

DOES ROTARY PURSUIT DATA PREDICT MOUSE TASK PERFORMANCE? A PILOT STUDY

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ABSTRACT

Knight & Salvendy (1992) suggested that performance of mouse task depends on precision control and arm-hand steadiness. However, the claims lacked empirical support. This pilot study collected rotary pursuit data, measured by time-on-target (TOT), to assess participants' precision control ability. Performance of mouse task was operationalized using a Fitts' pointing task. Stepwise multiple regression revealed target diameter (D), distance amplitude (A), and TOT contributed to the variability of movement time (MT). Despite highly significant relations, the regression coefficients were so small that they offered little practical value. However, the results indicated that precision control ability is indeed predictive of the performance of mouse task. Several recommendations were made for subsequent studies, they include (i) psychomotor ability should be assessed using multiple trials, (ii) a wider range of ID values should be tested with, (iii) a multi-directional Fitts' paradigm should be employed, and (iv) the mouse task should be more representative of the direct manipulation paradigm.

INTRODUCTION

Despite the dramatic advances in computing technology since its inception, the computer mouse still remains the primary pointing devices for many users. The mouse has proven useful in a variety of computing tasks, whether it is browsing the Web or editing text documents. Collectively known as direct manipulation, common operations offered by the mouse include point-and-click and drag-and-drop. These interaction styles are intuitive and often allow users to accomplish their computing task without much difficulty. In fact, computer users are so accustomed to the interaction styles of the mouse that the relatively new touchpad pointing device had to be redesigned to match that of a mouse (MacKenzie, 2003).

Successful use of the mouse requires well-coordinated motor movements. Indeed, many human-computer interaction (HCI) researchers have recognized the importance of psychomotor abilities in HCI activities. Knight & Salvendy (1992) were among the first authors to suggest the relationship between psychomotor abilities and performance of computing tasks. Based on Fleishman's taxonomy of psychomotor abilities (Fleishman, 1975; Fleishman & Quaintance, 1984; Fleishman & Reily, 1992), Knight & Salvendy proposed that control precision and arm-hand steadiness are the fundamental determinants for manipulating a mouse.

Using the definitions from the taxonomy (e.g., Fleishman & Quaintance, 1984), control precision is the ability to make controlled muscular movements to adjust or position equipment control mechanisms, whereas arm-hand steadiness is the ability to make precise, steady arm-hand positioning movements where both strength and speed are minimized, but it does not extend to machine and equipment controls.

Other than precision control and arm-hand steadiness, other components of psychomotor abilities have also been reported in studies investigating various types of pointing devices. Among them are manual dexterity and finger dexterity. Manual dexterity is the ability to make coordinated movements of a hand and arm for manipulation of physical objects but it does not extend to equipment controls (Fleishman & Quaintance, 1984). Finger dexterity is similar to manual dexterity but it is more concerned with fine movements involving the fingers.

Some researchers found that certain components of the psychomotor domain could be used as indicators for performance of computing tasks. For example, Hwang (2001) evaluated types of pointing devices for use by patients with a variety of upper-limb motor impairments (e.g., cerebral palsy, spina bifida, muscular dystrophy, and quadriplegia). Participants' manual dexterity was first measured using the Minnesota Manual Dexterity Test (MMD) in terms of test completion times (CT).

Then, performance measures were obtained from a pointing task using various input devices (i.e., mouse, joystick, and trackball), operationalized using the Fitts' paradigm. Measures of movement time (MT) and index of performance (IP) were quantified from the task. MT was the time needed to move the cursor from one target on the screen to another. IP was a measure of relative difficulty for small targets. Significant correlations were found in both the CT-MT and the CT-IP pairs, indicating that manual dexterity was predictive of pointing task performance. In other words, it was found that the MMD Test was indeed a good measure for selection of pointing devices for people with upper-limb motor impairments.

Oftentimes, phenomena observed from one study may be only true for certain age groups. Therefore, information such as the age of study cohorts is invaluable for scrutinizing the generalizability of a study outcome. In addition, reporting of such information also provides a basis for comparing outcomes from one study to another. A similar analogy can be made to disclosing the psychomotor measures of study cohorts.

In Jacko et al. (2003), participants' right-hand finger dexterity data were measured using the Purdue Pegboard Test, for which the data were included as part of their demographics. In that study, the researchers investigated the effects of multimodal feedback on performance of a drag-and-drop mouse task, for older adults diagnosed with age-related macular degeneration (AMD). To provide a clearer understanding of the characteristics of the study cohorts, the psychomotor data were compared with other normative data: the norms of people with low vision (Tobin & Greenhalgh, as cited in Jacko et al., 2003) and the norms of the industrial job applicants (Tiffin & Asher, as cited in Jacko et al., 2003). However, unlike Hwang (2001), there was no attempt to determine whether finger dexterity was indeed relevant to participants' performance in the drag-and-drop task.

TAXONOMY OF PSYCHOMOTOR ABILITIES AND ITS LIMITATIONS

Originally developed for pilot and air force personnel selection (Fleishman, 1964), the taxonomy of psychomotor abilities was essentially a product of mathematical derivations based upon factor analysis. To briefly describe the development of the taxonomy, a large dataset was collected from a variety of laboratory-based psychomotor tests. Then, common abilities were delineated from the data using factor analysis. The resultant list was the fewest independent categories representing the most, if not all, aspects of the

psychomotor dimension. The categories were then semantically defined to describe the factorial commonality. The resulting categories and their definitions thus formed a taxonomy of psychomotor abilities.

There are some limitations associated with the psychomotor abilities taxonomy. These limitations are partly due to the approach used to develop the taxonomy; others are due to issues pertaining to the context in which the taxonomy is applied.

Due to the fact that the abilities were semantically defined, a certain degree of subjectivity is inevitable (Fleishman & Quaintance, 1984). As a result, interpretation issues may arise. Some researchers have utilized the taxonomy based on its semantic definitions without first determining whether a true abilities-performance relationship exists. For example, Knight & Salvendy (1992) linked specific components of the psychomotor dimension (i.e., control precision and arm-hand steadiness) to the performance of mouse task using the definitions from Fleishman's taxonomy, without offering any empirical evidence. While it is convenient to link abilities with performance based on judgments, the relationships clearly need to be empirically validated in the context in which the taxonomy is used.

All psychomotor abilities outlined in Fleishman's taxonomy are measurable using standardized tests. Inevitably, there may be some mismatch between the characteristics of the standardized test and that of the task itself. In other words, characteristics unique to the context may not match the ones of a standardized test. Therefore, the proposed linkage may be artificial. To illustrate, the rotary pursuit test is the standardized test for measuring precision control ability, which has been suggested as one of the psychomotor abilities required for mouse task (Knight & Salvendy, 1992). The test consists of a target rotating about the z-axis. A person's precision control ability is indicated by the amount of time he is able to use a stylus to move along with the target, commonly known as time-on-target (TOT). However, a certain disparity presents between the characteristics of the test and the mouse tasks, such as the limb movements required. Controlled arm-wrist movements, without any part of the limbs being supported on a surface, are required for the rotary pursuit test. On the contrary, mouse tasks mainly consist of relatively small wrist movements on a two-dimensional surface, usually with the forearm rested.

Taken together, the overarching concern is the predictive validity of psychomotor abilities. Said differently, it is the question of whether components of the psychomotor dimension are able to predict

performance in an applied setting as suggested by some researchers. In the context of this study, the setting of interest is the performance of direct manipulations (e.g., point, click, drag-and-drop) using the mouse, in the home and office environments.

PROBLEM DEFINITION

Based on the background information, it was determined that there existed a need to investigate the relationship between psychomotor abilities and the performance of mouse task. The purported psychomotor abilities needed for a mouse task, i.e., control precision and arm-hand steadiness, seemed to be extrapolated from Fleishman's taxonomy without supporting empirical evidence. Therefore, the main objective was to empirically investigate the relation between the psychomotor abilities as suggested by Knight & Salvendy (1992) and the performance of a mouse task.

The purpose of this study was to conduct a pilot investigation to empirically determine the relationships. According to Fleishman & Reily (1992), the rotary pursuit test is the standardized test for assessing control precision ability. Hence, it was decided to empirically determine whether control precision, as measured by the rotary pursuit task, was predictive of the performance of mouse task. To be more specific, we hypothesized that control precision ability is positively correlated with performance of mouse task.

Although the rotary pursuit test has been used extensively for assessments of handedness and eye-hand coordination, the use of such test has been scarce, if any, in HCI literature. Therefore, this could be among the first HCI study that incorporates data from a rotary pursuit test.

METHOD

The experiment was conducted with 15 college students (seven males and eight females), ages 18 to 30 years old. All participants self-reported as being right-handed regular mouse users. They also reported normal vision and no motor impairments.

A Lafayette photoelectric rotary pursuit unit (Model 2203ET) was used. The unit consisted of a light emitting target rotating beneath a circular glass template, adjusted at 45 rpm in a clockwise direction. In addition, a Lafayette digital stop clock (Model 54016) and impulse counter (Model 5822) were attached to the rotary unit. The pointing task was performed on a Java application

developed by International Business Machines (1999). The program was run on a Pentium-based 2.4 GHz computer with an Advueu 18.1-in flat panel display (Model EZ18A) at a resolution of 1152-by-864 pixels. The pointing device used was a neutral shaped Microsoft optical mouse.

With the rotary unit placed approximately at standing waist height, participants were instructed to track the rotating target using a stylus attached to the unit, without the tip of the wand contacting the glass template. To further control for undesired variance, participants were told to rest the tip of the stylus at the center of the circular glass template before the unit was switched on. After a practice trial, participants were tested once in the rotary pursuit task, which lasted for 60 s. Time-on-target (TOT) was recorded as the total time of photocell contact produced by each participant. Thus, a higher TOT is indicative of better control precision ability.

The Fitts' pointing task was performed following the rotary pursuit task. The application window was maximized to occupy the entire screen. Such measure was necessary to eliminate possible distraction due to irrelevant visual information on the screen. Two circular targets were positioned horizontally, with the mid-distance located at the center of the screen. The targets were colored red and black, and they became transparent when clicked. The target diameters were either 40, 80, or 160 pixels; whereas the between-target distance was varied at 50, 100, and 200 pixels. The combination of target diameter and distance produced nine conditions, which were randomly generated for each participant, with index of difficulty (ID) values ranged from 0.70 to 1.81 bits. Using the left mouse button, participants were required to alternately click the targets as quickly as they could. The performance measure was the average movement time (MT) taken to travel between the targets; a shorter MT represents better performance of mouse task. The pointing task ended when all combinations of targets had been acquired, which also marked the conclusion of the experiment.

RESULTS AND ANALYSIS

Transcription error caused data from one of the participants to be unusable. Therefore, only data from the remaining 14 participants were retained for analysis. Movement time (MT) was analyzed using stepwise multiple regression with target diameter (D), distance amplitude (A), and TOT included as possible explanatory variables. All variables were found to

Table 1.
Stepwise Multiple Regression for Movement Time (MT)

Steps	Variable Entered	Variable Removed	Partial R^2	Model R^2	C_p	F	p -value
1	D	--	0.176	0.176	26.41	26.41	< .0001
2	A	--	0.131	0.307	23.12	23.12	< .0001
3	TOT	--	0.044	0.351	8.20	8.20	.0049

significantly contribute to the variability of MT. A plot of studentized residuals revealed slight violation of the normality assumption. However, the normality assumption is not as vital as the linearity assumption (Agresti & Finlay, 1997), which was met. The results of the stepwise regression are displayed in Table 1. The final regression coefficients for D, A, and TOT were -9.03×10^{-4} , 6.23×10^{-4} , and -60.4×10^{-4} , respectively. Note the magnitudes are extremely small and offer little practical value.

To further investigate the relations between the explanatory variables and MT, correlational analysis was conducted. It found all variables were correlated with MT. The correlation for D-MT, A-MT, and TOT-MT were $r = -0.42$, $p < .0001$; $r = 0.36$, $p < .0001$; and $r = -0.21$, $p = .0188$, respectively. Both target diameter (D) and distance amplitude (A) were found to be in agreement with the prediction of Fitts' law, which states that MT has a direct relation with A but an inverse relation with D. In addition, the negative correlation between TOT and MT was as expected. Thus, it implies that precision control ability is indicative of mouse task performance. In another words, the results were in agreement with the relationship between control precision ability and performance of mouse task, as proposed by Knight & Salvendy (1992).

CONCLUSION AND DISCUSSION

This study serves as a pilot investigation toward validating the relationship between control precision ability and the performance of mouse task. Control precision ability was assessed using the rotary pursuit test, whereas performance of mouse task was operationalized using the Fitts' pointing task. The results indicated that movement time (MT) is directly related to distance amplitude (A) but inversely related to target diameter (D), which is in line with the prediction of Fitts' law. We were also able to demonstrate that control precision ability is indeed related to performance of a mouse task as proposed by Knight & Salvendy (1992), as evidenced by the significant negative correlation

between time-on-target (TOT) and MT. Although the results were promising, the study was marred by the small magnitudes of the regression coefficients. In particular, the regression coefficient for TOT was so small that it offered little practical value. The same issue can also be observed from the R^2 for TOT (see Table 1), which indicates that TOT accounts for only 4% of the variability in MT.

There were several explanations as to why the results were weak. One major drawback of this study was related to the approach used to assess participants' control precision ability. Although a practice trial was included, the actual assessment consisted of only one rotary pursuit trial. It was therefore plausible that the participants were not yet familiarized with the task. The foremost disadvantage of conducting assessment from a single trial is the inability to consider within-subject variability. Consequently, the data may not represent the true precision control ability. To increase the reliability of the assessment, future studies should allow multiple rotary pursuit trials from each participant. Second, Agresti & Finlay (1997) cautioned that inferences made from a fitted regression model are restricted to only the range of the tested variables. For this study, the range of ID values, which ranged from 0.70 to 1.81 bits, was rather narrow compared with the proposed range of 2 to 8 bits by Soukoreff & MacKenzie (2004). Therefore, it is speculated that such a narrow ID range might be insufficient to yield a representative sample of MT data, not to mention the lack of generalizability of the study outcomes.

Different angles of movement, rather than one-directional, should also be used in future studies. Besides improving generalizability, multiple directions would diminish the risk of confounding due to directional effect. It is further speculated that multiple directions would improve the magnitude of the relationship between TOT and MT. This is because the one directional Fitts' paradigm was mainly characterized by translational movements along the x-axis. On the other hand, the rotary pursuit task consists of not only translational movements along one dimension, but movements in the two-dimensional plane of the x- and y-

axes. Aside from the theoretical argument, the multi-directional task is also more representative of the actual mouse task, because mouse movements are rarely one-dimensional in the real world. Furthermore, it was later realized that the ISO 9241-9 standard contains specific requirements for conducting studies with Fitts' paradigm, particularly on ways to overcome the issue of directional bias. Hence, requirements set forth by the ISO standard should be investigated and incorporated in future studies.

Finally, it was felt that the Fitts' task employed in this study may only represent one aspect of the mouse task in the real world situation. To elaborate, the pointing task is similar to the point-and-click operation and that it differs from the drag-and-drop operation, which is another common mouse task under the direct manipulation paradigm. Therefore, we feel that future studies should also include data from drag-and-drop mouse tasks.

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