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Recognition of animal locomotion from dynamic point-light displays

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Abstract. To date, studies of biological motion have been restricted to displays of humans filmed (or synthesised by computer) with lights attached at the major joints. Observers can readily extract meaning from such displays. There have been no studies to assess the generality of this ability by assessing observers' accuracy in identifying various animals solely on the basis of biological motion. An experiment is reported for which biological-motion displays were created from the stop-action photographs taken by Muybridge in the last century. Naive observers could reliably identify the animals involved when biological-motion displays were animated, but not when they were given static views of dot positions. Thus the ability to interpret biological motion is general and is not restricted to human movements.

1 Introduction

In a 'point-light' or 'biological-motion' display points of light, or reflective material, are attached to the limbs of a walking human who is then filmed while engaging in various activities such as walking, running, and lifting. A large number of experiments have been conducted with the aid of such displays (eg Johansson 1973; Kozlowski and Cutting 1977; Runeson and Frykholm 1981; Fox and McDaniel 1982). The first studies in which such displays were used were conducted by Marey (1895), who photographed humans wearing black clothes painted with white dots and lines. Recent research has employed computer simulations of walking humans (eg Todd 1983; Mather et al 1992). Naive observers are remarkably proficient at interpreting such displays and are able, for example, accurately to judge the gender or even identity of the actor. Theoretical models have proposed general-purpose schemes for extracting structure from biological-motion displays based on hierarchical vectorial analysis (Cutting and Proffitt 1981), or on assumptions of rigid connections between points (Webb and Aggarwal 1982). Recent data have cast doubt on these models, providing instead support for recognition based on characteristic motion patterns (Mather et al 1992).

However, all previous studies of biological motion have been restricted to human figures. The experiments have not required observers to discriminate the figures from alternative stimuli. It is therefore not clear whether we are peculiarly proficient at recognising fellow humans by their motion patterns, or whether we have a general ability to identify biological forms on the basis of their motion patterns. In an experiment reported here we assessed how well naive observers can identify various animals on the basis of biological-motion displays. The stop-action photographs taken by Muybridge in the last century (available in Muybridge 1979) provide a large library recording the locomotion of many animals. On the basis of the time intervals between successive photographs, recorded by Muybridge from his action sequences, a number of animals were selected which offered a wide range of animal forms and which had been sampled at time intervals of 50 ms or less [to ensure activation of early motion processes—see Mather et al (1992)]. All animals selected were depicted in sideways views as the animal moved across the field of view. The photographs were scanned into a computer, and animated with the aid of a commercial computer-animation software facility. Biological-motion displays were created by positioning bright dots at the major joints of each animal in each animation frame.

We had intended to animate the motion displays at a natural rate derived from the sampling intervals specified by Muybridge. However, informal observations of the displays indicated that at this rate the animals appeared to be moving too quickly. We therefore conducted a preliminary experiment to measure apparent locomotion rate using full views of the animals (rather than point-light displays) so that we could subsequently present apparently natural locomotion in the recognition experiment.

2 Experiment 1: Apparent speed of locomotion

2.1 *Method*

2.1.1 *Subjects*. Six subjects took part, three male and three female.

2.1.2 *Stimuli and apparatus*. Motion sequences representing eight different animals were selected from Muybridge (1979): camel, goat, baboon, elephant, cat, horse, man, and dog (details in table 1). Individual frames were scanned as halftone images into a Dell 333D computer with the aid of a Logitech ScanMan, and animated with the use of DeluxePaint Animation. Animations were presented on a Hitachi CM2087ME monitor (72 Hz frame rate, noninterlaced). Figure 1 shows two examples from the animation sequences. A full step cycle of each animal was animated, positioned to remain in the centre of the screen (as though the camera were panning). The animation frames could, therefore, be cycled through continuously. The natural locomotion speed was calculated for each animal on the basis of Muybridge's figures (table 1), and five more rates were calculated, corresponding to decreases of 20%, 40%, 60%, and 80%, and an increase of 20% (values established from pilot observations).

Table 1. Details of the images used in experiments 1 and 2. The plate numbers and frames refer to Muybridge (1979) and SI is the sampling interval used by that author. SIs used in experiments 1 and 2 were 32% longer to the nearest time possible given the 14 ms sampling interval of the graphics display. The number of frames used in the present work is the number required to depict a full step sequence of the animal's locomotion; where this number was greater than the frame number given in Muybridge (1979), extra frames were added to complete a step cycle or to reduce the sampling interval between frames (dot positions in the extra frames were interpolated from the immediately preceeding and succeeding frames). The size of image used is the visual angle subtended by the animal's body. (In Muybridge's work, the image of the horse was of horse and jockey; the image of the jockey was deleted from each frame in the present work.)

Animal	Data from Muybridge			Experiments 1 and 2	
	SI/ms	plate	frames	frames	size/deg
Baboon	42	748	11-24	14	2.03
Camel	37	738	1-16	16	2.77
Cat	28	719	1-12	12	1.59
Dog	41	709	1-6	6	1.85
Elephant	36	733	1-24	24	2.39
Elk	32	692	1-20	22	2.23
Goat	29	679	4-17	14	2.39
Horse	31	626*	1-15	15	3.21
Kangaroo	32	753	1-9	18	2.83
Lion	42	728	1-12	39	3.72
Man	41	62	1-11	11	1.30
Ostrich	41	772	1-12	24	2.39
Ox	48	669	1-16	19	3.81
Pig	31	675	1-13	13	3.37

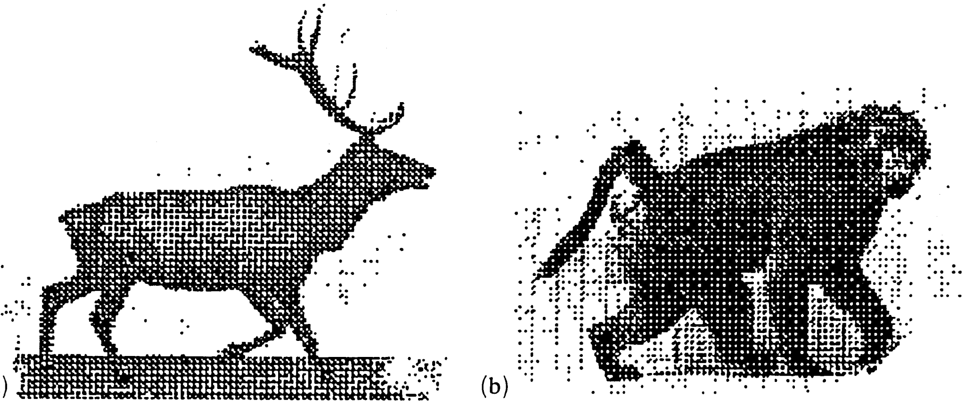

Figure 1. Examples of the animals used in the experiments: (a) elk and (b) baboon. These static views were digitised from photographs in Muybridge's work (1979). In biological-motion displays, only bright dots at the locations of major joints were visible.

2.1.3 *Design and procedure.* There were 48 different stimuli (eight animals at each of 6 speeds). Each subject was shown each stimulus once during an experimental session. After each presentation he/she was required to judge whether the rate of movement was faster or slower than a 'natural' pace. Each subject performed in five sessions in total, so making five observations of each stimulus.

2.2 *Results*

A logistic function was fitted to the psychometric function for each animal [by the use of regression analysis (Berkson 1953)] relating total percentage (across subjects) of 'faster' responses to presentation speed. The 50% point of the function (P_{50}) was calculated, which defines the speed at which subjects saw the motion as natural.

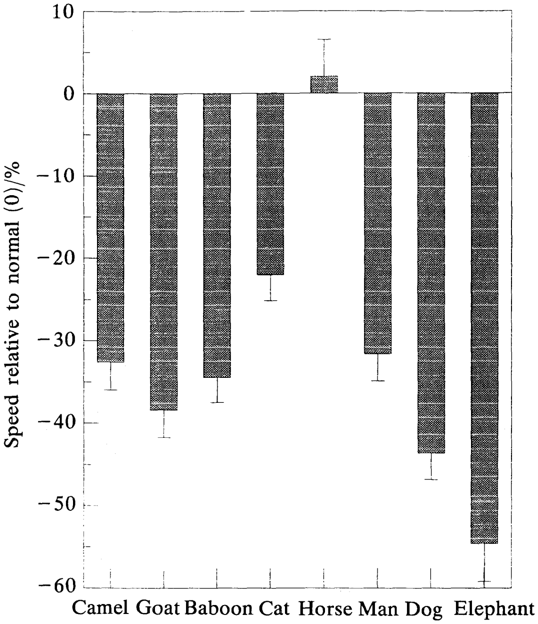

Figure 2. Results of experiment 1, showing speed [as a proportion of the 'correct' speed derived from Muybridge (1979)] at which observers judged each animal to be moving at a natural rate. Speeds represent 50% points of psychometric functions, established by Logit analysis. Error bars represent SEs of the estimates. Observers were shown full views of the animals, not biological-motion displays.

Figure 2 depicts the P_{50}s for the eight animals. With the exception of the horse, all animals had to be presented at slower-than-'correct' rates of motion to appear natural.

2.3 *Discussion*

The amount by which the motion sequence had to be slowed down to appear natural differed between animals. The horse did not need slowing down, the man had to be slowed by 31%, whereas the elephant had to be slowed by 55%. This pattern of data is not consistently related to the nominally correct time interval between frames (table 1), for example the cat and goat have the shortest intervals (28 ms and 29 ms, respectively) and the baboon and dog the longest (42 ms and 41 ms, respectively). Nor is it related to the real size of the animal, since the horse and elephant are the largest animals used, yet are at opposite extremes of the data. It is possible (but impossible to verify) that Muybridge's timings are incorrect. Muybridge states that "the interval of time between each successive exposure is stated in one-thousandth parts of a second, as recorded by a chronograph with a tuning fork making 100 single vibrations in a second". Presumably the measurements involved some interpolation, since the period of the fork oscillation was 10 ms.

All of the animals are shown trotting or running across the field of view, perhaps as a result of the difficulties in getting them to perform for Muybridge's camera. It may be that observers tend to judge the apparent speed of the animals relative to the speed at which they most often see those animals move. Elephants and camels usually move slowly, so are judged to be moving too quickly in the animations, whereas horses are often seen galloping so their speed is seen as natural.

Whatever the reason for the lack of correspondence between calculated ('correct') and perceived natural walking speeds, on the basis of this experiment we decided to present all of the animation sequences in experiment 2 slowed down by 32% relative to the speed calculated from Muybridge's data, to ensure the most natural appearance.

3 Experiment 2

3.1 *Method*

3.1.1 *Subjects*. Twelve subjects took part, four male and eight female. None of the subjects had taken part in experiment 1.

3.1.2 *Stimuli and apparatus*. Fourteen animals were selected from Muybridge (1979), and computer animation sequences for them were prepared as described in 2.1.2. Table 1 lists the details of the images used. To create biological-motion displays, dots were added to each frame of each animation sequence, at the locations of the major joints of the animal (ankle, knee, hip, shoulder, elbow, wrist, or their equivalent), and in addition a 'head' dot was placed at the point where the top of the backbone meets the skull. Skeletons depicted in Young (1962) were used as an aid to correct dot location, so any errors in dot location are likely to be small [data in Cutting (1981) for human stimuli indicate that even drastic mislocation of dots does not preclude correct interpretation]. When part of an animal's body was occluded during motion, the relevant dot was omitted from the display. Dots subtended 0.16 deg. Dot intensity was 128 cd m^{-2}; the remainder of the image was black (0.1 cd m^{-2}). As mentioned above, presentation rate was fixed at 32% slower than Muybridge's rate for each animal. The relative size of the animals as seen on the screen did not necessarily reflect their real relative sizes, and subjects were informed of this fact. The visual angle subtended by each animal is shown in table 1, and was calculated by using the distance between the shoulder and hip dots for each animal (with the exception of the ostrich, where the total body length was used).

3.1.3 *Design and procedure.* There were three experimental conditions: static, dynamic, and identification. The static-condition task was performed first by all subjects. A single static view of each animal—selected from the biological-motion sequence—depicting dot positions with the animal at 'full-stretch' was shown to the subject. The subject was given a list containing the names of all the animals used, and was required to select the name of the animal he/she had been shown. Subjects were allowed to choose a particular name as many times as they wished, although they were told that each animal was only presented once. Order of presentation was randomised across animals and subjects. This task was included to establish how well observers could identify animals on the basis of static dot locations.

The dynamic-condition task was performed after the static-condition task. Each subject was shown the full animation sequence for each animal. At each presentation the subject was again required to identify the animal from a list provided. Order of presentation of the animals was randomised. Finally, the identification-condition task was performed. This was the same as the static-condition task except that the subject was shown a static view of the complete animal rather than dots only, to check whether any inability to do the other tasks reflected an inability to recognise the animal per se. Figure 1 shows two of the views used.

If subjects can exploit the dynamic information in biological-motion displays to identify animals, then performance in the dynamic-condition task should be better than performance in the static-condition task.

3.2 *Results*

In figure 3 the mean percentages of correct identifications in the static and the dynamic conditions are shown. On average subjects were correct in 19.05% of static presentations and 43.45% of dynamic presentations. The probability of being correct by chance was 7% (1/14, because there were fourteen animals in the list). Performance in the static-condition task was not significantly better than chance levels according to cumulative-binomial probability theory (the threshold percentage is 22.4%). However, performance in the dynamic-condition task was well above the threshold level for significance, reaching a probability of $p < 0.0002$. A t test confirmed that performance in the dynamic-condition task was significantly better than performance in the static-condition task ($t_{11} = 5.73$; $p < 0.0001$). Subjects could

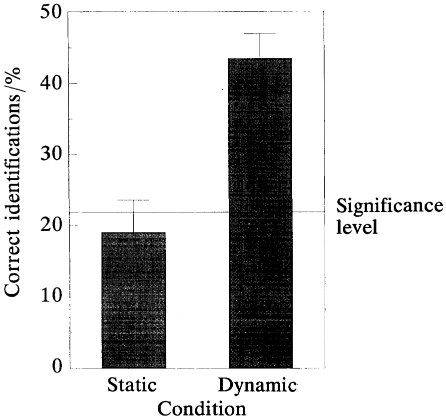

Figure 3. Mean percentage of animals correctly identified from biological-motion displays. 'Static' represents results when observers were shown a single static view of the dots defining each animal. 'Dynamic' represents results when observers viewed the full animation sequences. The horizontal line represents the threshold probability for significance at the 5% level according to cumulative-binomial probability theory. Vertical bars represent SEs.

identify almost all animals perfectly in the identification-condition task where they were shown a full view of each animal. The total percentage correct was 97%. There were 5 errors in the 168 identifications: two confusions between cat and lion, two confusions between dog and lion, and one subject who identified a dog as a baboon.

In tables 2 and 3 the results are broken down in terms of individual animals. Table 2 shows results in the static-condition task, and table 3 shows results in the dynamic-condition task. In the static condition, only six of the fourteen animals were correctly identified at levels greater than chance: the three bipeds (man, ostrich, and kangaroo), the camel, the cat, and the horse. Clearly there are static-form cues which allow the bipeds to be discriminated from the quadrupeds; the ostrich and the kangaroo were confused with each other to a significant degree. In the dynamic condition, twelve of the fourteen animals were identified at levels significantly above chance.

Table 2. Results in the static-condition task broken down by animal. An asterisk in a cell denotes that the animal presented in that column was named as the animal in that row at a rate significantly above chance (* $p < 0.039$, ** $p < 0.007$). Cells falling along the diagonal correspond to correct responses.

	Animal named	Animal presented													
		1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Baboon				**										
2	Camel		**				*								
3	Cat			**											
4	Dog														
5	Elephant														
6	Elk							*							
7	Goat					**									
8	Horse		**						*					*	
9	Kangaroo									**			**		
10	Lion			**											*
11	Man											**			
12	Ostrich									**			**		
13	Ox	*													
14	Pig														

Table 3. Results in the dynamic-condition task, broken down by animal. For details refer to table 2.

	Animal named	Animal presented													
		1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Baboon	**				*									
2	Camel		*				**							**	
3	Cat			**		*									
4	Dog			**	**										
5	Elephant					*					*				
6	Elk	**	*												
7	Goat						*	**							
8	Horse		*		*			*	**						*
9	Kangaroo									**					
10	Lion										**				
11	Man											**			
12	Ostrich												**		
13	Ox													*	
14	Pig														

The two exceptions were the elk—which was consistently named as the camel—and the pig which tended to be confused with the horse. The other most significant confusions were between ox and camel, cat and dog, and baboon and elk.

4 General discussion

Subjects could consistently identify animals on the basis of dynamic cues in biological-motion displays, and not when only static cues were provided. When animals were misidentified, the confusions tended to be between animals similar in terms of their size or locomotion (eg cat and dog, elk and camel). Thus our ability to interpret such biological-motion displays is a general one, rather than being one specialised for human figures. Performance in the dynamic-condition task was significantly better than chance, but was less than perfect. Higher levels of performance may be possible with improved stimulus materials (slower rates of locomotion and shorter sampling intervals, which would enhance activation of early motion processes). However, there would be considerable practical problems in generating new animation sequences of a wide variety of animals.

All of the subjects were informed that they were to be shown sequences depicting moving animals. The question arises as to whether the displays spontaneously elicit reports of biological motion in completely naive observers.(1) Supplementary observations were made using six subjects who were told nothing about the displays, but asked to describe what they saw. Three subjects were shown quadrupeds, and immediatey recognised the display as depicting an animal, though were not certain of the animal's identity. Three subjects were shown bipeds. One subject was shown a kangaroo and instantly recognised it as an animal, suggesting a bird after 2 - 3 s. The other two subjects were shown an ostrich. Each took several seconds to report 'something running'. One observer reported "well, it's a man running ... no it's not, it's an animal, a giraffe or something with a long neck". These observations bear out the conclusion that the visual system has a general ability to interpret biological-motion displays appropriately, but that the information available is not sufficient in many cases for exact identification. Given that performance with static full views of the animals is near perfect, why does the system have this general ability at all? There may be many natural situations where form cues are obscured or corrupted because of lighting conditions or occluding objects, so information from motion cues could provide an alternative to form-based identification processes which rely on prior shape segmentation and analysis. Motion cues may also be useful not only for recognition per se, but also for classifying an unknown animal as a biped or a quadruped, and for judging its real size.

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