AIMING WITH THE HAND TOUCHING THE TARGET: THE ROLE OF PROPRIOCEPTIVE INFORMATION BETWEEN THE HANDS

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When two hands work on one target, we hypothesize that proprioception from one hand facilitates performance with the other. We tested this hypothesis by removing visual feedback during an aiming task. Kinematics of arm transport and aiming accuracy from the right hand, either holding a stylus or using the index finger, were compared between conditions in which the left hand touched or did not touch the target. Kinematics showed that aiming movements of the right hand exhibited a shorter movement time and deceleration phase when the left hand was touching the target, compared to when it was resting beside the body. Constant error results revealed less error when the left hand was touching the target than when it was not. Surprisingly, aiming with a stylus had a relatively smaller aiming error than aiming with the index finger, contrary to our expectation. We discussed the internal communication of proprioception and its role in guiding aiming movements.

Key words: aiming, bimanual, proprioception

MOUVEMENT DE VISÉE AVEC LA MAIN TOUCHANT LA CIBLE : LE RÔLE DES INFORMATIONS DE LA PROPRIOCEPTION ENTRE LES MAINS

Nous avons émis une hypothèse que la proprioception provenant d’une main facilitait le rendement de l’autre main lorsque les deux mains travaillaient sur une cible. Nous avons testé cette hypothèse en supprimant les rétroactions visuelles au cours d’une tâche de visée. La cinématique du bras mobile et l’exactitude de la visée de la main droite, soit en tenant un stylet ou en utilisant l’index, ont été comparées dans deux situations : la main gauche qui touchait la cible et la main gauche qui ne touchait pas la cible. La cinématique a démontré que les mouvements de visée de la main droite présentaient une durée de mouvement plus court et une phase de décélération lorsque la main gauche touchait la cible, contrairement à lorsque celle-ci était laissée sur le côté du corps. Les résultats continus d’erreurs ont révélé moins d’erreurs lorsque la main gauche touchait la cible que lorsqu’elle ne lui touchait pas. Curieusement, et contrairement à nos attentes, le mouvement de visée avec un stylet présentait une plus faible erreur de visée comparativement à lorsque l’index était utilisé. Nous avons discuté de la communication interne de la proprioception et de son rôle pour guider les mouvements de visée.

Mots clés : visée, bimanuel, proprioception

INTRODUCTION

In prehension, humans essentially depend on visual feedback before contacting the object. Proprioceptive information plays a more important role after the hand contacts the object (1,8). The role of proprioception allows humans to sense the position and the speed of movement of their limbs. This type of feedback is believed to provide information about the body; however, it can also give information about the location of objects in the environment. In a bimanual task, the hand that holds the object provides additional proprioceptive information about that object while the other hand manipulates the object (2,5). To quantify the facilitation of proprioceptive information from the left hand, we conducted an experiment by asking the right-handed subjects to perform an aiming task with their right hand, without the benefit of vision. We expected that aiming performance would improve if subjects were allowed to touch the target by their left hand. Furthermore, we expected that aiming performance would get worse if proprioceptive feedback from both the left and the right hands were removed.

METHODS

Subjects

Eight healthy right-handed university students, from 23 to 39 years of age (mean: 29.5 standard deviation: 5.2) participated in the experiment. Subjects had normal or corrected-to-normal vision, and provided informed consent. Participants had no prior knowledge of the experiment.

Apparatus

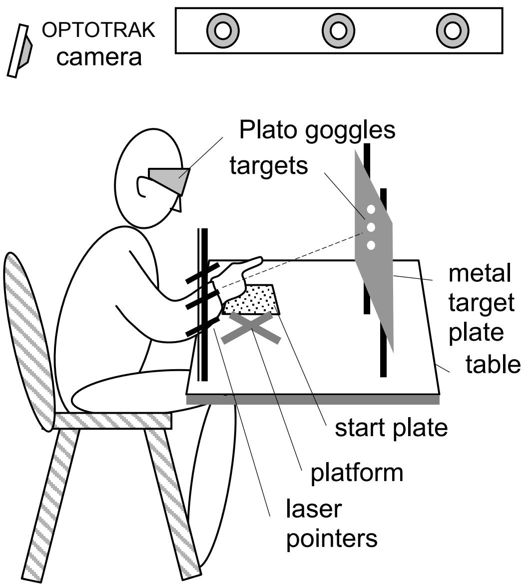

Figure 1: Illustration of experimental setup.

Subjects were required to perform the aiming task by reaching and touching targets on a vertical metal plate in front of them. To block out the vision feedback during aiming, subjects wore Plato goggles (Translucent Technologies, Toronto, Canada). These goggles were wired into the experimental setup so that when the subjects began their movement, the goggles' lenses became opaque, blocking visual feedback during the aiming task. The subjects rested the hand with the ulnar side of the palm on the start plate. The start plate was a metal circle (7.5 cm in diameter) placed on a platform (l = 15.2 cm, w = 15.2 cm, h = 9.5 cm) that attached onto a table (68.5 cm in height. Figure 1). An aluminum tape on the ulnar side of the palm completed a circuit when the hand was placed on the start plate. As soon as the hand broke contact with the start plate, the disconnection of the electrical circuit indicated the start of movement. This triggered the goggles to block visual feedback, keeping the level of illumination constant.

Each subject performed a total of 60 trials. In half of the trials, subjects pointed to targets using the right index finger and in the other half they used a latex stylus, which simulated a fake finger. In addition, each subject performed trials in which their left index finger was placed behind the target on the metal plate before they aimed for that target. The latex stylus was 10 cm long, 2 cm wide at the base, 0.7 cm wide at the rounded tip and stuffed with cotton (Figure 2). Subjects made a fist around the stylus base holding it between the index and the middle finger. The length of the stylus extended the same length as their index finger.

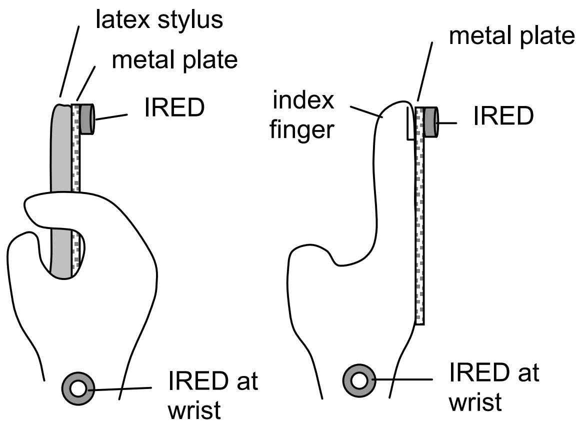

Figure 2: Schematics for aiming with the fake finger (left) and aiming with the index finger (right).

A small metal plate was attached to the stylus in the stylus conditions and to the index finger in the finger conditions. The tip of this metal plate elicited a change in voltage when it contacted the target area. Voltage data from the OPTOTRAK Data Acquisition Unit (ODAU, Northern Digital, Waterloo, Ontario, Canada) was used to calculate the end of the movement. Movement time (MT) was defined from when the hand broke contact from the start plate to when the tip of the stylus made contact with the target plate.

Target location was counterbalanced by the experimenter among three positions along the surface of a vertical metal target plate (l = 20cm, w = 0.1cm, h = 23cm). This metal plate was 14.5 cm above the table. Target location 1 was on the top (28.5 cm above the table), 2 was in the middle (24.5 cm above the table), and 3 was on the bottom (20.5 cm above the table). We used 3 laser pointers (Class IIIA Laser Product, Zhongshan, China) clamped to a ring stand to mark the location of each of the targets. There was a bump behind the metal plate for each of the targets so that when the left index finger was placed behind one target, haptic information from this finger provided additional information on the location of the target.

Data collection and analysis
Infrared emitting diodes (IREDs) measured the 3D position of all three targets as well as on the subjects' wrist and the tip of a small metal plate that was attached to their finger or to the stylus. The OPTOTRAK 3D motion analysis system (Northern Digital, Waterloo, Ontario) was used to obtain the position data of each target and the tip of the finger or stylus at the end of each trial. The three-dimensional position of the IREDs over time was sampled at a frequency of 200 Hz (every 5 milliseconds) by each of the six cameras. The position data from the wrist was used to calculate the peak velocity (PV), time to peak velocity (TPV), time after peak velocity (TAPV), and percent time after peak velocity (%TAPV) during aiming. When the tip of stylus contacted the target plate, the position data from the tip of the stylus was compared to 3D target position. Position data consisted of x, y, z coordinates. The x-axis corresponded to the direction of movement. The y-axis was horizontal with positive on the right and negative on the left. The z-axis was vertical with positive on the top and negative on the bottom. These data were used to calculate constant errors (CE) and variable errors (VE) about the y-axis and z-axis.

Data were submitted to a 2 (pointer: stylus, finger) × 2 (target: hand behind plate, hand not behind plate) × 3 (target locations: 1, 2, 3) repeated measures analysis of variance. Dependent measure were MT, PV, TPV, TAPV, %TAPV, CEy, CEz, VEy, VEz. Results significant at $p < .05$ are reported.

RESULTS

Analysis of movement time revealed a main effect of target. When aiming to targets on the metal plate with the left index finger behind the target, movement time was shorter (618 ms) compared to aiming to the metal plate without the left index finger behind the target (702 ms), $p = 0.011$. Peak velocity decreased as the target location increased from 1 (837 mm/s) to 2 (798 mm/s) to 3 (785 mm/s), $p < 0.001$. The period of time to reach peak velocity decreased as the target location increased from 1 (224 ms) to 2 (209 ms) to 3 (206 ms), $p = 0.007$. Time after peak velocity was longer when aiming to the target without the left index finger behind it (490 ms) compared to aiming to the target with the left index finger touching it (404 ms), $p = 0.009$. Target contact with the left index finger had a shorter percent time after peak velocity (65%) than not touching target (70%), $p = 0.004$. Also, the percent time after peak velocity was least when aiming to target 1 (66%) and greater when aiming to target 2 (68%) and 3 (68%), $p = 0.002$.

Constant error and variable error in the horizontal y-axis yielded no significant results; however, in the vertical z-axis they both did. CEz was greater when aiming with the finger (12.3 mm) compared to aiming with the fake finger (1.4 mm) $p = 0.038$. Also, aiming to the target with the left finger touching the targets revealed less CEz (0.4 mm) than aiming to the metal target plate only (13.3 mm), $p = 0.038$. The analysis of CEz yielded an interaction between the pointer used and the target. Specifically, when the left hand touched the target, aiming by the right index finger (-2.4 mm) or using a stylus in the hand (3.2 mm) exhibited small error in the z axes. However, when the left hand did not touch the target, aiming by the index finger exhibited a larger CEz (21.4 mm), compared to using the stylus (5.2 mm).

Analysis of VEz revealed a main effect of target location. Aiming to target 1 had more variability (9 mm) than aiming to target 2 (8 mm) and 3 (8 mm), p = 0.037.

Table 1: Results of dependent variables

	Pointer		Target		Target Location		
	stylus	finger	touched	not touched	1 (high)	2 (middle)	3 (low)
MT (ms)	673	646	618*	702*	653	661	664
	54	39	41	54	46	46	48
PV (mm/s)	811	802	820	794	837*	798*	785*
	53	43	44	54	51	46	46
TPV (ms)	215	210	214	212	224*	209*	206*
	15	13	14	15	16	13	14
TAPV (ms)	458	436	404*	490*	429	453	459
	41	28	29	42	34	34	35
%TAPV	68	67	65*	70*	66*	68*	68*
	1	1	1	1	1	1	1
CEy (mm)	1	2	-2	5	2	1	2
	4	5	4	6	4	4	5
CEz (mm)	1*	12*	0*	13*	7	6	8
	7	4	3	8	5	5	6
VEy (mm)	6	7	7	7	8	6	6
	0	1	0	1	0	1	0
VEz (mm)	7	9	8	9	9*	8*	8*
	1	1	1	1	1	1	1

Note: MT, movement time; PV, peak velocity; TPV, time to peak velocity;
TAPV, time after peak velocity; %TAPV, percent time after peak velocity
CE, constant error; VE, Variable error; * p > 0.05

DISCUSSION

A successful aiming task requires collaboration from the motor system, the sensory systems and memory. In this study, visual feedback was removed at the onset of movement for all experimental conditions, and therefore, the effect of sensory memory about target location to guide aiming is constant across all conditions.

According to visuomotor hypothesis, the efficiency of aiming is determined by integrating the visual information with the concurrent motor output (3,4). When the hand is approaching to the vicinity of the target, visual information of target location is used to adjusted movement by means of closed loop control. The process is reflected by the duration of the deceleration phase. In this study, when the right hand was aiming to target with the left hand touching the target, the kinematic landmarks showed shorter movement duration and a smaller proportion of the deceleration phase than aiming without the left hand touching the target. Since subjects' visual feedback loop was blocked out by using the Plato goggles, the sensorimotor integration in the guiding of aiming movement in this study is by all means other than through visuomotor channels. Results suggested that the movement adjustments during the guided phase might be carried out by integrating proprioceptive information with motor output. When the left hand touched the target, spatial information such as the location of the target can be perceived by sensing the configuration of the left limb and the location of the fingertip. In this sense, the coordination between two hands in this type of bimanual task is mapping the tip of the right hand to the tip of the left hand.

In interpretation of coordination modes of the bimanual task, one view believes that the motions of two separate hands are synchronized and controlled by a common coordinative structure (6); whereas, the other view insists that the control mechanisms for two limbs are distinct (7). However, there is cross-talk between the two control mechanisms (7,9). Results from this study suggested that internal communication of proprioceptive information between hands might be one of the essential components for this type of cross-talk. The cross-talk of proprioceptive information between the two hands can be very efficient in guiding aiming movements when visual information is not available. This statement is supported by our result that constant error was dramatically increased (13.3 mm) when the left index finger was not touching the target, compared to when the left hand was touching the target (0.4 mm).

If integrating of proprioceptive information with motor commands is valid for guiding aiming movement between the two hands, we would expect that aiming with the index finger should have less aiming error than aiming by holding a stylus in the hand. In the latter scenario with a tool, the proprioceptive information from the tip of the stylus is not direct, compared to the tip of the index finger. Our results contradicted this idea ─ a large constant error was found when aiming with the natural finger (12.3 mm) than when aiming with the fake finger (1.4 mm). A possible reason for this contradiction is rooted in the design of the pointer. In order to quantify the moment when the finger or the stylus contacted the target, a piece of metal plate was attached to the nail side of the index finger (Figure 2). The IRED that was designed to indicate the location of the fingertips was attached to the side to this metal plate. When aiming with the index finger, subjects could have touched the target with the pad of the finger whereas when aiming with the stylus, they could have touched the target with the tip of the stylus. We estimated that the difference between touching with the pad of the finger and touching with the metal tip would account for a discrepancy of approximately 10 to 15 mm between the two conditions. If this discrepancy due to the use of the metal plate was partialed out, we would expect that aiming with the index finger would show less constant error than aiming with the fake finger. A better experimental method for monitoring the pad of the index finger would reveal less constant error.

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