Pressure or Movement?
Usability of Multi-Functional Foot-Based Interfaces

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ABSTRACT

Despite considerable prior work exploring foot-based interaction techniques, direct comparisons of the performance of these approaches have been lacking. Here, we compare the performance of the two most common approaches found in previous studies: rocking (applying pressure to different parts of the foot) versus rotating and sliding, considering the use case of a hands-free interface intended for seated musicians. Participants performed a number of representative operations, such as setting the tempo of a metronome, using the two strategies. Results indicate superiority of the rotating and sliding approach, both in completion time and responses to NASA TLX questionnaires, although rocking was preferred by some participants due to its ergonomics and subtle movements required for parameter-controlling tasks. Beyond the comparison itself, the decisions we faced related to menu design and feedback for our use case may offer helpful insight for the design of future foot-based interfaces.

ACM Classification Keywords

H.5.2. User Interfaces: Input devices and strategies; Interaction styles

Author Keywords

User Experience Design; Foot-Controlled Input; Hands-free interface; Interaction Design.

INTRODUCTION

Hand-based input dominates human-computer interaction. However, channeling all such interaction through the hands may be sub-optimal, both from the perspective of capacity and the associated risks of injury, e.g., repetitive strain injury. Furthermore, various activities such as music, sports, and medicine, impose significant non-computer-interaction demands on our hands, motivating consideration of interaction with the computer using other parts of the body [22].

Encouragingly, foot-based interaction has been shown to achieve performance that is within the range of hand-based interfaces, both for simple target-pointing tasks [8] and for non-accurate spatial tasks [12]. These results motivate further exploration of foot-based interfaces for additional interaction tasks.

Despite considerable research exploring foot-based interaction, there has been little work, to date, evaluating competing approaches as to their performance and user experience. To evaluate the effectiveness of the competing approaches, we carried out a systematic comparison of performance and user experience of two of the most popular techniques (pressure and movement), in the context of foot-based menu selection and parameter control for a musical performance user interface. This choice of application was motivated as an obvious use case in which users' hands are typically occupied, and additional control is often required. The techniques we investigated and the results obtained should apply equally to other foot-based interaction by seated users.

Use of pedals for foot-based interaction is also common, but pedals are typically limited in the interactions they afford, and pose safety issues such as risk of tripping [20]. The instrumented shoes we employ in the present study afford similar input capabilities through pressure sensing or tapping detection, and can be used at arbitrary physical locations.

The primary contribution of this paper is our examination of a number of design choices related to foot-based menu interaction. This involved a series of studies that compare task performance with pressure- and movement-based menu control. Additionally, we investigate factors including the suitable range of motion for such interaction and the influence of sitting vs. standing posture.

RELATED WORK

Frequently used foot gestures for interaction include tapping [2], scrolling [17], rotating [6, 22], stepping [21], kicking [5], and rocking [1, 3, 13].

Tapping of the toe is generally preferred to the heel, owing to its comparatively low effort and historical operation in pedals [20]. In addition, tapping is considered as a body-based gesture with a high level of social acceptability [15], as it can be considered a subtle, everyday motion.

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The scrolling motion, which is the smooth displacement in a specific direction, has been commonly used as a foot interaction technique. Foot-based scrolling has been shown to achieve throughput that is approximately 70% of the hands for simple target-pointing tasks [8] and 60% of the speed for non-accurate spatial tasks [12]. Saunders et al. investigated foot-based scrolling control of a cursor displayed on-screen and showed advantages in that a user can focus on the display rather than looking at their feet [17].

Rotating the foot is the abduction or adduction foot movement pivoting at the ankle [20]. This rotating foot movement can be divided mainly either heel or toe rotating movement and both showed similar performance, but heel rotation is expressed as more preferred movement [18]. When interacting with a user interface, the rotating foot movement is normally associated with the selection of items in a radial pie menu. However, due to the limited range of foot rotation, only a portion of the circle can be used, which reduces the angular extent that can be allocated to each menu item [22]. Despite this limitation, foot rotation was found to be the least physically demanding method for foot interaction [6], and offers advantages of greater ease of movement, as well as reduced fatigue, compared to horizontal and vertical movement [19]. Given these advantages, rotation was used for foot-based interaction in a medical image manipulation application task [6].

Modified foot steps during gait have also been used for interaction, allowing the user to control media player functions, simply by altering their normal jogging steps, e.g., with deliberately shifted steps to the left or right, or by double-stepping on either foot [21]. Such interaction may, however, be problematic in terms of the risk of injury.

Work has also been done examining the dexterity of using kicking as a gesture. Han et al. found the feasibility of kick gestures in mobile contexts, where hands occupied, by distinguishing up to five directions and two velocities for kick gestures from users [5]. Yet, the segmentation of the interaction range of kick gesture depends on the user and errors can be caused, so a customized range may be preferred over a conservative range to enhance the robustness of the system [17].

Another technique, foot rocking, involves applying pressure selectively to one part of the foot, typically the toe, heel, left or right side. Paradiso et al. measured pressure with force-sensing resistors embedded in the floor [13], while Fukahori et al. used footwear with sock-or-shoe based sensors [3], The latter employed the foot rocking technique in a study investigating the use of 29 patterns of pressure over one or both feet, e.g., pressure on left heel and right toe, to control functions such as map navigation and phone control [3].

Recently, combinations of gestures have been explored in the design of foot-based interactions. For example, Saunders et al. implemented 22 combinations, using four foot actions (toe tap, heel tap, whole foot tap and kick) in three directions (forward, side, and back) with both feet [17] to control conventional desktop applications. There lies the possible danger, however, that applying potentially arbitrary foot gestures to a multitude of functions could introduce a complex mapping that would quickly overwhelm users. For a diverse set of applications, a one-to-many mapping of gestures to functions across different applications may be criticized as risking inconsistency. Saunders et al. note that some of their functions were difficult to learn, even with the addition of a "help screen" [17]. In contrast, a non-overlapping mapping would require a large collection of gestures and their corresponding mappings to be memorized by users. As a result of the complexity of this gesture set, Fukahori et al. obtained low accuracy (56.2%) on leave-one-out cross validation and noted that their gesture set resulted in participant fatigue [3].

Use of a menu hierarchy may be unavoidable in order to extend foot-based interaction to a non-trivial number of operation, without the risk of such a complexity of mapping. Otherwise, foot-based interaction may be best restricted to limited tasks such as media player control [17] or the simple operation of answering a phone call or playing/pausing a music player.

COMPARING FOOT-BASED INTERACTION APPROACHES

Our music practice and performance support interface was designed to allow for comparisons between different approaches to foot-based interaction. To determine the set of functions that would be most useful to include in this interface, we first conducted a survey among 26 randomly selected musicians, 12 of whom were professional, to prioritize a set of possible options.

function	# pro	# amateurs
page turning	11	10
zooming on music sheet	4	5
record and replay	7	7
metronome control	9	1

Table 1: Number of professionals and amateurs requesting each of several features for computer support of their musical performance or practice.

The resulting menu hierarchy used in our experiments followed directly from the survey results, above. However, we emphasize that the objective of this work was not to evaluate the simple music practice and performance support system, but rather, to use it as a vehicle for experimentation on fundamentals of foot-based interaction.

As such, for each of the requested functions, we considered how best to design the interaction such that it would allow for our comparison of task performance on each of the fundamental aspects of menu selection, parameter control, and positioning.

After identifying the functions and parameter controls to be implemented in the system, we set out to determine whether foot movement or pressure were superior interaction techniques for these.

Foot Motion Options

Given the advantages of foot rotation over linear movement [6, 18, 19], as previously discussed, we relied primarily on heel rotation for menu selection and single parameter-controlling tasks. For tasks involving two parameters, such as spatial positioning in 2D planes, combined control of the parameters using the *x-y* position of one foot showed better performance than separating the axes across the feet [19]. We therefore used horizontal and vertical sliding foot movement for the task requiring control of two parameters. Where three parameters must be controlled, we employ both feet, using one foot as above for *x-y* position, and the second foot for control of zoom. Since inconsistent spatial mappings can negatively impact performance [19], we use linear sliding (forward/backward) for this purpose.

Button-Press Design Choices

For the foot pressure approach, we first sought to understand, through a pilot test, the trade-offs between a simple "direct button press" and a "select-then-confirm" menu design. The former allowed users to activate the desired function directly by exerting pressure on the corresponding portion of the foot, while the latter required a two-step procedure of first selecting the desired function by left/right pressure, and then activating it by a confirmation gesture, in our case, pushing the toe.

In previous work, Fukahori et al. found that repeatedly performing a separate "press" for confirmation could be a cause of fatigue [3]. To avoid this problem, we opted to use the interaction style of pressing a part of the foot and holding it to change parameter values, then releasing pressure to confirm the selection.

In the pilot, participants were shown a horizontal array of four items marked with letters "A" through "D", and were asked to click on the menu items, which were displayed one at a time, in counterbalanced order. Following a training session to familiarize themselves with the two approaches, participants proceeded to the experimental trials. Response time for each task and the number of errors made were recorded automatically. Testing was performed on four lab members, ages 21-35 (μ = 26, σ = 6.2) (2F/2M).

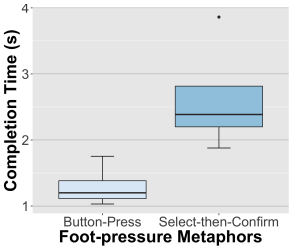


Figure 1: Box plot of completion time

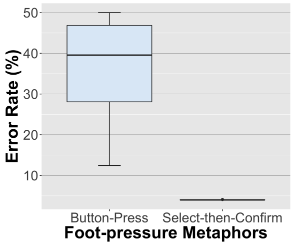


Figure 2: Tukey box plots of error rate

The pilot results indicated a significant time advantage of the direct button push (average 1.2 s) against "select-then-confirm" (average 2.6 s) (Figure 1) at the cost of increased error rate (Figure 2). Since we typically expect high accuracy for menu-selection tasks, we conduct the full experiment using the "select-then-confirm" metaphor in conjunction with pressure control. This offers the additional advantage of a consistent interaction style with the foot movement condition, and allows for selection between more than four menu options, using only one foot. However, for parameter control, users are generally more tolerant of small errors, so we employ the direct button push metaphor for such tasks.

As described in the remainder of this section, to minimize strain and physical fatigue for foot movement, we determined the comfortable extent of foot rotation and translation through pilot testing. All pilots were performed with the same apparatus as used in the final experiment, as described in Figure 7.

Determining the Comfortable Region of Foot Movement

Inspired by Zhong [22], who investigated the range of comfortable foot rotation, we carried out a similar pilot test to determine the region of comfortable foot rotation and translation.

The test involved nine participants (6F/3M), aged 21-45 (μ = 27.8, σ = 7.8) and 157-185 cm in height (μ = 172 , σ = 8.5) who were asked to slide their feet horizontally or vertically as far as they could comfortably while controlling a menu in both sitting and standing positions. Analysis of the results indicated that the maximum comfortable vertical sliding distances from a resting position were μ = 25.2 cm forward and μ = 23.9 cm backward while standing, and μ = 19.1 cm forward and μ = 20.2 cm backward while seated. For horizontal movement, the gap between the two feet in resting position was approximately μ = 20.7 cm for both sitting and standing positions. The maximum comfortable horizontal sliding distances from that starting stance were μ = 22.9 cm leftward and μ = 24.1 cm rightward while standing, and μ = 24.0 cm leftward and μ = 24.8 cm rightward while sitting.

Since our design is intended for musicians who are seated, we chose 20 cm as the "comfortable region" for both horizontal and vertical foot displacement.

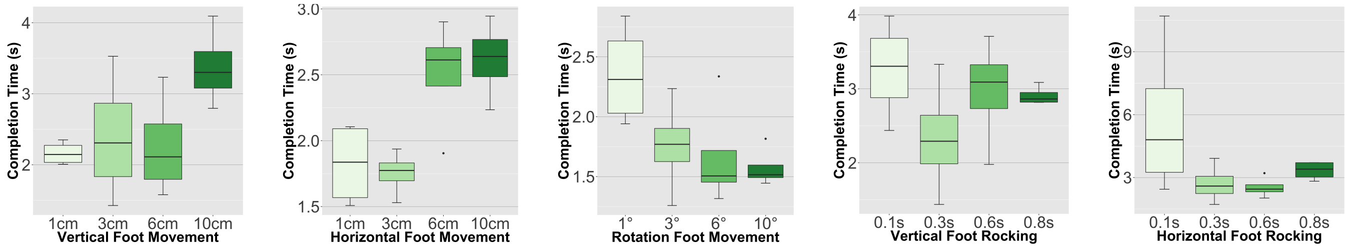
Zhong et al. found the active range of motion for heel rotation to be from -33±10° to 53±13° and chose -20° to 40° as the usable range for their experiments [22]. We adopted these values for our system.

Determining Increments for the Foot Interface

Using the comfortable region for foot movement found in the previous subsection, we proceeded to determine suitable parameters for other elements of the foot-based interaction through a second pilot. Linear and radial sliders with values between 0 and 10, spaced at uniform intervals, were displayed one at a time. Participants were asked to set the sliders to different values, which were displayed on screen, and their task-completion times were recorded.

We tested four possible increments of slider movement, 1, 3, 6, and 10 cm, and similarly divided foot rotation into four increments of 1, 3, 6, and 10°. For the foot pressure conditions, we compared completion time periods of 100, 300, 500, and 800 ms before the application of pressure was registered as intentional.

The pilot involved two main conditions of input method to adjust the value of a slider: scrolling combined with rotating the foot or through foot pressure alone. Within the scrolling and rotation condition, we tested (1) vertical displacement, (2)



(a) Vertical foot movement (b) Horizontal foot movement (c) Foot rotation (d) Vertical foot rocking (e) Horizontal foot rocking

Figure 3: Tukey box plots of interaction parameters evaluated in pilot study

horizontal displacement, and (3) foot rotation about the heel. Within the foot pressure condition, we tested (4) pressure to the toes or heel, and (5) pressure to the left or right side of the foot. Participants carried out a series of four blocks of ten trials in each of the five conditions, for a total of $4 \times 10 \times 5 = 200$ trials. Four participants (2M/2F), aged between 21 and 29 (μ = 24.5, σ = 3.4) carried out the pilot test. Results of linear foot sliding are shown in Figures 3a and 3b. Averaging across vertical and horizontal movements, performance was best with values of 1 cm (μ = 1.9 s, σ = 0.2 s) and 3 cm (μ = 2 s, σ=0.6 s). However, some participants reported that 1 cm increments were too small to control reliably, and led to greater fatigue than the 3 cm value. We therefore chose 3 cm as the best increment value to control parameters through linear foot sliding in both horizontal and vertical directions. Results of foot rotation are shown in Figure 3c. The 10° radial increment had the fastest average completion time (1.5 s). However, as the radial increment increased, more foot rotations would be required to affect non-trivial changes of parameter value, and thus, users would likely experience greater fatigue. As a compromise, we opted to use a radial increment parameter of 3° for the full experiment. Foot rocking demonstrated minimal completion time when a time delay of 0.3 s was used. This was true for both vertical rocking (Figure 3d), μ = 2.3 s, σ = 0.7 s) and horizontal rocking (Figure 3e), μ = 2.7 s, σ = 0.9 s), so we adopted a time delay of 0.3 s for the pressure-based interaction technique.

Overall, the foot movement techniques yielded shorter average completion time than foot pressure, and rotational foot movement was superior to linear foot movement. Horizontal foot movement achieved faster completion time than vertical foot movement, confirming the results of Velloso et al. on a Fitts' Law task [19]. For the foot pressure-based interactions, foot pressure to the toe and heel (vertical) outperformed foot pressure to the left and right sides (horizontal).

DESIGN FOR A MUSICAL PERFORMANCE INTERFACE

We then applied the results from our pilot studies to the design of an example interface intended to support musical performance. The interface implemented sample tasks to allow us to compare performance in menu navigation and parameter control between two interface paradigms: method A based on foot movement/rotation, and method B based on foot pressure. Our evaluation of performance for these tasks was based on conventional quantified measurements, e.g., measuring isometric performance [4, 16].

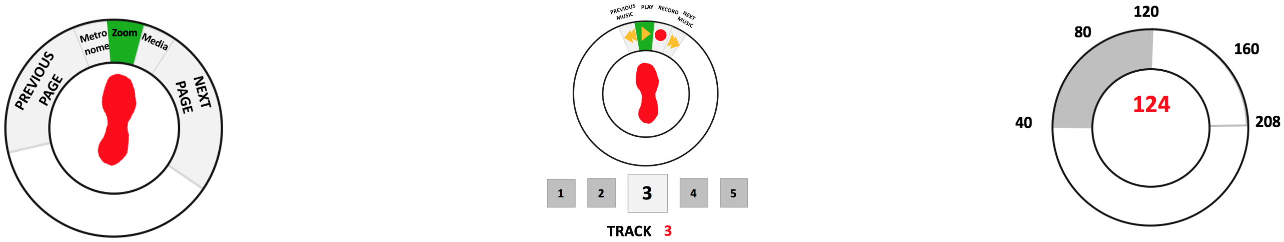
We designed a separate menu system for each paradigm, one radial in shape for the former, one horizontal for the latter. They share a common method for selection and confirmation of menu items to enable comparison of user's performance on three tasks: media player control, setting a metronome tempo, and navigating sheet music. The menu items, gray in color, are highlighted green when selected, and will change to dark yellow when this selection is confirmed.

In the radial menu system for movement-based control (Figure 4), foot rotation is the main interaction method for menu selection tasks and controlling single parameters. Menu items in selection tasks are always located in the comfortable region (-20° to 40°) to minimize fatigue while operating, divided equally into the number of menu items in equal degrees. To select a menu item, users first rotate their right foot to point at the aimed item, then tap the foot to confirm the selection. The orientation of the foot is displayed at the center of the menu to give participants feedback and avoid the need to look at their foot (Figure 4a). For parameter control, the user can increase values by rotating in a clockwise direction, and decrease them by counter-clockwise rotation. For controlling multiple parameters, such as scrolling a view in 2D, horizontal and vertical sliding movement was implemented.

In the horizontal menu for pressure-based interaction, selections function according to the "select-then-confirm" paradigm (Figure 5). Pressing the left or right portions of their right foot, and confirm the selected function by pushing down on the toe switch between different menu items. For parameter control, the "button press" paradigm was implemented for its perceived easier control and lower reaction times found in the pilot test.

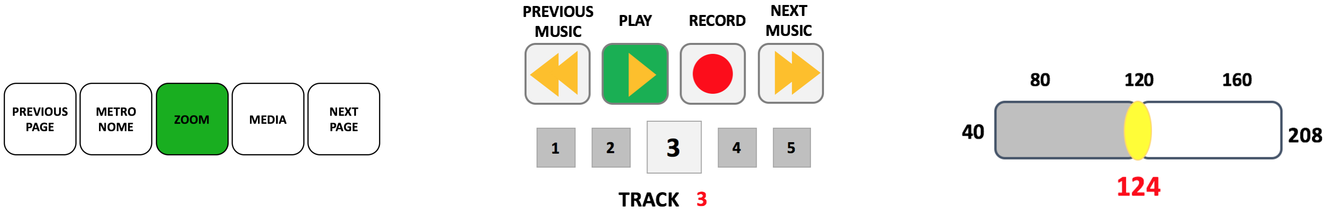
Main Menu

The main menu allows choices between the different functions and flip pages of the sheet music. For rotation-based control (method A), the pie-shaped menu (Figure 4a) was divided equally into three sub-menus, with the middle one divided equally again for selection of metronome, zoom control, and media functionality. The page turning function was located in the main menu as desired by most subjects, and was used



(a) Main menu (b) Media menu (c) Metronome indicator

Figure 4: Radial interface



(a) Main menu (b) Media menu (c) Metronome indicator

Figure 5: Horizontal interface

frequently in the playing process. In accordance with the frequency of function usage and Fitts' law, we placed it at the outer ends of the menu and allocated most menu space to it.

For control based on foot pressure, the same menu items were placed in a horizontal array (Figure 5a). Users could move the highlighted green menu item to the left or right by pressing the corresponding portion of the right foot continuously for 0.3 s and operate the sub-menu function by pushing the toe. If there was no response detected in the sub-menu after 3 s (hold time), in both the pressure-based and rotation-based menu, users would be returned to the main menu.

Media Player Task

Target selection, one of the most fundamental and frequently studied of interaction tasks [4, 16], was tested in our context by control of media player functions.

The media player sub-menu consists of four buttons: Previous Track, Play/Pause, Record/Stop, and Next Track. For foot rotation control (method A), the buttons of media menu were each placed in an equally divided pie menu (Figure 4b). For foot pressure control (method B), they were placed in a horizontal row (Figure 5b). Available/selected track numbers are displayed in a horizontal array below the buttons, with the selected track centered in a light gray box larger than the others in the middle.

In the media menu, users can perform sequential selection tasks. For example, a task could be "Play the fifth track" when the user is in the main menu. The user then needs to select the media menu, select the correct track number, and start the playback by selecting the "Play" button. Three seconds after completion, the user would be returned to the main menu to move on to the next task.

Metronome Task

Expanding on the basic target selection task, we also consider the problem of value selection, that is, target selection over a large number of choices. To do so, we used the metronome control functionality, in which the user can set the tempo between 40 and 208 beats per minute [9]. In this case, continuous adjustment, rather than discrete selection, is appropriate.

For rotation-based control, the range of values is mapped to an arc of 180° (Figure 4c). Tempo was increased or decreased by one step every angular displacement of 3°.

For pressure-based control, the range is mapped to a horizontal slider (Figure 5c). Pressure exerted to the left (or right) sole of the right foot causes the value to decrement (or increment) of the value every 0.3 s. Given the large range of values, acceleration was employed to double the increment or decrement step after every three continuous increments or decrements. After reaching the target value and 3 s of inactivity, the user is returned to the main menu for the next task.

Scroll and Zoom Task

Another fundamental interaction task explored in our experiment is that of scroll and zoom, which we tested in conjunction with region selection within the music sheet (Figure 6). The two-dimensional scrolling operation was similar to the resizing task of Velloso et al. [19], while zoom was inspired by the foot-based pedal experiments of Klamka et al. [11]. However, foot-rocking gestures, in particular for such operations, have not been studied to the same degree as foot movement. For this condition, we based our design on the user-defined gesture set described by Fukahori et al. [3].

During the experiment, participants were asked to fit the red box view box into the blue target box. When the target was reached and held for three seconds, the task was considered completed. We compared scrolling (two parameters) to scroll and zoom (three parameters), with the latter requiring use of both feet. The left foot controls zooming in and out of the score page, either by sliding the foot vertically (method A) or pressing the toes or heel (method B). The right foot controls the scrolling of the displayed area by two directional scrolling movements (3 cm per increment) on the horizontal plane (method A) or exerting foot pressure (300 ms holding per increment) (method B).

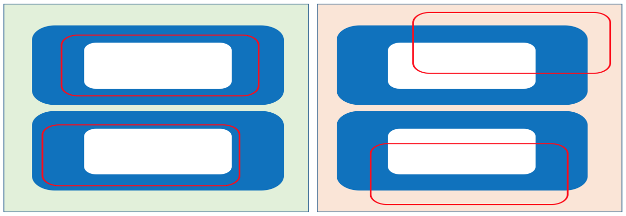


Figure 6: Zoom task: correct (left) vs. wrong (right) selection

COMPARISON OF FOOT PRESSURE AND MOVEMENT

Apparatus and Procedure

Since the literature found no significant difference between dominant vs. non-dominant feet regarding Fitts' Law tasks [19], we opted for an interactive design in which menu parameters were controlled by sliding, rotating or rocking with the right foot. Foot motion was tracked by a VICON optical motion capture system and foot pressure was detected by Teensy 32-bit microcontroller with force-sensing resistors (Interlink FSR 402 sensors) integrated in the insoles (Figure 7). These sensors were positioned as shown in Figure 7, co-located with the highest concentration of physiological mechanoreceptors on the foot, and thus, ideally situated for characterizing user perception during foot-based interaction [7, 10]. Visual feedback was provided on a 24" flat panel LCD display.

Throughout the experiment, which took place in a controlled laboratory environment, participants were asked to sit in a relaxed position, with their hands and feet unconstrained. Comparisons were made between completion time and responses to NASA TLX questionnaire of different foot controlling methods.

Participants began the experiment on the main menu and were instructed to perform a sequence of tasks that required selecting various sub-menus and performing certain actions, including parameter adjustment and returning to the main menu. They were presented with different control tasks employing the functions described above, e.g., setting the tempo of the metronome, navigating a particular portion centering on a certain bar of the musical score, and playing an accompaniment music through a visual display.

Figure 7: Shoe controller prototype and positions of foot pressure sensors (red dots).

A calibration session was completed at the beginning of training in order to customize the detection thresholds for rocking gestures according to foot size and leg strength of each participant. Participants then carried out a training phase to familiarize themselves with the system, performing a simplified version of the experiment task involving each type of foot movement or pressure input for ten randomly generated menu tasks in each method.

After a short break to minimize fatigue effects, the main experiment was conducted, involving twelve generated tasks (4 different types of tasks × 3) in each round. The experimental trials were performed with two foot operation methods presented in an ABBA or BAAB fully counterbalanced order in order to mitigate learning effects. Following the experiment, participants were asked to complete a post-test NASA-TLX questionnaire rating all the methods in terms of mental, physical, and temporal demands, as well as overall performance, frustration, and effort.

Results

Experiments were performed by 18 subjects (10 male) aged 20-56 years ($\mu = 27$, $\sigma = 7.8$). All participated voluntarily and signed a consent form that was approved by the university's Research Ethics Board. The experiment lasted approximately 45 minutes and subjects were compensated CAD $10 for their participation. Their results were recorded, and questionnaires were given to gather information about their preferences as well as other feedback.

Participant feedback to the post-test questionnaire indicated a preference (by 13 out of 18 participants) for the approach of aiming to select and then tapping to confirm, because of its similarity to object selection by mouse, and its greater ease of use, as reflected in the results of our NASA-TLX questionnaire. Three participants preferred pressing the toe for confirmation, instead of tapping citing it as a natural response to the selection task, while two participants did not report any preference.

Through the result of the NASA TLX questionnaires (Figure 8), we found that the foot pressure interface demanded two

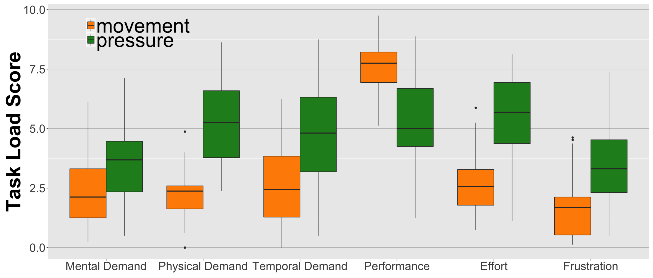


Figure 8: Tukey box plots of NASA-TLX questionnaire responses

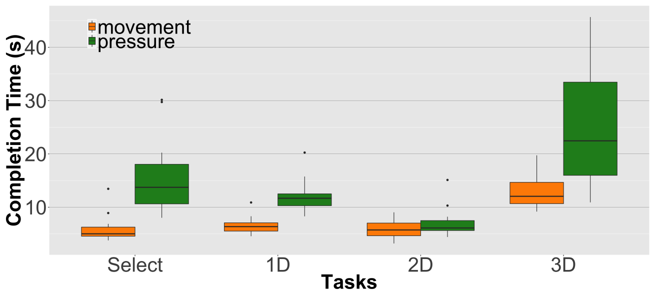


Figure 9: Tukey box plots of all tasks with two different approaches (orange=movement, green=pressure)

times higher effort, and had lower performance than the foot movement interface. A paired-samples t-test was conducted as well via the default package in R [14]. We discovered significant differences between two foot interaction approaches in the score of effort and the score of performance by showing $t(18) = 4.97$ ($p < 0.01$) in effort and $t(18) = 4.64$ ($p < 0.01$) in performance scores. The mental demand had similar work load scores, with scores of 2.3 for foot movement and 3.5 for foot pressure. Again, a paired-sampled t-test found that the difference was significant, $t(18) = 3.04$ ($p < 0.05$).

Completion time of foot pressure and movement was also analyzed according to tasks (Figure 9) via the default package in R, followed by Holm-Bonferroni adjustment of the resulting p-values to account for multiple comparisons. Intermediate values, e.g., of metronome tempo, as it is being adjusted to reach the target value, are ignored, and therefore the only relevant quantitative measure is completion time, and error rate is not considered here.

In the menu selection task, foot rotation outperformed the "select-then-confirm" metaphor option with the average completion time in 5.7 s, as opposed to 15.3 s in the latter; $t(18) = 7.29$ ($p < 0.01$). For the single-parameter task of setting the metronome tempo, the average task completion time was 6.5 s and 12 s for the movement and pressure interface, respectively; $t(18) = 6.94$ ($p < 0.01$). However, for the two-parameter "box cursor" task, involving 2D positioning of the user box over the music sheet, average completion time was 5.8 s and 7 s for the foot movement and pressure interface, respectively; $t(18) = 1.48$ ($p = 0.62$), indicating no significant difference between the interfaces. Lastly, in the three-parameter task of adjusting the user box to fit the target box, average task completion times were 12 s and 24.6 s for the movement and pressure interface; $t(18) = 4.95$ ($p < 0.05$).

Discussion

Our analysis of completion time and responses to the NASA TLX questionnaires revealed that foot movement outperformed foot pressure for general tasks. Participants similarly indicated a preference for foot rotation movement, with one describing it as a "very direct and intuitive" interface, seeing the parameters selected when she pointed her foot at it. Other feedback on movement-based foot control also includes easy understanding and comprehension of its similarity to mouse movements, fast operation, and more accurate control.

Interestingly, although task completion time with foot pressure was longer than with foot movement, three participants noted a strong preference for the former. In the training session, two participants expressed difficulty understanding how the "select-then-confirm" method worked, and indicated their preference for the foot-rocking, which required only a small gesture to control parameters, compared to foot movement. Other comments include:

- Foot pressure interface takes less effort, thanks to its subtle controlling movement
- In the tasks where a large distance is needed in foot movement, they can operate the task continuously using foot pressure interface
- Personal interests, where some found the operations of exerting pressure on the foot very entertaining

Although our results did not demonstrate significant differences between interaction techniques for the modestly complex task of 2D positioning, they did once a third dimension of control was added. We speculate that this was the consequence of greater cognitive load and physical coordination effort required for parameter control involving both feet. For example, pushing one foot to activate a function might affect balance, even while seated, which could perturb the position of the other foot. For this reason, we found some participants would hold their other foot in the air when they were trying to push the box, as confirmed during post-experimental debrief. Thus, rocking both feet simultaneously is highly unnatural, even when seated.

Effect of Pose

Sitting imposes obvious limitations on mobility and the range of target applications that can be supported [20]. Nevertheless, we had participants perform the experiment while seated, since we expected this to allow foot gestures to be performed with less fatigue and easier maintenance of balance.

To investigate whether this hypothesis was correct, we conducted a small supplemental study with four subjects (all male) aged between 20 and 27 (μ = 24, σ = 2.9), to compare performance between seated and standing poses, with these conditions presented in counterbalanced order. The experimental tasks were otherwise identical to the main experiment.

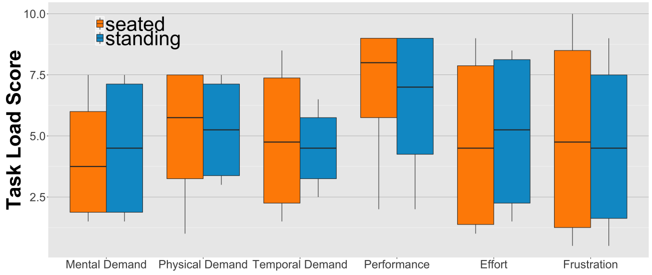


Figure 10: Tukey box plots of NASA-TLX questionnaire responses (orange=seating, blue=standing)

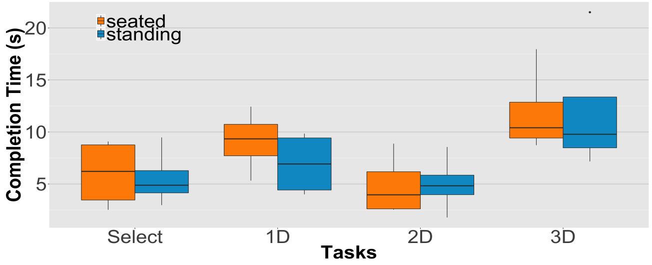


Figure 11: Tukey box plots of all tasks with two different approaches (orange=seating, blue=standing)

The results of the NASA-TLX questionnaire responses (Figure 10) indicated only small differences between standing and sitting poses. Similarly, Tukey box plots of completion time (Figure 11) show only minor differences apart for the 1D parameter control task, for which, interestingly, standing outperformed sitting. Despite this possible performance benefit, participants commented on the greater effort for maintaining balance while performing the tasks. Although we cannot draw conclusions from the limited data of this supplemental study, it suggests that the relationship between ease of balance, range of foot gestures, and time performance merits further exploration.

FUTURE WORK

In this section, we discuss additional factors that should be considered when deciding between foot-based interaction options. Designers of foot-based interfaces also need to be cognizant that performance could be affected by other factors such as the number of parameters and increments to control, ergonomics of the foot-based interactions (comfortable area, directions of the foot, interaction metaphor) and balance. In addition, adding haptic effect through the foot could be suggested to achieve the better performance when a user operate selection or parameter control task.

Parameter Customizing

Further customization of interaction parameters may be appropriate to support improved individual performance. These parameters include:

- Range of motion: The range of motion in which participants could move their legs comfortably is dependent not only on individual leg height, but on direction of movement, and also, for vertical movement, on standing vs. sitting pose.
- Movement increments: The amount of linear or angular movement required to register an increment involves a balance between sensitivity (rate of adjustment) and controllability (precision). As discussed in association with the results of Figure 3, both small and large values of movement per increment were associated with increased fatigue.

  However, the choice of optimal movement increment may well be affected by the number of items in the menu. For the pilot, in which the target menu consisted of ten values, 10 °radial increments were found to offer the best performance (Figure 3c), but for a larger number of items, a smaller movement increment may be preferable so as to reduce the risk of fatigue when rotating. Alternatively, an accelerator function, such as those adopted for our experiment (Metronome control task), may be employed to increase the step size, temporarily, during scrolling.
- Threshold level of pressure: We calibrated the threshold pressure needed for a gesture to be registered to the specifics of foot size and leg strength of individual participants. However, we did not take into account varying foot position, which could affect foot pressure delivered under normal force.
- Hold time: The hold time in our experiment was set as a constant. However, it may be appropriate to customize this parameter according to factors such as age and experience of the user.

Haptic Effects

Overshoots were sometimes observed during the experiment. To reduce this problem, one might consider conveying haptic feedback through the foot to indicate significant transitions, e.g., generating a virtual detent at the boundary between every 10 increments of a parameter value. Grane et al. demonstrated a reduction in mental load and improved accuracy for rotary menu selection tasks with the provision of such haptic feedback [4].

CONCLUSION

We compared the performance of two most common approaches for foot-based interaction, namely pressure and movement, in the context of a foot-based interface for seated musicians. Parameters for the two interaction styles were determined through pilot testing, with the aim of minimizing fatigue and maximizing performance. The results indicated that foot movement was the preferred interaction method, exhibiting faster task-completion time and more positive user feedback on NASA TLX questionnaires than the alternative of foot pressure. However, foot pressure was viewed as requiring less effort, in particular for continuous controlling, thanks to its ergonomics and subtle movement. In addition, performance could be affected by other factors, including user pose, parameter customization, and tactile feedback, so interface designers should keep them in mind.

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