Effects of input device and motion type on a cursor-positioning task

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EFFECTS OF INPUT DEVICE AND MOTION DIRECTION ON A CURSOR POSITIONING

TASK[1]

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Running head:

Motion effect on manipulating input device

Summary.—Many studies have investigated the performance of using nonkeyboard input devices under static situations, but few of them have considered the effects of motion direction on manipulating these input devices. This study with twelve men compared their performance of using four input devices (three trackballs: currently used, trackman wheel and erectly held trackballs as well as one touch screen) under five motion directions of static, heave, roll, pitch and random movements. The input device and motion direction significantly affected the movement speed and accuracy, and their interaction significantly affected the movement speed. The touch screen was the fastest but the least accurate input device. The erectly held trackball was the slowest, whereas the error rate of the currently used trackball was the lowest. The impairments of the random motion on movement time and error rate were larger than those of other motion directions**.** Taking the objective and subjective evaluations into account, the trackman wheel and currently used trackball were more efficient for operation than the erectly held trackball and touch screen under the motion environments.

INTRODUCTION

Background

Graphical user interface has been widely used in computer interaction since 1984 (MacKenzie, Kauppinen, & Silfverberg, 2001). Nonkeyboard input devices such as mice, touch screens, trackballs and joysticks are fundamental input devices of graphical user interface. Users manipulate the nonkeyboard input device to control cursor movement to select menus, targets or icons; hence, point-and-click is one of the major tasks of the nonkeyboard input devices. Over 90% of organizational tasks and daily personal input tasks use the mouse as an information input device (Woods, Hastings, Buckle, & Haslam, 2002), but some work situations such as those involving a moving vehicle, or a small work station where there is no enough space for mouse placement or manipulation, are not suitable for using the mouse as an input device. As a result, trackballs, joysticks and touch screens are used in these particular work environments (e.g., the information center or main machine control room of a ship). Operators who work in these places have been often asked to manipulate a nonkeyboard input device to select targets or commands (e.g., to identify a point of interest on radar display). This kind of application may require the operators to rapidly and accurately select items at several different positions in the operation interface, while the vehicle goes through abrupt motions.

Input Device Comparison

Grandt, Pfendler, and Mooshage (2003) indicated that the input performance could be improved by designing an appropriate user interface or selecting a suitable input device in the combat operation center on a battle ship. For input device selection, it is necessary to consider user tasks, user characteristics, and user's work environment, as pointed out by many studies (International Organization for Standardization (ISO) 9241 part 9, 1994; Preece, Rogers, Benyon, Holland, & Carey, 1994; Chan, Hsu, Kung & Chen, 2006). ISO-9241 part 9 (1994), non-keyboard input device requirements, lists

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proper input devices based on the requirements of different tasks, e.g., pointing, selecting, dragging, tracing, tracking, scanning, and data entry. Albert (1982) compared seven kinds of input devices in terms of speed and accuracy of positioning a cursor, and the results showed that the touch screen was the fastest but least accurate input device, and the trackball had the highest accuracy among these input devices. Numerous studies compared the trackball with the mouse in terms of movement time and error rate (Sperling & Tullis, 1988; Cushman & Rosenberg, 1991; Mackenzie, Seller, & Buxton, 1991; Kabbash, MacKenzie, & Buxton, 1993; Accot & Zhai, 1999; Chaparro, Bohan, Fernandez, Kattel, & Choi, 1999). Most of their findings indicated that the performance of the mouse was better than that of the trackball in terms of speed as well as accuracy. Lee (2005) compared the touch-pad and trackball mouse on posture angles, muscle activities and completion time. His results showed that the trackball mouse significantly decreased completion time but had a larger elbow angle. Hsu and Wang (2003) evaluated three kinds of trackballs and the results showed the thumb-operated trackball acquired the highest rating in posture angle and muscle activity (electromyography). In addition, the thumb-operated trackball was suitable for long periods of work. However, these comparisons were all executed under stationary situations. The results could be different if these input devices were manipulated in a motion environment (Hill & Tauson, 2005; McLeod, Poulton, Ross, & Lewis, 1980).

Motion Effects on the Manipulation of Nonkeyboard Input Devices

Ship motion typically consists of heave, roll, pitch, yaw, sway, and surge movements (see Fig. 1). Heave, surge, and sway are linear movements; roll, pitch, and yaw are angular movements (Brown, 1985; Bittner & Guignard, 1985). Pingree (1988), in a review, indicated that for most ships the dominant motions were heaving, rolling, and pitching at frequencies below 1 Hz. Brown (1985) pointed out that severe ship motion could cause a task to become more difficult, as well as lead to human performance degradation. Bittner and Guignard (1985) indicated that ship motion could affect the performance of tasks using display and control equipment on board a ship. McLeod, et al. (1980) found that using a joystick to execute tracing tasks was affected by ship motion. Lewis and Griffin (1978) and McLeod and Griffin (1989) reviewed many studies dealing with the effects of whole-body vibration on continuous manual control performance. They found that the vibration frequency, magnitude, direction and amplitude significantly affected the performance of using joystick or other input devices. Furthermore, these effects occurred more in the vertical vibration on vertical tracking movement. Griffin (1990) indicated that motion affected the accuracy of small or precise manual movements. Dobie (2003) indicated that ship motion had detrimental effects on both gross (e.g., standing, walking, carrying out operation and maintenance tasks) and fine motor skills (e.g., delicate control adjustment and computer operations). Hill and Tauson (2005) pointed out that soldiers' input tasks were seriously affected by vehicle motions. Although many studies in the literature investigated the effects of motion on continuous manual control, most of them focused on the specific motion direction (vertical vibration) and input device (joystick). Few studies investigated the effects of motion direction on manipulating a trackball or touch screen.

[Insert Fig. 1 about here]

Objectives

Most of the input tasks on board a ship are point-and-click, and the trackball is one of the major input devices used (Grandt, et al., 2003). However, touch screens have been widely and successfully used in many fields, and there is a trend of increasing use of touch screens on moving environments for better quality and more robust outcomes than a mouse used in moving environments (Albinsson & Zhai, 2003). In order to improve the performance of input tasks in a motion environment, one needs to better understand the effects of motion on using nonkeyboard input device. The aim of this study was to investigate the effects of motion direction on the performance of point-and-click tasks by using three kinds of thumb-operated trackballs and a touch screen (see Table 1).

[Insert Table 1 about here]

METHOD

Participants

Twelve volunteer male employees who were all research engineers of the Chung-Shan Institute of Science and Technology participated in this experiment. They were not apt to be motion sickness and their ages ranged from 22 to 30 years (mean = 26.5, SD = 2.54). They all had a corrected visual acuity of 0.8 or better, as well as normal color vision. All participants were right-handed, experienced mouse users but had no previous experience with using either a trackball or touch screen. Each participant signed a letter of consent and got the ratification by the human factors division prior to the experiment and was paid US$ 10 after the experiment.

Experimental Design

This study focused on the point-and-click operation in a 2D interface, which was one of the most important input modes on naval vessels. The operator needed to move the cursor onto a graphical object, which may be located anywhere on the screen, then pressed a button to select the target or command. An experiment was conducted to investigate the effects of input device and motion direction on a cursor positioning task. Participants performed multi-directional point-and-click tasks by using various input devices under different motion directions. A fully within-subjects repeated measure design was applied. The independent variables, input devices (four levels, three trackballs and one touch screen) and motion directions (five levels, static, heave, roll, pitch and random) were all within-subject factors. Dependent variables were the movement time (millisecond) and error rate (%). Movement time was the time between two successive clicks, and error rate was the percentage of targets selected outside the circle target. A two-way repeated measure ANOVA was used to examine the effects of input device and motion direction on the movement time and error rate. P-values less than .05 considered as statistically significant. To prevent order effects, orderings of motion direction and input device were counterbalanced. The Duncan's multiple-scope test was used to do the post hoc test, as it could effectively detect the variation between two average observation values (Montgomery, 2001). It was hypothesized that the effects on movement time or error rate were different when users manipulates different input devices to execute the cursor positioning tasks under different motion directions.

Apparatus

The experiment was conducted in a cabin mounted on a Stewart motion platform, which had six degrees of freedom. Its capacity displacements of heave, sway and surge were ±200 mm, ±250 mm and ±250 mm, respectively, and the angles of roll, pitch, and yaw were $\pm15^{o}$, $\pm15^{o}$ and $\pm17^{o}$, respectively. Positioning tasks were performed on a Pentium-class desktop PC running Windows XP. The input devices and visual display were three trackballs (a currently used, a trackman wheel and an erectly held trackballs) and a 17-inch Color TFT LCD touch screen with 1024×768 resolution. Brief descriptions of these devices are listed in Table 1. The experimental software was developed by Visual C++. The gain (sensitivity) value of the trackballs was set to the equal and high value (= 6) in the Window XP driver software for setting pointing device speed.

Procedure

The whole-body motions which were heave (0.3 Hz, ± 100 mm), roll (0.3 Hz, ± 8°), pitch (0.3Hz, ± 8°) and random motion, a combination of the three motion directions were provided by the Stewart platform. The motion modes presented in this study were revised from the motion modes of a 500 ton displacement patrol ship proposed by the United Ship Design and Development Centre (Chou, 2005).

Participants were interviewed to gather their basic information before the experiment. Each participant was requested to evaluate his health and degree of motion sickness by filling out questionnaires developed by Wertheim, Ooms, De Regt, and Wientjes (1992) at the beginning, in the middle, and at the end of the experiment. The degree of motion sickness was assessed on the misery scale, which rates discomfort on a scale of eleven points ranging from no problems (0) to vomiting (10). The participants were told to use their preferred hand to move the cursor to capture the targets as quickly and accurately as possible. After reading the experimental instructions, participants adjusted the seat height and distance for their comfort, and then a 60-minute practice was offered before each session of the experiment for the participants to become familiar with the subsequently used input device and the task under static and motion environments. After the practice and ten minutes rest, the participants started the experiment. At the beginning of the experiment, participants positioned the cursor toward the center circle of the operating interface and clicked it to commence a trial. A pair of circle targets (diameter = 6.4 mm) of which one was filled green with a black crosshair pointer (+) and another was filled red with a black minus sign (-) appeared. Participants moved the cursor to click the green circle, and then moved the cursor to click the red circle. The black crosshair or minus sign changed to white when the subject successfully clicked inside the boundary of the green or red circle. Clicking outside the red circle after successfully clicking on the green circle was defined as an error and a beep sounded whenever the participant clicked outside either circle. The elapsed time between every two successful clicks was recorded. After both circles were successfully selected, a new pair of circles would be generated randomly. This process continued until all trials in a set were completed. A set consisted of twenty-four point-and-click trials (one motion direction; three different distances; eight different angles). The distances between pairs of circles were 64, 128 and 192 mm, and the approaching angles were 0^o (→), 45^o (↗), 90^o (↑), 135^o (↖), 180^o (←), 225^o (↙), 270^o (↓) and 315^o (↘) (see Fig. 2.). Each participant completed a session (five blocks) with the same input device in five different motion directions. Each block consisted of three repeated sets in the same motion direction. Each participant needed to complete four sessions with four different input devices on four separate days and finish 1440 point-and-click operations in total. Each session lasted approximately an hour long. The device assessment questionnaires regarding the opinion of using an input device in different motion directions were filled after each block and session. The questionnaire (7-point scales) was based on the ISO 9241 part 9 Annex C (1994), with some added questions concerning the effect of motion direction on input performance.

[Insert Fig. 2. about here]

RESULTS

The scores of the misery scale were very low (< 2) in this experiment, which showed that none of the participants suffered from motion sickness. Similarly, the questionnaires on health reported little change in the participants' sense of well-being. Hence, it may be assumed that performance was directly affected by Motion direction or Input Device. The overall summary of the Mean Movement Time and Error Rate under the levels of independent variables is listed in Table 2.

[Insert Table 2 about here]

Movement Time

The results of the ANOVA showed that the main effects of both Input Device ($F_{3, 33} = 22.97$, $p < .01$) and Motion direction ($F_{4, 44} = 89.40$, $p < .01$) were significant, and so was the interaction between the Input Device and Motion direction ($F_{12, 132} = 5.31$, $p < .01$). The interaction is showed in Fig. 3.

[Insert Fig. 3. about here]

Further analyses for each input device and motion direction were conducted and the results indicated that there were significant simple main effects of Input Device (all $p < .01$) and Motion direction (all $p < .01$) on the Movement Time for each motion direction and Input Device, respectively. For Input Device, the results of the Duncan test showed that the Movement Time of using trackball-3 was significantly longer ($p < .05$) than that of using other Input Devices, whereas the touch screen was used the fastest ($p < .05$) in each motion direction. Compared with trackball-1, trackball-2 was used faster in the static situation; nevertheless, there was no significant difference on heave, roll, pitch and random motions. Regarding Motion direction, the random motion had the most serious effect on the Movement Time of manipulating all Input Devices (all $p < .05$). The effect of pitch or roll was significantly larger than that of heave or static when using either trackball-3 or touch screen ($p < .05$); however, there was no significant difference between roll and pitch or between static and heave. Table 3 lists the details of the Duncan test.

[Insert Table 3 about here]

Error Rate

The ANOVA indicated that the main effects of both Input Device ($F_{3, 33} = 119.1$, $p < .01$) and Motion direction ($F_{4, 44} = 45.9$, $p < .01$) were significant; however, their interaction was not significant.

For Input Device, the Duncan test showed that the Error Rate of the touch screen was significantly higher than that of other input devices ($p < .05$), while the trackball-1 had a significantly lower ($p < .05$) Error Rate than that of trackball-2 and trackball-3. There was no significant difference in Error Rate between trackball-2 and trackball-3. For Motion direction, the Duncan test showed that the effect of random motion on Error Rate was significantly higher than that of the static, heave, roll and pitch motion directions ($p < .05$), and the Error Rate of roll and pitch was significant higher than that of heave and static. However, there was no significant difference in Error Rate between the roll and pitch or heave and static. Table 4 lists the details of these results.

[Insert Table 4 about here]

Device and Motion Effect Assessment Questionnaires

At the end of each block and session, participants were given a questionnaire to rate their manipulation, comfort, performance, and preference for different input devices and the effects of different motion directions. Results of the questionnaire are presented in Table 5. In terms of manipulation, Table 5 (a) shows the force required in using trackball-1 or touch screen was significantly larger than that of using trackball-2 or trackball-3. With respect to comfort, using touch screen more often led to soreness or fatigue in the arm than other input devices, and using trackball-1 was also more often associated with soreness or fatigue in the arm than trackball-2 or trackball-3. Using touch screen would more often cause fatigue in the neck or shoulder than trackball-2 or trackball-3. Regarding performance, the accuracy of using touch screen was significantly lower than for using trackball-1 and trackball-2. In terms of overall preference, the participants preferred the trackball-2 to trackball-3 and touch screen.

Table 5 (b) shows the results of participants' subjective evaluation of the motion effects on manipulating the Input Device. The results showed that the Motion direction significantly affected the input performance for the mentioned input devices. The Duncan test showed the effects of random motion on the point-and-click task were the largest, whereas the static and heave motions had the least effect. The effects of roll and pitch were in the middle.

[Insert Table 5 about here]

DISCUSSION

Input Device

No matter whether in the static or other four motion directions, the touch screen was the fastest but least accurate input device in this experiment. This finding was consistent with the subjective evaluation and previous studies (Albert, 1982; Muratore, 1987). The reason could be that the touch screen provided a direct interaction within display and input. Users could simply move their fingers to touch the targets on the screen rather than manipulating an auxiliary input device to the targets. This intuitive interaction resulted in faster movements than other input devices under any motion direction. On the other hand, the small targets (diameter = 6.4 mm) of this study were more easily affected by motion and obscured by fingers, which could lead to high error rates. This result was congruent with a previous study (Beaton & Weiman, 1984). Such problems could be solved by enlarging the target size or using pen-like tools to make more pointing accurate.

In addition, the subjective evaluations also showed that most of the participants felt their arm was prone to fatigue or soreness with using a touch screen during the experiment. This could be attributed to the high frequency of repetition because of high error rate and an elevated arm or shoulder accompanying the use of the touch screen. This finding showed that the touch screen was inappropriate for high frequency repetition and small target tasks. (Preece, et al., 1994).

In terms of the trackball, the movement time of using trackball-3 was longer than that of the other input devices in static and all motion directions. This could be explained in that the trackball size and weight of trackball-3 were smaller and lighter than those of trackball-2 and trackball-1, thus, trackball-3 could be affected more easily by motion. With respect to the accuracy, the touch screen had the highest error rate in these input devices, and the accuracy of the trackball-1 was significantly higher than that of the trackball-2 and trackball-3. The heavier weight and bigger size of a trackball could increase the stability when the trackball was manipulated in motion environments, therefore, reduce the error rate.

The subjective evaluation indicted that it took more force to move trackball-1 than trackball-2 and trackball-3. Again, this could be due to the larger ball size and heavier weight of trackball-1. Consequently, using trackball-1 resulted in fatigue or soreness more often than trackball-2 and trackball-3. After the overall evaluations, the trackball-2 and trackball-1 were the better selections of nonkeyboard input device in the motion environments.

Motion direction

The results of this experiment indicated that motion direction affects the speed and accuracy of manipulating nonkeyboard input device on the point-and-click task. The random motion had the most negative effect on the movement time and error rate. This is probably because the motion directions of the random motion were unknown in advance, and thus it increased task difficulty. Therefore, the movement speed and accuracy could be decreased. This result was not only consistent with the subjective evaluation that the negative effects of random motion on performance in the point-and-click task were the largest, but also similar to the previous studies that the ship motion affect the control performance (McLeod, et al., 1980; Bittner & Guignard, 1985; Brown, 1985).

In addition, roll and pitch motions also affected the performance of the nonkeyboard input device manipulation but these effects were smaller than those of the random motion. This outcome could be explained by the predictability of motion direction of roll or pitch motions; hence, subjects could adjust their manipulation to respond these motions. This finding was also similar to the results of subjective evaluation.

The heave motion did not affect the performance of using the nonkeyboard input devices on movement time and error rate. The result was not consistent with previous findings that vertical motion impaired performance with other input devices such as a joystick or control lever to track targets (Lewis & Griffin, 1978; McLeod & Griffin, 1989). This is probably because the heave motion of this experiment was a smooth vertical movement of low frequency (0.3 Hz) and the task was also different from previous studies. Hence, the effects of the heave motion were few and its results were similar to those of the static conditions. In addition, different input devices were used, which could be one of the reasons for the difference in results, since most of the previous studies used a joystick as a control device rather than the trackballs and touch screen used in the present study. As a result, performance with trackballs or a touch screen may have been affected less by the heave motion. This result was also consistent with the subjective evaluation that there was no different effect between the static and heave motions.

Gain Effects

The gain was an important factor related to the movement time and accuracy of point-and-click task (Sanders & McComick, 1993). The operator moved the cursor to the approximate desired position by gross-adjustment movement, and brought the cursor precisely to the target by fine-adjustment movement. Hence, the determination of an optimum gain value needed to take the amplitude and target size into account. Thompson, Slocum and Bohan (2004) pointed out that when the amplitude was greater than 40 mm or target size was greater than 5 mm, the movement time was benefited from the high gain (= 8). In this experiment, because the amplitudes (64, 128 and 192 mm) were all longer than 40 mm and the target size (6.4 mm) was also bigger than 5 mm, high gain could contribute to a better input performance. Hence, the gain of the current study was set as 6. However, the effects of gain on movement time and accuracy could be affected by the motion conditions and trackball characteristics. For example, for fine-adjustment movement, the high gain value of this experiment may have a disadvantage on the control of the lighter and smaller trackball (trackball-3). Hence, the relationships among gain, trackball size and weight, as well as motion conditions deserve further investigation.

Limitations and Further Works

In reality, the heave oscillation of a ship is bigger than the capacity limitation of the Stewart platform. Hence, only the smaller oscillation of the heave motion can be simulated. The effect of heave motion on the input performance can be bigger if the real situation is simulated. This limit could be solved by combination of virtual reality and platform motion in the future. In addition, the different gain setting of trackballs in various motion directions could lead to different input performances. Currently, only the input performance of the same gain setting for the three trackballs was compared. Future research should include the investigations of the optimal gain value on different trackball sizes, weights, and motion conditions.

In conclusion, this study indicated that motion direction and input device affected the input performance of cursor positioning task. The effects associated with random motion were the largest, followed by the pitch or row motions. However, the heave motion did not affect the manipulative performance. After the objective and subjective evaluations, trackball-1 and trackball-2 were more efficient for operation than trackball-3 and touch screen under motion environments. When designers selected the touch screen as an input device used in motion environments, the target size and operation frequency required further consideration.

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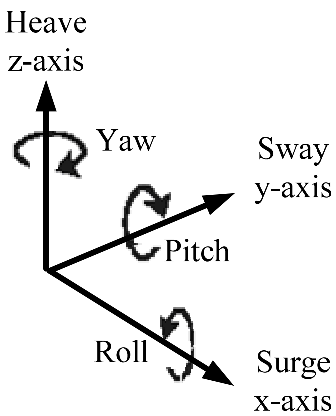
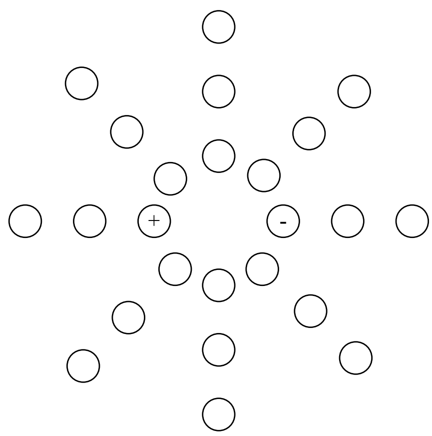


FIG. 1. The modes of ship motion



(a) Interface layout

(b) A sample experimental condition

FIG. 2. Interface layout and a sample trial

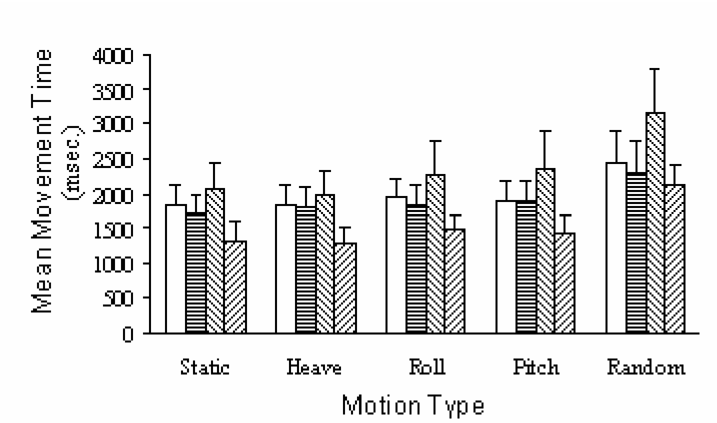


FIG. 3. Mean Movement Time by Motion direction and Input Device

□ Trackball-1 ▤ Trackball-2 ▧ Trackball-3 ▨ Touch screen

TABLE 1 Input Device description

Type/Brand		Description
	Trackball-1 (current used trackball)	Ball Control: thumb Buttons control: index finger Ball diameter: 50 mm Ball weight: 83.08 g
	Trackball-2 (trackman wheel trackball)	Ball Control: thumb Buttons control: index finger Ball diameter: 33.5 mm Ball weight: 25.35 g
	Trackball-3 (erectly held trackball)	Ball Control: thumb Buttons control: index finger Ball diameter: 18.5 mm Ball weight: 18.18 g
	Touch Screen	Continuous resolution , Light Transmission: 72% RS-232 interface 1024 * 768 resolution

TABLE 2 Summary of the Mean Movement Time and Error Rate

	Trackball-1		Trackball-2		Trackball-3		Touch Screen	
	MMT[a]	MER[b]	MMT	MER	MMT	MER	MMT	MER
Static	1826	2.4	1723	4.5	2071	4.9	1316	32.3
Heave	1848	1.6	1805	4.8	1992	5.5	1285	35.2
Roll	1949	2.1	1845	6.8	2247	6.8	1474	42.0
Pitch	1899	3.7	1886	7.6	2348	7.5	1428	39.3
Random	2417	9.1	2294	12.8	3152	14.2	2113	59.3

[a]Mean Movement Time (millisecond).
[b]Mean Error Rate (%).

TABLE 3 Summary of Duncan test results on Movement Time

(a) For all Input Devices on each Motion direction

		Touch Screen	Trackball-2	Trackball-1	Trackball-3
Static	MMT [a]	1316	1723	1826	2071
	Group [b,c]	A	B	C	D
Heave	MMT	1285	1805	1848	1992
	Group	A	B	B	C
Roll	MMT	1474	1845	1949	2247
	Group	A	B	B	C
Pitch	MMT	1428	1886	1899	2348
	Group	A	B	B	C
Random	MMT	2113	2294	2417	3152
	Group	A	B	B	C

[a]Mean Movement Time (millisecond)
[b]Values with the same letter are not significantly different.
[c]Significant at $\alpha = .05$ level.

(b) For all Motion directions on each Input Device

		Static	Heave	Pitch	Roll	Random
Trackball-1	MMT [a]	1825	1848	1898	1948	2416
	Group [b,c]	A	A	A		
			B	B	B	C
Trackball-2	MMT	1723	1805	1886	1844	2294
	Group	A	A			
			B	B	B	C
Trackball-3	MMT	2017	1992	2348	2247	3151
	Group	A	A	B	B	C
Touch screen	MMT	1316	1285	1428	1474	2113
	Group	A	A	B	B	C

[a]Mean Movement Time (millisecond).
[b]Values with the same letter are not significantly different.
[c]Significant at $\alpha = .05$ level.

TABLE 4 Summary of Duncan test results of Error Rate

(a) Input Device

Input Device	N	Error Rate [a]	Duncan grouping [b,c]		
Trackball-1	60	3.78	A		
Trackball-2	60	7.30		B	
Trackball-3	60	7.78		B	
Touch Screen	60	41.62			C

(b) Motion direction

Platform motion	N	Error Rate [a]	Duncan grouping [b,c]		
Static	48	11.03	A		
Heave	48	11.80	A		
Roll	48	14.39		B	
Pitch	48	14.49		B	
Random	48	23.86			C

[a]Error rate (%)
[b]Values with the same letter are not significantly different.
[c]Significant at $\alpha = .05$ level.

TABLE 5 Result of questionnaire

(a) Mean subject rating of Input Device

Questions	Touch screen	Track-ball-1	Track-ball-2	Track-ball-3	Sig.[b]
Manipulation					
1. Force required to activate the input device (1: Very high; 7:Very low)	4.41[a] A	4.16 A	6.25 B	5.75 B	†
2. Operating rhythm					-
3. General effort required operate the input devices					-
Comfort					
4. Soreness or fatigue in wrists					-
5. Soreness or fatigue in fingers					-
6. Soreness or fatigue in arms (1:Very high; 7:None)	3.92 A	5.00 B	6.58 C	6.75 C	†
7. Fatigue in neck or shoulder (1:Very high; 7:None)	4.91 A	6.00 A B	6.41 B	6.33 B	*
8. Posture required to operate the input device					-
Performance					
9. Accuracy (1:Very difficult to be accurate; 7:Very easy to be accurate)	4.00 A	6.75 B	5.58 B	4.58 A B	*
Over preference					
10. Overall operation of input device (1: Very bad; 7: Very good)	4.17 A	4.83 A B	5.67 B	4.42 A	*

Questionnaire adapted from ISO 9241-9.

Note.—Participants responded on 7-point scales.

[a]Mean score: the higher the better.

[b]*$p < .05$, † $p < .01$, - not significant.

(b) Mean subjective rating of Motion direction effect on input performance

Effect of motion direction	Static	Heave	Roll	Pitch	Random	Sig.[b]
Trackball-1	7[a] A	6.67 A	5.67 B	5.17 B	3.42 C	†
Trackball-2	7 A	6.42 A	5.50 B	5.67 B	3.08 C	†
Trackball-3	7 A	6.50 A	5.83 B	5.42 B	2.75 C	†
Touch Screen	7 A	6.50 A B	5.67 B	5.67 B	3.42 C	†

Note.—Participants responded on 7-point scales (1: the worst effect; 7: the least effect)

[a]Mean score: the higher the better.

[b]† $p< .01$.