Recognition of Self-Generated Actions From Kinematic Displays of Drawing

 Günther Knoblich and Wolfgang Prinz
 Max Planck Institute for Psychological Research

Five experiments addressed the question of whether individuals can distinguish between self-generated and other-generated actions when seeing their visual effects. Each experiment consisted of a recording session in which participants drew familiar and unfamiliar characters without receiving visual feedback and a recognition session in which they provided self-or-other judgments (SOJs) to indicate whether a kinematic display reproduced the visual effects of their own actions. The main results were that self-generated and other-generated drawing can be distinguished, that the familiarity of character shapes does not influence the accuracy of SOJs, and that velocity information is crucial for the identification of self-generated drawing. The ability to determine authorship from kinematic displays of drawing provides evidence for the contribution of action-planning structures to perception.

Ever since Johansson (1973) provided striking demonstrations that moving point light displays can generate a vivid percept of a walking person, the perception of biological motion has been an important topic in event perception. Subsequent studies demonstrated that biological motion is recognized very rapidly (Johansson, 1976), that infants show a preference for dynamical displays of biological motion (Fox & McDaniel, 1982), and that they are sensitive to the coherence in such displays early in infancy (Bertenthal, Proffitt, Kramer, & Spetter, 1987). Sensitivity to biological motion has also been demonstrated in cats (Blake, 1993). Oram and Perrett (1994) reported that a population of cells in the macaque monkey’s temporal cortex is specialized for the detection of biological motion. Further studies have shown that various attributes can be derived from moving point light displays of biological motion, including gender (Barclay, Cutting, & Kozlowski, 1978; Kozlowski & Cutting, 1977), the weight of objects lifted by a person (Runeson & Frykholm, 1981), and the species of animals (Mather & West, 1993). Even complex attributes such as the emotions expressed in dance (Dittrich, Troschanka, Lea, & Morgan, 1996) and the meaning of gestures used in American Sign Language (Poizner, Bellugi, & Lutes Driscoll, 1981) can be identified from point light displays.

Following the lead of Gibson’s (1979) ecological approach to visual perception, theoretical explanations for how attributes are derived from displays of biological motion have typically focused on identifying perceptual invariants provided by the displays. One such invariant is the center of moment, that is, the center of the relative movement of shoulders and hips (Cutting, Proffitt, & Kozlowski, 1978). Cutting et al. (1978) demonstrated that the center of moment is used to identify the gender of a person in moving point light displays. With their kinematic specification of dynamics principle, Runeson and Frykholm (1983; see also Runeson, 1994) provided a more general account of how the kinematics of moving point light displays might specify the dynamics of the underlying movements, expectations, and intentions. According to this principle, invariants can be derived from particular anatomical, biomechanical, and dynamical constraints on the kinematics of a movement that hold for biological motion alone. Such invariants allow the observer to directly perceive the dynamics of a movement when observing its kinematics.

But biological motion is special in another respect as well. It reflects the effects of actions that were planned by an organism. Waves hit the beach and apples fall from a tree according to physical laws, but the motions of animals and humans are preceded by plans to achieve certain ends, such as approximating a food source or driving home from the office. This aspect has received less attention in the ecologically oriented research. The reason might be that early ecological psychology (Gibson, 1979) emphasized the mutual coupling of organism and environment and, as a result, deemphasized action planning. Being active, according to the original approach, is mainly understood as moving through the environment and picking up invariants and affordances. In this sense, the activity of the observer leads to a co specification of information about the observer and information about the environment (Gibson, 1979). Extensions of the ecological approach devoted to action emphasized the role of self-organization and intentional dynamics for action planning and certainly broadened its applicability (Shaw, Kadar, Sim, & Repperger, 1992; Shaw & Kinsella-Shaw, 1988; Turvey, Shaw, Reed, & Mace, 1981). Nevertheless, as noted by Jeanerod (1999), it is hard to see how action planning can be explained in interactionist terms (i.e., without referring to internal representations). Therefore, in this article, we take a representational approach to action planning in which being
active is conceptualized as making certain things happen in the world or, more precisely, planning to generate certain perceivable effects in the environment (Prinz, 1997).

One aspect of environmental information, the “authorship” of action effects, is of great importance in this context. How does one know that a certain aspect of the perceptual input is generated by oneself (an effect of a self-generated action) and not by someone else (an effect of an other-generated action)? This question can be asked for situations in which perceivable effects follow an action immediately (online recognition of self-generated effects) and situations in which the temporal contingency between action and action effects is removed (offline recognition of self-generated action effects).

In online recognition, temporal contiguity between an action and its perceivable effects is probably the most important way to determine whether a perceivable change in the environment is self-generated or generated by another. For instance, when you press a light switch, the light comes on immediately, and you experience yourself as the “author” of this effect. Problems arise when self-generated and other-generated action effects coincide temporally. For example, if you turn a knob to adjust the air conditioning and as an effect the television comes on, you might become confused, until you notice that another person turned on the television at the same moment.

The efference copy theory proposed by von Holst (1954) provides a solution to the question of how those aspects of sensory input that result from our own actions can be distinguished from signals due to changes in the outside world. It claims that an efference copy of each motor command is compared with the actual input and used to identify self-generated changes. Taking the notion of efference copy as a starting point, several recent studies have addressed the cognitive and neural mechanisms of online recognition of self-generated effects (see Jeannerod, 1999, for an overview). Blakemore, Wolpert, and Frith (1998) demonstrated that the cerebellum plays a central role in predicting specific sensory consequences of one’s own movements. Their data show that signals produced by the cerebellum lead to cancellation of sensory responses to self-generated tactile stimulation. Others have used ambiguous situations to determine which conditions online recognition of self-generated effects breaks down (Dapra et al., 1997; Fourneret & Jeannerod, 1998; Wegner & Wheatley, 1999). Dapra et al. (1997) found that normal individuals quite often confused their own hand with the experimenter’s hand in a situation in which they could not be sure whether they observed a video image of their own hand producing a certain movement or the hand of the experimenter producing the same movement. Schizophrenic patients were unable to perform correctly in this task.

The focus of our research is the offline recognition of self-generated action effects. We hypothesize that there are idiosyncrasies in the kinematics of self-generated action effects that enable self-recognition in situations in which actions and action effects do not temporally coincide. This hypothesis is derived from the common coding approach to perception and action (Prinz, 1992, 1997), the central assumption of which is that representations activated while one is perceiving events and representations activated while one is planning actions are commensurable. Both types of representation refer to events in the external world. Actions are represented as events that have not yet occurred but should occur as the result of an action. Hence, actions are coded in terms of the perceivable effects they should generate. The actual movement that leads to the occurrence of these effects in the perceptual input is automatically activated whenever the effects are intended. Similar views can be found in motor theories of speech perception (Liberman & Mattingly, 1985; MacKay, 1987) and theories of serial learning (Hoffmann & Koch, 1998).

Recent evidence from neuroscience shows that common coding may not only be a useful concept at a functional level; it may also occur on the level of single neurons in the brain (Rizzolatti & Arbib, 1998). Gallese, Fadiga, Fogassi, and Rizzolatti (1996) reported neurons in Area M5 in the premotor cortex of the macaque monkey that fired when the monkey grasped an object or merely watched the experimenter grasping an object. Recently, Decety and Grèzes (1999) reviewed brain-imaging studies that addressed the question of a common neural coding for perception and action in the human. They concluded that there is evidence for common coding on a neuronal level at which late products of perception and early antecedents of actions meet.

If the common coding theory is correct, some temporal and spatial characteristics of action effects ought to reflect characteristics of action planning, because it is highly likely that an actual effect occurring in the outside world bears similarities to its anticipation in some respects. A further plausible assumption is that the spatial and temporal characteristics coded in the representations that guide action planning vary from person to person. Because these representations determine the actual effects occurring in the outside world, the latter should also comprise some individual characteristics. Therefore, temporal and spatial characteristics of action effects may provide cues that allow one to identify self-generated actions.

Only a few studies in the literature have addressed the question of whether individuals can identify themselves when observing dynamic displays of self-generated versus other-generated action effects offline. All of these studies were dedicated to the recognition of one’s own gait. Wolff (1931) reported an experiment in which individuals saw films of a person walking with face blocked out and bodily appearance disguised by loose clothing. The participants could recognize themselves nearly perfectly when they were observing such films later, whereas they were less accurate in recognizing their acquaintances. More recent studies used Johansson’s (1973) point light technique to isolate the kinematics of gait more rigorously. The results were controversial. Whereas Cutting and Kozlowski (1977) found no advantage for the recognition of one’s own gait, Beardsworth and Buckner (1981) found an advantage.

One problem with moving point light displays of gait is that they are very complex, and the information contained in them is hard to experimentally control. For instance, it would be difficult to separate the spatial and temporal components of the kinematics in such displays. Moreover, the rich kinematic information of the displays may be used to derive invariants that are not related to action planning per se (Runeson & Frykholm, 1983). Because we were most interested in whether action-related structures contribute to perception, and we wanted to be able to systematically vary the information provided by the display, we used trajectories of drawing. The perceivable effects of drawing movements consist of simple trajectories with two spatial dimensions and one temporal dimension, and it is relatively easy to control the information
provided in such a trajectory. Furthermore, drawing is a complex skill, and action planning ought to play an important role in drawing productions (Van Sommers, 1984).

The temporal contiguity between drawing actions and their visual effects can be removed by first recording drawing trajectories without providing visual feedback. Later, the visual effect that would have been seen if there had been visual feedback can be replayed by having a moving point reproduce the kinematics of the trajectory. If observers can distinguish between moving dot displays that reproduce self- and other-generated trajectories, one can conclude that the kinematics of the self-generated trajectory provide information on which the judgment can be based.

In the following, we first report how the stimulus set for the later studies was prepared. Then we report five experiments that addressed the question of whether offline recognition of self-generated action effects is possible and which aspects of the trajectory can be used to discriminate self-generated from other-generated action effects.

Preparation of a Character Set

Three factors that might provide cues to discriminate between a self-generated and an other-generated trajectory are (a) the familiarity of the character, (b) the spatial and temporal information provided by stroke sequences, and (c) the segmentation of the character. These factors were taken into account when we prepared the characters to be used as models in the experiments. The character set systematically varied the familiarity of letter shapes by including scripts that are known and not known to German writers. By varying familiarity, one can determine whether individual characteristics of character shapes are important for determining authorship.

The spatial and temporal patterns in the production of consecutive strokes depend on geometric properties of the model. Because velocity changes might provide especially prominent cues, we selected characters systematically varying in geometric properties that are related to velocity changes in the associated trajectories. This allows one to assess whether velocity changes are an important cue. A further temporal cue that might be important is the duration of pen lifts. To be able to assess the relevance of this cue, we included characters that are likely to be drawn with and without lifting the pen into the character set. The characters were taken from six different scripts that best matched our goal to systematically vary cues related to familiarity and the spatial and temporal information provided by stroke sequences. Figure 1 shows an example character for each script.

The trace produced while copying the same character may be segmented in different ways (Goodnow & Levine, 1973; Meulenberg et al., 1996; Rosenbaum et al., 1995). A segment refers to a part of the trajectory that is produced without lifting the pen from the drawing pad. The number and ordering of segments as well as the drawing direction in each segment may vary. Previous research has shown that such cues can inform the identification of written characters (Babcock & Freyd, 1988; Flores d’Arcais, 1994), and they might also be used to identify self-generated drawing. Because one cannot be entirely sure that such cues activate action-related representations and not other types of representations (coding abstract sequence information, for instance), participants were instructed to use a certain segmentation in the later experiments.

However, there is a possibility that individual characteristics of drawing that are not related to segmentation are also lost when people are instructed to use a certain segmentation. To be able to control for segmentation without asking writers to use a nonpreferred segmentation too often, we conducted a pilot study (N = 8) to determine whether there is a preferred segmentation for the selected characters and whether this segmentation is chosen by the majority of writers under natural conditions. This was the case for 37 of 39 familiar characters and 122 of 139 unfamiliar characters. These characters were included in the final character set.

Experiment 1

The first experiment addressed the question of whether the kinematics of drawing trajectories contain characteristic aspects that allow for their recognition as self-generated. If such individual characteristics exist, one should be able to distinguish between self- and other-generated trajectories even when there is a long delay between carrying out the actions to produce certain characters and seeing the visual effects of these actions. To create such a situation, we asked individuals to draw a set of characters while not receiving any visual feedback (recording session). A week later, they were asked to provide self-or-other judgments (SOJs) for self- and other-generated trajectories to determine whether self-recognition is possible (recognition session). This task requires individuals to classify visual action effects they have never seen as self-generated or other generated. The recording session and recognition session occurred 1 week apart to rule out short-term memory effects related to internal feedback generated during drawing.

Whether the duration of pen lifts provides a cue to determine authorship can be determined by comparing recognition rates for characters that require the writer to lift the pen during production.
and characters that do not. If the duration of pen lifts provides a cue, SOJs should be more accurate for characters requiring pen lifts. A further possible cue for self-recognition is the familiarity of the character that is reproduced by a trajectory. If SOJs are more accurate for trajectories reproducing familiar characters, it is likely that letter shapes provide an important cue. By contrast, if SOJs are not influenced by familiarity, it is more likely that dynamical cues are used to determine authorship. Because different participants may tend either to magnify or minimize the model while copying it, the size of the trajectory might provide a further cue. To control for this cue, we scaled all trajectories to a fixed size before presenting them. It is unlikely that such a scaling reduces the "naturalness" of the stimulus, because many studies in the area of handwriting research show that drawing times for a letter vary only slightly over a wide range of sizes (Hollerbach, 1981; Stelmach & Teulings, 1983).

Method

Participants. Twelve participants were recruited from advertisements displayed at the University of Munich and published in local newspapers. Five of them were male. All participants were paid. They ranged in age from 22 to 34 years. All participants were right-handed and had normal or corrected-to-normal vision. Not until the second session were they informed that the experiment focused on recognition of self-generated actions.

Material. Arrows and small numbers indicated the preferred segmentation determined in the pilot study for each of the 159 characters that were used as stimuli in the recording session (see Figure 2 for two examples). The characters subtended a visual angle of approximately 4°.

The stimuli in the recognition session consisted of moving dot displays that reproduced the kinematics of self- and other-generated trajectories. The original trajectories were prepared for the recognition session in several steps. After smoothing the data using an algorithm proposed by Mottet, Pardy, & Athènes (1994), we determined pen velocity at each point in time. Then we determined the start and the end of each trajectory as the first and last samples for which velocity and pen pressure were zero. In a last step, the overall trajectory was scaled to a fixed width or height (100 pixels in screen coordinates). Two scaling factors were determined for the x and y dimensions, respectively. To preserve relative velocities and spatial proportions, we scaled the dimension having the smaller scaling factor according to that factor and adjusted the other dimension accordingly. The range of horizontal and vertical visual angles subtended by the displays varied between 3° and 6°.

Apparatus. The stimuli were presented on an Apple Vision 17-in. (43-cm) monitor with a horizontal resolution of 800 pixels and a vertical resolution of 600 pixels. The vertical sync frequency was 75 Hz. We recorded movements using a WACOM graphics tablet with a sampling rate of 75 Hz, a horizontal resolution of 15,000 dots, and a vertical resolution of 11,250 dots. These devices as well as a second Apple Vision 17-in. monitor were controlled by an Apple Power PC. The sampling rate of the graphics tablet was synchronized with the screen refresh rate. Keypresses were recorded by a PsyScope button box (Cohen, MacWhinney, Flatt, & Provost, 1993).

Design and procedure. During the recording session, participants copied each of the 159 stimuli of the character set. After the instruction, participants sat down in front of the stimulus monitor at a distance of about 60 cm. The graphics tablet was located in between the monitor and the participant. In each trial, a character appeared in the center of the monitor. Participants had 5 s to copy the character displayed. No visual feedback was given; that is, only the character to be drawn was visible on the stimulus screen during the drawing period. Participants did not see their drawing hand, because a cover was attached to the graphics tablet. The experimenter observed a 1:1 copy of the emerging trace on a control monitor. There were four conditions under which a trial was repeated: (a) The copying of a character was not completed within 5 s, (b) the indicated segmentation was not used, (c) the trajectory differed from the model in its geometric properties (e.g., a corner appeared round), and (d) the trajectory was undersized or oversized (i.e., the trace was smaller or more than three times the size of the model on either the x or y dimension).

During the recognition session, participants went through 159 trials. In each trial, two moving dot displays reproducing the same character were observed in succession. One of the displays reproduced the drawing of the participant himself or herself, and the other display reproduced the drawing of another participant randomly chosen from the remaining sample of 11 persons. The display reproducing self-generated drawing appeared randomly first or second. The task was to judge whether the first or the second trajectory was self-generated. The moving dot did not leave a trace on the screen. The time course was as follows: After a random intertrial interval that lasted between 1 and 3 s, the number 1 was displayed in the center of the computer monitor for 1 s. Afterward, the screen went blank for 500 ms, and a dot (3 pixels high and 3 pixels wide) appeared in the middle of the screen for 300 ms and then reproduced the first trajectory. After a pause of 500 ms, the number 2 was displayed in the center of the screen for 1 s. The monitor went blank for 500 ms, and the dot appeared in the middle of the screen for 300 ms and then reproduced the kinematics of the second trajectory. Finally, the question "1 or 2?" appeared in the center of the screen until a button was pressed.

Results and Discussion

For each participant, we computed the proportion of correct SOJs. Because the guessing probability was .5, values significantly greater than .5 indicate that participants recognized self-generated trajectories of drawing. Values greater than .5 could not be due to response bias (e.g., choosing the first display more often), because self-generated trajectories were presented first or second equally often.

The mean proportion of correct SOJs over all participants and characters was .59 (SD = .10). This value was significantly above chance level, r(11) = 3.06, p < .05. Therefore, participants recognized some aspects of the kinematics of their own drawing from the moving dot displays. Self-generated trajectories of familiar characters yielded slightly greater proportions of correct SOJs (M = .61, SD = .13) than self-generated trajectories of unfamiliar characters (M = .58, SD = .11). However, the difference was not significant, r(11) = 0.59, p = .57. Moreover, the proportion of correct SOJs for unfamiliar scripts was significantly higher than guessing probability, r(11) = 2.57, p < .05. These results make it unlikely that the familiarity of the characters was the main determinant of recognition performance. The average proportions of correct SOJs were .59 (SD = .10) for characters consisting of one segment and .58 (SD = .12) for characters consisting of two or

Figure 2. Labeling of characters to indicate a unique production mode.
more segments. Hence, there was no advantage for characters consisting of two or more segments. If recognition performance had been mainly based on the duration of pen lifts, one would have expected better recognition performance for such characters.

The results of Experiment 1 show that individuals can distinguish between self-generated trajectories and other-generated trajectories. This is true for trajectories reproducing familiar characters as well as unfamiliar characters. The latter result suggests that participants did not base SOJs on stored shape representations of letters because, in that case, familiar characters should have been classified correctly more often than unfamiliar characters. Moreover, trajectories reproducing characters consisting of more than one segment were classified correctly as often as those reproducing characters consisting of one segment. Therefore, the duration of pen lifts did not provide a reliable cue on which to base SOJs.

Experiment 2

In Experiment 1, each trial entailed one trajectory that was self-generated and one that was selected randomly from the remaining 11 participants. This fact suggests an alternative explanation that is not related to the recognition of self-generated actions. The different base rates in the recognition session may have enabled participants to discriminate between self- and other-generated trajectories on the basis of regularities in the self-generated trajectories that were easily learned because they were presented more often than trajectories generated by each other person.

We conducted Experiment 2 to test this perceptual learning hypothesis. The hypothesis predicts that regularities in the kinematics of other-generated trajectories can also be detected. To test this prediction, we displayed only other-generated trajectories in the recognition session, and one of the two trajectories in a pair always came from the same participant. The other trajectory was chosen randomly from the remaining participants. If the perceptual learning hypothesis is correct, individuals should be able to detect which of the trajectories in each pair belongs to the same person across trials. If the self-recognition hypothesis is correct, however, participants should not do as well as in Experiment 1 because of the lack of idiosyncratic action effects inherent in self-generated trajectories.

Method

Participants. Twelve participants were recruited from advertisements displayed at the University of Munich and published in local newspapers. Six of them were male. All participants were paid. They ranged in age from 19 to 33 years. All participants were right-handed and had normal or corrected-to-normal vision. Not until the second session were they informed that the experiment focused on recognition of self-generated actions.

Material and apparatus. The material and apparatus were the same as in Experiment 1.

Design and procedure. The recognition session was the same as in Experiment 1 with one exception. Instead of one other-generated and one self-generated trajectory being displayed in each trial, two other-generated trajectories were displayed in each trial. For instance, Participant 1 always saw one trajectory produced by Participant 2 and one trajectory produced by one of the remaining participants (3–12) in each trial. Hence, each participant was given one other participant’s trajectories as the constant ones, and each participant’s trajectories served as constants for another participant.

We explained to the participants that one trajectory in a trial was always produced by the same person, whereas the other was produced by a person randomly chosen from a large sample of individuals. They were instructed to indicate whether the first or second of the displays was generated by the person who remained the same across trials.

Results and Discussion

The mean proportion of correct answers over all participants and characters was .50 (SD = .12). Mean proportions correct were .52 (SD = .12) for familiar characters and .50 (SD = .12) for unfamiliar characters. None of these values differed significantly from guessing (p > .10). Hence, the results of Experiment 2 ruled out a perceptual learning explanation for the self-recognition effect obtained in Experiment 1. Individuals were not able to detect regularities in the kinematics of another person across trials. Rather, the results support the interpretation that the participants in Experiment 1 based SOJs on individual characteristics of self-generated trajectories.

Experiment 3

In Experiments 1 and 2, the two trajectories that were presented within each trial of the recognition session were scaled with respect to overall size, but they were not time normalized. Hence, the overall duration of the two trajectories could vary quite substantially. Therefore, the overall duration of the trajectories might have provided a cue for self-recognition. The participants might have estimated the absolute duration of the two trajectories presented in each trial of the recognition session and compared both trajectories with respect to their duration. In this case, self-recognition could be explained by a strategy of estimating the duration of intervals, comparing their duration, and relating the results of that comparison to general knowledge about being a fast or slow writer.

This explanation can be ruled out by matching the overall duration of the self- and other-generated trajectories presented together in each trial of the recognition session. We achieved this match by scaling the overall duration of the other-generated trajectory to be the same as the duration of the self-generated trajectory. If participants base their judgments on differences in the overall duration between self- and other-generated trajectories, they should not be able to recognize self-generated trajectories under these conditions. In contrast, if self-recognition depends on individual characteristics of the kinematics of self-generated trajectories, the results should be the same as in Experiment 1; that is, participants should be able to distinguish between self-generated and other-generated trajectories.

Method

Participants. Twelve participants were recruited from advertisements displayed at the University of Munich and published in local newspapers. Four of them were male. All participants were paid. They ranged in age from 21 to 36 years. All participants were right-handed and had normal or corrected-to-normal vision. Not until the second session were they informed that the experiment focused on recognition of self-generated actions.
Material and apparatus. The material and apparatus were the same as in Experiment 1 with one exception. A different spatial algorithm and an additional temporal scaling algorithm were applied to prepare the trajectories for the recognition session. The scaling was done in the following steps. For each self- and other-generated trajectory, the height and the width of the circumscribing rectangle were computed and used as estimates for the height and width of the trajectory, respectively. Using these estimates, we computed two scaling factors for the x and y dimensions, respectively. The smaller factor was chosen to scale both dimensions of the other-generated trajectory. This transformation did not alter the relative velocity and the spatial proportion of the trajectory, whereas scaling each dimension with separate factors would have altered these elements. The scaled other-generated trajectory had exactly the same height or exactly the same width as the self-generated trajectory, and the remaining dimension could slightly differ. In a second step, overall duration was scaled. A time scaling factor was determined by dividing the duration of the other-generated trajectory by the duration of the self-generated trajectory. Then a data structure consisting of the same number of samples as the self-generated trajectory was created. Finally, the time scaling factor and linear interpolation were used to compute the spatial position of each sample from the original other-generated trajectory.

Design and procedure. The design and the procedure were the same as in Experiment 1.

Results and Discussion

The average rate of correct SOJs over all participants and characters was .57 (SD = .04), only slightly lower than in Experiment 1. Self-generated trajectories of familiar characters were recognized as often (M = .58, SD = .12) as self-generated trajectories of characters from unfamiliar scripts (M = .57, SD = .03). The proportions of correct SOJs for familiar scripts, t(11) = 2.26, p < .05, and unfamiliar scripts, t(11) = 6.76, p < .001, were significantly higher than guessing probability. This result rules out the familiarity of the characters as a main determinant of recognition performance. Mean proportions of correct SOJs were .58 (SD = .04) for characters consisting of one segment and .56 (SD = .08) for characters consisting of two or more segments. Again, the duration of pen lifts could not be used as a cue for self-recognition.

The results show that recognition of self-generated trajectories was not based on an estimation of the overall duration of the two trajectories presented together in a trial. If that hypothesis were correct, recognition performance should have broken down with both trajectories in a trial having the same duration. The results support the claim that individual characteristics in the kinematics of drawing allow one to distinguish between self-generated and other-generated trajectories. The lack of difference between familiar characters and unfamiliar characters replicated the results of Experiment 1. Stored letter representations did not influence recognition performance. Moreover, consistent with Experiment 1, the results demonstrate that the duration of pen lifts did not provide a cue for self-recognition.

Experiment 4

In Experiments 1–3, the spatial and temporal characteristics of drawing trajectories were both preserved. Although the participants never saw more than one point at a time when watching moving dot displays, they may have constructed a mental image of the trace from consecutive positions of the moving dot. Such a static trace image may have allowed them to recognize purely spatial characteristics of their own drawing. In that case, self-recognition would be a function of the match between the image generated while perceiving the trajectory and a shape representation stored in memory.

To exclude this possibility, we presented trajectories with constant velocity in Experiment 4. If self-recognition is achieved by matching mental images against memory representations, performance should not deteriorate, because the lack of velocity information should not hinder the construction of a static trace image from the moving dot display. Alternatively, if the temporal component is a necessary condition for self-recognition to occur, individuals should not be able to recognize self-generated trajectories when the temporal component is removed.

Method

Participants. Twelve participants were recruited from advertisements displayed at the University of Munich and published in local newspapers. Five of them were male. All participants were paid. They ranged in age from 20 to 32 years. All participants were right-handed and had normal or corrected-to-normal vision. Not until the second session were they informed that the experiment focused on recognition of self-generated actions.

Material and apparatus. The apparatus was the same as in the earlier experiments. The scaling of overall size and overall duration of the two trajectories shown in each trial was the same as in Experiment 3. The other-generated trajectory was scaled to match the self-generated trajectory in overall size and overall duration. In addition, velocity information was removed from each trajectory by normalizing the mean Euclidean distance traveled between two samples to a constant value.

Design and procedure. The design and the procedure were the same as in Experiments 1 and 3.

Results and Discussion

The average rate of correct SOJs over all participants and characters was .52 (SD = .04), that is, very close to guessing probability. This rate was significantly smaller than that obtained in Experiment 3, t(11) = 3.19, p < .01. Removing the temporal component from the trajectory reduced the proportion of correct SOJs. Self-generated trajectories copying familiar characters were recognized slightly more often (M = .54, SD = .08) than self-generated trajectories copying unfamiliar characters (M = .52, SD = .05). However, the proportion of correct SOJs did not significantly exceed chance level for either familiar characters, t(11) = 1.78, p = .10, or unfamiliar characters, t(11) = 1.23, p = .23.

The participants were not able to distinguish between self- and other-generated trajectories when the moving dot reproducing these trajectories moved with constant velocity. The proportion of correct SOJs was almost at chance level when velocity information was removed. Therefore, the temporal component of the kinematics is a necessary condition for self-recognition to occur. The results speak against the interpretation that self-recognition is achieved by matching mental images against purely spatial representations.

Experiment 5

In Experiments 3 and 4, self-generated trajectories were left untouched, whereas the trajectories generated by other persons
were scaled to match the self-generated trajectories in overall size and overall duration as closely as possible. These transformations may have reduced the "naturalness" of the other-generated trajectories. Therefore, the recognition performance observed in Experiment 3 may have been due not to individual characteristics in the kinematics of the self-generated trajectories but to the naturalness of the display.

We conducted Experiment 5 to rule out this explanation. This time self-generated trajectories were scaled to match the trajectory of another person as closely as possible in overall size and overall duration. To do so, we applied exactly the same scaling approach to self-generated trajectories that was applied to other-generated trajectories in Experiment 3. If the naturalness of the display is the main cue on which SOJs are based, the other-generated trajectories should be considered as self-generated under these conditions. If individual characteristics in the kinematics of the trajectories allow distinguishing between self- and other-generated trajectories, the pattern of results should be the same as in Experiments 1 and 3.

Method

Participants. Twelve participants were recruited from advertisements displayed at the University of Munich and published in local newspapers. Four of them were male. All participants were paid. They ranged in age from 21 to 36 years. All participants were right-handed and had normal or corrected-to-normal vision. Not until the second session were they informed that the experiment focused on recognition of self-generated actions.

Material and apparatus. The material and apparatus were the same as in Experiment 3 with one exception. In each trial of the recognition session, participants saw an other-generated trajectory that reproduced exactly the kinematics of drawing as recorded in the recording session and a self-generated trajectory that was scaled to have the same overall size and overall duration.

Design and procedure. The design and the procedure were the same as in Experiments 1 and 3.

Results and Discussion

The mean overall proportion of correct SOJs was .57 (SD = .09). Therefore, the size of the self-recognition effect was comparable to the effects obtained in Experiments 1 and 3. Participants recognized self-generated trajectories, even though they were scaled to match other-generated trajectories in overall size and overall duration. Trajectories reproducing familiar characters were recognized slightly more often as self-generated (M = .59, SD = .08) than trajectories of unfamiliar characters (M = .57, SD = .10).

Average proportions of correct SOJs were significantly above chance level for both familiar scripts, t(11) = 3.82, p < .01, and unfamiliar scripts, t(11) = 2.26, p < .05. Moreover, the average proportion of correct SOJs for characters consisting of one segment (M = .58, SD = .10) was not smaller than the average proportion of correct SOJs for characters consisting of two or more segments (M = .56, SD = .12). Consistent with Experiments 1 and 3, the duration of pen lifts did not improve self-recognition.

The pattern of results is the same as in Experiment 1 and Experiment 3. Trajectories reproducing familiar as well as unfamiliar characters were recognized. The results rule out the alternative explanation that SOJs were based on the naturalness of the display. Instead, they provide further evidence that individual characteristics in the kinematics of drawing trajectories were used to determine which of the trajectories were self-generated and which were generated by others.

Analysis of Recognition Performance as a Function of Geometric Properties

The results of Experiments 1, 3, and 5 show that it is possible to detect individual characteristics in the kinematics of drawing movements and recognize the visual effects of self-generated actions accordingly. Experiment 4 demonstrates that self-recognition is not possible when the temporal component of the kinematics is removed from the trajectory. Therefore, velocity information seems to be the crucial component for self-recognition. The various geometric properties of the characters that were used as stimuli allow an analysis that can provide further evidence that self-recognition is guided by the velocity profile of the trajectory.

Many studies in the area of drawing research (Lacquaniti, Terzuolo, & Viviani, 1983; Viviani & Schneider, 1991; Viviani & Stucchi, 1989) have shown that velocity changes in an end-point trajectory of drawing are closely related to the geometric properties of the stimulus. Some of these properties result in marked velocity changes, whereas others do not. By comparing the recognition rates for trajectories that include marked velocity changes with those that do not, one can determine whether this cue helps to determine authorship. For that purpose, trajectories were assigned to four different categories according to whether they were reproductions of characters consisting of straight or curved lines (or both; Category 1), characters having at least one corner (Category 2), characters having at least one loop (Category 3), or characters having corners and loops (Category 4; see Figure 3).

Trajectories in Category 1 were drawn by a single stroke and therefore velocity changes were sparse (i.e., there was only one acceleration phase and one deceleration phase in these trajectories). Trajectories in Category 2 provide more information about velocity changes, because to draw a corner one needs to reduce velocity to almost zero before reaching the corner and increase it again thereafter. Thus, if additional velocity changes provide an important cue for self-recognition, the trajectories in Category 2 should be recognized more often as self-generated than trajectories in Category 1. Trajectories in Category 3 also provide more information about velocity changes than those in Category 1, because to draw loops one must reduce velocity substantially and increase it again after having drawn the loop. Hence, recognition rates should also be higher for trajectories in Category 3 than for those in Category 1. Recognition rates should be highest for

![Figure 3](image-url)
trajectories in Category 4 because they contain the most velocity changes.

The consistent pattern of results obtained in Experiments 1, 3, and 5 makes it very likely that recognition was based on the same aspects of the dynamic displays in all of these experiments. Hence, we merged the data from all participants (N = 36) to analyze the influence of velocity changes on SOJs. We used only trajectories of characters consisting of one segment for this analysis. Because the geometric properties in question are always connected to a single segment, most characters consisting of more than one segment are ambiguous with respect to these properties and cannot be categorized uniquely. Therefore, the following analysis is based on trajectories reproducing 101 characters that were drawn without raising the pen. Table 1 shows the number of characters in each category, the average proportion of correct SOJs, and the standard deviations in each of these categories.

Trajectories reproducing characters having at least one corner (Category 2) were recognized more often as self-generated than trajectories of characters consisting only of straight or curved lines (Category 1). The difference was statistically significant, t(35) = 2.98, p < .05. However, the average proportion of correct SOJs for trajectories in Category 1 was also significantly above chance level, t(35) = 2.67, p < .05. Moreover, trajectories of characters having at least one loop (Category 3) led to a higher proportion of correct SOJs than trajectories in Category 1. However, the difference was only marginally significant, t(35) = 2.13, p = .08. Consistent with these results, the average proportion of correct SOJs for trajectories reproducing characters having corners and loops (Category 4) was especially high. Although this result fits nicely into the pattern, one should interpret it cautiously, because there were only two characters in this category, and the standard deviation was high. Overall, the results of the analysis are consistent with the assumption that velocity changes provide an important cue for the recognition of self-generated action effects.

In a further step, we included familiarity in the overall analysis of the three experiments. Familiar characters were recognized slightly more often as self-generated in all of the experiments. However, the difference was never significant in a single experiment. Comparing all participants with respect to that variable in one test may reveal a hidden influence of familiarity that could not be detected because of the small samples in Experiments 1, 3, and 5. Overall mean proportions of correct SOJs were .59 (SD = .10) for familiar characters and .57 (SD = .09) for unfamiliar characters. The difference was not significant, t(35) = 1.47, p = .30. Therefore, even when the sample was largely increased, no significant influence of familiarity on the accuracy of SOJs could be detected.

<table>
<thead>
<tr>
<th>Measure</th>
<th>Straight or curved lines</th>
<th>At least one corner</th>
<th>At least one loop</th>
<th>At least one loop and one corner</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of characters</td>
<td>.40</td>
<td>.47</td>
<td>.12</td>
<td>2</td>
</tr>
<tr>
<td>M</td>
<td>.55</td>
<td>.60</td>
<td>.61</td>
<td>.72</td>
</tr>
<tr>
<td>SD</td>
<td>.12</td>
<td>.10</td>
<td>.15</td>
<td>.35</td>
</tr>
</tbody>
</table>

General Discussion

Collectively, the results support the notion that the kinematics of end-point trajectories of drawing contain information enabling individuals to judge whether they are self-generated or generated by others. Participants were able to distinguish the visual effects of their own drawing from the drawing of others when watching moving dot displays reproducing action effects they had not seen before. However, self-recognition was not possible when the dot moved with constant velocity.

In Experiment 1, participants judged self- and other-generated trajectories that were both transformed only in size to rule out overall size as a recognition cue. The recognition rate obtained was reliably above chance level. However, there were different base rates for self- and other-generated trajectories in this experiment. Whereas self-generated trajectories were seen in each trial, trajectories of each other person were seen only in each 11th trial. Therefore, perceptual learning during the second session is a possible alternative explanation.

Experiment 2 tested this alternative explanation. Participants judged only other-generated trajectories during the second session. Individuals were not able to detect regularities in the kinematics of another person whose trajectories were presented in each trial. This result rules out perceptual learning as an alternative explanation, because perceptual learning should occur for self- and other-generated trajectories and vary as a function of the base rate.

A further alternative explanation was ruled out in Experiment 3. Because the trajectories were not matched for overall duration in the first experiment, the participants might have used a strategy of estimating time intervals and relating these estimates to their knowledge of writing and drawing fast or slow. Therefore, the overall size and the overall duration of the two trajectories presented in each trial were matched in Experiment 3 so that the overall duration of the other-generated trajectory was exactly the same as the overall duration of the self-generated trajectory. Despite this fact, self-recognition did occur, as in Experiment 1. The result speaks against the interpretation that self-recognition is based on the estimation of overall duration.

Experiment 4 addressed the question of whether the spatial or the temporal characteristics of the kinematics of the trajectory provide the most important cues for self-recognition. The participants judged moving dot displays that were matched in overall size and overall duration. Moreover, the dot moved with constant velocity, so any temporal idiosyncrasies were removed as a recognition cue. The results showed that self-generated action effects could not be identified in this situation. Therefore, velocity information and not purely spatial characteristics provided the information that was used to determine whether a trajectory was self-generated or other generated.

In the last experiment, we tested whether the transformations applied to other-generated trajectories to match duration harmed the naturalness of the stimulus. In this case, self-recognition in Experiment 3 may have been based on choosing the trajectory that appeared more "biological." The results show that the transformations applied to other-generated trajectories can also be applied to self-generated trajectories without reducing the accuracy of SOJs. Therefore, the transformations did not reduce the naturalness of the stimulus.
The familiarity of characters did not exert a significant influence on self-recognition, as shown by the lack of a significant effect of familiarity in Experiments 1, 3, and 5 and in the overall analysis. Trajectories reproducing familiar characters and unfamiliar characters were recognized equally often as self-generated. Therefore, self-recognition cannot be due to a process that matches mental images generated while watching the moving dot display against representations of letter shapes stored in memory. If the latter were the case, one would have expected that individuals are able to recognize trajectories reproducing familiar characters as self-generated but not trajectories reproducing unfamiliar characters.

The results also provide hints about which aspects of the kinematics of a trajectory allow one to recognize self-generated action effects. Our first guess that the duration of pen lifts between the drawing of two segments might provide an important cue was not confirmed. Recognition did not vary as a function of the number of segments in Experiments 1, 3, and 5. Therefore, the duration of pen lifts did not provide an additional cue.

Nevertheless, self-recognition occurs only if temporal information is present in the trajectory. When velocity information was removed from the trajectory, recognition performance dropped to chance level (see Experiment 4), whereas self-recognition could be achieved whenever the temporal component was present (Experiments 1, 3, and 5). In our view, this result is very hard to explain by a purely perceptual account. Such accounts would have to presume that a mental image of the trajectory or of a part of the trajectory is created and matched against some sort of shape representation. The lack of effect for familiarity shows that this type of explanation does not hold for whole letter shapes. Even if one makes the somewhat implausible assumption that there are purely perceptual representations of production units such as single strokes or stroke combinations, one would have to predict that the temporal component of the trajectory is not crucial for recognition. However, self-recognition becomes impossible when velocity information is missing and is therefore not based on purely spatial characteristics of the trajectory. In contrast, temporal information is very important for the planning of actions. Therefore, the results are consistent with the view that self-recognition is enabled by structures that are also involved in action planning.

The analysis of recognition rates for characters that differ with respect to geometric properties provides further evidence for the interpretation that temporal information and especially major velocity changes are crucial for self-recognition. Trajectories reproducing characters that included corners or loops yielded higher recognition rates than trajectories of characters consisting of straight or curved lines. The former characters require the drawer to change velocity more dramatically during the production of a character. One could claim, however, that these characters entail richer spatial information and it was this information that was used to make the self–other distinction. This claim is not supported by the present finding that the removal of velocity information deteriorates self-recognition for all characters. Thus, it appears to be velocity information and not figural complexity that accounts for self-recognition.

The recognition of self-generated action is not wholly dependent on major changes in velocity, because the effect was also present in symbols drawn without dramatic velocity changes. An interesting possibility that could explain self-recognition in more continuous trajectories is that general laws relating the geometry of a character to the kinematics of an end-point trajectory are modulated by certain individual characteristics. There is extensive evidence that such a relationship can be described by a single parameter (Lacquaniti et al., 1983; Viviani, Baud-Bovy, & Redolfi, 1997; Viviani & Stucchi, 1989). Idiosyncratic deviations from the general principle may provide cues for the recognition of self-generated actions.

The ability to determine authorship from kinematic displays of self- and other-generated action effects shows that there are contributions of action-related structures to perception, as claimed by the common coding approach (Prinz, 1992, 1997). The central hypothesis of the common coding approach is that perception and action systems use commensurable codes. Hence, while one is perceiving the effects of an action, the same representations are activated that were involved in planning the action when it was carried out. When planning an action, these representations are activated by internal processes to specify which events should occur as the result of the action in the perceptual input. When observing an action, the common representations are activated by external events, whenever these events bear similarities with the effects of self-generated actions. Lately, the common coding approach has been further developed by Hommel, Müsseler, Aschersleben, and Prinz (in press) to provide a general framework for event coding. Ballard, Hayhoe, Pook, and Rao (1997) have provided a computational account of a common representational level for perception and action in terms of deictic codes. SOJs provide one way to access such a common level.

References


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