

Changes in the amplitude and direction of goal-directed hand movements in the lack of visual information

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Received: November 22, 2005

Accepted: February 21, 2006

The goal of the present investigation was to determine the precision of goal-directed hand movements in the lack of visual information. The movement amplitude and direction was examined under different experimental conditions. Subjects were ten female and ten male university students. The motor test was drawing 10 cm long straight line and 24 cm long zigzag line in four different experimental conditions. 1) The drawing with open eyes was followed immediately with drawing with closed eyes. 2) The drawing was executed from memory in the lack of visual information. 3) Drawing with restricted amplitude or direction. 4) Drawing with verbal feedback. The errors of the target distance and the lateral deviations from the target were different under the different experimental conditions. The largest errors and underestimation of the target distance occurred in drawing horizontal straight line with closed eyes. No statistically significant gender differences were found. It is concluded that the practice, adjustment of single movement parameter to the target, and the verbal feedback assist better the accuracy of unseen goal-directed hand movement than the recent visual memory.

Keywords: drawing with closed eyes, motor memory, underestimation of target distance, verbal feedback

In daily life, we come across many tasks that require reaching to, manipulating, and displacing objects. The control of these seemingly simple skills is rather complex. Therefore, this issue has received considerable attention in the relevant literature. The accuracy of hand movements is influenced by many factors. A goal-directed hand movement is most accurate when one's hand is visible throughout the movement towards a visible target, and become less accurate when either the hand or the target or both are not visible during movement execution (5, 7, 16). In the lack of visual information the vestibular and, primarily, the kinaesthetic cues are used to control the movements of the

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hand (2, 11). Developmental studies have demonstrated that already younger children possess adequate kinaesthetic ability to control hand movements (1, 6, 9, 26). The precision of a goal-directed hand movement is affected by different factors at all phases (initiation, execution and stop) of that movement. Data were published to show the importance of visual background information for planning the goal-directed hand movements (12, 16). The articular conformity of the shoulder joint and position of the hand constitute additional determinants of hand movements (4, 21, 22). During the execution of the movement, the parameters like direction, amplitude, and movement time play important role in the accuracy of that goal-directed hand movement (3, 14, 19, 23, 27). A distance effect, namely, a decrease in aiming performance as a function of movement amplitude was described, and related to the storage of target location in memory (15). The analysis of the acceleration and deceleration phases of hand movement showed that movement variability increased during the deceleration phase (19).

Based on the above data, the present study addressed two questions: first, how is the kinaesthetic information assisted by short-term visual memory, by previous experience, and by verbal feedback? Second, how the kinaesthetic control of drawing is influenced by restriction of either the direction or the amplitude of the hand movement? Our intention was to compare the effect of different experimental conditions on the same motor task in the same subject to determine which of them assist well the precision of unseen hand movement.

Subjects and Methods

Subjects

Subjects were university students, 10 women and 10 men, aged 20 ± 0.9 years. All were right-handed with no known neuromuscular deficits. All participants gave informed consent prior the beginning of the experiment. The local ethics committee has approved this experiment.

Experimental set-up and procedure

The subject sat comfortably at a table. He/she was asked to draw lines on an A4 (21×29.7 cm) section paper with a pencil. The sheet was changed for each experimental condition. Four series of drawings were done. 1) The first task was to draw 10 cm long straight line, then 24 cm long zigzag line. The site of start and stop were marked (Fig. 1). The first drawing was done with open eyes, thereafter three drawings with closed eyes. The subject was required to draw lines in horizontal direction. Afterwards the drawing was repeated in vertical direction, again the first trial with open eyes and three trials with closed eyes. Participants moved their hand from the left to the right in drawing horizontal lines, and from top-down to draw vertical lines. The starting point was marked with a bottom of 2 mm in diameter, and the subject placed on it the fingertip of the index finger of his/her left hand. The distance between the target and the

endpoints was measured and given in mm. The lateral deviation was measured with the perpendicular line to the straight line linking the start point with the target. The most accurate line was assessed, which showed the ability of the participant to execute precise movement in the lack of visual information. However, the turns of zigzag lines were not evaluated. 2) The subject was asked to draw three 10 cm long horizontal straight lines, then three 24 cm zigzag lines on a new section paper with closed eyes, based purely on memory from the previous experience. In this case, the experimenter put the subject's hand on the start point, and all trials were done with closed eyes. The smallest error was assessed. 3) Allowing variation of a single movement parameter with an appropriate plastic frame: (a) drawing with limited length and unlimited direction, and, (b) drawing with unlimited length and limited direction (Fig. 2). The plastic frame was placed over the section paper. The subject was asked to draw a straight line from one border of the frame to the opposite border. The distance between the two borders was 10 cm. Thus, the length of the line was fixed, but the direction might be divergent from the target. On the other frame (b), the direction was limited with a 2 mm wide directing gap, but the length of the line might be different. 4) The task was drawing 10 cm long straight lines, then 24 cm long zigzag lines in the same way as in the first condition, but the subject was informed verbally about the result after each trial. The words used for information were: right, short, long, upward and downward. The time interval between the four consecutive experimental conditions was 1 minute, but within each experimental condition, the drawings followed each other immediately.

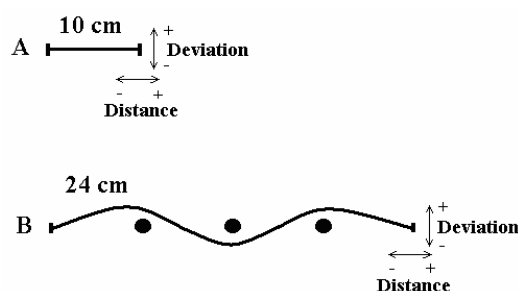


Fig. 1. Scheme of the measurement of straight (A) and zigzag (B) lines

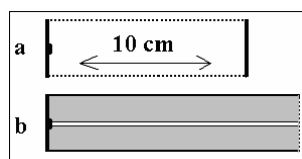


Fig. 2. Scheme of the plastic frame. (a): Limited length (10 cm) and unlimited direction, (b): limited direction and unlimited length

Data analysis

Descriptive statistics (mean $\pm$ SE), paired *t*-tests, as well as ANOVA were used for statistical analysis of the data. A *p* value of <0.05 was considered statistically significant.

Results

The accuracy of the goal-directed hand movements decreased in the lack of visual information. However, the errors both in amplitude and in direction of hand movements varied with the experimental conditions. ANOVA revealed significant differences of target distance among the experimental conditions (for women: $F_{(4,36)}=6.41383$, $p<0.0005$; for men: $F_{(4,36)}=2.84898$, $p<0.03$). The variability of the deviations from the target was significant only for the men: $F_{(4,36)}=2.63816$, $p<0.05$. In spite of that, drawing zigzag lines is a more complex hand movement than drawing straight lines. No statistically significant difference was found either in amplitude or in direction of the two form.

Effects of visual memory

The largest differences between the target and the endpoints occurred during drawing with closed eyes immediately after drawing with open eyes (Figs 3, 4). No significant gender differences were found. Commonly an underestimation of the target distance occurred during drawing horizontal straight lines. Although the vertical straight lines terminated before the target, but the errors were smaller than the errors of the horizontal lines. However, the difference between the horizontal and the vertical errors was statistically not significant. Similarly, the length of the zigzag lines was underestimated both for the horizontal and vertical drawings (Figs 3, 4).

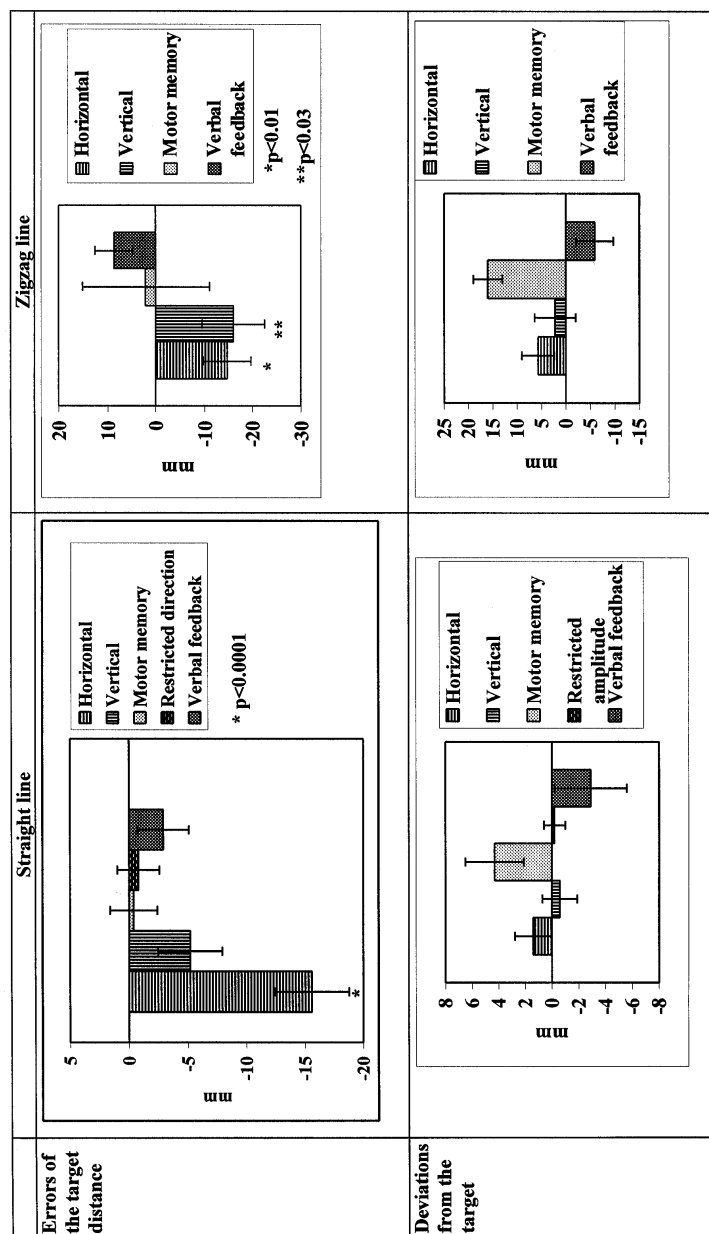
Deviations from the target occurred in both direction, and the errors were smaller than the errors in amplitude (Figs 3, 4).

Effects of earlier experience

Drawing based only on previous experience showed different results in men and women. Women produced the smallest errors in the target distance under this condition. On the contrary, both men and women made the highest errors in the direction of the lines (Figs 3, 4). Both underestimation and overestimation of the target distance occurred. The lines deviated mainly upward.

Effects of parameter restriction

During this type of drawing with closed eyes, the subject had to concentrate on a single parameter of the movement, i.e. either on the length or on the direction of movements.

Fig. 3. Changes (mean $\pm$ SE) in the amplitude and direction of female's drawing under different experimental conditions with closed eyes

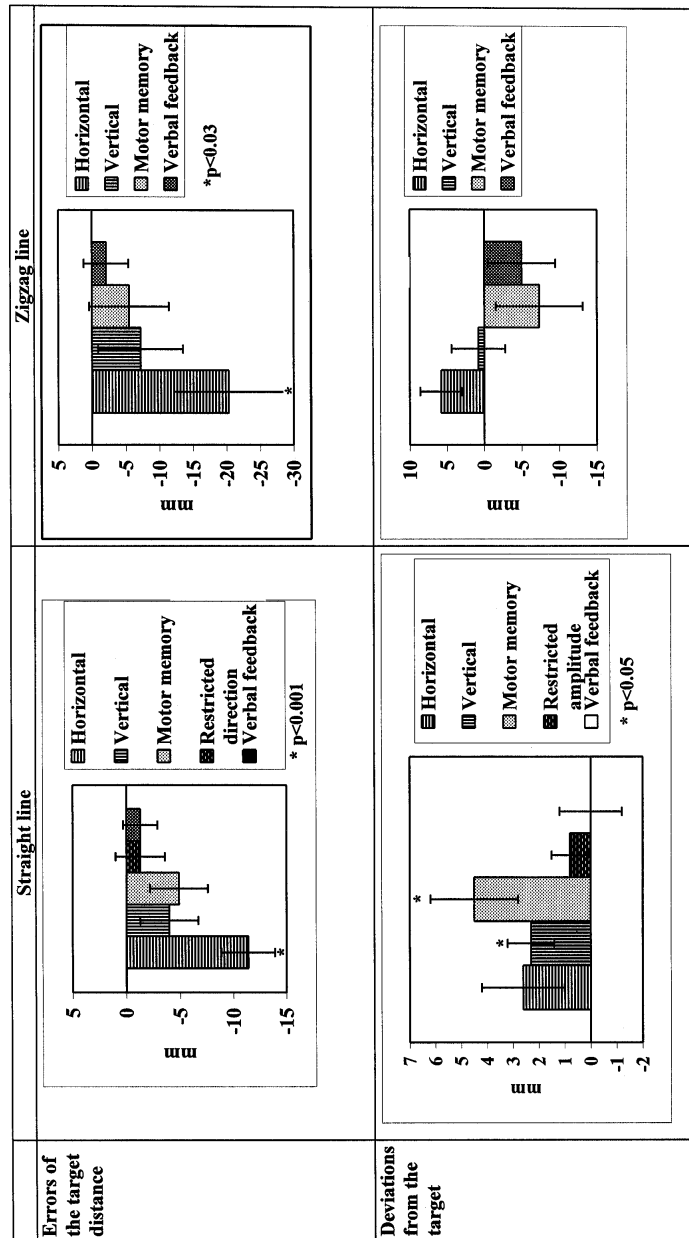


Fig. 4. Changes (mean $\pm$ SE) in the amplitude and direction of male's drawing under different experimental conditions with closed eyes

The errors were not significant in any cases, (Figs 3, 4). The target distance was underestimated or overestimated, and deviations from the target occurred both upward and downward, but dominance to upward might be observed. No significant gender differences were found.

Effects of verbal feedback

The drawing was done similarly to the first experimental condition, but the subject was informed about the result of each drawing. Statistically insignificant errors occurred both in the amplitude and in the direction of drawings (Figs 3, 4). Though women produced somewhat higher errors, the gender differences were not significant statistically.

Discussion

The present results show the changes of amplitude and direction of goal-directed hand movements under various experimental conditions. Considering the importance of visual guidance in control of goal-directed hand movements, we have expected that recent visual memory supports correctly the precision of drawing with closed eyes. By other words, it has been presumed that immediately after drawing with open eyes, the subject remembers to the target distance and direction during drawing with closed eyes. However, the significantly smaller errors under the other experimental conditions, examined in this experiments, have shown that visual memory is not the most effective support for the accuracy of unseen hand movements. This result is consistent with the suggestion that visual and proprioceptive feedback may be combined in fundamentally different ways during human reaching movements (24). It is interesting that in spite of drawing zigzag lines is more difficult than drawing straight lines; no statistically significant differences between the errors of straight lines and zigzag lines were found. However, it is important to emphasize that the turns of zigzags were not assessed; we measured only the error of target distance and the deviation of endpoints from the target.

An invariable result was the underestimation of the target distance during drawing with closed eyes. It occurred in all experimental conditions, but the most significant underestimation of the target distance appeared during drawing horizontal straight lines with closed eyes. The mechanism of underestimation of the target distance is not well known. It was suggested that the major source of errors is visual (8, 18, 20). The drawing with open eyes is guided by kinaesthetic feedback sensations and visual information. The visual signals stop the movement right at the target. In the lack of visual information, the movement is guided by the kinaesthetic feedback and the recent visual memory. The direct visual information is more effective than the recent visual memory, so the relative dominance of kinaesthetic, mainly proprioceptive feedback activity may stop the movement earlier, probably by activation of the antagonists. However, the errors of vertical drawing are smaller than the errors of horizontal drawing, in spite of the similar visual memory. The main difference between the horizontal and vertical drawing is the direction of hand movements. The horizontal

drawing is more familiar than the vertical one. Therefore, the horizontal drawing is habitual while the vertical drawing requires higher attention. This suggestion is consistent with the effect of earlier experience. At this instant, the subject is guided by his/her earlier practice, i.e. by the recall from motor memory, and the recent visual memory exerts no major disturbing effect. Thus both small underestimation and overestimation of the target distance occur.

The control of amplitude and direction component of hand movement might be separated (17, 25). In the present experiments, the separation of the two parameters reduced the errors. The drawing with closed eyes is more precise if only a single parameter (either the amplitude or the direction) must adjust to the target.

The average errors of amplitude or of lateral direction of drawing were not significant statistically when the subjects were informed verbally about their results. Similar effect of appropriate verbal feedback was found, and the brain areas playing an important role in motor learning were shown by positron emission tomography (13).

During the experimental session, the errors of target distance decreased from the first experimental condition to the last. Within each experimental condition, the drawings followed each other immediately, but the consecutive experimental conditions were separated by 1-minute intervals. This procedure suggests that motor learning (practice) produces the decrease in errors. It is true that the same target distance was used in all trials, but the experimental conditions were different. No sign of learning appeared within a given experimental condition during the consecutive three drawings. Furthermore, the variety of lateral deviations from the target in each experimental condition contradicts to an essential role of motor learning during the small number of trials in these experiments.

There are data in the literature showing that males' underestimations were significantly lower than females' (10). However, in the present study none of the statistical comparisons revealed no significant gender differences between the results of women and men. In spite of this, some comparisons are worthy to mention. It is interesting that the previous experience is more effective in women than in men. The errors of target distance of zigzag lines are more variable in women than in men, and the underestimation of the target distance is more pronounced in men than in women. Finally, the men produced larger deviations from the target than women did. These results do not prove significant difference of manual skills between women and men. Therefore, we believe that the ability of manual skills is more an individual than a gender attribute.

In summary, the present results support the following conclusions:

- 1) The changes of amplitude and direction of goal-directed hand movements with closed eyes is different under the different experimental conditions. The changes of direction occur towards both directions, while the changes of amplitude appear as underestimation of target distance. The practice and the verbal feedback give better support to the goal-directed hand movements than the recent visual memory.

- 2) The target distance is underestimated in drawing horizontal lines immediately after closing the eyes. The previous experience and the verbal feedback reduce the underestimation of the target distance.
- 3) The drawing is more precise if a single parameter, either the amplitude or the direction, has to adjust to the target.
- 4) There is no significant difference between manual skills of women and men.

Acknowledgements

The grant from the Hungarian Society of Sport Sciences supported this investigation. The authors thank Mrs. D. Beatrix Varga for her technical assistance.

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