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Using Direct and Indirect Input Devices: Attention Demands and Age-Related Differences

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Abstract

Researchers have suggested that attention is a key moderating variable predicting performance with an input device [e.g., Greenstein & Arnaut, 1988] without directly assessing the attention demands of devices We hypothesized that the attentional demands of input devices would be intricately linked to whether the device matched the input requirements of the on-screen task. Further, matching task and device should be more important for attentionally reduced groups, such as older adults. Younger and older adults used either a direct (touch screen) or indirect (rotary encoder) input device to perform matched or mismatched input tasks under a spectrum of attention allocation conditions. Input devices required attention – more so for older adults, especially in a mismatch situation. In addition, task performance was influenced by the mach between task demands and input device characteristics. Though both groups benefited from a match between input device and task input requirements, older adults benefited more and this benefit increased as less attention was available. We offer an *a priori* method to choose an input device for a task by considering the overlap between device attributes and input requirements. These data have implications for design decisions concerning input device selection across age groups and task contexts.

Keywords

Human-computer interaction; direct manipulation; indirect manipulation; cognitive translation; older adults; attentional demands

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General Terms: Input device design, input device choice, screen design, experimentation, Human Factors, aging, attention

1. INTRODUCTION

Cell phones, car navigation systems, and computerized farm equipment are all often used in multi-task scenarios yet little information exists concerning the attentional demands of input devices used in these systems. Attentional requirements associated with input devices might be influenced by: device types, input task variables, and user variables. In this study we examined the importance of a match between human movement, input task demands, and the age of the user operating a device in a multi-task scenario.

1.1 Direct and Indirect Input Devices

Indirect and direct input refers to how data or commands are entered into a system [Jacob, 1996]. Indirect devices translate some action of the human body into data. Examples include a computer mouse, a rotary encoder (containing a knob for movement and a button for activation), or a joystick. Although these devices have different physical attributes they share the cognitive commonality of mental translation between the human body and the machine. For example, moving a mouse forward moves a cursor *upward* on a screen. The spatial translation required has been shown to be cognitively demanding, particularly for older adults experiencing normal age-related decline in spatial ability [Charness, Holley, Feddon, & Jastrzembski, 2005]. Mental translation is also involved in the amount of gain offered by an indirect device; a small movement with a device may produce a large movement on a screen and vice versa. The user must translate the physical distance moved to the virtual distance moved and such translation affects performance and perhaps attentional requirements [Charness et al., 2005; Walker, Philbin, & Fisk, 1997; Wickens, 1998]. Yet it is because of this translation that indirect devices can offer great precision for on-screen tasks.

Direct devices have no intermediary; the movement of the body equals the input to the machine. Examples of direct devices are touch screens, light pens, and voice recognition systems. Direct devices do not require conscious mental translation; the movement effort matches the display distance and performance may be predicted by Fitts' Law type functions [Rogers, Fisk, McLaughlin, & Pak, 2005]. For older users, the directness of operation can result in faster acquisition, operation, and accuracy with the interface [Charness et al., 2005]. Other benefits include the option for ballistic movement. Direct devices do not necessarily produce unilaterally better performance; they can cause performance difficulties for some input tasks due to fatigue, accidental activation, or a lack of precision [Gokturk & Siebert, 1999; Meyer, Cohen, & Nilsen, 1994].

One might conclude that indirect devices should be more attention demanding than direct devices due to the translation required. Indeed, it has been implied that direct devices may “involve less cognitive processing than the actions required with the keyboard and mouse” [Greenstein & Arnaut, 1988, p. 513]. Differential cognitive demands were implicated in a study by Martin and Allan [1991] wherein they found varied performance on a digit-span test across input device types. However, the findings were mixed and attention was not systematically varied across the tasks.

Thus there is conjecture and limited evidence that indirect devices are more attention demanding than direct devices. However, attention demands have not been systematically investigated to determine qualitative and quantitative performance changes as attention is withdrawn from the task. Moreover, this issue has not been addressed in the context of other relevant variables such as the task demands or the age of the user.

1.2 Task Variables

Performance can be determined by the match between type of input device (direct or indirect) and input requirements [Jacob et al., 1994; Rogers et al., 2005]. Degree of match refers to the relationship between input device characteristics (e.g., precise, can quickly repeat) and input requirements (e.g.., precise, repetitive). Meaningful patterns are sought during interface design to allow prediction and reduce the need to test every type of device with every type of task [Jacob et al.]. The ability to predict and specify a match is relevant to the practice and the science of interface design specification. However, previous research on input devices has not examined the match between the device and the task to be performed, but instead compared one device to another to find the “best” device. Input tasks investigated in previous research have varied widely and included target acquisition and positioning tasks [Albert, 1982; Charness et al., 2005; Walker et al., 1997], menu selection [Charness et al.; English, Engelbart, & Berman, 1967], tracking tasks [Hancock, 1996], document annotation [Bekker, van Nes, & Juola, 1995], text entry [Juul-Kristensen, Laursen, Pilegaard, & Jensen, 2004], and scrolling tasks [Chipman, Bederson & Golbeck, 2004]. Perhaps not surprisingly the findings are mixed. In one study, menu selection was faster using a direct rather than indirect device [Karat, McDonald, & Anderson, 1986] whereas in another study of menu selection experienced users were faster with an indirect device but novices were faster with direct devices [English et al.].

The mixed results may be due to tasks being categorized at the level of the overall task (i.e., menu selection, document annotation) rather than in terms of specific input requirements. For example, there are numerous ways to select from a menu such as linking from hypertext, scrolling to view all menu options, or via a drop-down box or “combo” box. Thus, the overall task of menu selection is composed of multiple low-level input requirements at the level needed to predict performance with a device [Rogers et al., 2005]. Input requirements include input precision or amount of repetitive motion. The input requirements may or may not match well with the attributes of the input device. For example, a menu selection task via hyperlinks is a pointing task, where a target is acquired and selected. A menu selection task via a combo-box requires target acquisition, pointing, potentially a sliding motion, visual search of options, a second round of precise target acquisition (as the cursor cannot move outside the combo box or the box will close and the task will abort), and pointing to the desired selection. Thus, input requirements are more specific than overall task type and may better organize research findings when the attributes of an input device are considered.

Some prior research efforts have categorized input-device tasks into their input requirements and compared effectiveness of devices [Rogers et al., 2005; Valk, 1985]. When an input device was mismatched to an input task, such as using a keyboard to manipulate the “sliding” of an indicator to a certain value, performance was inferior to a match between device and input task requirements [Rogers et al.; Valk]. When an input device was matched to an input task, such as using a touch screen to select large buttons for a selection task, performance was not only faster than with a mouse but user group differences (i.e., between young and old adults) were minimized [Murata & Iwase, 2005]. These studies suggest that the concept of matching task demands to input device characteristics is an important one. The practical benefit of considering input requirements in conjunction with input device is that early in the design process one or the other is often amenable to change.

An ill-defined aspect of the device to input-task match/mismatch is the relative attentional demand imposed by input requirements. A mismatch between device characteristics and input requirements is likely to be a source of increased attentional demand [e.g., Schneider & Fisk, 1982; Wickens, 1984], as in the keyboard/sliding example from Valk [1984]. The stability of match or mismatch relationships across device and input requirements has been shown to be affected by age-related characteristics of the user [Rogers et al., 2005]; thus, age should remain an important predictor, perhaps even more so when attentional demand is examined.

1.3 Younger Compared to Older Adults

Age-related differences affect which device is optimal for a task [Charness et al., 2005; Rogers et al., 2005]. For example, Charness et al. found that use of a direct input device minimized age differences for a menu acquisition task that primarily involved pointing. A similar investigation by Jastrzembski, Charness, Holley, and Feddon [2005] found that older adults benefited initially from an indirect device when performing a pointing task immediately followed by keyboard entry. In Rogers et al., age-related performance differences with direct and indirect devices interacted with input task demands; in general, older adult performance was more sensitive to whether there was a match between input device characteristics and input requirements.

Age-related changes in attention [Rogers & Fisk, 2001] indicate that the age of the user would interact with attentional demands of input devices. Older adults exhibit characteristics of reduced attentional resources when compared with younger adults [e.g., Madden, 1986; Tsang & Shaner, 1998] and have more difficulty performing tasks when divided attention is required [Korteling, 1994; Kramer, Larish, & Strayer, 1995; Park, Smith, Dudley, & Lafronza 1989; Ponds, Brouwer, & Van Wolffelaar, 1988]. Thus, if differing attentional demands are required across input devices based on the tasks performed with them, older adult performance should suffer more than younger adult performance when they have less attention available for the task.

2. OVERVIEW OF THE EXPERIMENT

The goal of the current study was to understand attention demands of input devices as a function of input requirements. Input requirements were manipulated by the type of on-screen control used (widget) and the specific task performed with the control. Input requirements were divided into four categories: pointing, repetitive, precision, or ballistic, (selected based on the findings of Rogers et al. [2005]). The input devices chosen were direct and indirect. Two categories of input requirements matched the direct device (pointing & ballistic) and two matched the indirect device (precision & repetitive). The input requirements that matched one type of device provided a mismatch for the other device. These matches or mismatches were determined by the affordances of the device (i.e., pointing matched the affordances of the touch screen).

We manipulated attention allocation via a dual-task procedure. Participants performed an input task and a video-game simultaneously (described below). Participants either allocated 100, 80, 50 or 20 percent of their attention to the input task (thus, 0, 20, 50, or 80 attention was allocated respectively to the video-game task). This paradigm is a “between-task dual task” [Schneider & Fisk, 1982] and is representative of time-sharing tasks [Pashler & Johnston, 1998; Wickens, 1980]. Such procedures have been shown to successfully create differential attention allocation levels within a single study [Gopher, 1993]. In this way, we specifically manipulated the amount of attention participants had available for use of the devices. Therefore, changes in performance with the devices from the 100% available attention condition indicated changes due to the amount of attention available to participants [Navon & Gopher, 1979; Norman & Bobrow, 1975]. Thus, if performance time increased as a function of reduced attention we attributed the resulting performance resource function to differential attention requirements for operation in a matched versus mismatched scenario [Norman & Bobrow; Shiffrin & Schneider, 1977].

We included the grouping variable, age, for two reasons. From an applications perspective, understanding age-related differences in device design is a growing need [Fisk, Rogers, Czaja, Charness, & Sharit, 2004]. From a theoretical perspective, known age-related changes in attention suggest that any attention allocation effects should be accentuated. If match/mismatch of input task demands and device characteristics are indeed an attentional phenomenon, then a mismatch should slow older adults' performance differentially compared to younger adults' performance. Hence, the individual difference variable (age) served as a crucible to better define the match/mismatch phenomenon as a function of task demands [Kerr, 1973] or a function of attention [Schneider & Chein, 2003].

3. METHOD

3.1 Participants

Twenty-four younger (aged 18 to 25, mean = 20.1 years, SD = 1.3 years) and 24 older (aged 60 to 70, mean = 65.2 years, SD = 3.0) adults received course credit or monetary compensation. All participants were right-handed [Oldfield, 1971], fluent English-speakers, with corrected or uncorrected near and far vision of at least 20/40. Participants completed the following ability tests: vocabulary [Shipley, 1940], reverse digit-span [Wechsler, 1997], digit symbol substitution [Wechsler, 1981], and simple and choice reaction time. There were no ability differences between input device conditions within age groups, and age-related differences between age groups were typical of those reported in previous research [e.g., Rogers, Hertzog, & Fisk, 2002]. That is, younger adults reported higher self-ratings of health and performed better on the digit-symbol substitution task, reverse digit-span task, and simple and choice reaction time tests; whereas older adults had completed more years of education and produced higher vocabulary scores (all p's $< .05$).

3.2 Materials

3.2.1 Entertainment System Simulator task software—The Entertainment System Simulator (hereafter referred to as the Simulator) was locally developed using Visual Basic [Rogers et al., 2005] to mimic a home entertainment system with radio, CD, and weather information controls (see Figure 1). We used the Simulator to keep input operations within a familiar task. The program recorded time to complete an input task (i.e., a finger press on the touch screen or a button push on the rotary encoder). The Simulator collected all input information from the touch screen and rotary encoder from the start to end of each task. All screen text was >= 14pt font.

3.2.2 Tasks and input requirements—Input requirements (Figure 1) were a combination of the control and the task demands. We developed tasks that varied in their input demands to assess the match concept. Use of up/down controls could be via either a pointing task or one that involved repetitive control pressing, depending on how many presses were required. Using few presses (<4) was considered a pointing task whereas using multiple presses (>10) was considered a repetitive task. No task included 5-9 presses.

Slider controls were operated by moving an indicator along a slider to a prescribed value. Using a slider could be either a precision task, when the goal value was a short distance from the start position (<20mm) or a ballistic task when the goal value was far from the start position at the end of the slider (>40mm). No task required a goal value of 21-39mm.

3.2.3 Dual task software—The second task, a spatially and attentionally demanding video-game, consisted of dots falling on a screen with a two-dimensional bin at the bottom that participants moved left and right to collect dots as they fell (Figure 1). Dots fell at a fixed rate, calibrated to be fast enough so no participant could catch 100% of the dots. The video game task was shown on the left monitor and participants moved the bin via the arrow keys with their left hand.

3.2.4 Attention instructions—Participants were told to divide their attention between the two tasks in terms of effort. For example, instruction for the 80/20 condition consisted of "For this next block of trials, please devote 80% of your effort toward the video game and 20% toward completing the steps on the Simulator."

3.2.5 Equipment—The equipment is illustrated in Figure 1. Participants operated either the touch screen or the rotary encoder with their right hand to complete the Simulator tasks. The touch screen was a DataLux LMV10 resistive touch screen attached to the desk. The active, touchable screen was 10.4 inches in diameter. The rotary encoder was a small box with a knob and button. The knob moved between on-screen controls and the button activated the controls. The knob was 1.5" in diameter. The box was 3.25" long × 1.5" wide × 1" high and secured to an extension from the table to the right of the participant. A keyboard was used to operate the video game task with the left hand.

Computers running at 333 MHz with 128 MB of RAM were used for the study. The monitor for displaying the video game task was 19" in diameter and participants were seated approximately 18" from the monitor. A second computer of the same specifications collected data for the Simulator task, from either the touch screen or the rotary encoder input device.

3.2.6 Arrangement of input devices and displays—The tasks were presented on separate monitors and operated with different input devices (Figure 1). The Simulator task instructions were presented above the Simulator display which was presented on the touch screen monitor. Participants used either the touch screen or the rotary encoder as the input device. However both input devices manipulated the on-screen controls visible on the touch screen monitor to equate the display characteristics across conditions.

3.2.7 Design and procedure—The independent variables were: Attention (20/80, 50/50, 80/20, 100/0) and Match (Match, Mismatch). Both variables were within-participant as every participant was exposed to both matches and mismatches with their assigned input device across the entire spectrum of attentional allocation. Device type (touchscreen, rotary encoder) was a between-participants variable. Age (Younger Adults, Older Adults) was a quasi-independent grouping variable. The primary dependent variable for the Simulator tasks was time spent completing an input task. We also measured accuracy of performing the input requirements. Performance accuracy was the dependent variable for the video game task.

Participants were tested individually or in groups of two in separate cubicles. Following informed consent participants completed the ability tests followed by a five to ten minute break. They then received written instructions for the Simulator and video game tasks, along with instruction on what it means to divide attention. The experimenter then gave a demonstration of the tasks and answered questions. After two guided practice trials, participants performed the first section of Simulator tasks. Participants took mandatory five minute breaks after each attentional condition. They completed twenty practice trials and one hundred experimental trials total over three days (one hour per day).

4. RESULTS

4.1 Manipulation Check

To assess whether participants were able to divide attention as directed, we examined performance (percentage of dots caught with the bin) on the video game task via an Age × Device × Attention ANOVA. We converted the scores to z-scores to make the comparisons between age groups graphically meaningful (Figure 2), but analyses for the manipulation check were conducted on the untransformed data. If participants divided attention as directed, their performance should change according to the amount of attention directed to the video game task and those scores should be similar across devices within each attention condition. As shown in Figure 2, participants *were* able to change the amount of effort allocated to the video game task; that is, scores were better when more attention was devoted to the task. There was a significant main effect of Attention whereby score worsened as attention was reduced, $F(1,44) = 68.5$, $p < .05$, $\eta_p^2 = .94$. There was a main effect of Age whereby older adults generally performed less accurately than younger adults, $F(1,44) = 142.07$, $p < .05$, $\eta_p^2 = .76$, which we expected due to the motor control and speed required by the video game task. However, there was no Device × Attention interaction, ($p = .84$), Device × Age interaction ($p = .37$), nor was there a main effect of Device, ($p = .21$), meaning there was no apparent differential effect in the attention devoted to the video game task across the two device groups or across the two age groups. These data suggested participants allocated their attention as instructed and both device groups followed instructions similarly. This allowed us to consider the match/mismatch between input device and input requirements as an indicator of performance. For example, it was not the case that direct device users followed our attention allocation instructions differently than indirect device users. There was an Age × Attention interaction, $F(2,88) = 27.83$; $p < .001$; $\eta_p^2 = .39$; older adults did not have as wide a range in scores from the 20% to 80% attentional conditions as younger adults.

4.2 Analyses of Time to Complete Input Requirements

There were two main questions of interest pertaining to the match between the task demands and the device characteristics. First, does a match between input device and task demands predict performance with a device? Moreover, as attentional resources decline (whether due to the addition of the video game task and/or age-related differences in attentional ability) does that match become more crucial?

Response time for input tasks was the chosen measure of performance. Accuracy on the Simulator was above 99% for all groups, which indicated no accuracy/response time trade off and allowed the use of response time as a measure of performance. The time required to complete a single input task on the Simulator was used as an index of the attentional demands [for a review of the history of using time as an index of attentional demands see Posner, 1978; also see Reinvang, 1998; Shiffrin, 1988; Shiffrin & Schneider, 1977]. The results showed match or mismatch did impose relatively different attentional demands that interacted with both age and attention allocation.

4..2.2 Matching task demands to input device—We assessed performance for four input requirements that differed in whether the task demands matched the characteristics of the input device. Pointing tasks and ballistic tasks were presumed to be best suited to the touch screen whereas the repetitive tasks and precision tasks were expected to be better matched to the rotary encoder.

A 2(Age) × 2(Match) × 4(Attention) repeated measures ANOVA was performed on z-scores of the response time data. Z-scores were computed to standardize the amount of time spent on each type of input requirement; for example, due to the nature of the tasks, repetitive controls took far longer to operate than did the pointing controls no matter what the input device, age group or match/mismatch condition ($M_{pointing}$ = 19.4 seconds vs. $M_{repetitive}$ = 4.8 seconds). We were interested in the relative speed with which these tasks were performed when there was a match or mismatch with input device. Thus, z-scores were computed using the grand mean across attentional conditions, input requirements, and age groups. Older adults were slower in general than younger adults, $F(1,46) = 108.16$, $p < .01$, $\eta_p^2 = .70$, and response times increased as less attention was devoted to the task, $F(3,138) = 35.97$, $p < .01$, $\eta_p^2 = .44$. Older adult response times increased more than younger adult responses as soon as they divided their attention, $F(3,138) = 10.24$, $p < .01$, $\eta_p^2 = .18$, in line with prior research on older adult attentional abilities [see McDowd & Shaw, 2000, for a review].

An interaction of attentional allocation, match, and age group indicated the importance of a match for each age group, and how that match increased in importance as attention was taken away from the task, $F(3,130) = 3.99$, $p < .01$, $\eta_p^2 = .08$. In general, when less attention was available, response times increased. However the response times of older adults in a mismatched situation increased differentially compared to those using an input device matched to the task (Figure 3).

Planned contrasts for each age group between matched and unmatched response times in each attentional condition generally indicated that a mismatched task took longer than a matched task (p’s < .01). Exceptions were for the older adults in the 100% attentional condition and for younger adults in the 50% attentional condition (p’s = .55 and .06). That older adults were unaffected by a mismatch in the 100% attentional condition supports the claim that the amount of attention available interacted critically with match/mismatch in older adult performance. It is unknown why younger adults did not perform faster in a matched situation at 50% attention.

Thus the match between task demands and input device features does seem to be important. Younger adults may be better able to compensate for a mismatch, even when their attention was divided. However, older adults benefited from a match between device and task as soon as their attention was divided, and their need for a match increased as less attention was available for the task. In sum, using input devices clearly required attention. Withdrawal of attention had the largest impact for older adults and especially when they were using an input device mismatched to the input requirements.

5. DISCUSSION

The central question of this research related to the attentional demands of input devices and how those demands are moderated by input requirements and user age. The results showed that using an input device required attention and the demands on attention were greater for a mismatch of device and input requirements, for older adults relative to younger adults, and the most attention was demanded from older adult users using a device mismatched to the input requirements. We directly controlled and tested the concept of a match or mismatch between device and input requirements put forth by Rogers et al. [2005]. Further, we examined the notion that a match/mismatch was linked to attentional resources by controlling the amount of attention available. This produced observable functions in performance that depended on available attentional resources. Not only was the match/mismatch hypothesis supported, one of the potential *causes* of why there would be performance differences was validated: attention influenced performance differently in matched versus mismatched conditions. The differential difficulty experienced by older adults in a mismatch scenario provided evidence of an attentional cause, and was further supported by their increasing response times as less attention was available, compared to using a device matched to the input requirements.

Previous descriptions of differences between devices focused primarily on their physical or perceptual characteristics [Card, MacKinlay, & Robertson, 1990; Foley, Wallace, & Chan, 1984; Jacob, 1996; Jacob et al., 1994] or declared a particular class of devices to be less cognitively demanding than another [Greenstein & Arnaut, 1988]. However, the relationship between tasks and devices is lawful and predictable under the match/mismatch paradigm.

5.1 Design Recommendations

The present data, along with other studies in the literature converge on the following recommendations. First, the design of the interface should be made with consideration for the choice of the input device. For example, a slider control (requiring precision) and an up-down control (requiring pointing or repetition) may accomplish the same task goal (to set a value.) If a touch screen is chosen as the input device for a system, on-screen controls should be selected that match the characteristics of that input device. For example, a slider control or keypad may be used in place of up-down controls when settings are expected to change a great amount during operation. This will help to avoid repetitive movement with the direct device.

Older adults' performance suffered more than younger adult performance due to attentional demands of the input device itself pulling attentional resources from the task and thus hampering performance. However, older adults did benefit from operating an input device that matched the demands of their task. Choosing either a direct device or an indirect device may be appropriate for older adults depending on the demands of the task. Indeed, these results indicate that a match can prove more important for older adult users than avoiding translation or gain in input devices.

In the present study match was defined as using a touch screen for pointing and ballistic tasks and a rotary encoder for repetitive or precision tasks. This does not encompass all available input devices and input requirements, including input devices not yet imagined or created. The benefit of the current study was to provide a theoretical structure in which to explore and map out other matches and mismatches. Designers may use the current information to design interfaces well-matched to direct and indirect input devices (taking into account any idiosyncrasies of a particular device.) Further research and testing of the match/mismatch theory should complete the map of device/task space to offer solid guidelines for any input device and task.

5.2 Conclusion

In addition to everything else that requires attention in a task context, the input device itself also imposes attentional demands. This finding should be considered during the interface design process and the input device selection process. If attention must be devoted across multiple tasks, a match is critically important for older adult users (and also benefits younger adults). Thus the relative benefits of a device for reducing attention demands must be weighed against the costs of that device if precision or repetitive tasks must be performed.

Though in some cases direct devices may be easier for older adults to use, this experiment demonstrates that is not always or even often the case. “Easier” very much depends on the interaction of variables and we can increase speed of use by carefully matching device and input requirements. This is an important step forward in our knowledge of the attentional demands of input devices and the design of input displays.

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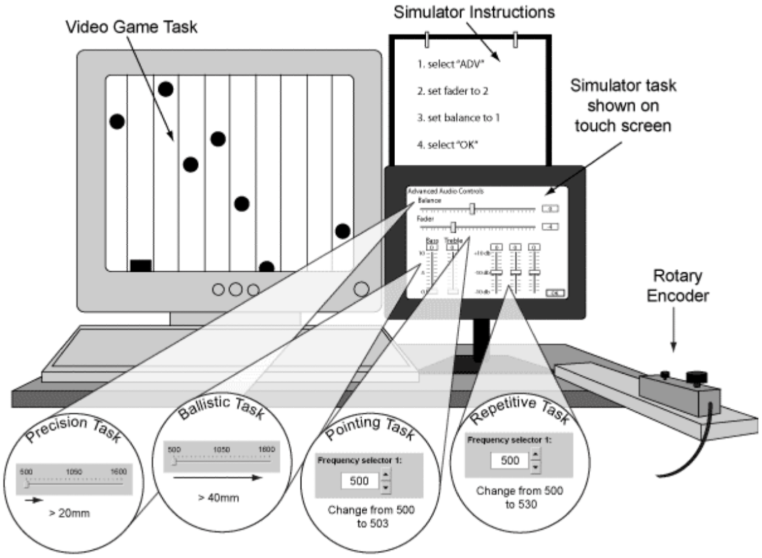

Figure 1.

Arrangement of the two tasks and input devices. Callouts illustrate exemplars of the four input requirements shown on the Simulator.

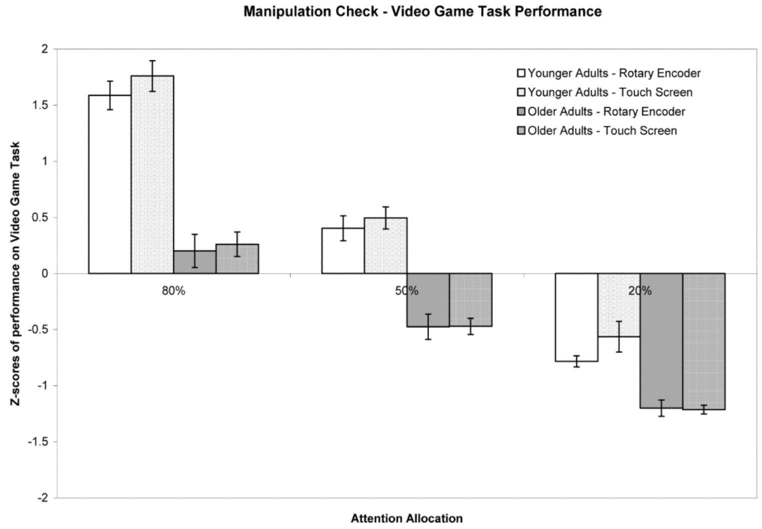

Figure 2.

Analysis to determine if participants distributed attention as instructed. Scores were converted to z-scores to show relative performance of older and younger adults. Standardized scores are presented for each attentional allocation condition. Bars represent standard error.

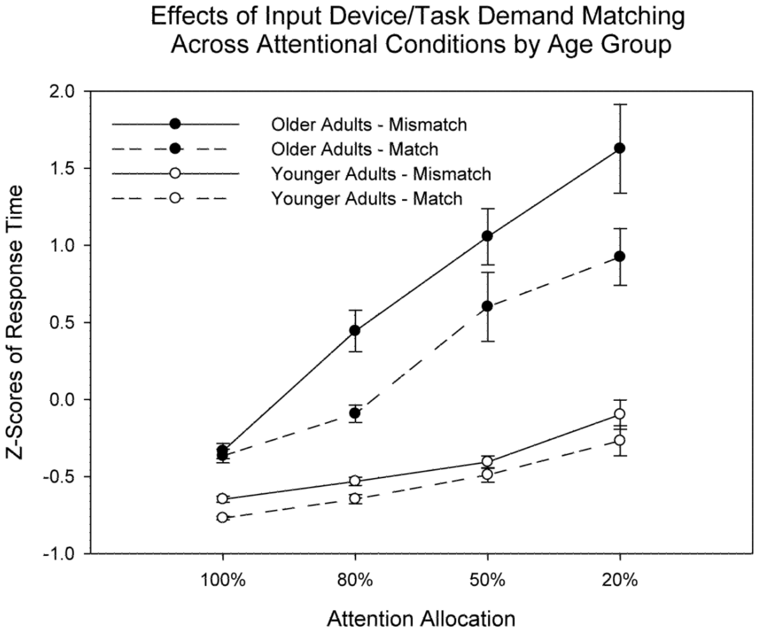

Figure 3.

Graphical analysis of the importance of a match between device characteristics and task demands as a function of attention for younger and older adults. Scores were converted to z-scores to show relative performance of older and younger adults. Bars represent standard error.