Fitts' Law Predictions with an Alternative Pointing Device (Wiimote®)

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A Nintendo® Wiimote® enabled testing of both zero- and first-order of control for a Fitts' Law-style pointing task using the same device. The Wiimote® differs from standard computer input devices in that the user has available a full range of three- dimensional motions. Participants were assigned to one of the two orders of control and completed a pointing task that included 50 trials on three sets of boxes, each a different size and distance from each other. Results indicated that participants using the Wiimote® as a zero-order input device (i.e., directly controlling cursor position) were roughly 2.5 times faster at completing the task than those using the Willmote® as a first-order device, (i.e., controlling cursor velocity). As expected, participants using the first-order controller had smaller effective distances than those using the zero-order control scheme. Surprisingly, no meaningful differences were found between the two groups for overall error rate. This raises interesting questions for the future of three-dimensional control devices.

In the ever-changing environment of human-computer interaction, it is necessary to constantly evaluate and adapt the latest tools to ensure the most effective use of technology. The Nintendo® Wiimote® provides an interesting opportunity to research novel input devices because the Nintendo® Wiimote® can utilize the same physical device for multiple orders of control in novel ways. A standard computer mouse uses a two-dimensional plane to manipulate items on a two-dimensional display, but as technology advances, it may become more important to have functionality in a three-dimensional space (Williams, 1993). With this new hypothetical necessity, devices capable of manipulating three-dimensional spaces may become important. A mouse may not be enough to guarantee easy use if the interface occurs in more dimensions than the pointing device is capable of manipulating. Joysticks, previously the customary pointing device for first order of control input, limit the range of motion with fixed bases, for better or worse, also limiting the user's ability to incorporate multiple orders of control simultaneously. Previous research has determined that zero order of control pointing devices, such as computer mice or styli, are superior to other forms of device input, such as a track ball, on pointing tasks (Card, English, & Burr, 1978; MacKenzie, Sellen, & Buxton, 1991), but these devices are limited by a two dimensional range of movement. MacKenzie et. al (1991) showed the stylus outperformed the mouse on their pointing task, presumably because of the naturalness of the gesture. Similar findings could be expected from a Wiimote® if we liken its functionality to that of an oversized stylus. In earlier research, mice were considered optimal pointing devices, despite their movement limitations, because their high degree of stimulus-response compatibility (Fitts & Deininger, 1954).

Unlike the previously mentioned computer input devices the Wiimote® provides practically limitless range of motion and its functionality is limited only by the computer interface and the user's inherent capabilities. In order to ascertain its utility, however, empirical research needs to be sought out to confirm the device's ease of use, ease of integration with computer application, and superiority to other modes of computer input. While the second two needs are beyond the scope of the current study, we expect Fitts' Law to apply and for pointing time to be a linear function of movement distance divided by target width. However, the exact performance parameters at different orders of control are hard to anticipate; hence the current experiment.

Acknowledging the ubiquitous nature of zero-order pointing devices in everyday computer use in the form of a mouse, stylus, track pad, and the like, we expected that participants using the Wiimote® as a zero-order control device will be faster at a pointing task than participants using the Wiimote® as a first-order device. Furthermore, as first-order devices are generally harder to use (MacKenzie, et al, 1991), we also expected participants using the zero order of control to make fewer mistakes. That is, the error rate for first-order users should be higher.

Finally, participants using the Wiimote® as a first-order device will be moving more slowly, we expect that they will be more accurate at gauging distance. Therefore, we expected participants with the first-order regimen to have a smaller effective movement distance.

METHOD

Participants

Thirty-nine students, both undergraduate (*N* = 37) and graduate (*N* = 2) between the ages of 18 and 40 (*M* = 19.97, *SD* = 3.7) from a midsize research university participated either as volunteers or for credit towards a course requirement. Twenty-two of the participants were female and seventeen were male. Twenty-four of the participants indicated they had used a Wiimote® before and all participants indicated having normal or corrected to normal vision. Seventeen participants indicated that they played video games for more than an hour in the past week. None of the above demographics had a significant differential impact on error rate or performance times.

Stimuli and Materials

Measurements were taken using an Apple® Macbook® running Darwiin Remote v.5 (available at http://sourceforge.net/projects/darwiin-remote/) with custom software running in Java 1.5, using the Java Swing package for the graphical interface.

Each pair of boxes below (Figures 1-3) represent a single within-subject condition and were arbitrarily labeled small (75 pixels wide X 75 pixels high, 1085 pixels apart), medium (200 pixels wide X 200 pixels high, 440 pixels apart) and large (600 pixels wide X 700 pixels high, 40 pixels apart). All three box conditions were viewed on a 13” widescreen notebook monitor at a resolution of 1280 X 800.

The boxes were red in color (not shown) against a black background. Movement data from the Nintendo® Wiimote® was captured by Bluetooth® wireless technology and also via an external infrared sensor bar mounted to the top of the monitor. These data streams were recorded by the Darwiin Remote program described at the beginning of this section.

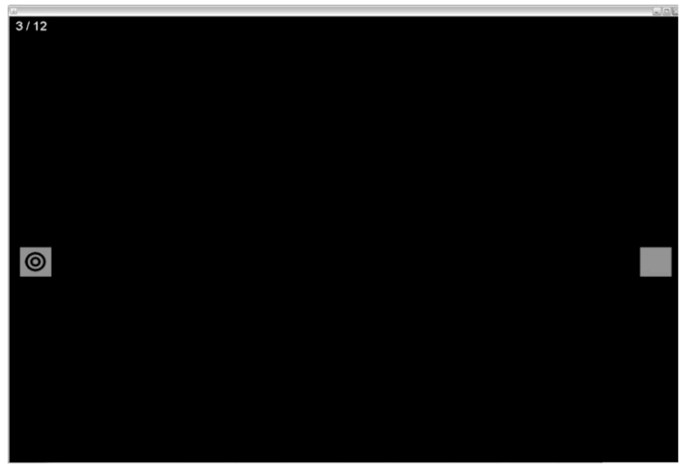

Figure 1. Small box condition.

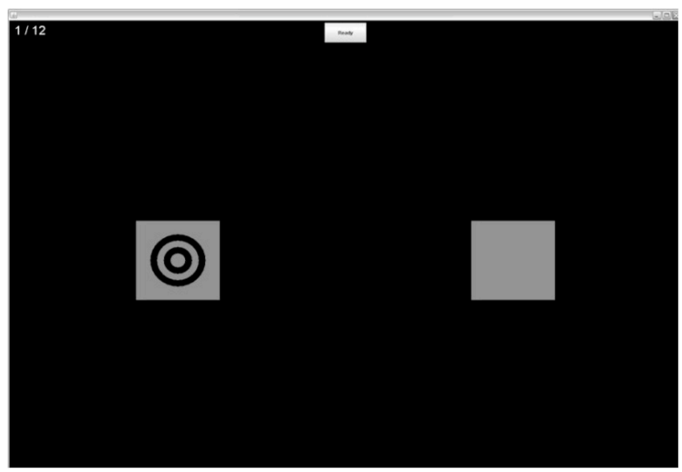

Figure 2. Medium box condition.

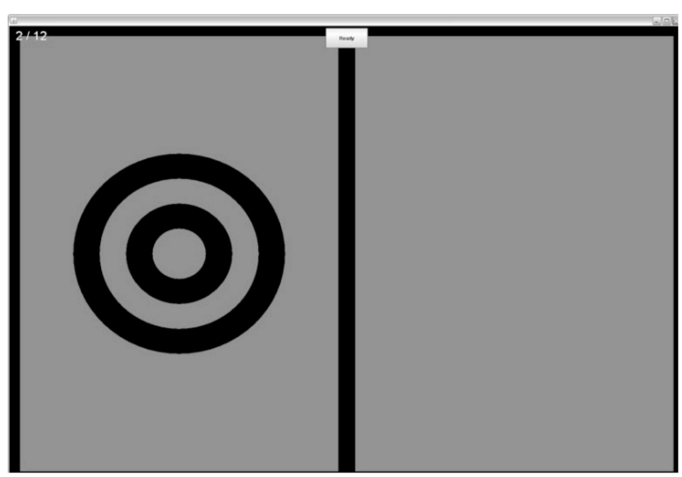

Figure 3. Large box condition.

As mentioned previously, the pointing device used in this study was a Nintendo® Wiimote®. Essentially the Nintendo® Wiimote® is a remote control, wireless pointing device that has the ability to be used as a 0^{th} order or 1^{st} order control device however, the orders of control were mutually exclusive.

Zero order of control pointing devices such as the Wiimote® used in this study control cursor absolute position. A movement to the left, right, up, or down was directly proportional to the left, right, up, or down movement of the cursor on the monitor. As a first order of control, the Wiimote® in this study controlled the directional velocity of the cursor. A twist of the wrist left or right or a tilting of the wrist up or down was directly proportional the velocity of the cursor on the monitor in the direction indicated. An excellent review of orders of control and control theory can be found by Jagacinski and Flach (2003).

Design

During the task, a black target appeared on the one of the boxes to indicate the box they were to select. After selecting this box, the target immediately moved to the opposite box and the process was repeated. In this way, each participant contributed forty-nine end-point data points to the within subjects design. Order of control was a between-subjects condition in the current design with subjects randomly assigned to each.

The native index of difficulty (ID) for each pair of boxes above was calculated using the Shannon formulation of Fitts' Law:

$$MT = A + B \log_2(D/W +1) \quad (1)$$

where A and B are constants (derived from empirical data), D is the distance to the target item, W is the width of the target item and (D/W +1) represents the ID of the target item. When movement endpoint data is available however it is recommended that the *effective* ID is used instead (Soukoreff & Mackenzie, 2004).

Because this study had endpoint data available in the form of point to point distance movement the *effective* ID was calculated for each pair of boxes as:

$$ID_e = (D_e/W_e +1) \quad (2)$$

where the *effective* distance (D_e) is the actual point to point distance moved by the user and the *effective* width, weighted by error rate, (W_e) is defined as:

$$W_e = \begin{cases} W \times \dfrac{2.066}{z\left(1 - \dfrac{Err}{2}\right)} & \text{if Err} > 0.0049\%, \\ W \times 0.5089 & \text{otherwise} \end{cases} \quad (3)$$

The larger the discrepancy between the native ID values and the ID_e values the more suggestive that the pointing device being used is not a good fit to the task being accomplished (Jagacinski & Flach, 2003).

Procedure

Participants gave informed consent, were seated in front the monitor, and were given verbal instructions about the use of the Wiimote® and the task involved. Participants were randomly assigned to use the Nintendo® Wiimote® as a 0^{th} order or 1^{st} order control device. They performed practice trials moving the Nintendo® Wiimote® back and forth between the different pairs of boxes mentioned above. There were 15 practice trials for each box condition, totaling 45 in all. After successful completion of the practice trials, participants completed 50 back-and-forth trials in each box condition, thereby contributing 49 distance measurements. Box conditions were randomly ordered between participants. Participants were also instructed to move as quickly and as accurately as possible. Following the completion of the experiment, participants were given a short debriefing and encouraged to ask questions should they have any.

RESULTS

The data collected for the first twenty participants was used to create a model of the relationship between movement times and *effective* index of difficulty (ID_e). To model the original data, the *effective* ID (ID_e) of each box condition was calculated for each participant. A regression of the *effective* ID and the corresponding movement times showed a good fit with the data (0^{th}: r = .87; 1^{st}: r = .91) and the empirically derived constants, mentioned in equation 1 above, describing our model appear in Table 1 below.

Table 1. Empirically derived Fitts' Law constants as a function of order of control.

Order of Control	A (constant)	B (slope)
Zero-order	116 ms	264 ms/bit
First-order	227 ms	968 ms/bit

Following this, data collected from an additional 19 participants were used to empirically test the fit of the model. The movement times collected from these participants were highly correlated with the model's predictions of movement times based on the second group's set of *effective* IDs (0^{th}: r = .86; 1^{st}: r = .88).

Figure 4 illustrates the fit of the regression line with the obtained data (collapsed across box condition) as well as a visual comparison between the two orders of control. The first order of control data appeared to be much slower at all levels, almost two and a half times slower, than the zero order of control. This difference was significant, $t(17) = 8.16$, $p < .001$. Also, the regression line indicated a linear relationship among the various conditions with the larger and closer box sizes having shorter movement times than the smaller, more distant box sizes, following Fitts' law.

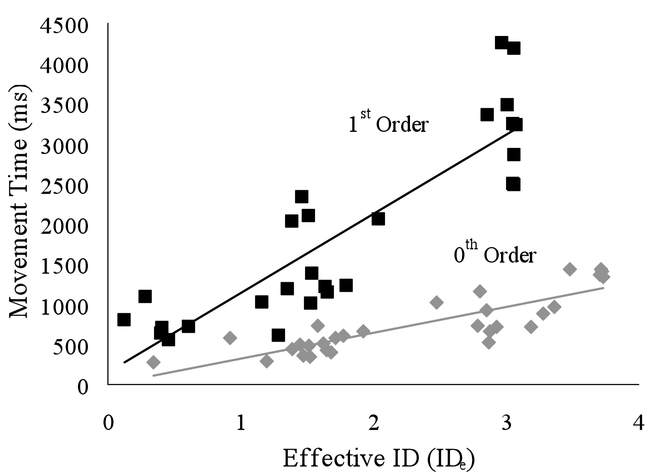

Figure 4. Predicted Movement Time as a function of ID and order of control.

Participants in the zero-order condition made errors on 12% of the trials, while participants in the first-order condition made errors on 21% of the trials. This difference was not statistically reliable but did suggest a trend in the expected direction, $t\,(17) = 1.87$, $p = .08$.

Table 2. Native (calculated) IDs, Mean *effective* ID (ID_e), and Mean *effective* Distance (D_e - in pixels) as a function of box condition and order of control.

Box Condition	Native ID	Mean ID_e	Mean D_e
Small Boxes			
0^{th} Order	3.95	3.35	1150
1^{st} Order	3.95	3.02	1152
Medium Boxes			
0^{th} Order	1.68	2.28	640
1^{st} Order	1.68	1.62	595
Large Boxes			
0^{th} Order	.093	1.32	556
1^{st} Order	.093	.677	298
Collapsed			
0^{th} Order	1.91	2.32	782
1^{st} Order	1.91	1.77	682

In comparing the two orders of control, results indicated (Table 2, above) that participants using the first- order of control device had a smaller effective distance than the participants using the zero-order of control device (there was a small but unreliable reversal in the small box condition). Collapsed across box conditions the D_e difference is statistically reliable, $F(1, 17) = 17.91$, $p = .001$.

The three box conditions (small, medium, and large) represented a reasonable range of native ID values, as seen in Table 2 above. Interestingly, in all box conditions, the mean *effective* IDs (ID_e) for the 1^{st} order condition were smaller than the mean *effective* IDs for the 0^{th} order condition. This may seem counterintuitive at first; why would a 1^{st} order of control device have a smaller *effective* index of difficulty? Remember however, the *effective* ID is calculated by dividing the click-to-click distance by the width of the target (adjusted for error) as seen in equations 2 and 3 above. Participants in the 1^{st} order of control condition were much slower than participants in the 0^{th} order condition and tended to click just inside the target boxes thereby reducing their *effective* distance (D_E – the numerator); which in turn lead to a decrease in *effective* ID. Collapsed across box condition, this difference is statistically reliable, $F(1, 17) = 13.95$, $p = .002$. As stated above, large differences between native IDs and *effective* IDs indicate a bad fit between the pointing device and the task at hand; a result possibly being suggested here.

DISCUSSION

Participants using a the Wiimote® as a first order of control device, those controlling velocity, took longer to move from point to point, but they had a smaller effective distance than those using it as a zero-order device (i.e., a positional control). This would indicate that when using a free moving input device, it is still prudent to allow the user to control position rather than velocity on the device. While not unexpected, this is an important design consideration; simply because a device is able to support novel control modes does not mean it should be use that way.

Future studies could follow a number of directions suggested by the present research. First, a comparison could be made between a restricted-movement input device such as a mouse and a versatile, free-movement input device such as a Wiimote®. In real applications for long-amplitude movements, the mouse is not always ideal, as it must occasionally be lifted and re-positioned mid-move (e.g., when making a long movement and bumping into the keyboard). The Wiimote® has no such limitation.

On the other hand, the Wiimote's® unlimited range of motion may have been a hindrance for some participants in the first order of control; therefore, it may also be valuable to analyze the differences between this device and that of a joystick as two ways of inputting information in the same order of control. The wide movement range may also have impacts in terms of user fatigue and repetitive strain.

Second, it may be useful to evaluate devices like the Wiimote® in applications that require movement in more than two dimensions.

Our experiment does have some limitations. Both sets of participants were evaluated on the same set of box size and distances. The generalizability of the model might have been improved if the second wave of participants had been evaluated on conditions made up of box sizes located between and in different positions then those used for the previously collected data. This would have given us a better sense of prediction. Also, individual differences between the participants did not significantly affect the data because they came from a largely homogeneous group. Before alternative computer input devices can be rationalized for large-scale application, they should be tested on participants with more universal characteristics.

In the ever-changing technological environment, increased functionality with computer input devices will become more important as computer applications change. The present research is only a small step in the direction of evaluating the types of devices that one can use to interact with technological advances. Much like the research of MacKenzie, et al (1991), our data reveals the zero order of control input device to be superior in movement time activities to the first order of control device.

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