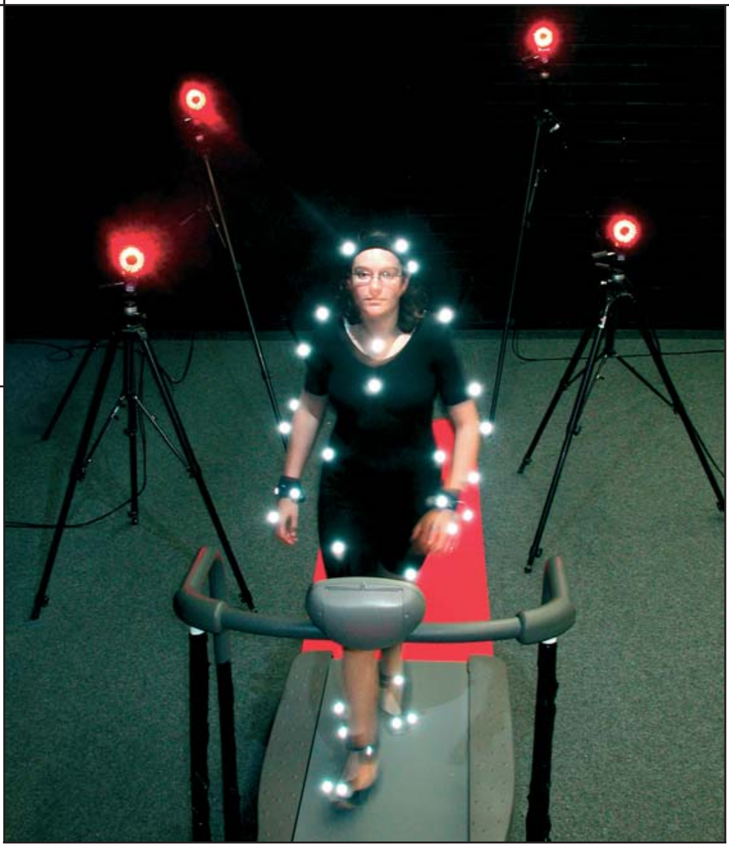
Cat walk and western hero - motion is expressive

Nikolaus F. Troje



Imagine you are at the train station to pick up a friend. The train has just arrived, the doors open and arriving travellers are flooding the platform. You scan the crowd and suddenly you see your friend. He was in one of the last carriages and he is still quite far away. You cannot recognize his face. Also other characteristic features such as voice, clothing, or the style of his hair are not yet available. Your only source of information is the particular way your friend walks.

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• **The information** channel that you used is old in terms of evolution. Many animals are virtually blind with regard to stationary images and process visual cues only by means of motion. It is mainly a privilege of vertebrates to be able to see still images and not even all of them can do this as well as humans can. In fact, we have to employ a trick. Like other biological photoreceptors the sensitive structures in the human eyes react only to changes in light flux. We achieve the required changes by means of micro-saccades: Even if we seem to fixate a small dot, the eyes are never really still. They tremble with small amplitude such that luminance edges of the visual environment constantly change their position on the retina. Whereas this mechanism works well in the central parts of our visual field, the peripheral parts remain blind as long as there is no motion. The photoreceptor density and therefore the spatial resolution is much lower in those parts of the retina and the small movements of the micro saccades are too small to provide sufficient retinal image movement.

For any animal, motion is an essential part of the visual environment. The ability to detect animate motion and to adequately react to it is a basic requirement for survival. Adequately reacting to other creatures often means either flight or attack. In both cases this has to be done as fast as possible. If the other animal is a co-specific, complex social responses may be required. The partner needs to be classified in terms of sex, age, social status and other attributes of biological, psychological or social relevance. Motion patterns are an important source of information in that respect providing information not only about the actions of another creature but also about its identity.

The human species is characterized by a highly developed social structure and maybe the most complex communicative behaviour in the whole animal kingdom. A central prerequisite for such social complexity is the ability to recognize other people individually. Almost all our sensory modalities are used in that process: Vision, audition, olfaction. One of the most important cues is certainly the face of a person. However, biological motion is also playing a major role in that respect. We can recognize a friend by the way he moves and we can attribute sex and age to people that we have never seen before. Motion provides us with a first impression about a person's emotions and personality traits and influences whether we find someone sympathetic or even sexually attractive.

The BioMotionLab at the Department of Biopsychology of the Ruhr University is dedicated to a broad study on how our brain performs visual processing of complex animate motion patterns. The project is funded by the Volkswagen Foundation and is subdivided into three complexes: Firstly, we explore how information is encoded in animate motion patterns and how this information can be retrieved. Secondly, we want to know which parts of this information are really obtained by the human visual system and, therefore, are behaviourally relevant. Finally, we apply a number of physiological methods to obtain insight into the neural mechanisms underlying visual processing of biological motion (Fig. 2).

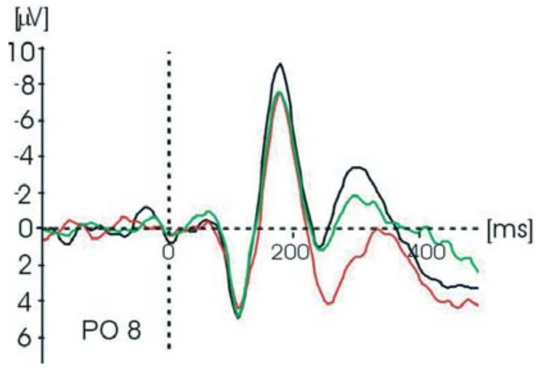
If we recognize a person in a real-world situation we can usually rely on a whole orchestra of different cues. In order to investigate the significance of a particular cue, however, we need to design psychological experiments in which we can isolate it from other cues. To uncouple animate motion from other sources of information we employ a method that has first been introduced into experimental psychology by the Swedish Psychologist Gunnar Johansson some 30 years ago. Johansson had his subjects wear a black suit and filmed them in a dark room such that his subjects were not visible at all. However, what could be seen was a set of small point-lights attached to the central joints of their bodies. As long as his subjects did not move, the point-lights appeared as an unstructured array of isolated white dots in front of a black background. However, when the subjects start to move, the visual system of an observer needs only a fraction of a second to organize the cloud of dots into a coherent percept of a moving person. Only a little more time is needed to discriminate men from women and to extract biological and social features of the moving person from the display.

In our laboratory, we employ a modern variant of this technique to quantitatively record a person's motion (Fig. 3). The captured motion is later analysed, can be manipulated, if needed, and is finally visualized to view the results. The motion capture process is based on an array of nine CCD cameras which track the three-dimensional trajectories of small retro-reflective markers with high spatial and temporal resolution. As in Johansson's seminal experiments, the markers are attached to the surface of a person. So far, we collected motion from more than 100 different persons. Each of them performs a whole set of different moves including walking and running with different velocities, throwing or kicking a ball, lifting objects or knocking on a door. At the moment, we are mainly investigating normal walking behaviour. Even though walking primarily serves locomotion it still contains plenty of information about the walking person.

If we use the recorded motion data to generate point-light displays on a computer screen and play them back to observers, they can determine the sex of the walker in about 75% of the cases (Fig. 4). The recognition performance, however, depends on the orientation from which the point-light walker is presented. Best sex classification is achieved in the frontal view. Apparently, this view contains diagnostic features which are less visible from other viewpoints. What are these features? Employing further experiments we try to answer this question. In these experiments we decompose the motion data into its components. We then recombine them such that only certain parts retain their sex-specific information whereas others are normalized and therefore become useless for sex classification. If such a manipulation does not influence recognition performance, the respective component does not contain information relevant for the task. However, if performance drops, then we know that we manipulated a sensitive part of diagnostic, sex-specific information.

Decomposing biological motion is done in several ways. To begin with, we distinguish between structural and dynamic information. Even though the point-light displays reveal information only when they move, this information is nevertheless not only dynamic. Mediated by the motion of the dots, the geometry of the body becomes apparent and therefore structural features such as shoulder width or leg length. We therefore generate point-light displays in which we replace each individual's structural data by a common structure derived in terms of the average across all male and female walkers of our data base. If observers can still determine the sex of the walkers, they could have used only purely dynamic information to do so. Similarly, we construct point-light displays in which each walker keeps his or her individual structure but is normalized with respect to the dynamic part of the

Fig. 2



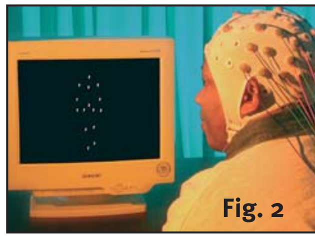


Fig. 2

Top: Event-related potential (ERP): This method isolates a specific response to the visual stimulus from the complex electro-encephalogram by averaging across many stimulus presentations.

Bottom : Watching the brain at work: While the participant in this experiment is observing a series of point-light displays, an array of surface electrodes is recording the electro-encephalogram.

Abstract

The way a person moves reveals information about his or her actions but also about the identity of the person including many attributes of biological and psychological significance. We have developed a framework which allows to extract such information from animate motion patterns and we investigate to which extent it reflects information processing in the human visual system.

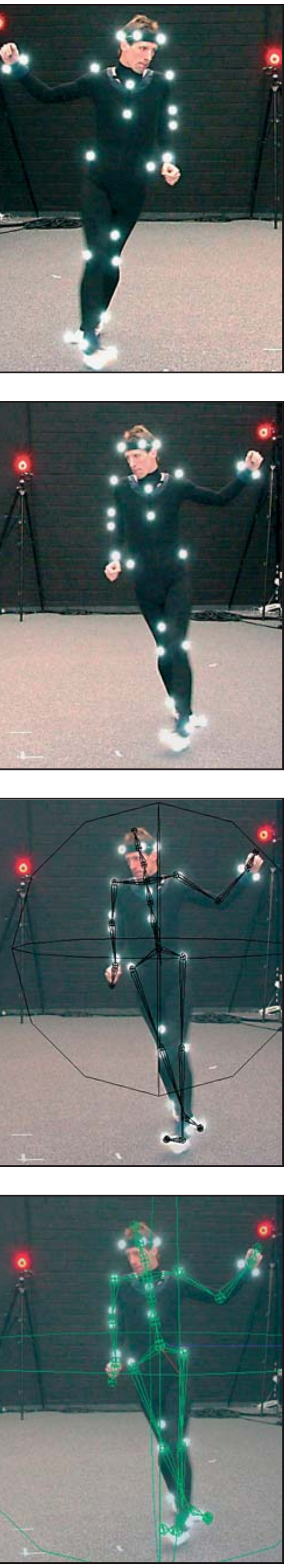


Fig. 3

Retroreflective markers are used to record the motion of a person. Later the data can be analysed and edited.

representation. Our experiments show that the dynamic part of the overall information is much more important for sex classification than the structural part (Fig. 4).

However, which are the details of the differences between male and female walking styles? To characterize these differences and to visualize their complex intercorrelated pattern, the walking data contained in our data base are projected into a mathematical space which is constructed such that linear combinations of existing walking patterns would result in naturally looking walking patterns again. In this space, we can apply established methods from linear statistics and pattern recognition to search for axes, which best represent the differences between male and female walkers (Fig. 5). Such an axis can then be visualized in terms of simple point-light or stick-figure displays. This way, we can not only visualize the transitions between male and female walking patterns, but we can also exaggerate them (Fig. 6). The resulting caricatures of male and female walkers both confirm well-known prototypes: The super-man shows the gait of the hero in a classical western movie. He appears straddle-legged, the elbows are held away from the body, and the wide shoulders are performing a significant lateral sway. The super-woman, on the other side, appears rather slim. The elbows are held close to the body and the upper body shows only little lateral motion. However, there is a significant rotation of the hip which becomes particularly salient because it is in counter phase to the vertical motion of the legs (http://www.biomotionlab.de/Demos/BMLwalker.html). In summary, the statistical exaggeration of the differences between male and female walking patterns unveils a property that the human species shares with many other animals. The male seems to take many efforts to occupy as much space as possible and to appear bigger than he actually is. Like in pigeons where the male puffs up his feathers or like in lions where the male evolves its mane, we find in our species sex-specific differences in the way to move which eventually result in men to appear bigger and heavier. Women, on the other hand, present themselves less obtrusive and probably employ more subtle signals.

We are interested to whom these signals are addressed and what role they play in the context of mate selection and sexual attractiveness. In a series of psychophysical experiments we present our point-light walkers to a number of observers and let them rate their sexual attractiveness. Female observers are first shown with male walkers and vice versa. The observers are informed that they see only walkers of the other sex and they are instructed to indicate the perceived attractiveness on a rating scale that ranges from 1 (not attractive at all) to 6 (very attractive). In a second experimental block, we show female walkers to our female observers and male walkers to our male observers. In this case the instruction reads: “Indicate your opinion about how attractive this walker appears to the respective other sex.”

Based on the data from this experiment we determine axes in our motion space that would best account for the data. The axes are then visualized as before and inspected with respect to the features they are carrying. Such visualizations can be viewed at our webpage (http://www.biomotionlab.de/Demos/attractiveness.html). The results are surprising. If we ask men to rate female attractiveness we basically find the sex axis that we derived from the previous analysis. An unattractive woman looks like a man and shows his wide shoulders, lateral body sway and other typically male features. An attractive woman, on the other side, is a feminine woman. Her motion pattern differs in any detail from the one shown by men. She is slim and she does not show any lateral body sway but a pronounced hip rotation in counter phase to the motion of her feet. In addition, a new feature becomes apparent which is not part of the sex-axis but can still be interpreted in terms of occupying (or not occupying) space: A woman which is considered to be very attractive by male raters places her feet almost on a straight line showing the typical walk of professional models that coined the term “cat walk”.

When we analyse the data obtained from female observers rating female walkers according to their assumed attractiveness to men we get a completely different picture. Attractiveness is no longer associated with femininity but is expressed in vigorous, powerful but relaxed motion with a large contribution of vertical movement. An un-attractive woman is not a particularly masculine woman but rather appears stiff, uneasy, and nervous with little vertical motion components. Apparently, there is a huge discrepancy between what men consider attractive in women and what women think that men find attractive. In contrast, the ratings about male attractiveness are much more consistent: Both women and men consider a combination of vigour, power and determination to be attractive.

Our research is not restricted to sex and attractiveness. Our visual system is able to retrieve many other attributes from biological motion patterns. At the moment, we are investigating which components of the motion patterns are relevant for person identification and how emotional attributes are encoded in biological motion. Psychophysical experiments are designed to test whether the artificial algorithms that we developed are relevant models for motion processing in the brain. At the same time, we are employing physiological methods, with which we can record activation patterns across the human cerebral cortex while the subject is performing a biological motion recognition task (Fig. 2).

Our work produces applications which spread into different fields. The sensible motion analysis methods that we developed are well suited for the differential diagnosis of neurological diseases, which are often accompanied by movement disorders. In particularly during early stages of diseases such as Multiple System Atrophy of Morbus Parkinson, when a carefully targeted therapy would be most efficient, a precise and reliable diagnosis is often hard to achieve with standard methods.

A completely different area of application for our work is less concerned with the analysis of animate motion but rather with its synthesis. Computer games as well as realistic computer graphics in feature films have achieved an impressive degree of realism, which makes it often impossible to distinguish the animated stuntman from the real actor -- at least as long as he does not move. The realism of the static avatars themselves, with sophisticated modelled surface properties and physically perfect simulations of complex illuminations are in fierce contrast to the perceived realism of their movements. This discrepancy expresses the enormous sensitivity of the human visual system to detect even the slightest inconsistencies in animate motion patterns and it also shows the lack of sound theoretical models that can be used to attribute individuality and emotion to artificial motion. With our work we try to bridge this gap. An understanding of the mechanisms underlying visual information processing in our brain will help us to develop algorithms to enable artificial characters to move in a psychologically convincing way.

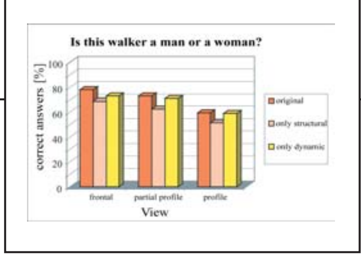


Fig. 4
Is this walker a man or a woman? Participants have to make a decision after being shown with point-light walkers. Performance is best if the walkers are shown in frontal view and lowest if they are shown in profile view. Furthermore, performance depends on the information provided. With only dynamic information being available, performance is better than with only structural information.

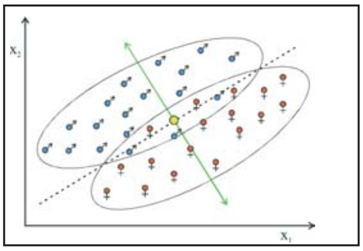


Fig. 5
Differences between male and female walking can be characterized using a linear motion space. Using methods from pattern recognition and linear statistics, we derive an axis (green line) which best represents these differences. The result can be visualized in terms of point-light displays or stick figures showing walkers which represent points along this axis. The dashed line shows the best separation plane. Symbols: male and female walkers, yellow circle: average walker.

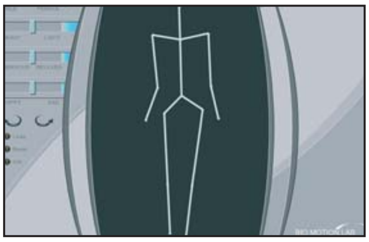


Fig. 6
Different walking patterns in men and women. While these static pictures illustrate the structural differences between men and women, the differences in dynamics are shown in an interactive animation available at http://www.biomotionlab.de/Demos/BMLwalker.html

Info

Knowledge-based vision: what does our brain know about the relation between time, space and gravity?

The visual system uses implicit knowledge to replace missing information or to resolve ambiguities. For instance, can an observer employ the relation between temporal and spatial scales under constant gravity conditions? For the same reason that a long pendulum swings slower than a short pendulum, large animals make less steps in a given time interval than small animals. Using this relation it should be possible to derive the size of an animal from its step frequency.

The experiment: Observers are presented with a point-light display of a walking dog and they are instructed to adjust the size of this dog to a number of reference objects (cactuses, poles) in the environment (see Figures). The results show that the perceived size in fact depends on the step frequency: The larger the step frequency the smaller appears the dog. The data reflect the inverse quadratic relation between spatial and temporal scales which is mediated by gravity. Apparently our visual system "knows" about this physical law.