Interaction can hurt - Exploring gesture-based interaction for users with Chronic Pain

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ABSTRACT

Chronic Pain is a universal disorder affecting millions of people, influencing even the most basic decisions in their lives. With the computer becoming such an integral part of our society and the ever-expanding interaction paradigm, the need to explore potential computer interactions for people with Chronic Pain has only increased. In this paper we explore the use of gesture-based interaction as a medium with which these users can perform the base operations of computer interaction. We show that, for gestural pointing and selection, modeling users' interaction space and multimodal interaction performed the best in terms of throughput.

CCS CONCEPTS

• **Human-centered computing** → **Empirical studies in accessibility**.

KEYWORDS

Gesture Interaction; Chronic Pain; Accessibility

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1 INTRODUCTION

Pain warns us that something isn't quite right, a normal sensation triggered in the nervous system to alert someone to possible injury and the need to take care of one's self. When pain persists, it robs people of productivity, well-being, and, for many with extended illness, their very lives. When pain signals keep firing in the nervous system for weeks, months, even years, this is called "Chronic Pain" [31] (pain lasting longer than 3 months). Currently, Chronic Pain has become a universal disorder, a serious and costly public health issue, with a range of prevalence in the general public from 7% [9] to 55% [2]. Regardless of where the actual number falls, Chronic Pain is a huge challenge, causing a reduced ability to work and difficulties in performing everyday activities [21]. Additionally, the issue of Chronic Pain will continue to grow as 80% to 85% of

persons experience a significant health problem that predisposes them to Chronic Pain after age 65. This pain tends to be less head, abdominal, and chest pain and more joint pain [15], which affects even the most basic of daily activities.

One area of computer interaction that relies heavily on a user's ability to move and interact is touchless gestural interaction. Touchless gestural interaction has become increasingly popular with the introduction of commodity hardware such as the Xbox Kinect and the Leap Motion. Gestural recognition has traditionally been the focus of gesture research, while implementations have focused on coarse gestural recognition (i.e. shape identification). However, commodity gestural recognition hardware has become increasingly more precise with devices demonstrated to be accurate up to a sub-millimeter level [20] with low latency [10]. Due to this increased precision, studies have started looking at gestures not simply for coarse actions, but for more fine use cases such as cursor navigation [10, 25], a prime tenet in standard graphical interaction.

The standard method of interaction for gestural input involves the user holding their arms out in mid-air. This results in fatigue [36, 40] which is commonly referred to as "Gorilla Arm Syndrome" [11]. This gestural fatigue problem has been investigated and solutions developed for the general population. For example a gestural interaction approach called "Personal Space" [25] allowed the user to rest their elbow during interaction as well as define their area of interaction. This rested gestural interaction attempted to reduce repetitive wrist movement compared to the mouse, which has been strongly associated with hand impairments [41], by shifting primary motions from the wrist and hand to larger muscle groups such as the forearm and shoulder areas. Several studies were conducted on standard users using this approach and uncovered a few benefits: fatigue was greatly reduced [25], performance degradation when switching hands was minor when compared to the touchpad and mouse [24], and pairing gestural cursor navigation with speech based selection yielded no significant loss in throughput [19]. Each result by itself is interesting, but the combination shows promise for users with Chronic Pain. Unfortunately, the techniques and workarounds that have been incorporated in standard gesture interaction, have never been applied or tested on a user population that feels fatigued, stress, and pain from movements that a "typical" user would not with the same amount of interaction.

In this paper we explore whether touchless gestural interaction is suitable for users with Chronic Pain. We divided the interaction into two problem spaces: 1.) *Gestural Pointing* – use of a user's body to control interaction location and direction and 2.) *Gestural Selection* – gestures used to hold, release, or select items within an interaction system.

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2 RELATED WORK

2.1 Gestural Interaction

Gestural Interaction is a technique that uses gestures from the body to interact with a computer. This type of interaction technique has been studied for over three decades since Richard Bolt's first implementation in "Put-That-There" [8]. Recent devices such as the Xbox Kinect, Leap Motion, and Myo Armband have gained popularity among researchers, with some capable of sub-millimeter accuracy in static situations [20]. These devices have demonstrated the potential use of gestural interfaces in medical professions that require sterile environments [7, 29, 40], as an accessibility device for those with impairments [4, 19], and in mixed reality environments with head mounted displays [13]. [32] looked into the use of the Xbox Kinect for point-select tasks. The experiment utilized a 2D and 3D multi-directional task to evaluate the pointing device. The study found Kinect's throughput was lower for the 2D task, but outperformed the mouse in the 3D task. They also found that Fitts' law extended into gestures similarly to the mouse in the 2D task and at a higher rate in the 3D task.

The "Come As You Are" design principle [37] states that users should not be required to wear a glove or specific markers to interact with the system [40]. In gestural interaction this means a "barehanded interaction style" where users interact with the computer without any device or wires attached. This approach has been described to be superior to previously used gestural input devices where gloves are used [39]. This approach was also utilized to demonstrate human-computer interaction using gestures that are natural and relaxed [14].

2.1.1 Gestural Fatigue. Fatigue is one of the biggest issues with gestures after prolonged interaction [34]. A simple method of overcoming this issue is to allow users to rest their elbows on a chair armrest [14, 34]. Brown et al. implemented this method to perform cursor navigation with 2 possible modes of input: the whole hand and finger pointing. Jude et al. implemented a very similar approach to the previous whereby cursor navigation was done with the whole hand, but the user's input space was first modeled during a calibration stage [25]. Guinness et al. [18] modeled the input space with a sphere as opposed to the previously used quadrilateral [25]. All these approaches make the same claim: performing gestural interaction from a rested position results in a more comfortable interaction and reduces the fatigue inherent to gestural interaction.

2.1.2 Gestural Pointing. Recently touchless gestural pointing has been implemented in one of two general pointing methods. The first, "ray pointing," is a popular approach used by many designers [5, 10, 23, 28] which uses ray casting to determine where the user is pointing [23]. This method is rapid but inaccurate [12]. Conversely, 'whole hand pointing' directly maps the 2D movements of the hand (by dropping one dimension) to the 2D cursor on screen [10]. The user can then move their hand or finger within this navigation space to move the cursor on screen. This method has been shown [10, 12, 25] to be both rapid and accurate, even without visual feedback [12].

2.1.3 Gestural Selection. We use the term "gestural selection" to mean hand gestures used to select or 'choose' virtual objects in 2D or 3D. The two most popular and common forms of gestural

selection are "grab" and "pinch," both of which have been used extensively [14, 17, 38, 42]. A third option is "grasp," [6, 27]. Brown found that the finger tap gesture, which was considered the closest gesture to a mouse selection, performed inadequately for use in their experiment [10]. To combat this, [10] implemented a bi-manual selection method, where users used their other hand to press the space bar when the cursor was over the target. Other researchers [22, 25, 33] used a 'hover-select' or 'dwell' method which required the user to hover over the target for between 250 and 1500 milliseconds.

2.2 Chronic Pain Related Diseases and Conditions (CPD)

Acute and chronic are the two basic types of pain and they differ greatly. While acute pain is a normal sensation triggered in the nervous system to alert an individual to possible injury and the need to take care of themselves, Chronic Pain is persistent. With Chronic Pain signals can keep firing in the nervous system for weeks, months, or even years [31]. People with Chronic Pain disorders are often saddled with impairment of physical and social functions, as well as sleep disturbance, anxiety and depressive disorders. These associated symptoms may have further negative impact on a patient's total life situation and might affect the patient as much as the pain [3]. There are dozens of potential Chronic Pain conditions, however, the conditions that would be most effected by the continued use of gesture interaction would be Osteoarthritis (OA), Rheumatoid arthritis (RA), Fibromyalgia syndrome (FMS), and Carpal Tunnel Syndrome (CTS). The prolonged and specific gesture use of hand, arm, shoulder, and upper back cause the aforementioned conditions the most stress. This is not an exhaustive Chronic Pain list, but does focus on conditions that would typically feel discomfort and pain in most of the major muscle and joints area that are attributed to gesture-based interaction. The amount of pain is correlated to how much users use the mouse; higher amounts of pain leads to lower usage [1].

3 METHODS

3.1 Participants

17 participants between the ages of 18 - 53 were recruited (F=9, M=8). Participants' computer use ranged from 1 to 50 hours per week with a median of 30 hours. All participants were volunteers with previously diagnosed conditions.

3.2 Apparatus

A symmetrical mouse (Logitech M-U0032-O) allowed participants to use either hand, and the Leap Motion captured gestures. Participants were encouraged to position peripherals for their best comfort. Researchers adjusted the angle and position of the Leap Motion to maximize recognition and comfort.

3.3 Gesture Pointing

To evaluate Gestural Pointing we explored three conditions, a mouse (default) and two gestural (Rested-Uncalibrated [10], and Rested-Calibrated [25]). For Rested-Uncalibrated gestural interaction, participants were allowed to rest their elbow on a surface,

Figure 1: The gestures used for selection, with the open pose at the top and the closed pose at the bottom. From L-R: grasp, grab, pinch.

which is known to reduce fatigue. The cursor was linearly mapped to the interaction space and bounded to the length of the participants arm to ensure they would not have to lift their arm from the table to reach far ends of the screen. The Rested-Calibrated interaction is based on ‘Personal Space’ [25], the user definition of the four edges of interaction are used to build a quadrilateral which are mapped to screen coordinates. The use of these two different methods allows us to explore if there is a benefit to modeling the user’s interaction space, or if a simple linear-map would suffice.

3.4 Gesture Selection

To evaluate the Gestural Selection problem space, we investigated a proposed standard vocabulary for touchless gestural interaction for selection tasks – analogous to a drag-and-drop action performed with a mouse. Natural and intuitive gestures, as outlined in the literature review, were developed as well as a keyboard button input condition. The three versions of gesture interactions are called *grab*, *pinch*, and *grasp* (Figure 1).

3.4.1 Interaction Design. The design for selection gestures are based on the 4 usability principles for gestures proposed in [30]: 1) easy to perform and remember, 2) intuitive, 3) metaphorically and iconically logical towards functionality, and 4) ergonomic. [30] recommended a static pointing-like gesture for selection; however a later study indicated that a dynamic gesture is preferred over static gestures for selection [16]. Further, the *grasp* gesture was based on the R-family of gestures, which is used in real life for precision grip [26].

3.5 Task

For the gestural pointing task, standard ISO9241-9 Fitts evaluation with the ring-of-circles task was used with throughput which is a standard pointing performance metric [35]. Our task had three unique target distances (A): 350, 700, 1400 and three unique widths (W): 64, 96, 128, both measured in pixels. This produced index of difficulties between 1.90 and 4.52 bits, which falls within the lower end of the recommended 2-8 bits [35].

An ISO9241-9 evaluation task was also used during the gestural selection evaluation. However, in this case only one target size (700 px) and width (96 px) was used for all interactions. Each subject was asked to perform the task using one of the gestural selection input methods: grab, pinch, grasp, and multimodal (button).

3.6 Procedure

The participants were first shown a 1-minute video detailing the pointing task. Once completed the participants were shown both a short video explaining the the mouse interaction and a longer, 3 minute video outlining the gestural interaction. The gesture interaction video included an explanation of the calibration process. A researcher was present to address participants questions following the video.

When the gestural pointing task began, participants would perform the task once using each method, totalling 3 tasks per round. Each task is done with a different task profile, ensuring participants would not be able to learn the task or guess the position of each target. A practice session consisting of 12 trials was performed before the full task of 70 trials. The 3 tasks in the first round were followed by a 2 minute break, after which participants were asked to perform the exact same tasks as before, in the same order, and on the same task profile. The training task was not present in the second round.

For the gestural selection task, participants would perform a similar task as the gestural pointing but with half the number of trials. After each task completion, the user would perform the task again using a different input method: grab, pinch, grasp, and a multimodal approach where a button was used to initiate selection with the other hand. The order of the input methods was randomized as to, once again, limit the chance that some form of learning effect would be present. To remain consistent, the “Rested & Calibrated Interaction” from the previous portion was used for cursor control. Participants were encouraged to pause and rest for as long as they required between rounds. During these breaks, the experimenter would engage with the participants and collect their thoughts and impressions about the previous interaction.

Upon completion, participants were interviewed about their experience with the various interactions detailing their prior use of each device and their preferences, comfort, and fatigue experienced with those devices during the experiment. The entire experiment lasted between 45 to 60 minutes barring any extended break requests by the participants.

4 RESULTS

4.1 Gestural Pointing

Levene’s test showed the variance for throughput was not equal $F(2,48)=5.9$, $p=.005$. Hence Welch ANOVA was used for hypothesis testing, which showed there was a statistical significance on the effect of interaction on throughput, $F(2,30)=5.90$, $p<.001$. A Games-Howell posthoc test showed there was a statistical difference between Mouse and Gestural: Uncalibrated ($p<.001$), and Mouse and Gestural: PersonalSpace ($p<.001$).

Figure 2 is a Fitts regression which visualizes the impact of Index of Difficulty on Movement Time. Both gestural interactions had Y-intercepts closer to zero: 200 for uncalibrated and 236 for

Figure 2: Visualization of the Fitts task per interaction based on. The black line is regression over the means while the red lines are quantile regression lines at .159 and .841, hence 66% of the points fall within the red lines.

PersonalSpace, the mouse was at 479. Gestural: PersonalSpace had higher goodness of fit measured in Pearson's r (.65) followed by Gestural: Uncalibrated (.57) and the mouse (.39). The model errors calculated in Root Mean Squared Errors (RMSE) was lowest on mouse (396) followed by Gestural: PersonalSpace (407) and Gestural: Uncalibrated (545).

4.2 Gestural Selection

A one-way repeated measures ANOVA showed that there was a statistical significant difference on the effect of interaction on throughput, $F(3,48)=7.44$, $p<.001$. Posthoc tests with Tukey's HSD showed a statistical difference between multimodal and the other three interactions (all $p<.001$) but no significant differences between any of the others (grab, grasp, and pinch). This significant difference can be contributed to a few factors that occurred during the gesture selection task. The first of which was the accuracy of the gesture actions at each of the targets. For non-Chronic Pain users, these actions pose little to no problem in terms of repetitive action. However, for these participants the combination of fatigue and simplification of actions due to pain aversion caused their individual actions to miss the targets, requiring more time and movement to complete each task. Each participant, regardless of number of breaks requested, noted that these factors contributed to their performance degradation during their exit interviews.

4.2.1 Qualitative Results. On both the exit surveys and interviews, participants were overwhelmingly in favor of the multimodal input method. All participants noted that multimodal input provided the best perceived accuracy as well as an experience that was more familiar. In addition, when using the gestural interaction methods, participants had increasing difficulty holding their hands steady when performing the individual input gestures causing the cursor to move during target acquisition and the target to be initially missed. Another consistent issue with the gesture input methods was that in some cases the interaction caused participants' Chronic Pain to "flair up" due to small repetitive motions. This was especially

evident in participants where wrist and hand pain was common (carpal tunnel and arthritis).

5 DISCUSSION AND CONCLUSION

The mouse had the best throughput while both gestural interactions had no significant difference. However, gestural interactions had a better Fitts' model in terms of RMSE and intercept. We believe this indicates gestural interaction could be better generalized to the population of participants with pain. Between the two gestural methods, PersonalSpace had better RMSE, Slope, and Pearson's r , which we believe demonstrates a benefit to modelling the individuals' interaction space, inline with previous research. Both gestural interactions also had higher slopes indicating smaller and/or further targets become harder to reach. This could perhaps be addressed by modifying the GUI to have targets that are larger for our target group.

The qualitative results also indicate that our users want the ability to re-position their hands constantly as this helps with pain conditions. This forced recalibration during gestural pointing, which reduced the overall experience. Future research should consider how the users interaction space can be re-modelled automatically without the need for manual calibration.

In conclusion, this research explored how gestural interaction can be suitable for people with Chronic Pain conditions and found that gestural pointing benefits from modeling users' interaction space. Additionally, a multimodal approach where the non-gesturing hand presses a button is better for selection. Our research indicates that these approaches could improve gestural interaction for people with Chronic Pain issues. While these findings are informative, future investigation is needed to investigate ways of combining these approaches without the need for a dual arm approach.

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