Evaluating Body Tracking Interaction in Floor Projection Displays with an Elderly Population

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Keywords: Large Display Interface, Floor Projection, Elderly, Natural User Interface, Kinect

Abstract: The recent development of affordable full body tracking sensors has made this technology accessible to millions of users and gives the opportunity to develop new natural user interfaces. In this paper we focused on developing 2 natural user interfaces that could easily be used by an elderly population for interaction with a floor projection display. One interface uses feet positions to control a cursor and feet distance to activate interaction. In the second interface, the cursor is controlled by ray casting the forearm into the projection and interaction is activated by hand pose. The interfaces were tested by 19 elderly participants in a point-and-click and a drag-and-drop task using a between-subjects experimental design. The usability and perceived workload for each interface was assessed as well as performance indicators. Results show a clear preference by the participants for the feet controlled interface and also marginal better performance for this method.

1 INTRODUCTION

Developed countries' populations are becoming increasingly older, with estimates that one third of the European citizens will be over 65 years old by 2060 (European Commission, Economic and Financial Affairs, 2012). With older age, vision perception is commonly negatively affected (Fozard, 1990) and the effects of sedentary lifestyles become more prominent. A computer system that could alleviate such problems through the use of large dimension displays and motion tracking interfaces could prove advantageous. More concretely, applications targeting engagement and physical fitness would provide extensive health benefits in older adults (World Health Organization, 2010).

Meanwhile, the release of low-cost body tracking sensors for gaming consoles has made it possible for gesture detection to be present in millions of homes. Sensors like the Kinect V1, of which more than 24 million units were sold by Feb. 2014 (Microsoft News Center, 2013), and Kinect V2, having 3.9 million units bundled and sold along with Xbox One consoles by Jan. 2014 ("Microsoft's Q2," 2014, p. 2). The popular access to this technology opens the way for more *user natural* ways of interacting with computing systems. Natural user interfaces (NUI), where users act with and feel like *naturals*, aim at reflecting user skills and taking full advantage of their capacities to fit their task and context demands from the moment they start interacting (Wigdor and Wixon, 2011). In addition to the body tracking sensors' unique interface capabilities they also provide exciting possibilities for automatic monitoring of health related problems through kinematic data analysis. For example, automated systems for assessing fitness indicators in elderly (Chen et al., 2014; Gonçalves et al., 2015), automatic exercise rehabilitation guidance (Da Gama et al., 2012), or diagnosis and monitoring of Parkinson's disease (Spasojević et al., 2015).

The coupling of body tracking depth sensors, such as Kinect, and projectors enable systems to not only track the user movements relative to the sensor but also the mapping of the projection surfaces. In a well calibrated system, where the transformation between the sensor and projector is known, this allows for immersive augmented reality experiences, such as the capability of augmenting a whole room with interactive projections (Jones et al., 2014).

In this paper we present the combination of floor projection mapping with whole body tracking to provide two modalities of body gesture NUIs in controlling a cursor. One modality is based on feet position over the display while the other uses forearm orientation (pointing). We assessed the interfaces with an abstraction of two common interaction tasks, the point-and-click and drag-and-drop, on an elderly population sample. The differentiation was done by evaluating the systems in terms of usability, perceived workload and performance. This work is an initial and important step in the development of a mobile autonomous robotic system designed to assist elderly in keeping an active lifestyle through adaptable exergames. The platform, equipped with a micro projector and depth sensor will be able to identify users and provide custom exergames through live projection mapping, or spatial augmented reality. The results from this experiment will not only help in the improvement of a gesture interface for such platform but also contribute to exergame interaction design.

2 RELATED WORK

While gesture based interaction is not a requirement for a NUI, it is an evident candidate for the development of such an interface.

An area where several in-air gesture interfaces have been proposed is in pan-and-zoom navigation control. In (Nancel et al., 2011) the authors investigated the impact three interaction variables had in task completion time and navigation overshoots when interacting with a wall-sized display. The variables were: uni- vs. bi- manual, linear vs. circular movements, and number of spatial dimensions for gesture guidance (in zooming). Panning was controlled by ray casting the dominant hand into the screen and activated by device clicking. Results showed that performance was significantly better when participants controlled the system bimanually (non-dominant hand zooming), with linear control and 1D guidance (mouse scroll wheel for zooming). A NUI for controlling virtual globes is introduced in (Boulos et al., 2011). The system uses a Kinect sensor to provide pan, zoom, rotation and street view navigation commands to Google Earth. The system presents an interesting possibility for a NUI as in-air gestures follow the same logic as common multi-touch gestures. Hand poses (open/close) are used to activate commands while relative position of the hands is used to control the virtual globe. For street view control it makes use of gestures that mimic human walk, swinging arms makes the point-of-view move forward while twisting the shoulders rotates it. The use of metaphors that make computer controls relate to other known controls is not uncommon. In (Francese et al., 2012) two different approaches for interfacing with Bing Maps were tested for their usability, presence and immersion. Using a Wiimote the authors built a navigation interface inspired in the motorcycle metaphor. A handlebar like motion controlled turning and right hand tilting acted as throttle. Additionally to the metaphor, altitude over the map was controlled by left hand tilting. The alternative approach used the Kinect to provide control and feedback inspired in the bird metaphor. Raising the arms asymmetrically enables turning, both arms equally raised or lowered from a neutral position control altitude and moving the hands forward makes the user advance; the controls are enhanced by providing feedback in form of a bird/airplane avatar. Descriptive statistic results showed high levels of usability and presence for both systems, with higher values for the latter. The use of torso angle to control an avatar in a virtual reality city and how this control method affected the user understanding of size proportions in the virtual world was investigated in (Roupé et al., 2014). The system uses forward/backward leaning and shoulder turning to move and turn in the respective direction. It was tested on participants chosen for their knowledge in urban planning and building design, and compared to the common first-person-shooter mouse/keyboard interface. The results show that the system navigation was perceived as both easier and less demanding than the mouse/keyboard, and that it gave a better understanding of proportions in the modelled world.

Beyond navigation interface, gesture NUIs have been studied in the context of controlling computerized medical systems. This is particularly important in the surgery room where doctors must maintain a sterile field while interacting with medical computers. In (Tan et al., 2013), the authors present their Kinect based system for touchless radiology imaging control. It replaces the mouse/keyboard commands with hand tracking controls where the right hand controls the cursor and the left hand is used for clicking, the activation of the system was done by standing in front of the Kinect and waving. Tested for its qualitative rating with radiologists, 69% considered that the system would be useful in interventional radiology. The majority also found it easy to moderately difficult to accomplish the tasks. Similarly, in (Bigdelou et al., 2012) the authors introduced a solution for interaction with these systems using inertial sensors instead. Here the activation of the gesture detection was made by using a physical switch or voice commands.

Several exploratory research studies have been made to find the common gestures that naïve users would naturally perform. In (Fikkert et al., 2009) the authors found, by running an experiment in a Wizard of Oz set-up, that when asked to perform tasks in a large display participants would adopt the point-and-click mouse metaphor. In (Vatavu, 2012), participants were asked to propose gestures for common TV functions. The gesture agreement was assessed for each command and a set of guidelines proposed. Contrary to what was shown in (Nancel et al., 2011) for pan and zoom gesture, here one hand gesturing was preferred. Hand posture naturally emerged as a way of communicating intention for gesture interaction.

When designing a NUI that supports in-air gestures one must be aware of the "live mic" issue. As the system is always listening, if not mitigated, this can lead to false positive errors (Wigdor and Wixon, 2011). Effective ways of countering the "live mic" problem are to reserve specific actions for interaction or reserve clutching mechanism that will disengage the gesture interpretation. The review made by the Golod et al. (Golod et al., 2013) suggests a *gesture phrase* sequence of gestures to define one command, where the first phase is the activation. The activation serves as the segmentation cue to separate casual from command gestures. Some example guidelines are the definition of activation zones or dwell-based interactions. In (Lee et al., 2013), from a Wizard of Oz design, the authors tried to identify gestures for pan, zoom, rotate and tilt control. More importantly, by doing so they identified the natural clutching gestures for direct analogue input, a subtle change from open-hand to semi-open. Similarly, the system proposed in (Bragdon et al., 2011) used the hand palm facing the screen for activating cursor control. (Hopmann et al., 2011) proposed two activation techniques: holding a remote trigger, and activation through gaze estimation. These two activating techniques plus the control (trigger gesture of showing the palms to the screen) were tested for their hedonic and pragmatic qualities. Results showed that both the trigger gesture and remote trigger scored neutral on their hedonic and pragmatic scales. However, gaze activation scored high in both scales, achieving a "desired" rating.

Although much less common that vertical displays, interactive floors and floor projected interfaces possess unique features. In (Krogh et al., 2004) the authors describe an interactive floor prototype, controlled by body movement and mobile phones, which was set-up on a large public library hall. This arrangement enabled them not only to take advantage of the open space, filled by the large projected interface, but also from its public function of promoting social interaction. These types of interfaces were proposed as an alternative to interactive tabletops (Augsten et al., 2010), useful for not being as spatially restraining as the latter. In their study the authors also explored the preferred methods of activation for buttons in these floors, being feet *tap* their final choice of design.

Even though the literature on *NUI* is extensive, our review shows that most research has been made with exploratory or pilot design and could be advanced by validation studies. Furthermore, while most studies target the general population, usually their samples are not representative of the elderly portion and thus ignore their specific impairments and needs. To generally address their visual perception impairments and support their needs of physical activity and engagement we focused our research on large interactive floors. In order to better understand how this population can interact with such an interface we proposed the following question:

- When designing a NUI to be used by an elderly population in floor projection displays what interaction is best?

This was narrowed down by limiting the answers to two types of interface control: arm ray casting, commonly studied for vertical displays, and a *touch screen* like control, where the user activates interaction through stepping on the virtual elements. Considering the goals of an interface we chose three elements to be rated: usability, workload, and performance. As one method would provide clear mapping at the expense of increased physical activity (stepping), the other would free the user from such movements while requiring him to mentally project their arm into the floor. Therefore, we hypothesized that differences for each of the three evaluation elements would exist when considering the two NUIs proposed. To test this hypothesis, the two proposed modes of interface control were developed and tested on an elderly population sample for two types of tasks where they were evaluated in terms of usability, perceived workload and performance. We expected that ray casting would provide better results as it is more widely used for interaction with large displays and requires little physical effort by the user.

3 METHODS

3.1 Modes of Interacting

Two modes of interacting with the computer were developed based on the kinematic information provided by a Kinect V2 sensor and a display projection on the ground. In the first, henceforth named "*feet*", the cursor position is controlled by the average position of both feet on the floor plane;

activation upon the virtual elements by the cursor is performed by placing the feet less than 20cm apart. For the second mode of interaction, named "*arm*", the forearm position and orientation is treated as a vector (from elbow to wrist) and ray casted onto the floor plane, the cast controls the position of the cursor (as schematized in Figure 1), while activation is done by closing the hand. Due to low reliability of the Kinect V2 sensor in detecting the closed hand pose, during the experiment this automatic detection was replaced by the visual detection done by the researcher in a Wizard of Oz like experiment.

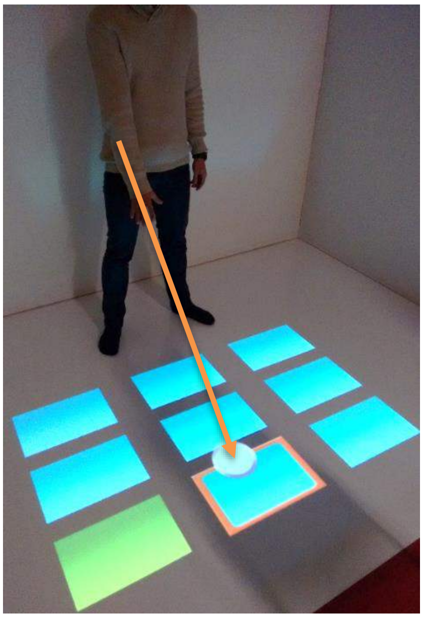

Figure 1: Controlling the cursor position through forearm ray casting.

3.2 Experimental Tasks' Description

The interfaces were tested in two different tasks to give a broader insight into what kind of interactions with computers our two systems would impact. A task to mimic the traditional point-and-click and another the common drag-and-drop.

In both tasks the participant controls a circular cursor (ø 17 cm) with 1 second activation duration, meaning that the activation gesture (feet together or hand closed) must be sustained for 1 second for the cursor to interact with the virtual element it is positioned on. This activation is represented on the cursor itself, which changes colour in a circular way proportionally to the duration of the gesture.

3.2.1 Point-and-Click Task

In the point-and-click task a set of 9 rectangles (40 cm x 25 cm) are projected in the floor, on a 3 by 3 configuration, separated 12 cm laterally and 8 cm vertically as shown in Figure 2. Out of the 9 rectangles 8 are distractors (blue) and one is the target (green). Every time the target is selected it trades places with a distractor chosen on a random sequence (the same random sequence was used for all participants). The purpose of the task is to activate the target repeatedly while avoiding activating the distractors. Performance is recorded in this task as a list of events and their time tags, the possible events being: target click (correct click); background click (neutral click); and distractor click (incorrect click). In this task, maintaining the activation pose while moving the cursor from inside a rectangle to outside, or vice versa, resets the activation timer.

Live feedback is given by drawing different coloured frames around the rectangles. An orange frame is drawn around the rectangle over which the cursor is located. Upon activation the frame changes colour to red if the rectangle was a distractor or green if it was the target. This frame remains until the cursor is moved off the rectangle.

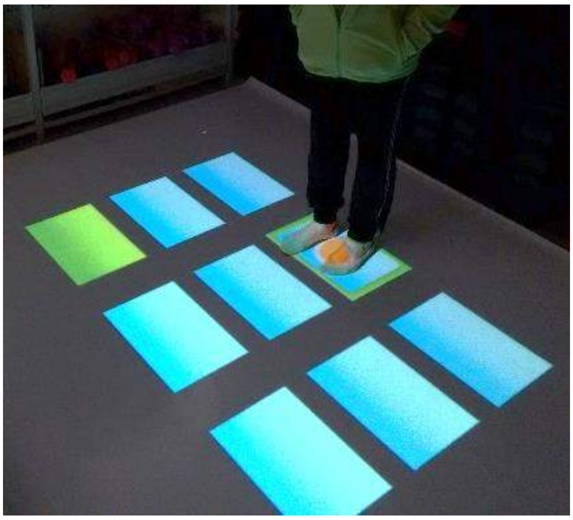

Figure 2: Point-and-click task being performed with the "*feet*" interface.

3.2.2 Drag-and-Drop Task

In the drag-and-drop task 4 rectangles (40 cm x 25 cm) are projected on the ground, spaced 70 cm horizontally and 40 cm vertically, 3 of which are blue distractors and one is the target (green). In the centre a movable yellow rectangle (30 cm x 19 cm) is initially shown, as presented in Figure 3. The participant can "*grab*" the yellow rectangle by activating it, once it has been "*grabbed*" it can be dropped by activating it again (joining the feet or closing the hand, depending on mode of interaction). The purpose of the task is to "*grab*" the yellow rectangle and "*drop*" it onto the target repeatedly. Every time this is done successfully the yellow rectangle is reset to the centre and the target changes places with one of the distractors in a random sequence (the sequence was kept constant across all participants). Performance is recorded as a list of events and their time tags, the possible events for this task are: grab yellow (correct grab); attempt to grab anything else (neutral grab); drop yellow on target (correct drop); drop yellow on background (neutral drop); and drop yellow on distractors (incorrect drop). As before maintaining the activation pose while moving the cursor from a rectangle to outside, or vice versa, resets the activation timer. Likewise, a set of coloured frames are used to give live feedback to the users. An orange frame highlights any rectangle under the cursor. Once activated, the frame of the yellow object changes to green indicating that is being dragged by the cursor. Dropping it on a distractor will create a red frame around the distractor, oppositely dropping it on a target will show a green frame around it.

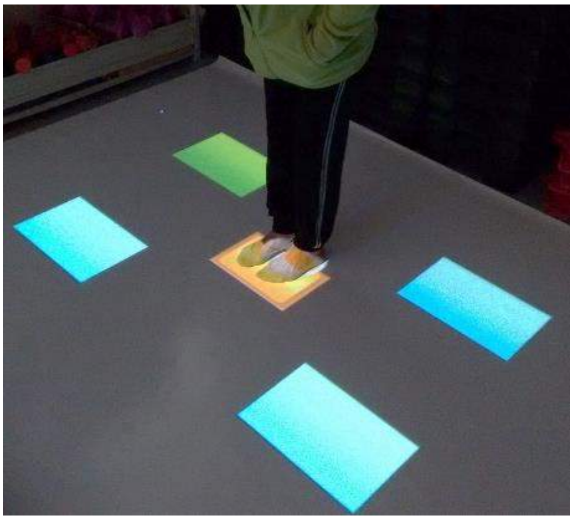

Figure 3: Drag-and-drop task being performed with the "*feet*" interface.

3.3 Technical setup

The hardware was setup in a dimly illuminated room and a white plastic canvas was placed on the floor to enhance the reflectivity of projection. A Hitachi CP-AW100N projector was positioned vertically to face the floor. This arrangement enabled a high contrast of the virtual elements being projected and an area of projection greater than what our tasks needed (150 cm x 90 cm). A Microsoft Kinect V2 was placed horizontally next to the projector, facing the projection area (Figure 4).

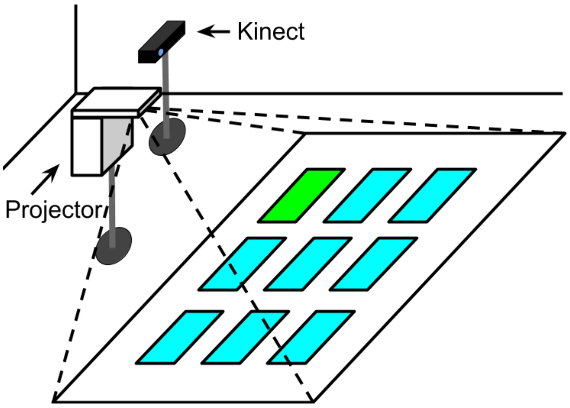

Figure 4: Experimental setup diagram.

3.4 Sample

The target population of the study were community dwelling elderly. A self-selecting sample of this population was recruited at Funchal's Santo António civic centre with the following inclusion criteria:

1. Being more than 60 years old;
2. Do not present cognitive impairments (assessed by the Mini Mental State Examination Test (Folstein et al., 1975));
3. Do not present low physical functioning (assessed by the Composite Physical Function scale (Roberta E. Rikli, 1998)).

The experiment took place over the course of 2 days at the facilities of the civic centre municipal gymnasium for the elderly. Nineteen participants (ages: M = 70.2 SD = 5.3) volunteered and provided written informed consent, 3 males and 16 females. The participants were randomly allocated to each condition, 10 being assigned to the "*feet*" and 9 to the "*arm*" condition of interaction.

3.5 Experimental Protocol

The experiment followed a between-subjects design. The participants were asked to answer questionnaires regarding identification, demographical information and level of computer use experience. They were evaluated with the Composite Physical Function Scale and Mini Mental State Examination Test.

During each individual participant trial, the point-and-click task was explained and shown being performed through example according to the participant experimental condition. This was followed by a training period and then by a 2 minutes' session while performance metrics were recorded. Lastly the participant was asked to fill the System Usability Scale (SUS) (Brooke, 1996) and NASA-TLX (TLX) (Hart and Staveland, 1988) questionnaires. After it, the same procedure was followed for the drag-and-drop task.

3.6 Analysis

For each participant data consisted of: SUS score and TLX index (both measured from 0 to 100), and task related performance, as described in sub-sections 3.2.1 and 3.2.2. Normality of the data distributions was assessed using Kolmogorov-Smirnov test for measurements concerning performance. The variables that showed such a distribution are highlighted in Table 1 and Table 2. For the pairs (between conditions) of measurements that fitted the assumption of normality, parametric t-tests were used, when significant differences in the pairs variances were present, shown by the Levene's test, equal variances were not assumed. All the others pairs were tested with Mann-Whitney's U test. Differences in the SUS and TLX scores (ordinal variables) between conditions were also tested with Mann-Whitney's U test. All statistical testing was done using 2-tailed testing at α .05 with the IBM software SPSS Statistics 22.

4 RESULTS

4.1 Point-and-Click Task

For the "*feet*" condition, in the point-and-click task the descriptive statistics are presented in Table 1, were we can observe very low values of incorrect clicks, and high median scores for the SUS, which is considered to be a good value when over 68. The descriptive statistics for the "*arm*" condition are also presented in Table 1. Higher values of neutral and incorrect clicks are visible compared to the previous condition. Similarly, it can be seen a decrease in the median of the SUS usability score and an increase of the TLX workload index.

Table 1: Descriptive statistics of the measurements for the point-and-click task.

	"Feet" Interface		**"Arm" Interface**	
Variable	***Median***	***Interquartile Range***	***Median***	***Interquartile Range***
SUS	91.25	21.25	72.50	25.00
TLX	23.75	27.71	40.83	18.33
Correct	29.50	10	28.00^{n}	15
Neutral	1.00	2	4.00^{n}	7
Incorrect	0.00	1	2.00^{n}	3

^{n} Normally distributed

Results revealed significant higher System Usability Scale scores for the participants interfacing with their feet compared to the participants interfacing with their dominant arm, U = 18.5, p < .05, with effect size r = -.4997. The Task Load Index scores were not significantly different for both interfaces, U = 24.5, p > .05 (Figure 5). The number of correct and neutral clicks was not significantly different for both interfaces, U = 40.5 and U = 29.0, p > .05, respectively. However, it was found that there was lower number of incorrect clicks for the participants interfacing with their feet compared to the participants interfacing with the arm, U = 15.0, p < .05, r = -.5863 (Figure 6, where circles represent outliers and stars extreme outliers).

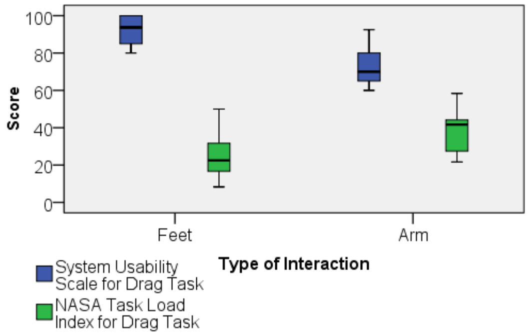

Figure 5: System Usability Scale and Nasa-Task Load Index scores for the point-and-click task.

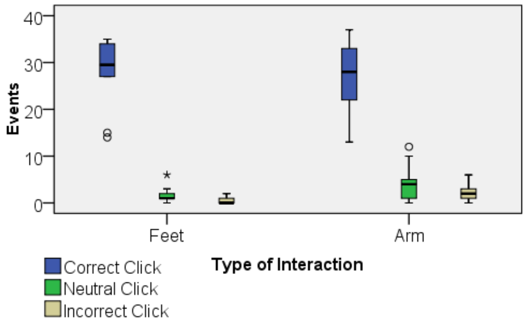

Figure 6: Participants' performance on the point-and-click task.

4.2 Drag-and-Drop Task

The descriptive statistics for the “*feet*” condition, in the drag-and-drop task are presented in Table 2, were we can observe low values of incorrect drops and no neutral drops (accidental drops). The values of usability are very high and workload moderately low. In the “*arm*” condition of the drag-and-drop task we can see, in Table 2, a marginally good value for the SUS usability score, barely over 68. The TLX workload has relative medium levels and neutral drops (accidental) are present.

Table 2: Descriptive statistics of the measurements for the drag-and-drop task.

	“Feet” Interface			**“Arm” Interface**
Variable	***Median***	***Interquartile Range***	***Median***	***Interquartile Range***
SUS	93.75	16.25	70.00	21.25
TLX	22.50	16.46	41.67	22.50
Correct Grab	14.50^{n}	8	11.00^{n}	9
Neutral Grab	13.50^{n}	4	10.00^{n}	9
Correct Drop	14.00^{n}	7	10.00^{n}	10
Neutral Drop	0	0	1.00^{n}	3
Incorrect Drop	0.00	0	0.00	0

^{n} Normally distributed

The results indicated again a significantly higher System Usability Scale score and lower Task Load Index score for the *Feet* interaction condition, with U = 9 and U = 17, p < .05, effect size r = -.6777 and r = -.5247 respectively (Figure 7). There were no significant differences for the normally distributed data with correct grabs, neutral grabs, and correct drops, t(17) = .565, t(17) = .863 and t(17) = 1.336, p > .05, respectively. Neutral drops were significantly higher in the “*arm*” interaction condition, U = 10, p < .05, r = -.7595 and there were no significant differences between the number of incorrect drops, U = 44.5, p > .05 (Figure 8).

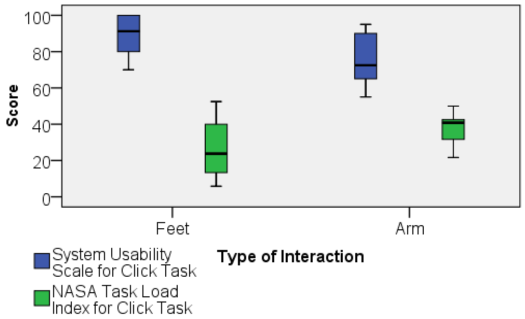

Figure 7: System Usability Scale and Nasa-Task Load Index scores for the drag-and-drop task.

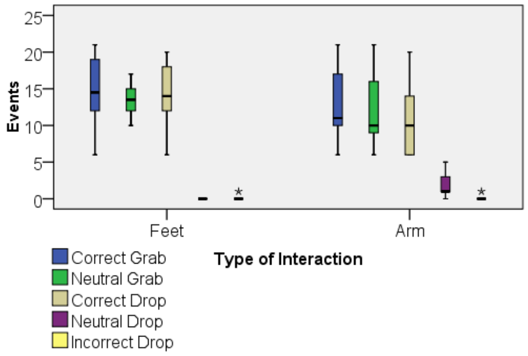

Figure 8: Participants’ performance on the drag-and-drop task.

5 DISCUSSION

For both the point-and-click and drag-and-drop tasks it was found that there is a significant impact on system usability, being the “*feet*” interaction method preferable in both cases. With the “*feet*” modality achieving high levels of usability, scores over 90, while the “*arm*” had levels of usability around 71, very close to the standard lower limit of good, 68. In the case of perceived workload indexes, for the point-and-click there were no significant differences found between the conditions. While for drag-and-drop the “*feet*” interface was significantly less demanding to use by the participants. In both cases, workload indexes for the “*feet”* were around 23 while for the “*arm*” the values were situated around 41. Although interfaces similar to our “*arm*” method have been the focus of previous research (Bragdon et al., 2011; Nancel et al., 2011) and shown to be a method that participants naturally display (Fikkert et al., 2009; Lee et al., 2013; Vatavu, 2012), in our experiment we found sufficient evidence that an alternative way of interacting with projected floor elements is preferred by elder people. This preference by the participants for the “*feet*” interface might be linked to the simpler mapping of the cursor control provided, which is known to have a lowering effect on cognitive load (Mousavi Hondori et al., 2015; Roupé et al., 2014). Finally, in terms of performance, for the point-and-click task were observed very low numbers of neutral and incorrect clicks (although significantly higher for the “*arm*”) and comparable number of correct clicks. Similar results were found in the drag-and-drop task, with low numbers of neutral and incorrect drops for both methods and analogous values of correct grabs, neutral grabs and correct drops. Still, the “*feet*” interface was again better, with the number of neutral drops being significantly lower than in the "*arm*" interface. Albeit these differences, the remaining performance indicators were shown not to be significantly different. Therefore, caution is advised in the interpretation of these results as proof of a clear performance advantage provided by any of the interfaces.

6 CONCLUSIONS

Due to the increasing number of elderly in developed countries and the specific needs of this population we tried to get an insight of the desirability of different modes of controlling interaction in interactive floors. A medium which, by being easily scaled, can mitigate the visual perception deficits associated with old age, and can promote physical activity. Thus, in this work, two methods of interacting with virtual elements projected on the floor were developed and tested for differences in their usability, perceived workload and performance ratings by an elderly population. The interfaces consisted on either controlling the cursor with the direct mapping of feet position onto the projection surface or, alternatively, by mapping the cursor position to the participant's ray-casted forearm on the surface. These interfaces were tested on two different tasks, one mimicking a point-and-click interaction, the other a drag-and-drop. Although the NUI research field is extensive there is a lack of studies that approach the floor projected interfaces and studies with the elderly are even rarer. This study gives a successful insight into the preferred modes of interaction for this elder population. Contrary to our initial guess, the results showed that from the two proposed methods the "*feet*" interface was superior in all the domains measured. It was shown that this method was perceived as more usable in both the tasks tested and at least less demanding in terms of workload for the drag-and-drop task. In terms of performance a marginal advantaged was shown also for the "*feet*" method. This insight delivered by the results will help in the development of systems aiming at providing full body NUI for floor projection displays such as in mobile robots.

ACKNOWLEDGMENT

The authors thank Funchal's Santo António municipal gymnasium for their cooperation, Teresa Paulino for the development of the experimental tasks and Fábio Pereira for his help during the data collection process.

This work was supported by the Fundação para a Ciência e Tecnologia through the AHA project (CMUPERI/HCI/0046/2013) and LARSyS – UID/EEA/50009/2013.

REFERENCES

Augsten, T., Kaefer, K., Meusel, R., Fetzer, C., Kanitz, D., Stoff, T., Becker, T., Holz, C., Baudisch, P., 2010. Multitoe: High-precision Interaction with Back-projected Floors Based on High-resolution Multi-touch Input, in: Proceedings of the 23Nd Annual ACM Symposium on User Interface Software and Technology, UIST '10. ACM, New York, NY, USA, pp. 209–218. doi:10.1145/1866029.1866064

Bigdelou, A., Schwarz, L., Navab, N., 2012. An Adaptive Solution for Intra-operative Gesture-based Human-machine Interaction, in: Proceedings of the 2012 ACM International Conference on Intelligent User Interfaces, IUI '12. ACM, New York, NY, USA, pp. 75–84. doi:10.1145/2166966.2166981

Boulos, M.N.K., Blanchard, B.J., Walker, C., Montero, J., Tripathy, A., Gutierrez-Osuna, R., 2011. Web GIS in practice X: a Microsoft Kinect natural user interface for Google Earth navigation. Int. J. Health Geogr. 10, 45. doi:10.1186/1476-072X-10-45

Bragdon, A., DeLine, R., Hinckley, K., Morris, M.R., 2011. Code Space: Touch + Air Gesture Hybrid Interactions for Supporting Developer Meetings, in: Proceedings of the ACM International Conference on Interactive Tabletops and Surfaces, ITS '11. ACM, New York, NY, USA, pp. 212–221. doi:10.1145/2076354.2076393

Brooke, J., 1996. SUS-A quick and dirty usability scale. Usability Eval. Ind. 189, 194.

Chen, C., Liu, K., Jafari, R., Kehtarnavaz, N., 2014. Home-based Senior Fitness Test measurement system using collaborative inertial and depth sensors, in: 2014 36th Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC). Presented at the 2014 36th Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC), pp. 4135–4138. doi:10.1109/EMBC.2014.6944534

Da Gama, A., Chaves, T., Figueiredo, L., Teichrieb, V., 2012. Guidance and Movement Correction Based on Therapeutics Movements for Motor Rehabilitation Support Systems, in: 2012 14th Symposium on Virtual and Augmented Reality (SVR). Presented at the 2012 14th Symposium on Virtual and Augmented Reality (SVR), pp. 191–200. doi:10.1109/SVR.2012.15

European Commission, Economic and Financial Affairs, 2012. The 2012 Ageing Report.

Fikkert, W., Vet, P. van der, Veer, G. van der, Nijholt, A., 2009. Gestures for Large Display Control, in: Kopp, S., Wachsmuth, I. (Eds.), Gesture in Embodied Communication and Human-Computer Interaction, Lecture Notes in Computer Science. Springer Berlin Heidelberg, pp. 245–256.

Folstein, M.F., Folstein, S.E., McHugh, P.R., 1975. Mini-mental state. J. Psychiatr. Res. 12, 189–198. doi:10.1016/0022-3956(75)90026-6

Fozard, J., 1990. Vision and hearing in aging, in: Handbook of the Psychology of Aging. Academic Press, pp. 143–156.

Francese, R., Passero, I., Tortora, G., 2012. Wiimote and Kinect: Gestural User Interfaces Add a Natural Third Dimension to HCI, in: Proceedings of the International Working Conference on Advanced Visual Interfaces, AVI ’12. ACM, New York, NY, USA, pp. 116–123. doi:10.1145/2254556.2254580

Golod, I., Heidrich, F., Möllering, C., Ziefle, M., 2013. Design Principles of Hand Gesture Interfaces for Microinteractions, in: Proceedings of the 6th International Conference on Designing Pleasurable Products and Interfaces, DPPI ’13. ACM, New York, NY, USA, pp. 11–20. doi:10.1145/2513506.2513508

Gonçalves, A., Gouveia, É., Cameirão, M., Bermúdez i Badia, S., 2015. Automating Senior Fitness Testing through Gesture Detection with Depth Sensors. Presented at the IET International Conference on Technologies for Active and Assisted Living (TechAAL), Surrey, United Kingdom.

Hart, S.G., Staveland, L.E., 1988. Development of NASA-TLX (Task Load Index): Results of Empirical and Theoretical Research, in: Meshkati, P.A.H. and N. (Ed.), Advances in Psychology, Human Mental Workload. North-Holland, pp. 139–183.

Hopmann, M., Salamin, P., Chauvin, N., Vexo, F., Thalmann, D., 2011. Natural Activation for Gesture Recognition Systems, in: CHI ’11 Extended Abstracts on Human Factors in Computing Systems, CHI EA ’11. ACM, New York, NY, USA, pp. 173–183. doi:10.1145/1979742.1979642

Jones, B., Sodhi, R., Murdock, M., Mehra, R., Benko, H., Wilson, A., Ofek, E., MacIntyre, B., Raghuvanshi, N., Shapira, L., 2014. RoomAlive: Magical Experiences Enabled by Scalable, Adaptive Projector-camera Units, in: Proceedings of the 27th Annual ACM Symposium on User Interface Software and Technology, UIST ’14. ACM, New York, NY, USA, pp. 637–644. doi:10.1145/2642918.2647383

Krogh, P., Ludvigsen, M., Lykke-Olesen, A., 2004. “Help Me Pull That Cursor” A Collaborative Interactive Floor Enhancing Community Interaction. Australas. J. Inf. Syst. 11. doi:10.3127/ajis.v11i2.126

Lee, S.-S., Chae, J., Kim, H., Lim, Y., Lee, K., 2013. Towards More Natural Digital Content Manipulation via User Freehand Gestural Interaction in a Living Room, in: Proceedings of the 2013 ACM International Joint Conference on Pervasive and Ubiquitous Computing, UbiComp ’13. ACM, New York, NY, USA, pp. 617–626. doi:10.1145/2493432.2493480

Microsoft News Center, 2013. Xbox Execs Talk Momentum and the Future of TV. News Cent.

Microsoft’s Q2: record $24.52 billion revenue and 3.9 million Xbox One sales [WWW Document], 2014. . The Verge. URL http://www.theverge.com/2014/1/23/5338162/microsoft-q2-2014-financial-earnings (accessed 1.19.16).

Mousavi Hondori, H., Khademi, M., Dodakian, L., McKenzie, A., Lopes, C.V., Cramer, S.C., 2015. Choice of Human-Computer Interaction Mode in Stroke Rehabilitation. Neurorehabil. Neural Repair. doi:10.1177/1545968315593805

Nancel, M., Wagner, J., Pietriga, E., Chapuis, O., Mackay, W., 2011. Mid-air Pan-and-zoom on Wall-sized Displays, in: Proceedings of the SIGCHI Conference on Human Factors in Computing Systems, CHI ’11. ACM, New York, NY, USA, pp. 177–186. doi:10.1145/1978942.1978969

Roberta E. Rikli, C.J.J., 1998. The Reliability and Validity of a 6-Minute Walk Test as a Measure of Physical Endurance in Older Adults [WWW Document]. J. Aging Phys. Act. URL (accessed 12.29.15).

Roupé, M., Bosch-Sijtsema, P., Johansson, M., 2014. Interactive navigation interface for Virtual Reality using the human body. Comput. Environ. Urban Syst. 43, 42–50. doi:10.1016/j.compenvurbsys.2013.10.003

Spasojević, S., Santos-Victor, J., Ilić, T., Milanović, S., Potkonjak, V., Rodić, A., 2015. A Vision-Based System for Movement Analysis in Medical Applications: The Example of Parkinson Disease, in: Computer Vision Systems, Lecture Notes in Computer Science. Springer International Publishing, pp. 424–434.

Tan, J.H., Chao, C., Zawaideh, M., Roberts, A.C., Kinney, T.B., 2013. Informatics in Radiology: Developing a Touchless User Interface for Intraoperative Image Control during Interventional Radiology Procedures. RadioGraphics 33, E61–E70. doi:10.1148/rg.332125101

Vatavu, R.-D., 2012. User-defined Gestures for Free-hand TV Control, in: Proceedings of the 10th European Conference on Interactive Tv and Video, EuroiTV ’12. ACM, New York, NY, USA, pp. 45–48. doi:10.1145/2325616.2325626

Wigdor, D., Wixon, D., 2011. Brave NUI World: Designing Natural User Interfaces for Touch and Gesture. Elsevier.

World Health Organization, 2010. Global recommendations on physical activity for health.