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Effects of Hand Posture, Breathing Type, Arm Posture and Body Posture on Hand Errors

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This study consisted of 2 experiments. Experiment 1 examined the effects of hand posture, arm posture and body posture on hand error, while experiment 2 examined the effects of hand posture, breathing type and body posture on hand error. This study showed that more hand errors occurred in the nondominant hand, extended arm, normal breathing and standing compared with errors in the dominant hand, flexed arm, inspire–hold and sitting, respectively. This study advised people to use their dominant hand, flex their arm, inspire and hold the breath and support their body while performing fine manipulation tasks. Finally, hand error varied dramatically across the participants, indicating the need to screen individuals for fine manual manipulation tasks.

aiming   fine manipulation   hand tremor   pointing

1. INTRODUCTION

Human physiological tremor is an involuntary and approximately rhythmical oscillation within any limb segment [1]. The occurrence of human physiological tremor can be considered a ubiquitous property of the neuromuscular system arising from a highly complex interaction between the neural and the mechanical (limb) event [2, 3]. Additionally, human physiological tremor is also considered a kind of randomness or biological noise within the human motor system [4].

Neurophysiological studies have extensively examined the characteristics of physiological tremor in the hands and fingers of humans. For example, Morrison and Newell showed that the more proximal limb segments resulted in decreased finger tremor but these changes were not simply additive over the segments within a limb [5]. Raethjen, Pawlas, Lindemann, et al. investigated the influence of mechanical factors and subjects' attributes on hand tremor [6]. They revealed that the hand-tremor frequency significantly decreased with added inertia, negatively correlated with hand volume and was uncorrelated with grip force. Morrison and Keogh recorded the tremor profile of the hand and index finger during goal-pointing tasks [1]. Their results showed two prominent frequency peaks located between 2–4 and 8–12 Hz where the amplitude of the 8–12 Hz peak significantly increased with the accuracy requirement of the tasks.

Hand error is found to be a direct consequence of physiological hand tremor in fine manual manipulation tasks, such as welding, drawing and aiming. Undoubtedly, hand errors impair work quality and efficiency. Although physiological hand tremor cannot be eliminated, it can be reduced through some interventions. For example, physiological hand tremor can be reduced through visual reference, support of the body and the body member involved in static reaction, hand position and friction [7]. The direction of movement also affects hand tremor. Mead and Sampson investigated

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hand tremor in tasks where the participant needed to hold a stylus in specific arm movement tasks [8]. They demonstrated that most hand tremor occurred in the up–down plane, while the right–left and in–out errors were less frequent. In addition to the factors mentioned here, arm posture and breathing are also important to hand error in fine manual manipulation tasks. For example, the neuromuscular demand for extended arm posture is greater than for flexed arm posture, and normal breathing is associated with a rhythmical diaphragm movement that also hinders fine manual manipulation such as hand aiming.

The purpose of this study was to expand our knowledge of hand error. This study consisted of two relevant experiments. The first one aimed at examining the effects of hand posture, arm posture and body posture on hand error in fine manual manipulation tasks. The second experiment aimed at examining the effects of hand posture, breathing type and body posture on hand error in fine manual manipulation tasks.

2. METHOD

2.1. Experiment 1

2.1.1. Participants

Fourteen young males participated in this experiment. Their mean (*SD*) age was 23.2 (2.3) years (range: 20–29), mean (*SD*) height was 174.0 (7.4) cm (range: 162–186) and mean (*SD*) weight was 69.2 (11.2) kg (range: 53–90). None of the participants had any neurological or sensory disorders.

2.1.2. Experimental apparatus

The experimental apparatus included a pencil-like stylus (diameter of the stylus tip was 0.2 cm) and a stabilimeter (Takei Scientific Instruments, Japan). The stabilimeter provided a small circular hole (with a central 0.5-cm diameter hole) on its panel to test hand errors.

2.1.3. Experimental design and procedure

A three-factor factorial design was used to analyze the participants' hand errors for eight experimental conditions (2 hand postures × 2 arm postures × 2 body postures). The two levels of hand were the dominant hand and the nondominant hand. The two levels of arm posture were the fully extended (outstretched) arm and the fully flexed arm. The two levels of body posture were sitting and standing.

The participants were to abstain from any stimulant intake and excessive exercise on the days of formal experiments. For each trial, the participant was positioned in front of the stabilimeter placed on a height-adjustable table. The height of the stabilimeter was adjusted to reach approximately the participant's shoulder height. The horizontal distance between the stabilimeter and the participant was set at the participant's flexed arm length (flexed arm posture) or extended arm length (outstretched arm posture). The participant grasped the stylus, like a pen, maintaining a distance of ~3 cm between the stylus tip and his index finger. The participant then inserted the stylus tip into the small circular hole on the stabilimeter panel and held the stylus tip in the hole as steady as possible for 30 s. Any touch of the stylus on the rim of the hole was detected and counted by a digital counter. The total number of touches in the 30-s period was referred to as hand errors. Each participant performed the eight experimental conditions in random order, and the eight experimental conditions were repeated 10 times in about two weeks. For consistency, the participant was asked to breathe normally and keep his nontested hand hanging during the 30-s period. The participant was not given a backrest in the sitting posture. Each participant was allowed to practice all the eight experimential conditions several days prior to the formal experiments.

2.2. Experiment 2

2.2.1. Participants

Thirteen of the 14 participants of experiment 1 participated in experiment 2. The 13 participants had a mean (*SD*) age of 23.3 (2.4) years, the mean (*SD*) body height was 173.2 (7.0) cm and the mean (*SD*) body weight was 67.7 (10.2) kg.

2.2.2. Experimental apparatus

The apparatus in experiment 2 was identical to that in experiment 1.

2.2.3. Experimental design and procedure

A three-factor factorial design was used to analyze the participants' hand errors for eight experimental conditions (2 hand postures × 2 breathing types × 2 body postures). The two levels of hand posture were the dominant hand and the nondominant hand. The two levels of breathing type were normal breathing and closed glottis breathing after a maximum inspiration (inspire–hold). Classifying the two types helped to examine the effect of the movement of the diaphragm and respiration on hand error. The two levels of body posture were sitting and standing.

The experimental procedure for experiment 2 was similar to experiment 1, except that the participants performed the trials with a horizontally outstretched arm posture. Each participant repeated the eight experimental conditions, 6 times in about two weeks.

3. RESULTS

3.1. Experiment 1

Table 1 lists the means and standard deviations of hand errors of the 10 repetitions of each participant for all eight experimental conditions. Table 1 shows that the number of hand errors varied dramatically across the participants. For instance, participant I committed 49.0 hand errors, while participant F committed only 14.3 hand errors for the experimental condition of dominant hand, extended arm and sitting posture. Table 1 also summarizes the grand means and standard deviations of the 14 participants. These data revealed that there were more hand errors for the nondominant hand, extended arm and standing than for the dominant hand, flexed arm and sitting. For the eight experimental conditions, most hand errors occurred in the combination of nondominant hand, extended arm and standing condition, while the fewest in the combination of dominant hand, flexed arm and sitting. The greatest number of hand errors was ~15-fold of the least number of hand errors across the eight conditions.

TABLE 1. The Means (*SD*) of Hand Errors of the 10 Repetitions of Each Participant and of All 14 Participants for the 8 Experimental Conditions in Experiment 1

	Dominant Hand				Nondominant Hand			
	Extended Arm		Flexed Arm		Extended Arm		Flexed Arm	
Participant	Sitting	Standing	Sitting	Standing	Sitting	Standing	Sitting	Standing
A	45.5 (4.0)	54.8 (5.0)	13.0 (4.9)	15.7 (5.8)	47.2 (6.6)	57.1 (7.6)	15.4 (5.8)	18.7 (5.9)
B	30.1 (11.1)	41.4 (9.6)	10.5 (2.5)	11.4 (2.5)	37.8 (10.4)	50.3 (13.1)	11.5 (2.8)	13.7 (2.9)
C	35.5 (9.5)	48.0 (6.7)	0.5 (0.5)	2.2 (1.2)	51.4 (8.0)	60.7 (6.3)	3.2 (1.9)	5.5 (2.7)
D	43.1 (8.6)	48.3 (9.4)	1.8 (1.4)	4.1 (1.1)	51.3 (11.3)	54.2 (7.8)	2.3 (1.2)	3.6 (1.7)
E	58.4 (6.9)	70.6 (6.1)	2.4 (1.8)	4.3 (2.4)	63.1 (7.2)	75.5 (10.7)	5.5 (2.0)	11.0 (4.0)
F	14.3 (3.1)	19.4 (3.8)	0.4 (0.6)	0.5 (0.5)	12.1 (5.8)	20.5 (5.1)	0.6 (0.8)	0.9 (1.5)
G	26.2 (4.9)	36.4 (5.2)	0.6 (0.6)	1.2 (1.7)	29.5 (9.2)	45.1 (6.5)	0.8 (0.6)	2.4 (1.8)
H	31.7 (7.9)	39.4 (5.5)	2.0 (1.9)	2.1 (1.5)	33.4 (8.8)	42.3 (11.4)	3.2 (1.3)	6.1 (2.3)
I	49.0 (5.1)	57.3 (4.8)	1.5 (1.2)	4.1 (1.1)	57.3 (4.2)	67.7 (5.9)	4.1 (1.7)	6.9 (1.4)
J	20.7 (4.4)	27.7 (6.6)	1.0 (0.9)	1.3 (1.1)	25.7 (4.3)	35.2 (7.0)	0.8 (0.9)	1.6 (1.6)
K	37.5 (6.2)	45.3 (5.2)	2.8 (1.6)	4.1 (1.1)	41.8 (10.1)	48.4 (7.8)	4.7 (1.8)	5.3 (2.0)
L	47.1 (7.2)	56.1 (8.3)	7.8 (1.8)	10.2 (4.1)	63.1 (7.1)	74.4 (6.8)	11.7 (3.2)	17.3 (4.2)
M	44.4 (9.8)	60.0 (7.9)	6.1 (2.3)	8.6 (2.5)	53.3 (6.4)	70.8 (6.7)	13.6 (2.9)	20.3 (4.3)
N	30.0 (5.9)	39.8 (10.3)	1.9 (0.8)	2.5 (1.2)	38.9 (9.3)	44.7 (8.5)	3.0 (1.2)	4.4 (2.0)
all	36.6 (12.0)	46.0 (13.4)	3.7 (4.0)	5.1 (4.5)	43.2 (14.8)	53.3 (15.7)	5.7 (5.0)	8.4 (6.5)

TABLE 2. The Results of Analysis of Variance of Hand Errors in Experiment 1

Variable Source	*df*	*F*	*P > F*
Participant	13	12.33	<.001
Hand posture	1	13.81	<.001
Arm posture	1	918.26	<.001
Body posture	1	20.70	<.001
Hand posture × arm posture	1	2.82	.096
Hand posture × body posture	1	0.15	.698
Arm posture × body posture	1	8.91	.004
Hand posture × arm posture × body posture	1	0.01	.911
Error	91		

Analysis of variance (ANOVA) was used to analyze the means of hand errors of the 10 repetitions of each participant. Table 2 lists the results. It shows that the effects of hand posture, arm posture, body posture, and the interaction of arm posture and body posture on hand error were significant ($p < .001$). The significant interaction of arm posture and body posture indicated that when hand error comparisons were made between extended arm posture and flexed arm posture, different results emerged when body posture was considered. For example, Table 1 revealed that the difference in hand error between extended arm posture and flexed arm posture was greater for standing than for sitting.

3.2. Experiment 2

The means of hand errors in the six repetitions of each participant were analyzed statistically. Figure 1 shows that hand errors were much fewer in the nondominant hand, normal breathing and standing posture than in the dominant hand,

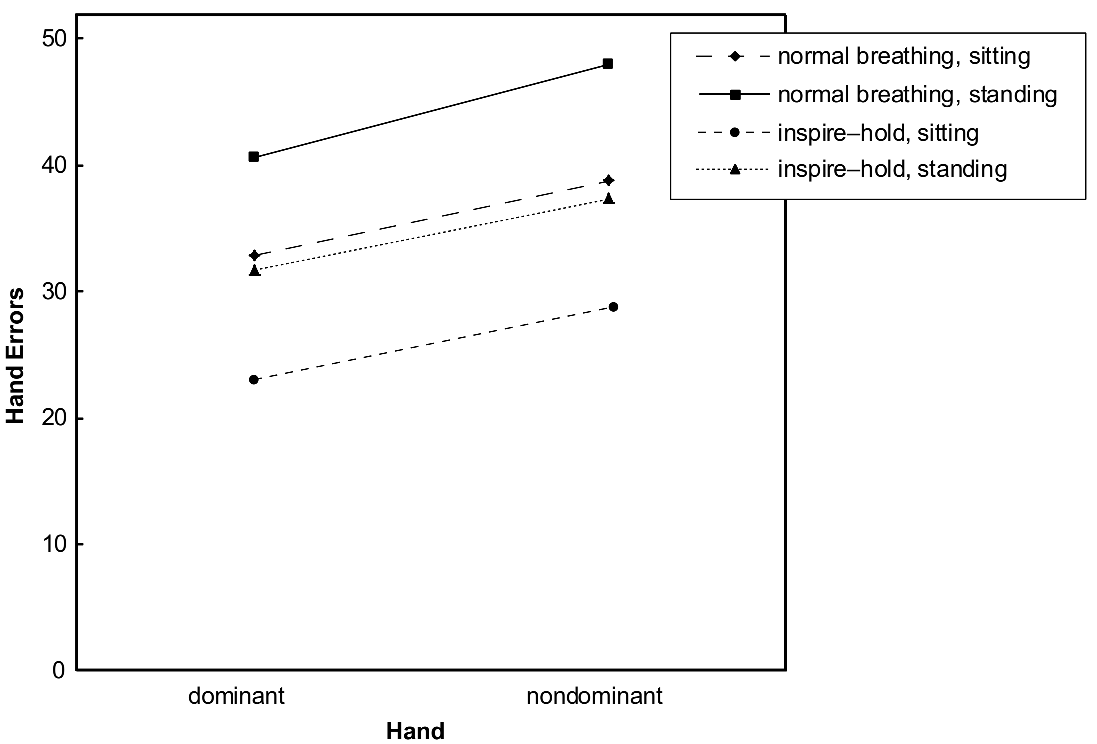

Figure 1. Means of participants' hand errors for the 8 experimental conditions in experiment 2 (*n* = 13). *Notes*. Hand errors = the number of touches.

TABLE 3. The Results of Analysis of Variance of Hand Errors in Experiment 2

Variable Source	df	F	*P* > *F*
Participant	12	100.46	<.001
Hand posture	1	99.27	<.001
Breathing type	1	252.58	<.001
Body posture	1	191.42	<.001
Hand posture × breathing type	1	0.58	.448
Hand posture × body posture	1	0.31	.577
Breathing type × body posture	1	0.01	.931
Hand posture × breathing type × body posture	1	0.29	.594
Error	84		

inspire–hold and sitting posture. Table 3 lists the results of ANOVA. It shows that only the effects of hand posture, breathing type and body posture on hand error were significant ($p < .001$).

4. DISCUSSION

This study showed that there were more hand errors of the nondominant hand than of the dominant one. This result was consistent with those reported in studies where the physiological hand tremor of the nondominant hand was greater than that of the dominant one [1, 9]. This study found a great difference in hand error between the nondominant and dominant hands. In experiment 1, the number of hand errors of the dominant hand was 85.5% of that of the nondominant one for extended arm posture, and 62.9% of that of the nondominant hand for flexed arm posture. The number of hand errors was 82.4% of that of the nondominant hand for sitting, and 82.8% of that of the nondominant hand for standing. Experiment 2 revealed the same phenomenon. The dominant hand control resulted in 6 errors fewer (~16% less) than the nondominant hand, regardless of the breathing type or body posture. Due to nearly the same mechanical and anatomical properties (such as limb volume, inertia or mechanical resonance) in the dominant and nondominant limbs, the significant differences in hand error between dominant and nondominant hand control could be attributed to the different neural contributions of the two hands.

Experiment 1 showed that hand error also highly depended on arm posture. For example, there were more hand errors for extended arm posture than for flexed arm posture. This could be attributed to the fact that extended arm posture was associated with a greater neuromuscular demand on the upper extremities due to the longer distance from the proximal limb to the distal limb (hand). There were ~10–16% fewer hand errors for flexed than for extended arm posture. The result implies that practitioners should be advised to flex their arms to improve their hand performance in fine manual manipulation tasks.

Although Mead and Sampson found no empirical basis to support the general assumption that sitting was any better than standing in terms of hand error [8], this study demonstrated contrary results. In this study, more body support and fewer limb segments taking part in the oscillation were responsible for the fewer hand errors in sitting. Neurophysiologic studies demonstrated the significance of external support on human physiological tremor. Morrison and Newell found that the amplitude of finger tremor decreased significantly as more proximal segments were progressively supported in the upper limb [5]. The results of this study were in line with Morrison and Newell's findings. Experiment 1 showed that hand error decreased by ~20–30% as the participants' posture changed from standing to sitting. In experiment 2, sitting posture resulted in ~9 (~22%) errors fewer than standing posture. The possible reason for the discrepancy between Mead and Sampson's [8] study and this one might be attributed to the difference in the tasks.

For example, Mead and Sampson examined dynamic arm movements, while this study investigated static pointing tasks. The findings of this study suggest that there should be body support during fine manual manipulation tasks.

The effect of breathing type on hand error was also significant and meaningful in lowering the number of errors. The main differences between normal breathing and inspire–hold were diaphragm movement and respiration activity. Hand error could be significantly reduced in inspire–hold by eliminating alternate upward and downward movements of the diaphragm and respiration activity. Experiment 2 found that inspire–hold resulted in 10 errors fewer (~25% less) than normal breathing, regardless of hand or body posture. Hence, this study suggests that workers should take advantage of the inspire–hold technique to significantly reduce hand error in fine manual manipulation tasks.

Although the participants demonstrated similar trends of hand error under the experimental conditions, hand error varied dramatically across the participants. For example, experiment 1 showed that participant F performed best in all eight conditions. Incidentally, participant F was the shortest participant (162 cm). Shorter people have a shorter distance from foot support or buttock support to the stylus tip, especially for extended arm posture, which might prove beneficial for reducing body and hand tremor. However, the argument that shorter people might perform better requires further investigation. The number of hand errors from the worst-performance participant could be several times greater than that from the best-performance participant. This implies that screening individuals is very important for improving hand performance in fine manual manipulation tasks.

All the participants of experiment 2 participated in experiment 1, too. This provided an opportunity to evaluate the test–retest reliability of hand error of the same experimental conditions (2 hand postures × 2 body postures) in the two experiments. Pearson correlation r analysis was performed on the 52 paired hand errors (13 participants × 4 experimental conditions), it showed a high test–retest reliability (r = .925). This result verified the validity of this study.

This study advises people to use their dominant hand, flex their arm, inspire and hold their breath, and to support their body while performing fine manipulation tasks. The limitation of this study is that we only provided a general knowledge of the effects of hand posture, arm posture, breathing type and body posture on hand errors in fine manual manipulation tasks. However, some other factors, such as participants' physical characteristics, gender, load, alcohol, etc., should also be examined to better understand their significance in hand error in fine manual manipulation tasks.

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