

Kinematic cues for the categorization of pointing movements made by hemiparetic stroke patients.

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Abstract

Our visual sensitivity to human movements is illustrated by our ability to recognize actions even with a minimal visual display. The present study investigates if professional expertise influences the precision of recognition and the visual cues used. We presented movements made by hemiparetic stroke patients and healthy subjects to expert (physicians and physiotherapists) and naive observers. Since stroke induces perturbations of hand trajectory and inter-joint coordination, we presented two types of computer animation (one dot representing the hand and stick diagram of the upper body). The observers had to score the pathological character of the movements.

The observers were able to differentiate patients according to their impairment level. The experts responded faster but, surprisingly, their responses did not differ from those of naive observers. The subjective judgment relied mainly on the quality of hand trajectory. The weak influence of postural information should be confirmed with more realistic displays.

1. Introduction

When observing other people we are able to understand and interpret their actions due to a particular sensitivity to human movement [1]. This corresponds to the hypothesis of a common coding mechanism for action and action recognition. One influential interpretation lies in the observation in monkeys of mirror neurons which fire when the monkey performs an action and when it watches the experimenter performing the same action [2].

The subjective rating of movement by observers has received much attention. There is evidence that observers may perceive dynamic information relating to actions from the observation of kinematics. For

example, the weight of lifted objects can be recognized from simple point light displays [3]. Observers can also recognize general information about the person from the observation of their movements: e.g. gender [4] or context related expectations [5]. Along this line, our aim is to investigate the ability of observers to categorize the “pathological” level of movements thanks to minimal kinematic displays. Since the degree of familiarity with the motor repertoire observed is important [6] we compared expert (clinicians used to movement recordings) and naive observers. We focus on the movements made by hemiparetic patients which are both well characterized and variable from a patient to another. Following stroke, motor disability is due to several impairments (muscle weakness and spasticity, loss of inter-joint co-ordination and incorrect timing which contribute to alterations in the trajectories of goal-directed movements. In addition, the patients may use compensation such as trunk flexion [7,8]. The scores of clinical scales thus reflect both the consequences of impairments and the development of compensatory strategies.

2. Methods

2.1 Participants

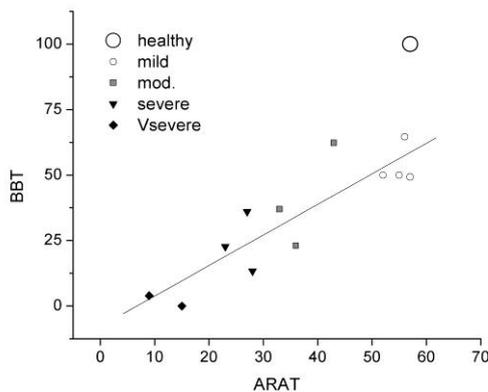
20 “observer” participants (10 experts and 10 naive) took part in this experiment which lasted approximately 40 minutes. The expert observers were clinicians (MD or physiotherapists) experimented in 3D movement recording (age 25-72 mean 38.6, two females); the naive observers were neither familiar with stroke patients nor with human movement recordings (age 28 to 40, mean 28.3, four females). All the participants had normal or corrected-to-normal vision. All the experiments were performed in accordance with the ethical standards laid down in the 1991 Declaration of Helsinki.

2.2 Movement recording and display.

The “actors” for the movement recordings were 3 healthy subjects and 12 patients with hemiparesis following a stroke (8 with right and 6 with left hemisphere damage, age 28- 79 mean 56.25, two females). All healthy subjects (age 42-56, mean 49, two females) were right handed. Scores of routine clinical tests were used to quantify the level of impairment and functional ability: Action Research Arm Test (ARAT) and Box and Block test [9].

For the recordings, the participants were seated on a chair in front of a table, approximately level with the navel. The task consisted of making three reciprocal movements to a target placed on a removable support 17 cm above the table at 90% of arm length. The starting position was with the hand on the abdomen. Healthy subjects performed with their right hands, the patients with their hemiparetic arms.

Figure 1 Range of impairment in the 12 patients. Diagram giving ARAT and BBT scores.



Recordings were made using an electromagnetic Polhemus system (acquisition frequency = 30 Hz) with 4 sensors attached on the manubrium, the acromion process, the upper third of the arm and on the dorsum wrist. The digitization of the trunk and upperlimb landmarks for reconstruction and the computation of joint rotations (trunk flexion/extension, upper arm elevation and elbow flexion extension) were performed according to [10].

The set of movements prepared for presentation included 3 different instances of repetitive pointing movements for each “actor” (i.e. 45 movements). Two kinds of graphical animations were prepared: the movement of a unique dot representing the hand (working point display WP), and a stick diagram of the trunk and upper limb (SD). The side view was presented in both cases.

2.3 Observation and judgement.

The WP and SD visualization were carried out in two sessions in a counterbalanced order. The observers were asked to rank the estimated quality of movement on a visual-analog scale from 0 (highly pathological) to 100 (healthy). They gave their response using the computer mouse in a forced choice paradigm. No feedback was given. Before the start of the experiment, the participants were shown a practice sample of 15 movements in each condition. The response was recorded, as well as the time taken to respond. The whole experiment lasted about 40 minutes.

2.4 Kinematic analysis

The following 11 kinematic variables were measured for each of the 3 repetitive pointing movements toward the target (peak velocity, mean acceleration, number of velocity peaks, curvature index, duration, delay between go and return, hand movement distance, amount of scapula displacement, trunk flexion, arm elevation and elbow extension). A principal component analysis (PCA), with normalized varimax rotation, was performed on the 10 variables obtained for the 45 movements.

2.5 Analysis of the subjective responses

The responses correspond to the visual rating of the impairment level by the observers were first analyzed according to the clinical level of impairment. Repeated measures ANOVA were performed with observer group (expert/non-expert) and display type (WP/SD) as factors and ANCOVA with the scores of ARAT and BBT as cofactors. Simple and Multiple Stepwise Regression analyses were performed to calculate the percentage of the variation of the responses due to the kinematics with Factors given by the PCA as independent variables.

3. Results

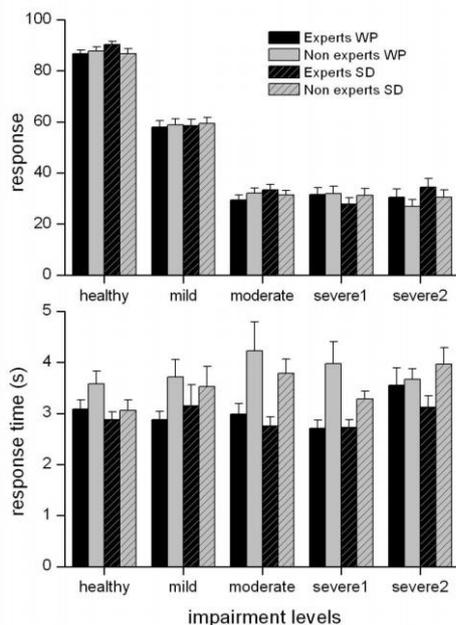
3.1 Kinematics of patient’s movements

The patients were selected in order to present a wide range of motor capacity (Figure 1). Their movements were slower than those of healthy subjects, with increased curvature and decreased smoothness. They used less elbow extension for reaching. The patients with a severe impairment were separated in two groups depending on the presence (severe 1) or absence (severe 2) of compensatory trunk flexion. The kinematic variables were very roughly scaled to the level of impairment with a great variability.

4. Subjective response on the impairment.

Repeated measures ANOVA demonstrated that the observers were able to scale the level of impairment (Figure 2 upper part, $F_{288,4} = 106.3$, $p < 0.0001$). Surprisingly, the responses made by the expert and non-expert observers were similar ($F_{288,4} = 0.12$, ns). The type of display did not influence the response ($F_{288,4} = 1.6$, ns) and there were no interactions. The observers were able to discriminate healthy subjects from patients (post hoc Tukey-Kramer) and patients with a mild impairment from the others. However, they did not discriminate patients with a moderate or severe impairment. ANOVA showed that the experts respond faster (~3s) than the non-experts (~3.5 to 4s) (Figure 2 lower part, $F_{288,4} = 17.2$, $p < 0.0001$). There were no significant difference with the level of impairment ($F_{288,1} = 0.8$, ns) or the type of display ($F_{288,1} = 2.3$, ns) nor interactions between factors.

Figure 2 Response and response time as a function of the impairment level.



The ability of observers to discriminate the level of impairment was confirmed by a regression analysis of the response as a function of ARAT and BBT after exclusion of healthy subjects ($p < 0.0001$ in all cases). ARAT score explained 24% and 20 % of the variance of the experts' responses and 30 and 27% of the non-experts' responses (WP and SD display respectively). BBT score, explained 19.7 % and 15.3 % of the experts' responses and 26.9 and 23.2% of the non-experts' responses (WP and SD display respectively).

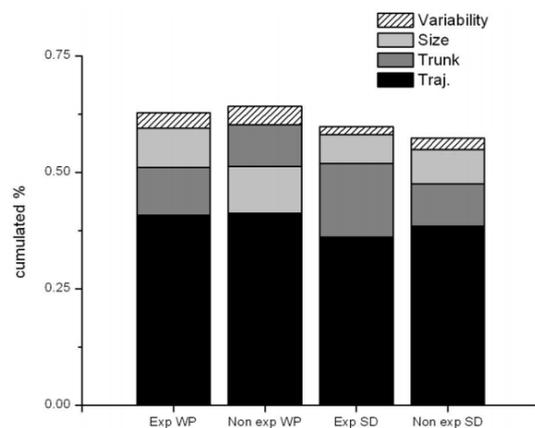
4.1 Subjective response and kinematics.

PCA was performed to summarize the kinematic variables. It yielded 3 factors which explained a total of 84.2% of the variance (Table 1). The first factor was correlated to the variables related to the quality of the hand trajectory. The second factor was likely related to subject size and the third to the presence of compensatory trunk flexion. Velocity and acceleration were moderately correlated to all three factors.

Table 1 PCA of the kinematic variables

	Factor 1	Factor 2	Factor 3
eigenvalue	6.48	1.76	1.02
% variance explained	58.94	15.96	9.29
Cumulated variance	58.94	74.90	84.20
	Quality of trajectory	Subject's size	Trunk compensation
Peak vel	-0.666	0.448	0.378
mean acc	-0.625	0.433	0.429
number peaks	0.950	-0.062	-0.140
curv. index	0.939	-0.100	-0.125
duration	0.883	-0.181	-0.359
delay	0.816	-0.188	-0.111
mov. distance	-0.350	0.872	0.078
scap. displacement	0.197	-0.256	-0.895
trunk flexion	0.250	-0.188	-0.885
arm elevation	0.136	0.818	0.282
elbow extension	-0.432	0.731	0.249

Figure 3 Multiple regression analysis of the response as a function of kinematic variables.



Multiple stepwise analysis was performed on the responses with as independent variables: the three PCA factors as independent variables, more a measure of movement variability (Figure 3). PC1, representing the quality of the trajectory, explained the most variance in all the conditions. Simple regression analyses were performed separately for each observer in order to obtain statistical differences. PC1 explained 39-45% of the response whatever the type of display ($F_{18,1} = 0.9$,

ns) or the group ($F_{18,1} = 0.3$, ns). The variability of movements across repetition explained 27-30% of the responses according to the condition, with no significant differences with the type of display ($F_{18,1} = 0.5$, ns) or between groups ($F_{18,1} = 0.2$, ns). The factor representing size explained ~9% of the response in PT condition, and ~7% in SD condition, but the difference was not significant ($F_{18,1} = 3.2$, ns). The factor representing trunk flexion represented ~9% of the response with a notable exception in the case of expert observing movements with SD display (17 ± 9 % of the response). The effect of the display was significant ($F_{18,1} = 5.35$, $p=0.03$), but not the group effect ($F_{18,1} = 3.52$, ns) or the interaction ($F_{18,1} = 3.50$, ns).

5. Discussion

In brief, this study demonstrates i) that observers are able to recognize impaired movements from observation and ii) that the most pertinent cues are linked to the quality of hand trajectory. The other dimensions of the movements (size, posture and regularity) play a much smaller role.

The observers, whatever expert or not, easily discriminated the healthy subjects from the patients, with a mild impairment. This fact may contribute to the discrimination and social handicap of patients with a good functional level. In contrast, observers were unable to differentiate between patients with moderate or severe impairment. This may be due to the fact that clinical scores involve grasping while we presented pointing movements.

In contrast to what we anticipated, the compensatory trunk movements were little used for categorization (e.g; the severe 1 and severe 2 groups of patients were scaled similarly). However, the SD display was quite crude. The study should be performed with more realistic presentations (avatars) before concluding.

The experts were faster to respond, perhaps because they felt more confident but, surprisingly their responses generally did not differ from those of non experts. The only tendency suggested that the experts were more sensitive than non-experts to the postural cues presented (i.e. cues related to compensatory trunk flexion visible on SD display).

The fact that the experts were not “better” for recognition is surprising. A study in dancers showed that personal habits of the motor repertoire were particularly important for brain activation during action observation [6]. A similar study is in progress with hemiparetic patients as observers to test this point.

6. Acknowledgements

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