Self recognition versus recognition of others by biological motion: Viewpoint-dependent effects

Daniel Jokisch ¶ §, Irene Daum §, Nikolaus F Troje #
Institute of Cognitive Neuroscience [§ also International Graduate School of Neuroscience],
Ruhr University Bochum, Universitätsstrasse 150, D 44780 Bochum, Germany; # also Department
of Psychology, Queen's University at Kingston, Kingston, Ontario K7L 3N6, Canada
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Abstract. We investigated the influence of viewing angle on performance in recognising the identity of one's own person and familiar individuals such as friends or colleagues from walking patterns. Viewpoint-dependent recognition performance was tested in two groups of twelve persons who knew each other very well. Participants' motion data were acquired by recording their walking patterns in three-dimensional space with the use of a motion capture system. Size-normalised point-light displays of biological motion of these walking patterns, including one's own, were presented to the same group members on a computer screen in frontal view, half-profile view, and profile view. Observers were requested to assign the person's name to the individual gait pattern. No feedback was given. Whereas recognition performance of one's own walking patterns was viewpoint independent, recognition rate for other familiar individuals was better for frontal and half-profile view than for profile view. These findings are discussed in the context of the theory of common coding of motor and visual body representations.

1 Introduction

Among the most biologically salient events are animate motion patterns. Humans can efficiently detect another living being in a visual scene and retrieve information about many features of psychological, biological, and social relevance. The ability to identify, interpret, and predict the actions of others is of particular relevance and essential for successful social interaction. Visualising the positions of the main joints of a walking human body by bright dots against a dark background (Johansson 1973) yields information from biological motion with reduced interference from non-kinematic cues. From such point-light displays observers can easily detect the presence of a human walker within 200 ms (Johansson 1976), determine his/her gender (Barclay et al 1978; Cutting 1978; Kozlowski and Cutting 1977; Mather and Murdoch 1994; Troje 2002a), and recognise various action patterns (Dittrich 1993). Kinematic cues from walking patterns also contain sufficient information to recognise identity, if observers are familiar with the persons to be presented (Cutting and Kozlowski 1977), and even to recognise oneself from a recorded point-light display of one's own movements (Beardsworth and Buckner 1981). Recognition performance in the latter studies was significantly above chance level, but information from biological motion failed to provide a cue for identity as reliably as facial information or voice information. When presented with gait patterns from six familiar persons, recognition performance varied between 35% and 40% for correct identifications of other persons, whereas the recognition rates for one's own gait pattern was about 60%.

Perceptual analysis of biological motion is performed by a specific neuronal network (Bonda et al 1996; Grezes et al 2001; Grossman and Blake 2001, 2002; Grossman et al 2000; Servos et al 2002; Vaina et al 2001) which is assumed to involve both the dorsal motion pathway as well as the ventral form pathway (Giese and Poggio 2003).

¶ Present address: F.C.Donders Centre for Cognitive Neuroimaging, PO Box 9101, NL-6500 HB Nijmegen, The Netherlands; e-mail: Daniel.Jokisch@fcdonders.ru.nl

Data from both pathways are integrated in a region around the superior temporal sulcus.

Whereas there exists a large body of literature about the impressive ability of the visual system to derive a coherent percept of a human body from a small number of moving dots, the principles underlying information encoding and retrieval are not yet fully understood. One important aspect is the viewpoint from which a walker is seen and its influence on our ability to extract information from biological motion. The knowledge about viewpoint-dependent recognition effects may provide insight into the mental representations and perceptual mechanisms of biological-motion processing. There is an ongoing debate whether visual representations of objects are viewpoint-dependent (Bülthoff and Edelman 1992; Tarr and Bülthoff 1995) or viewpoint-invariant (Biederman and Gerhardstein 1993, 1995). Viewpoint invariance indicates that object recognition is independent of the viewpoint of previous exposure to the object, whereas viewpoint dependence results in better recognition of objects presented from a familiar perspective.

The recognition-by-components approach of viewpoint invariance (Biederman and Gerhardstein 1993) is restricted to inanimate objects which fulfill specific criteria (objects must be decomposable into viewpoint-invariant parts, so-called 'geons'; structural descriptions of different objects must be distinctive; structural descriptions are identical over different viewpoints). Other approaches (Bülthoff and Edelman 1992) support that viewpoint invariance is valid for all object classes, independent of specific features. To reconcile both theories, viewpoint-independent recognition may occur at a basic level, whereas viewpoint dependence applies to a subordinate level. This view is supported by Foster and Gilson (2002). They showed that both image-based as well as structural representations can play a role, dependent on the object class and the level of object specificity. Recognition processes based on localised features seem to be more viewpoint-dependent, and generalisation is limited (Bülthoff and Edelman 1992).

Consistent with the latter theory, viewpoint dependence has been shown for unfamiliar faces (Hill and Bruce 1996; Hill et al 1997; Troje and Bülthoff 1996) and for familiar faces, with a pronounced ¾-view advantage and slightly longer response times to profile views than to frontal views (Bruce et al 1987). Observers' performance is worse at recognising one's own profile (which is an unfamiliar view of one's own face) compared with a frontal view, whereas there is no difference in response time between frontal and profile views of faces of highly familiar individuals (Troje and Kersten 1999). Taken together, these results provide strong evidence for the viewpoint dependence of recognition of identity.

In the domain of biological motion there is so far only one study on viewpoint-dependent recognition of identity in an artificial-learning paradigm (Troje et al 2005). This study yielded an overall advantage of frontal views compared to profile and half-profile views. Change of viewpoint from training to test resulted in a performance decrease. Viewpoint dependence has also been investigated in the context of gender classification based on biological-motion information (Mather and Murdoch 1994; Troje 2002a). As in the above-mentioned study, the frontal view seems to provide more information than the other views.

It is as yet unclear whether the results of Troje et al (2005) also apply to more ecological settings. Little is known about the representation of gait kinematics of familiar persons such as colleagues and friends with whom we interact in daily life. As one usually does not see one's own gait pattern from a third-person view, it is also of interest whether there is a dissociation between the mental representation of one's own gait pattern and the representation of other familiar gait patterns.

This question is of special relevance with respect to common-coding theory (Prinz 1997) which suggests that the motor and the perceptual system share representations

for the same actions. A similar approach has led to the direct-matching hypothesis (Rizzolatti et al 2001) which postulates that observation of an action induces resonance in the motor system of the observer. This resonance is considered to play a central role in action understanding. In the premotor cortex of monkeys 'mirror neurons' were found that discharge when the monkey performs specific hand actions and also when it observes another individual performing the same action (Gallese et al 1996). There is evidence that a 'mirror system', similar to that described in the monkey, also exists in humans. In contrast to the monkey mirror system, the human analogue is more flexible, since it reacts not only to goal-directed actions but also shows resonance behaviour to intransitive, ie not object-directed, actions. Evidence for such a flexible mirror system comes from studies applying transcranial magnetic stimulation (Fadiga et al 1995; Gangitano et al 2001), MEG-studies (Hari et al 1998), and from functional brain imaging (Buccino et al 2001; Iacoboni et al 1999). Even visual perception of point-light displays of biological motion has been shown to activate the premotor cortex, suggesting that the motor system of the observer may be recruited to interpret these simplified displays (Saygin et al 2004).

The view of shared representations of the visual and motor system as suggested by the common-coding theory and its successors has distinct implication for the recognition of one's own movement pattern and movement patterns of other persons. According to these theories, observations of actions are assumed to generally share visual and motor representations. Nevertheless, these shared representations should be more precise for the observation of one's own movements.

Behavioural experiments in support of common-coding theory show that, when observers watched videos of themselves or somebody else throwing a dart, they predicted the landing position more accurately in displays of themselves than in displays of others (Knoblich and Flach 2001).

The relation between motor representation and perceptual representation has also been discussed in the domain of speech. For instance, the motor theory of speech perception (Liberman et al 1967; Liberman and Mattingly 1985) assumes that the constituents of speech are not sounds per se but the articulatory gestures associated with the sounds which are shared by the speaker and the listener. According to common-coding theory, speech is perceived by mapping the articulatory gestures of the speaker onto the listener's motor repertoire (Skipper et al 2005).

The present study addressed two main issues: the first aim was to elucidate viewpoint-dependent effects in the representation of gait kinematics by exploring the influence of viewing angle on recognition performance. This was performed in a larger sample of different gait patterns as used in previous studies and by applying a more elaborate recording and presentation technique of gait patterns. The second aim was to examine recognition accuracy of one's own gait pattern compared to gait patterns of other familiar persons in order to draw conclusions on a differential representation of one's own movements relative to movements of other persons.

2 Material and methods
2.1 Participants
Two groups of twelve participants each took part in the experiment as models to acquire the kinematics of their gait patterns. All of them were staff at the Ruhr University Bochum (ten females, fourteen males; ages 21 to 42 years) and belonged to one of two different laboratories. All subjects had worked in one of these laboratories for at least 6 weeks, saw each other daily, and knew each other well by name. Twenty of the twenty-four subjects who supplied the motion data participated as observers in the experiment (nine females, eleven males; ages 21 to 42 years) which was undertaken with the understanding and written consent of each participant.

2.2 Stimuli

Motion data of the participants were acquired by recording their walking patterns in three-dimensional space with a motion capture system equipped with 9 CCD cameras (Oxford Metrics, Vicon 512). Participants were instructed to walk at a comfortable speed through the capture volume which was 7 m long. A set of 41 retroreflective markers was attached to their bodies. The system tracks the positions of the markers with a spatial accuracy in the range of 1 mm and a temporal resolution of 120 Hz. From these 41 markers, the trajectories of 15 'virtual' markers positioned at major joints (ankles, knees, hips, wrists, elbows, shoulders) and other points on the body (centre of the pelvis, sternum, centre of the head) were computed. Commercially available software (Bodybuilder, Oxford Metrics) for biomechanical modeling was used to obtain the respective computations. The data were normalised in size. Translational motion was subtracted such that the point-light walkers seemed to walk as if on a treadmill. By fitting a Fourier series to the data (Troje 2002b) the displays could be looped continuously to allow a variable presentation time.

The displays were presented in frontal view (FV, 0°), half-profile view (HV, 30°), and profile view (PV, 90°) as white dots on a black computer screen (figure 1). The walkers subtended 6.4 deg of visual angle at the viewing distance of 90 cm. They were computed in real time on a frame-by-frame basis and synchronised with the 85 Hz refresh rate of a 19 inch CRT monitor to ensure smooth, regular motion. Stimuli were presented with the use of Matlab with the Psychophysics Toolbox extensions (Brainard 1997; Pelli 1997).
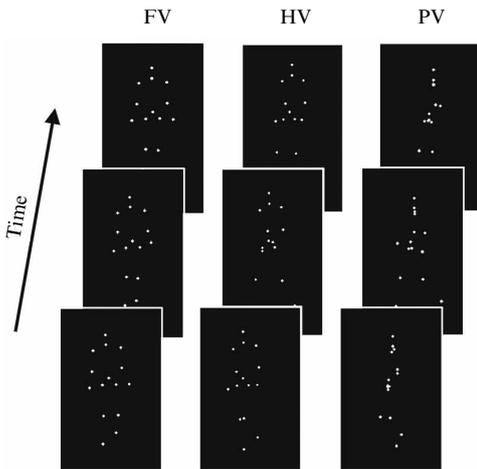
Figure 1. Categories of stimuli: point-light display in frontal view (FV), half-profile view (HV), and profile view (PV).

2.3 Procedure

Recognition performance was tested in a 12-alternative forced-choice paradigm. Before the experiment was started, the procedure was explained in detail to the observers. Thereafter, they were shown a list of names of all people to be presented, including their own.

Three blocks of 36 trials each were presented to the observers. The order of the trials within the blocks was randomised. Each block consisted of the gait patterns of the twelve members of each group, respectively. In each block all gait patterns were presented in three different orientations, resulting altogether in 36 trials per block. Accordingly, each subject observed 33 different gait patterns from colleagues and, in addition, his/her own gait pattern presented in three orientations. Therefore, self-recognition and recognition of others are represented in the ratio of 1 to 11 in the data set. Observers were presented only with gait patterns from members of their own group.

Consecutive blocks were separated by a short break. Stimulus presentation time was not limited. Each display remained on the screen until the observers indicated

that they had recognised the gait pattern by pressing a response button. Thereafter, a list containing name buttons of all persons being presented appeared on the screen. Observers were asked to indicate the name of the person by button press. Then the next trial started. Observers did not receive feedback on their responses.

The first block served to familiarise the subjects with the displays and to show them the whole range of different gait patterns in the sample. Only the second and third blocks were included in data analysis.

2.4 Data analysis

Data were analysed in two consecutive steps. First, overall recognition performance was analysed with a one-way ANOVA to determine the effects of the viewing angle. Recognition performance was defined as percentage of correctly identified walking displays. Greenhouse – Geisser adjustments to the degrees of freedom were performed when appropriate. This analysis did not distinguish between self recognition and recognition of others. Each observer provides in this analysis one percentage score for each viewing condition. This percentage score is based on the observation of 12 different gait patterns which were repeated one time. Note that in the experimental design self recognition and recognition of others are represented asymmetrically.

In the second analysis, recognition performance of one's own gait pattern and of gait patterns of others was analysed separately in order to elucidate differential viewpoint-dependent effects for self recognition and recognition of others. For recognition of others, a one-way ANOVA was conducted. In this ANOVA, each observer's percentage score per viewing condition was based on the observation of the 11 gait patterns of colleagues repeated one time. By contrast, recognition of one's own gait pattern was analysed non-parametrically because the number of observations was much smaller compared with recognition of others and, as a consequence, recognition rate was not distributed normally. In fact, on the level of a single observer, percentage score per viewing angle could only adopt the values 0%, 50%, and 100%.

3 Results

On average, mean scores for correct identification were 28.5% for frontal view, 26.9% for half-profile view, and 19.4% for profile view. Analysis of overall recognition performance by a repeated-measures ANOVA revealed a significant effect of viewing angle on recognition performance ($F_{2, 38} = 7.10$, $p = 0.003$). For frontal views ($p = 0.012$) and half-profile views ($p = 0.018$) recognition performance was significantly better than for profile views as tested a posteriori with Bonferroni adjusted measures (figure 2). In addition, recognition performance was converted into d' sensitivity values according to signal detection theory (Macmillan and Creelman 1991). The above-mentioned percentage scores of correct responses correspond to d' values of 0.94 (frontal view), 0.87 (half-profile view), and 0.57 (profile view).

The separate comparison of recognition performance of one's own gait pattern and of other persons' gait patterns indicated that only recognition of others was viewpoint-dependent ($F_{2, 38} = 7.57$, $p = 0.002$). Rates of correct identification were 28.6% for frontal view, 26.6% for half-profile view, and 18.4% for profile view. Again, for frontal views ($p = 0.008$) and half-profile views ($p = 0.018$) the percentage of correct identification was significantly better than for profile views. The corresponding d' sensitivity values are 0.94 (frontal view), 0.87 (half-profile view), and 0.53 (profile view).

Such a result, ie the similarity between overall performance and performance of recognition of others, is expected, given the fact that the only difference in the second ANOVA is that from each observer's percentage score the values of self recognition, which have a weight of only $\frac{1}{12}$, were sorted out.
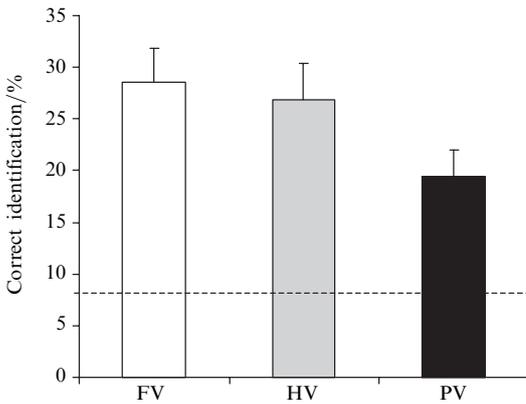
Figure 2. Overall percentage of correct identification for frontal (FV), half-profile (HV), and profile view (PV). Error bars indicate SEM. The dashed line indicates chance level.

By contrast, recognition performance of one's own gait pattern was virtually at the same level in all viewing conditions. Observers identified their own gait pattern correctly in 27.5% of the trials in the frontal-view condition ($d' = 0.91$) and in 30% of the trials in the half-profile view as well as in the profile-view condition ($d' = 0.97$) (figure 3). Statistical analysis revealed no significant effect of viewing angle on recognition rate ($\chi^2_2 = 0.08$, $p = 0.960$). Statistical power of the χ^2-test was analysed a posteriori by means of the G-Power software (Erdfelder et al 1996). The following parameters were used for analysis: effect size ω was set to 0.33, which indicates a medium effect size according to Cohen (1988) and corresponds to a population effect of 10%; the α-level was set to 0.05. For these parameters the statistical power was 0.91 and, therefore, the null-hypothesis was accepted.
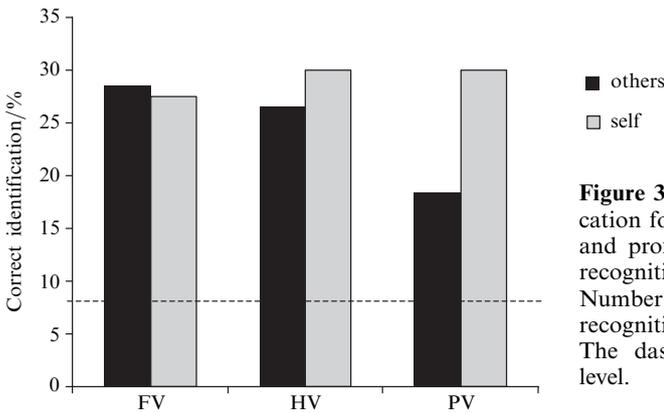
Figure 3. Percentage of correct identification for frontal (FV), half-profile (HV), and profile view (PV) separated for self recognition and recognition of others. Number of trials are different for self recognition versus recognition of others. The dashed line illustrates the chance level.

4 Discussion
The current results present further evidence that kinematic cues from biological motion provide information about the person's identity. This information can be transferred from real-life experience to reduced point-light displays of biological motion with only the kinematics visible. Overall recognition performance ranged between 19.4% ($d' = 0.57$) and 28.5% ($d' = 0.94$) in the current study. Nevertheless, information from biological motion failed to provide a highly reliable cue for individual identification. This could mean that either the information available is relatively weak, or it could reflect a problem with generalising information from real-world walkers to the point-light displays used in our experiments. The fact that observers who are taught to recognise and attribute names to individual point-light walkers (Troje et al 2005) reach performances of more than 90% correct responses argues for the latter explanation.

In comparison with earlier studies (Beardsworth and Buckner 1981; Cutting and Kozlowski 1977) absolute recognition rates in the current study were found to be lower. However, in these studies, the number of walkers was lower, too. If recognition performance is considered as d' sensitivity measures, the differences between the current study and the previous studies become marginal.

On converting the percentage of correctly identified persons in Cutting and Kozlowski's study (1977) and Beardsworth and Buckner's study (1979) to d' sensitivity measures, performance corresponds to a d' value of 0.79 (Cutting and Kozlowski 1977) and a d' value of 1.39 (self recognition) and 0.59 (recognition of others) in the study by Beardsworth and Buckner (1979).

Considering overall recognition performance in our study, we did not find such a clear difference in performance between self recognition and recognition of others. Cutting and Kozlowski (1977) as well as Beardsworth and Buckner (1981) used profile-view displays. Taking into consideration only the profile-view condition in our experiment, the current results are in general accordance with Beardsworth and Buckner's (1981) data.

As concerns the role of the viewpoint in recognition of identity of other people, individual features of gait kinematics can be extracted more efficiently when seen in frontal or half-profile view. This result is in accordance with the findings of Troje et al (2005). We speculate that the viewpoint dependence might be due to attention being automatically drawn to approaching people, resulting in increased exposure to frontal and half-profile views of gait patterns. This finding supports the hypothesis of a viewer-centred representation of biological-motion information from other individuals.

In contrast to viewpoint-dependent recognition of familiar individuals, recognition of one's own walking patterns was found to be independent of the viewing angle. The direct-matching hypothesis (Rizzolatti et al 2001) assumes that observation of a human action activates not only visual areas but also premotor areas. This mechanism might be the key to explaining the differences between representations of one's own gait pattern and gait patterns of familiar persons. When individuals observe their own movement patterns, they refer probably to motor representations associated with their own gait patterns. Motor representations of the metrics of one's own movements are clearly stored three-dimensionally providing an explanation for the viewpoint-independent recognition performance of one's own gait pattern. Moreover, it is quite unusual to watch one's own movements from a third-person perspective. As a consequence, we have little experience with visual feedback from our own locomotion movements. This view provides further support for the specific role of motor representations in the current task.

The assumption of a common coding does not provide an additional advantage in recognising the identity of other persons, but facilitates recognition of one's own movement patterns. Only when observing one's own movements the system that observes the action is identical to the system that has produced the action. For that reason, observers have to compare stored visual representations of gait kinematics of familiar persons with the actual kinematics provided by the point-light displays in order to recognise the identity of these persons by movement patterns.

Comparing the present findings on viewpoint dependence in biological-motion perception with those from face perception (Troje and Kersten 1999) we find an important difference. Whereas for face perception an advantage of frontal view in comparison to profile view emerges for the recognition of one's own person, such an effect was not observed for biological motion. For recognition of other familiar persons, the reverse pattern emerged: person identification does not vary with angle in faces, whereas there is a clear frontal-view advantage for biological-motion perception.

This dissociation supports again the assumption that information conveyed by the motor system contributes to the perception and recognition of one's own movements. Nevertheless, neither the mechanism to use only visual information nor the mechanism to use information from motor representation is perfect, given the substantial error rate. Information from biological motion in everyday life is mainly used for different purposes, such as estimating the smoothness and attractiveness of the movements of a possible partner or for inference of a person's emotions and personality traits from the way he or she moves. Moreover, deriving information from motor cognition in the context of self recognition might depend on the precision of one's own body scheme or the degree of experience with physical exercise.

In a recently published study, Loula et al (2005) investigated identity perception from bodily movements of different actions of one's own movements, movements of friends, and strangers. Visual sensitivity was highest to one's own motion. Sensitivity to friends, but not to strangers, was above chance level. One important finding was that recognition was action-dependent with best accuracy for dancing movements. In contrast, identity perception by walking movements was only slightly above chance level in this study. On the basis of their findings the authors concluded that both motor and visual experience define sensitivity to human actions.

Taken together, we can confirm earlier findings on person identification from biological motion (Beardsworth and Buckner 1981; Cutting and Kozlowski 1977). Even though error rates are rather high, performance is way above chance level. For recognition of familiar persons, the viewing angle plays an important role. Identity information can be extracted more reliably from frontal and half-profile view. Finally, recognition of one's own movements is independent of the viewing angle. We hypothesise that this is a consequence of a common coding of visual and motor representations according to the common-coding theory (Prinz 1997) and the direct-matching hypothesis (Rizzolatti et al 2001).

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