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Accuracy of non-visual directional pointing with various manual input devices

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A B S T R A C T

In a self-testing vision screener, examinees use an input device for pointing the orientation of the targets, which are presented inside the vision screener. Examinees operate the input device without visual feedback. In the present study, the suitability of pointing devices was evaluated for conditions such as are present in a self-testing vision screener. The evaluation consisted of an experimental assessment of pointing accuracy and recording subjective ratings while using the various devices. Six commercially available computer input devices – a joystick, a gamepad, a trackball, two track pads and a PC mouse - were evaluated under visual conditions similar to those that would be present when using a self-testing vision screener.

Pointing accuracy was found to vary significantly with the type of device ($F(3.2, 93.1) = 3.937$, $p = 0.009$) and the effect of the device on pointing accuracy was important (partial $\eta^2 = 0.120$). The most accurate pointing was achieved when participants used the joystick. Using the joystick, a mean of 96.8% ($SD = 4.3\%$) of pointing trials resulted in the correct orientation. If only diagonal orientations are considered, the correct pointing rate increased to a mean of 99.5% ($SD = 1.5\%$) when using the joystick.

In terms of the subjective ranking, the gamepad and the joystick achieved the best and the second best ranks respectively, whereas the trackball was the least preferred device.

Based on our findings, we recommend using a joystick as an input device in pointing tasks in order to minimize the effects of suboptimal visual feedback on motor performance. As for the particular case of testing visual acuity, various procedures are suggested. Thus, the effect of suboptimal visual feedback on the outcome of the acuity test is reduced.

1. Introduction

Suboptimal visual feedback may affect motor response in a pointing task. In a self-testing vision screener, erroneous motor responses may cause the failure of a vision test, despite good visual fitness of the patient. Such a failure could lead to legal issues, such as in investigations about the causes of a car accident. In addition, the failure of a vision test could generate unwanted costs because of the need for a more detailed visual examination of the patient failing the screening test.

Unfortunately, the literature does not provide enough information enabling to estimate the effects of a suboptimal visual feedback on motor response for conditions as met in a self-testing vision screening. This paper aims to investigate the accuracy in a non-visual directional pointing task in order to estimate the effect of a suboptimal visual feedback on the outcome of a self-testing vision screening. Our investigation is led by the hypothesis that different commercially available input devices affect motor performance in a self-testing vision screening in different ways.

Self-testing procedures are a means of improving efficiency in the screening of visual functions. To our knowledge, voice recognition and manual input devices have been implemented for recording an examinee's answers in a self-testing vision screening. The method based on voice recognition is constrained by the acoustical environment, in which the screening is carried out. An

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alternative way to record the answers in a self-testing screening is the use of a manual input device, such as an answering box, a keyboard (Johnston, 1968; Menozzi, 1995; Bach, 1996; Hoffmann and Menozzi, 1997), or a joystick (Gofin and Falk, 1991). In order to minimize the effects of uncontrolled lighting conditions, test charts are presented inside the vision screening instrument. Examinees are therefore required to gaze into the instrument in order to take the tests. For several reasons, examinees keep fixation into the instrument throughout the tests. First, the throughout fixation of the test chart prevents them from losing track of the ongoing test and the need to allocate time for retrieving the position of the actual target in the test chart. Second, variation in visual conditions, e.g. the variation of lighting or of demand of accommodation, may bias the results of the vision screening test. The throughout fixation of the test chart inside the instrument implies to operate the manual input device without visual feedback of one's motor response. The lack of visual feedback could affect accuracy while pointing and therefore generate faulty inputs, which then affect the results of the vision screening. Attempts have been made to include visual feedback within the vision screener (personal communication of Titmus company). However, the development of such a technique was abandoned because the combined presentation of the visual feedback and the vision test chart turned out to disturb the test procedure.

In vision screening, the required pointing accuracy depends on the type of vision test applied. When testing for visual acuity following the ISO 8596:2009 standard procedure, Landolt rings in eight equidistantly distributed orientations are presented. Therefore, pointing should occur with an accuracy of at least $<\pm 22.5^\circ$. Other vision screening tests may require an increased accuracy because a higher number of discriminations are required, such as 15 orientations when testing color vision by means of the Farnsworth – Munsell D-15 test. In some acuity tests only orthogonal oriented targets, e.g. Snellen's E, are used. In such cases, an accuracy of $<90^\circ$ is sufficient.

In addition to automated vision screening, the operation of manual input devices under suboptimal visual feedback conditions occurs in a variety of other tasks, e.g. in the tele-operation of surgical instruments, robots, cranes or drones. In car driving, manipulators, such as blinker, radio station selection, heater etc. may be operated without using visual feedback.

The literature offers some insight into how the accuracy of motor tasks varies with the availability of visual feedback (Rosenbaum, 2010). In general, the use of visual feedback improves accuracy but slows down the speed of a motor task (Woodworth, 1899). Gordon et al. (1994) investigated pointing performance in the absence of visual feedback by means of an experiment, in which participants used a tablet to point to targets presented on a separate display. The targets were visible before the start of the trial and were switched off during the pointing movement. Additionally, the sight of the arm and of the hand was blocked. Gordon et al. (1994) found that directional errors in pointing were less important than errors in the extent of the movement along the movement direction. Gordon et al. concluded that “movements are planned in a coordinate system that has its origin at the initial position of the hand”. An analysis of their data by eye, in which ellipses including 95% of the end position of the pointing trajectories are reported, reveal a pointing direction accuracy of about $\pm 8^\circ$. Based on the results of a similar experiment, Pantes et al. (2009) concluded that the directional pointing errors range between about 5° and 15°, depending on pointing orientation, the participant, and the visual memorization involved in the task. Pantes et al. (2009) report better accuracies for orthogonal pointing directions than for diagonal directions, a phenomenon that is present in a large variety of perceptual tasks (Appelle, 1972).

Brouwer and Knill (2007) were able to show, that performance in reaching tasks relies in part on the memorized location of objects. Moreover, the memorized location of an object affects a motor task even in cases, in which the visual information about the manipulated objects is available. Therefore, spatial memory could partly compensate for a lack of visual feedback. Li and Durgin (2016) have investigated the role of spatial memory in the perception of orientations. In their study, numeric estimates for azimuthal orientations ranging from -48° to 48° relative to straight ahead were obtained. The result of their experiment showed an exaggeration of perceived azimuthal orientation of about 26%. Such an exaggeration would almost inevitably cause a faulty response in a self-testing vision screening.

A large body of literature has evolved reporting about ergonomic design of computer input devices (an overview in Hinckley and Wigdor, 2012). One important design principle is to establish an acceptable level of compatibility between the manipulation task and the resulting action. Directional compatibility of motion, also termed “kinesthetic correspondence” (Hinckley and Wigdor, 2012), among other issues, has been addressed experimentally in a study by Worringham and Beringer (1998). Worringham et al. found that directional compatibility should primarily be based on the correspondence of motion of the relevant limb segment and motion of the cursor in the visual field of the observer, rather than on the correspondence between directions of motion of the input device and directions of motion of the cursor on the display. Some studies have addressed the effects of suboptimal visual feedback conditions when using manual input devices. In a task using a tablet computer, Causse et al. (2014) investigated the effect of practice and visual feedback on manipulation performance when the manipulation space and display space are dissociated. Causse et al. (2014) found that practice improves manipulation performance even in absence of visual feedback. However, practicing with visual feedback leads to better accuracy. A study by Ferrel et al. (2000) addressed the effects of changes in scale between the space of the manipulating hand and target representation space. Ferrel et al. (2000) used an electromagnetic stylus on a digitizing tablet as an input device. The results of their study demonstrated that adaptation to changes in control-to-display gain is driven by visual feedback, rather than by kinematic feedback during hand movements.

Summing up the literature, the quality and the availability of visual feedback affect the accuracy of manipulation actions. A lack of visual feedback may, in part, be compensated for by spatial memory. The contribution of spatial memory to motor performance has been investigated only for durations lasting a couple of seconds. It is therefore unclear, to what degree spatial memory may support motor actions for durations such as those involved in a self-testing visual screening. In the case of a simple test procedure, visual screening by means of self-testing instruments lasts several minutes (Menozzi, 2013). Durations of up to tenths of minutes are possible when sophisticated tests are adopted. Considering a vision test requiring the discrimination of eight orientations, as stated by the ISO 8596:2009 standard procedure for acuity testing, an accuracy of $<\pm 22.5^\circ$ or better is required. The above-reported accuracies for pointing orientation in cases of a short deprivation of visual feedback range from 5° to 15°. It is unclear whether a long deprivation duration decreases accuracy up to an extent that would critically affect the reliability of a vision test.

The present research work examined pointing accuracy while operating an input device for almost 3 min. The experiment required participants to point at various orientations while deprived from visual feedback regarding their motor actions. Six commercially available computer input devices were used.