137) and Static conditions (mean = 796, SD = 120) [$p < .05$]. The response times to the sBm/sPm prime condition (mean = 778, SD = 152) was not significantly different than those to the other prime conditions. A one-way items analysis revealed no significant effect of priming condition [$F(3, 60) = 1.71$, *ns*]

Response times to the unrelated-prime moving objects were 879 ms (SD = 135) and unrelated-prime static objects were 868 ms (SD = 129). Response times to the moving unrelated-prime differed from all the moving same-shaped primes (sBm/sPm, dBm/sPm, and sBm/dPm) [$t = 3.69$, $p < .01$; $t = 3.4$, $p < .01$, $t = 4.5$, $p < .001$ respectively]. Likewise, response times to the different static unrelated-prime (mean = 869, SD = 129) differed from the static same-shaped prime (mean = 796, SD = 120) [$t = 3.5$, $p < .01$].

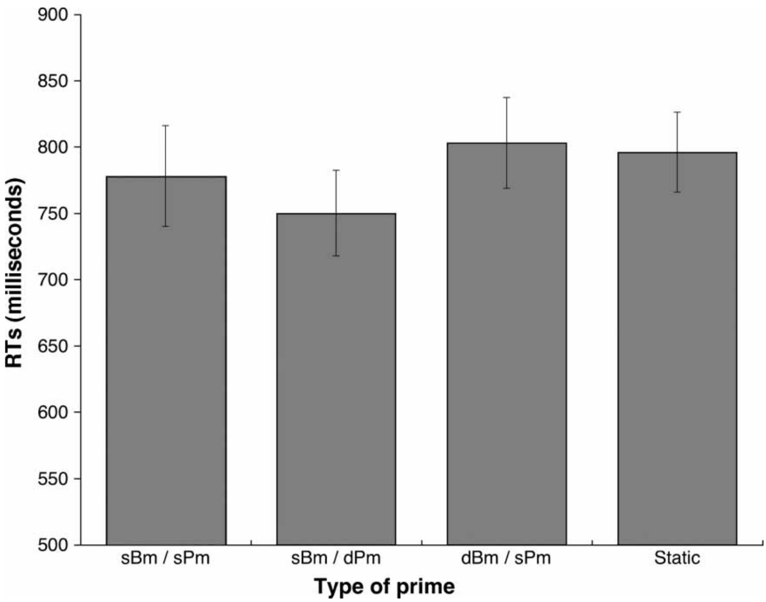

Figure 3. Plot showing the mean response times across the different priming conditions in Experiment 2. Error bars represent one standard error of the mean.

The mean number of errors made across each of the priming conditions was as follows: sBm/sPm, 8.6%; sBm/dPm, 18.4%; dBm/sPm, 11.7%; and Static, 15.2%. Error rates were subjected to a one-way ANOVA and we found a significant effect of priming condition by subject [$F(3, 45) = 3.62$, $MSE = 0.008$, $p < .05$] and by items [$F(3, 60) = 3.384$, $MSE = 0.008$, $p < .05$]. Post-hoc tests showed that participants were significantly more accurate in the sBm/sPm condition than in the sBm/dPm (Newman-Keuls, $p < .05$) and marginally, but not significantly, more accurate than the static prime ($p = .09$). There was no difference between error rates in the other conditions[1].

DISCUSSION

As in the previous experiment we again found evidence that the same shape object facilitated recognition. Moreover, when the same global motion as the

[1] Further analysis confirmed that our results were not due to a speed–accuracy trade off: we normalised the RT data based on the proportion of correct responses and re-analysed the data using a repeated measures ANOVA. As previously found, the results showed a main effect of object prime [$F(3, 45) = 3.06$, $MSE = 0.709$, $p < .05$] with faster RTs in the sBm/dPm than in either the dBm/sPm ($p < .05$) or static ($p = .05$) conditions. Again, differences between the RTs in the sBm/sPm condition and all other conditions did not reach significance.

target was present in the prime then recognition performance was further facilitated relative to when only the same part-based motion was primed. Thus global motion of the target was important for recognition, even though both body and part-based motion were equally diagnostic of target identity.

It is not clear why response times to the sBm/ sPm prime were not significantly faster than to either the dBm/sPm or Static priming conditions, since the same motion was present as in the target and therefore this condition was expected to facilitate recognition of the target. However, response accuracy was highest to the sBm/sPm prime relative to all other conditions and was significantly better than to the sBm/dPm condition with a trend towards being better than the Static condition. In any case, the response times to the sBm/sPm prime were not significantly slower than to the sBm/dPm, suggesting that global motion facilitated recognition.

EXPERIMENT 3

It is known that when local cues are not correlated with global information, integration across these cues is considered to be difficult (Braddick, 1993). Moreover, the correlation between global object motion and local part motion seems to be an attribute to which we are particularly sensitive. For example, children as young as 14 months show sensitivity to this correlation and they learn that an object with moving parts can move as a whole, e.g., objects with wheels 'roll' and that to certain movements of object parts is associated a specific path, (Rakison & Cohen, 1999; Rakison & Poulin-Dubois, 2002).

In the previous experiments we assigned global and local motion cues across the learned target objects in a random manner. Thus the local motion may not have been associated with the global motion pattern. For example, while a local part could be moving in an up/down, flapping manner, the body of the object may have been moving in a manner unrelated to the local motion, e.g., rotating instead of rising up and down. Furthermore, if local motion cues are unrelated to global motion then it could be conceivable, in terms of statistical likelihood, that the local cues represent different, segregated objects. As a consequence it is possible that local motion cues may have been ignored because they were not perceived as being correlated to global object motion.

In the following study, we designed moving target objects in which their part motion was perceived as associated with the overall body motion. First, we asked participants to rate the extent to which local part-based motions of objects were perceived as being correlated with the global object motion in the set of target objects used in Experiment 2 and a novel set of four objects. This rating study was conducted to allow us to choose stimuli for the main experiment where the local, part motion was perceived as being most related to the object motion.

Pre-test rating study. A group of 13 naïve participants rated the set of four moving target objects used in Experiment 2 and a set of four new objects with the same shapes as the previous targets but with novel motion configurations. This novel set was created in order to maximise the degree to which the part motion was related to the global object motion (e.g., flapping part motion and back forward translation for body motion). Participants were asked to rate on a 7-point scale (using corresponding keys on a keyboard) how much, in their opinion, the movement of each object's parts was related to or caused by the overall motion of the body (1 = not at all; 7 = completely related). As expected, the mean ratings for the 4 objects used in Experiment 2 were overall lower (3.7; 2.9; 4.3; and 4.7 for targets A to D respectively) than those of the 4 new objects, (6; 4.6; 3.5; and 5.3 for the new objects). We were confident that this new set of objects comprised of part and body motion information which were perceived as related (all objects obtained a rating ≥ 3.5) and were consequently selected as stimuli for Experiment 3.

METHOD

Participants

Twenty-one undergraduate students (13 males and 8 females) from Trinity College Dublin took part in the experiment either for course credit or a small payment. Their mean age was 23 years. All participants reported normal or corrected-to-normal vision and none took part in the previous experiments or in the pre-experiment rating study.

Stimuli and Materials

Four same-shaped target objects as used in the previous experiments were again used as stimuli in this experiment but the motion patterns of these new target objects were different: based on the rating study we used stimuli where the motion of the object parts was considered related to the overall motion of the body of the object. The same set of body and part motions used in the previous experiments (see Experiment 1) was used here but they were assigned to different objects and their parts. The global and the local motion vectors always differed at least one parameter (e.g., direction, frequency, speed) across the target objects. For example, if the parts were flapping then the object may be translating in a back-forth direction. As in Experiment 1, for simplicity, only the two identically shaped small parts of the object moved whilst the third remained stationary.

Design and Procedure

The experimental design and procedure were the same as those used in Experiment 2. In the training phase the target objects were moving, while in the test phase the same target objects were presented as static shapes. In the training phase of this experiment, the average number of repetitions of the training block required before performance criteria were met was 2.05 and the mode was 2 blocks.

RESULTS

Prior to analyses of the data, response times ± 2.5 standard deviations from the mean were removed from each participant's data set. This resulted in a removal of 5.5% of the data in total (all outliers were excessively slow responses). Further analyses were conducted on the response times to the correct trials only.

Response times to each of the priming conditions are shown in Figure 4. We conducted a one-way ANOVA on the response times across the priming conditions and found a main effect of priming by subjects [$F(3, 51) = 8.55$, $MSE = 2997$, $p < .001$] and by items [$F(3, 60) = 3.82$, $MSE = 3082$, $p < .05$].

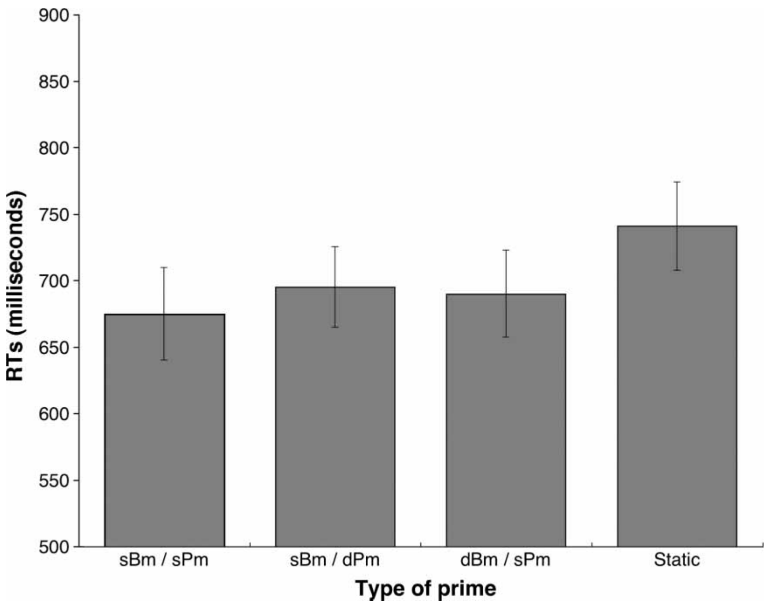

Figure 4. Plot showing the mean response times to the different priming conditions in Experiment 3. Error bars represent one standard error of the mean.

A post-hoc Newman Keuls analysis revealed that response times to the Static prime only (mean = 741, SD = 141) were significantly longer than to all other moving prime conditions (i.e., sBm/sPm mean = 675, SD = 148; sBm/dPm mean = 695, SD = 129; dBm/sPm mean = 690, SD = 139) ($p < .01$). There was no difference between the other motion prime conditions for either the subjects or items analyses. The response times to the moving (mean = 843 ms, SD = 132 ms) and static (mean = 832 ms, SD = 108 ms) unrelated-primes conditions were compared to the response times to the same-shape prime conditions. Response times to the moving unrelated-prime differed from all the moving same-shaped primes (sBm/sPm, dBm/sPm, and sBm/dPm) [$t = 6.49$, $p < .001$; $t = 7.8$, $p < .001$, $t = 6.6$, $p < .001$ respectively]. Likewise, response times to the different static unrelated-prime differed from the static same-shaped prime [$t = 5.1$, $p < .001$].

The mean error rates across each of the priming conditions were as follows: sBm/sPm, 7%; sBm/dPm, 12%; dBm/sPm, 13%; and Static, 13%. Participants' error rates across the main priming conditions were subjected to a one-way ANOVA. We found no effect of priming condition on error rates either by subjects [$F(3, 51) < 1$] or by items [$F(3, 60) = 1.393$, *ns*].

DISCUSSION

Our results suggest first, like the results of the previous experiments, that motion facilitates recognition relative to static primes. Furthermore, as in the previous experiments, we found an overall facilitation for object primes with the same shape as the target than primes of a different shape.

Importantly, we found that when local object motion relates, in a natural way, to the global motion of the object, then both patterns are important for recognition. In other words, if at least one—global or local motion information—was present in the prime, then recognition was facilitated. Therefore, a change in body motion could be compensated by the original part motion and vice versa for recognition. Thus, local motion of the objects parts could prime the identity of a target object even when the global motion pattern had changed.

GENERAL DISCUSSION

The aim of the experiments reported here was to investigate the role of different motion patterns on unfamiliar object identification, specifically global body and local part motion. Our stimuli were defined as a combination of shape and motion cues but object identity could be resolved from either shape or motion cues alone. We predicted that if motion was integrated into an object's representation in memory, then relevant motion available in the prime would facilitate the recognition of the target shape presented as static image and that this motion would further facilitate recognition relative to shape information alone. On the other hand, if form information was the only cue used for recognition, then we predicted no benefit for moving over static primes on the recognition of object shape.

In all three experiments we found a benefit for the same shape primes in novel object recognition. More pertinently, when the prime contained the same global or body motion as the learned target, recognition was further facilitated, even though the target did not move during the recognition test. Thus, these findings demonstrate, as other studies have previously shown (e.g., Newell, et al., 2004), that global motion is an important cue for object recognition even when spatial information is fully available.

Our findings also suggested that the type of motion that was related to target identification differentially affected recognition of the target. A prime included either the same body and part motions, same body motion only or same part motion only as the learned target object. In Experiments 1 and 2, only the global motion of the object facilitated target shape recognition but not local part based motion despite changes in the reliability of these motion cues across experiments. That is, whether a combination of global and local motion cues (Experiment 1) or separate global and local cues (Experiment 2) were diagnostic of object identity this made no difference to the outcome that global motion was more effective as a prime. Although it could be argued that the lack of priming effect for local motion cues could be due to a difficulty in segmenting the parts from the objects, in Experiment 3 we used the same objects as in both previous experiments but found that part motion facilitated target identification. Instead, one possible reason for the lack of facilitation from part motion in Experiments 1 and 2 was the accidental relationship between the two types of motion characterising the object, i.e. parts and body motion. Thus local motion may have been perceived as an accidental characteristic of the object if it was not readily associated with the global object motion and thus may have been effectively ignored or not integrated into the objects representation in memory. On the other hand, local or part-based motion may be considered a reliable characteristic only when the two motions were easily associated. Hence, in Experiment 3, the target objects were modified in order to enhance the perception of a more related or causal relationship between part and body motion during learning. This manipulation resulted in all motion conditions, i.e. body and part motion, facilitating identification of the target shape relative to the static prime.

Curiously, in all experiments, the presence of both relevant global and local motion in the prime did not facilitate target recognition more than the presence of either one or the other, even if both independently facilitated recognition (as in Experiment 3). This finding suggests that both global and local information may be independently accessible in the object's representation (cf. Kersten, 1998). Furthermore, the results of Experiment 1 and 2 may also suggest that the order at which different types of motion are accessible in the object's representation follows a typical global to local sequence (Navon, 1977). If global motion is processed initially before local motion, then when global motion is present in the prime it may be sufficient to facilitate recognition. This is indeed what we found in all our experiments. However, when local motion information was rendered more easily accessible in a prime, such that it was perceived as more related to global motion, then local motion could facilitate recognition as well as global motion, as we found in Experiment 3. On the other hand, local motion may not facilitate recognition when it is either difficult to resolve, because it is unrelated to global motion, or more difficult to remember because it is not associated with the global motion. Thus, if body motion is first resolved then it may be the case that part motion is more or less available for recognition depending on how semantically or perceptually related it is to the global motion of the object. Further research is required however to elucidate the role of global object motion on the encoding or retrieval of local or part-based motion in object recognition.

Whether global and local object motion is perceived and integrated into the representation of the object in memory may depend on demands on attentional resources (Pomerantz, 1983; Cavanagh, 1992). For example, whereas global motion patterns of an object may be readily perceived, perception of the motion of the parts of an object, particularly if that motion is unrelated or independent of global motion, may require more effort (Cavanagh, Labianca, & Thornton, 2001). Cavanagh et al. investigated the role of attention in object motion perception and found that object motion demanded attention even when the motion sequence was relatively simple (i.e., orbiting versus tumbling dot displays) or familiar (point-light walkers). Thus, if global and part-based motion are pitted against each other, as they are in our experiments here, it is likely that perceptual access to global motion will precede that to local motion if attentional resources are limited. On the other hand, we found that local motion did affect recognition when that motion was perceived as being related to, or causal of, global motion, suggesting that associated part motion affects attentional resources less than unrelated part motion. Our results may therefore suggest that the degree to which local motion is associated with global motion in an object determines whether both types of motion are integrated into its representation in memory.

It is also possible that task demands may dictate whether global and local motion patterns are accessed independently or separately. As an analogy, it is argued that the recognition of objects based on spatial structure alone is efficient when objects are distinguishable at a basic level. In other words, if the global shape, or the structural description, of an object is unique then recognition is generally robust to incidental changes in viewpoint, or illumination (Biederman & Gerhardstein, 1993). On the other hand, if objects are discriminable on the basis of local features or fine detail, then recognition is very sensitive to image-based changes such as viewpoint (Newell, 1998). It may be the case therefore, that global and local motion information is each accessed depending on the nature of the stimuli and task. If objects are discriminable on the basis of global motion alone then this may be sufficient for recognition. If the objects are not discriminable on the basis of global motion then more detailed motion information may be required. In other words although the twitching of the nose of a rabbit can be used as a cue to recognise the rabbit, the jumping of a rabbit constitutes a more relevant and salient cue to its identity than the twitching of its nose. Moreover, this may also be due to the inferential power of the two types of motion 'twitching nose' and 'jump' as in nature we can infer other characteristics from the capability to jump but much less from the capability of twitching the nose.

It is already known that both part-based and global object motion are important in the acquisition of object knowledge: the literature on developmental processes suggests that part-motion is as important for object recognition as global motion. For example, it is known that children from a very young age show sensitivity towards the dynamic characteristics of objects (Arteberry & Bornstein, 2002; Bertenthal, 1993; Nelson & Horowitz, 1987). Moreover, it is argued that children seem to rely both on global object motion and the movement of object parts in order to form their initial basic-level categories of objects in the world (Rakison, & Oakes, 2003; Rakison & Poulin-Dubois, 2002). Children can also rapidly acquire the association between object parts and their familiar motion; for example, they respond if the association between 'having wheels' and a rolling action is violated but not to a violation between 'having a roof' and a rolling action (Madole & Cohen, 1995) suggesting both that part motion and shape are associated in object memory and that part-based object motion seems to play an important role in object learning.

In sum, we have found evidence to corroborate earlier findings that motion is an important cue for object recognition and that objects are represented as spatiotemporal signatures in memory since both the shape and the motion patterns can prime the recognition of the shape of novel objects. Moreover, both the global motion of an object and the movement of its local parts are important sources of information for object identity. However, whereas global motion seems to be readily integrated into object representations, the role of local part motion in object recognition depends on more semantically related knowledge such as its association with the global motion and, possibly, on the demands of the task. Finally, our data suggest that global object and parts motion are independently accessed for object recognition. Whether this depends on attentional resources or the nature of object memory remains to be elucidated.

REFERENCES

Arteberry, M. E., & Bornstein, M. H. (2002). Infant perceptual and conceptual categorization: the roles of static and dynamic stimulus attributes. *Cognition*, *86*, 1–24.

Bearsdley, S. A., & Vaina, L. M. (2006). Global motion mechanisms compensate local motion deficits in a patient with a bilateral occipital lobe lesion. *Experimental Brain Research*, *173*, 724–732.

Beauchamp, M. S., Lee, K. E., Haxby, J. V., & Martin, A. (2002). Parallel visual motion processing streams for manipulable objects and human movements. *Neuron*, *34*, 149–159.

Bertenthal, B. I. (1993). Infants' perception of biomechanical motions: intrinsic image and knowledge-based constraints. In C. Granrud (Ed.), *Visual perception and cognition in infancy* (pp. 175–214). Hillsdale, NJ: Lawrence Erlbaum Associates.

Biederman, I., & Gerhardstein, P. C. (1993). Recognizing depth rotated objects: Evidence and conditions for three-dimensional viewpoint invariance. *Journal of Experimental Psychology: Human Perception and Performance*, *19*, 1162–1182.

Born, R. T., & Tootell, R. B. H. (1992). Segregation of global and local motion processing in primate middle temporal visual area. *Nature*, *357*, 497–499.

Braddick, O. (1993). Segmentation versus integration in visual motion processing. *Trends in Neurosciences*, *7*, 263–268.

Bulakowski, P. F., Bressler, D. W., & Whitney, D. (2007). Shared attentional resources for global and local motion processing. *Journal of Vision*, *7*, 1–10.

Burr, D. C., Morrone, M. C., & Vaina, L. (1998). Large receptive fields for optic flow direction in humans. *Vision Research*, *38*, 1731–1743.

Calvert, G. A, Brammer, M. J., & Iversen, S. D. (1998). Crossmodal identification. *Trends in Cognitive Sciences*, *2*, 247–253.

Cavanagh, P. (1992). Attention-based motion perception. *Science*, *257*, 1563–1565.

Cavanagh, P., Labianca, A. T., & Thornton, I. M. (2001). Attention-based visual routines: sprites. *Cognition*, *80*, 47–60.

Chen, Y., Nakayama, K., Levy, D., Matthysse, S., & Holzman, P. (2003). Processing of global, but not local, motion direction is deficient in schizophrenia. *Schizophrenia Research*, *61*, 215–227.

Christie, F., & Bruce, V. (1998). The role of dynamic information in the recognition of unfamiliar faces. *Memory and Cognition*, *26*, 780–790.

Cutting, J. E., Proffitt, D. R., & Kozlowski, L. T. (1978). Biomechanical invariant for gait perception. *Journal of Experimental Psychology: Human Perception and Performance*, *4*, 357–372.

Dittrich, W. H., Troscianko, T., Lea, S. E., & Morgan, D. (1996). Perception of emotion from dynamic point-light displays represented in dance. *Perception*, *25*, 727–738.

Giese, M. A. (1999). Evidence for multi-functional interactions in early visual motion processing. *Trends in Neurosciences*, *22*, 287–290.

Haxby, J. V., Hoffman, E. A., & Gobbini, M. I. (2002). Human neural systems for face recognition and social communication. *Biological Psychiatry*, *5*, 59–67.

Hill, H., & Johnston, A. (2001). Categorizing sex and identity from the biological motion of faces. *Current Biology*, *11*, 880–885.

Jellema, T., & Perrett, D. I. (2003). Cells in monkey STS responsive to articulated body motions and consequent static posture: a case of implied motion? *Neuropsychologia*, *41*, 1728–1737.

Johansson, G. (1973). Visual perception of biological motion and a model for its analysis. *Perception and Psychophysics*, *14*, 201–211.

Johnson K. L., Tassinary L. G. (2005). Perceiving sex directly and indirectly: meaning in motion and morphology. *Psychological Science*, *16*(11), 890–897.

Johnson K. L., Tassinary L. G. (2007). Compatibility of basic social perceptions determines perceived attractiveness. *Proceedings of the National Academy of Sciences USA.*, *104*(12), 5246–5251.

Kersten, A. W. (1998). A division of labor between nouns and verbs in the representation of motion. *Journal of Experimental Psychology: General*, *127*, 34–54.

Kersten, D., Knill, D. C., Mamassian, P., & Bülthoff, H. H. (1996). Illusory motion from shadows. *Nature*, 379, 6560, 31.

Knappmeyer, B., Thornton, I. M., & Bülthoff, H. H. (2003). The use of facial motion and facial form during the processing of identity. *Vision Research*, *43*, 1921–1936.

Knight, B., & Johnston, A. (1997). The role of movement in face recognition. *Visual Cognition*, *4*, 265–273.

Kourtzi, Z., & Kanwisher, N. (2000). Activation in human MT/MST by static images with implied motion. *Journal of Cognitive Neuroscience*, *12*, 48–55.

Kourtzi, Z., Bülthoff, H. H., Erb, M., & Grodd, W. (2002). Object-select responses in the human motion area MT/MST. *Nature Neuroscience*, *5*, 17–18.

Kourtzi, Z., & Nakayama, K. (2002). Distinct mechanisms for the representation of moving and static objects. *Visual Cognition*, *9*, 248–264.

Kourtzi, Z., & Shiffrar, M. (1999). The visual representation of three-dimensional, rotating objects. *Acta Psychologica*, *102*, 265–292.

Kozlowski, L. T., & Cutting, J. E. (1977). Recognizing the sex of a walker from a dynamic point-light display. *Perception and Psychophysics*, *21*, 575–580.

Krekelberg, B., Dannenberg, S., Hoffman, K. P. Bremmer, F., & Ross, J. (2003). Neural correlates of implied motion. *Nature*, 424, 6949, 674–677.

Kuhlmann, S., & Lappe, M. (2006). Recogniton of biological motion from blurred natural scenes. *Perception*, *35*, 1495–1506.

Lander, K., & Bruce, V. (2000). Recognizing famous faces: Exploring the benefits of facial motion. *Ecological Psychology*, *12*, 259–272.

Lander, K., Christie, F., & Bruce, V. (1999). The role of movement in the recognition of famous faces. *Memory and Cognition*, *27*, 974–985.

Langton, S. R. H., Watt, R. J., & Bruce, V. (2000). Do the eyes have it? Cues to the direction of social attention. *Trends in Cognitive Sciences*, *4*, 50–59.

Liu, T., & Cooper, L. A. (2003). Explicit and implicit memory for rotating objects. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *29*, 554–562.

Mandler, J. M. (1992). How to build a baby: II. Conceptual primitives. *Psychological Review*, *99*, 587–604.

Madole., K. L., & Cohen, L. B. (1995). The role of object parts in infants' attention to form-function correlations. *Developmental Psychology*, *31*, 637–648.

Malach, R., Reppas, J. B., Benson, R. R., Kwong, K. K., Jiang, H., Kennedy, W. A., Ledden, P. J., Brady, T. J., Rosen, B. R., & Tootell, R. B. H. (1995). Object-related activity revealed by functional magnetic resonance imaging in human occipital cortex. *Procedings of the National Academy of Sciences, USA*, *92*, 8135–8139.

Morrone, M. C., Burr, D. C., & Vaina, L. M. (1995). Two stages of visual processing for radial and circular motion. *Nature*, *376*, 507–509.

Navon, D. (1977). Forest before trees: the precedence of global features in visual perception. *Cognitive Psychology*, *9*, 353–383.

Nelson, C. A., & Horowitz, F. D. (1987). Visual motion perception in infancy: A review and synthesis. In P. Salapatek & L. Cohen (Eds.), *Handbook of Infant Perception. Vol. 2* (pp. 123–153). New York: Academic Press.

Newell, F. N. (1998). Stimulus context and view dependence in object recognition. *Perception*, *27*, 47–68.

Newell, F. N., Wallraven, C., & Huber, S. (2004). The role of characteristic motion in object categorisation. *Journal of Vision*, *4*, 118–129.

O'Toole, A. J., Roark, D. A., & Abdi, H. (2002). Recognizing moving faces: A psychological and neural synthesis. *Trends in Cognitive Sciences*, *6*, 261–266.

Pomerantz, J. R. (1983). Global and local precedence: selective attention in form and motion processing. *Journal of Experimental Psychology: General*, *112*, 516–540.

Puce, A., Allison, T., Bentin, S., Gore, J. C., & McCarthy, G. (1998). Temporal cortex activation in humans viewing eye and mouth movements. *Journal of Neuroscience*, *18*, 2188–2199.

Rakison, D. H., & Oakes, L. M. (2003). *Early category and concept development: Making sense of the blooming, buzzing confusion*. Oxford: University Press.

Rakison, D. H., & Cohen, L. (1999). Infants' use of functional parts in basic-like categorization. *Developmental Science*, *2*, 423–431.

Rakison, D. H., & Poulin-Dubois, D. (2002). You go this way and I'll go that way: developmental changes in infants' detection of correlation among static and dynamic features in motion events. *Child Development*, *73*, 682–699.

Stone, J. V. (1998). Object recognition using spatiotemporal signatures. *Vision Research*, *38*, 947–951.

Stone, J. V. (1999). Object recognition: view-specificity and motion-specificity. *Vision Research*, *39*, 4032–4044.

Thornton, I. M., & Kourtzi, Z. (2002). A matching advantage for dynamic human faces. *Perception*, *31*, 113–132.

Tsao, D. Y., Freiwald, W. A., Tootell, R. B. H., & Livingstone, M. S. (2006). A cortical region consisting entirely of face-selective cells. *Science*, 311, 5761, 670–674.

Vaina, L. M. (1998). Complex motion perception and its deficits. *Current Opinion in Neurobiology*, *8*, 494–502.

Valentine, T. (1991). A unified account of the effects of distinctiveness, inversion, and race in face recognition. *The Quarterly Journal of Experimental Psychology*, *43A*, 161–204.

Vuong, Q. C., & Tarr, M. J. (2004). Rotation direction affects object recognition. *Vision Research*, *44*, 1717–1730.

Vuong, Q. C., & Tarr, M. J. (2006). Structural similarity and spatiotemporal noise effects on learning dynamic novel objects. *Perception*, *35*, 497–510.

Wallis, G., & Bülthoff, H. H. (2001). Effects of temporal association on recognition memory. *Proceedings of the National Academy of Sciences of the U.S.A.*, *98*, 4800–4804.

Yantis, S., & Nakama, T. (1998). Visual interactions in the path of apparent motion. *Nature Neuroscience*, 1, 6, 508–512.

Yin, C., Shimojo, S., Moore, C., & Engel, S. A. (2002). Dynamic shape integration in extrastriate cortex. *Current Biology*, *12*, 1379–1385.

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