THE POSTURAL COMFORT ZONE FOR REACHING GESTURES

Mathias Kölsch
Dept. of Computer Science
University of California
Santa Barbara, CA 93106
matz@cs.ucsb.edu

Andrew C. Beall
Dept. of Psychology
University of California
Santa Barbara, CA 93106
beall@psych.ucsb.edu

Matthew Turk
Dept. of Computer Science
University of California
Santa Barbara, CA 93106
mturk@cs.ucsb.edu

We have proposed a method for objective assessment of postural comfort (Kölsch et al., 2003). We defined comfort as the range of postures that is voluntarily assumed despite the availability of other postures. Designing user interfaces within the limits of comfort zones can avert risks associated with unknown alternative use patters of the interface.

Here we report on a user study that investigated the comfort zone for free-hand gestures in the horizontal plane at about stomach height. This space is of particular interest to novel technologies such as gesture recognition and virtual reality. The results are in line with previous studies on postural discomfort, but improve on resolution and are not based on subjective, questionnaire-based data acquisition. This study also serves as an example for how to design studies for comfort evaluation.

INTRODUCTION

Motivated by the need for free-hand gesture-based interfaces for wearable computer systems, this study investigates the interaction space in front of the body. Gesture interfaces offer natural, easy, and mobile ways to communicate with a computer (Cutler, Turk, 1998; Kölsch et al., 2002). Yet, most research limits the choice of gestures to those that are easily recognizable, or employs habitual gestures out of convenience. Few projects (e.g., Pausch et al., 1990; Buxton et al. 1983) take a systematic approach.

An extensive body of human factors and ergonomics research investigates postures and motions that humans can articulate (e.g., Chaffin, Andersson, 1984; Grandjean, 1969; Salvendy, 1997; Woodson, 1992). For the range of arm/hand motions (Chaffin, 1973; Wiker et al., 1989), Grandjean states that the best grasping distance is about two thirds of the maximum reaching distance, the best reaching height is around elbow height (Grandjean, 1969). In addition to the work considering reachability and comfort, other topics relevant to space as an interaction area include the temporal characteristics of reaching movements and the precision and accuracy of such movements (Fitts, 1954; Fikes, 1993). Specific to spatial input is a survey (Hinckley et al., 1994). Care must be taken to ensure suitability of gestures to avoid muscle strain and fatigue even during long-term interaction.

We employed a method for objective assessment of postural comfort, where postural comfort is defined as a posture that does not elicit compensating motion of other body parts (Kölsch et al., 2003). With this method it is possible to evaluate user interfaces for their potential for unanticipated postures, which can open backdoors to risk-fraught interface uses. The results presented in this paper can guide designers of novel gesture interfaces and aide workspace design. They also empirically validate the previously proposed comfort zone conceptualization.

METHOD

A comfortable arm/hand motion is one that requires little or no trunk motion, provided that the trunk is free to move. Presenting a set of targets at various locations will elicit trunk motions for some locations, while not for others. The *comfort zone* is indicated indirectly as the range of targets which elicits little or no trunk motion (Kölsch et al., 2003). We hypothesize that there is such a range that satisfies most users, i.e., users will prefer to operate (are comfortable) therein. Following the terminology introduced in the mentioned paper, reaching distance is the primary motion and the object under investigation; body movements are the compensation. For this experiment, we were interested in free-hand gestures in the transverse plane, i.e., hand motions and postures at about stomach height of the standing human body without carrying any additional weights.

Design

We used a 13 x 2 within-participants design that studied the effect of 13 target locations and 2 interaction durations (5 and 20 sec). The target locations are depicted in Figure 1 as open circles. They were chosen to optimally sample the frontal transverse plane across angle and distance with respect to the right shoulder joint.

The dependent variables are the locations of the participants' shoulder joint and the top of the hand. Both trajectories were measured in time and in 3D space throughout each trial. Of particular interest were two derived measures from these variables, the shoulder motion from the initial starting position to the location at the end of each trial, and the distance between hand and shoulder.

Participants

Seven people from the campus community (age 21-30) participated in this study. All were naïve to the hypothesis and reported being right-hand dominant. We recorded their body and elbow heights from the floor and their arm lengths. Our participants' physiques spread from the 10th to the 90th percentile of the population as reported by Woodson (Woodson, 1992).

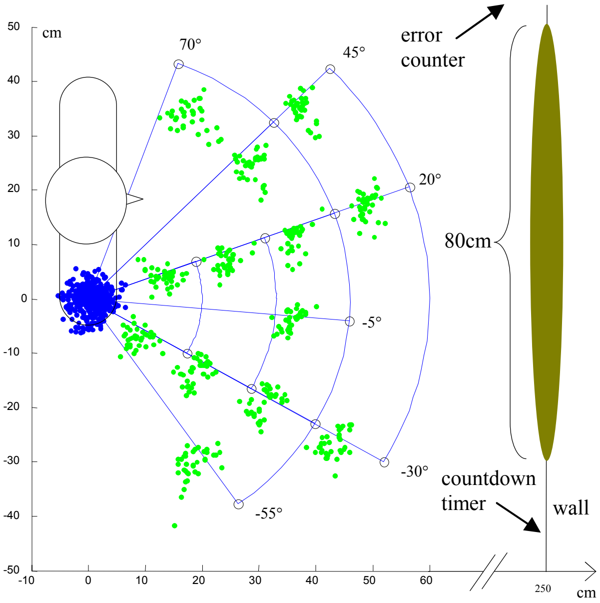

Figure 1: Plan view of the experiment setup: Shown are the 13 target locations (open circles at line intersections) and the size of the displayed object for the skill task on the right. Rays indicate the six azimuthal directions (-55°, -30°, -5°, 20°, 45°, and 70°); concentric partial circles depict the four radial distances (20, 33, 46, and 60 cm). Also shown are two measured values: The initial shoulder locations (dot cluster at coordinate system origin) and the hand locations during the trials (dot clusters left of targets).

Materials and Apparatus

The participants had one six degree-of-freedom tracker attached to the right hand and one above the right shoulder joint (see Figure 2). The tracker on the hand was placed at a distance of d_{tf}= 7cm from the fingertips. For each participant, a starting foot position was established such that the shoulder joint was at approximately the same horizontal location for all participants – the origin of our coordinate system. The target object that the participants had to reach for was a conventional computer trackball. The choice of device is irrelevant because its only objectives were to require the participants to keep their hands suspended in the air and to distract the participants from this fact. Furthermore, various input devices fare very similar with regard to perceived discomfort of use (Kee, 2002). The participants were told to use the trackball in a "finger walking" style to perform a simple skill task that required participants to roll the trackball forwards and backwards. Figure 1 shows a top-down view of the setup.

As stated, the skill task was designed to distract participants from the primary purpose of the study, namely measuring their comfort zone. In this task, participants were required to manipulate the trackball in order to prevent a rendered image of a spherical object from rotating. The spherical object was driven by a pseudo-random disturbance which would cause it to spin without intervention by the participant, exhibiting changing angular momentum. An error score was indicated to motivate the participant to do as good a job as possible at this secondary task.

Figure 2: A participant performing the skill task. Note the trackers on shoulder and hand, and the spiky sphere.

Posture pre-planning can change the way motions are performed (Rosenbaum et al., 2001). Therefore, we required participants to close their eyes during setup between all trials. They also wore headphones that effectively obscured all acoustic cues to location.

Procedure

A trial consisted of: 1) engaging the target at one of the 13 locations using the right hand, and 2) performing the skill task for a period of 5 or 20 seconds. After concluding a trial, the participants were told to briefly walk about, and thereafter go back to the initial position and close their eyes. This was implemented after pilot data showed a tendency to move less and less over the course of subsequent trials. We speculated that promoting a general level of walking would help reduce this ostensible impedance. The trackball was re-positioned to the next location and the countdown timer reset to the next duration period. On vocal command the participants would open their eyes, move towards the target, and execute the next skill task. The movement could be either only a primary hand/arm motion, or a composition of hand/arm and compensatory body movement. The target locations and motion durations were randomized.

Participants were told that the study tested motor skills, that they should focus on the skill task and produce as accurate performance as possible. They were prohibited to offload weight onto the trackball mounting structure. To avoid participants compromising comfort for speed, it was made explicit that the time between the instructor's start command and the participants starting the skill task did not matter. To reinforce the possibility for compensating body motions, the trackball was positioned well out of reach for a few test trials, necessitating a step forward to be able to touch the trackball. The entire experiment including a ten-minute break lasted about 1.5 hours per participant for three repetitions.

RESULTS

Pilot studies indicated that the variability of shoulder location during idle standing is less than 9cm (absolute distance from the starting position) and that shoulder movements of more than 9cm were caused by taking a step, a "significant compensating movement". The comfort zone is defined as locations in which the subject does not move the shoulder more than this threshold amount, referred to later as t_{nc}.

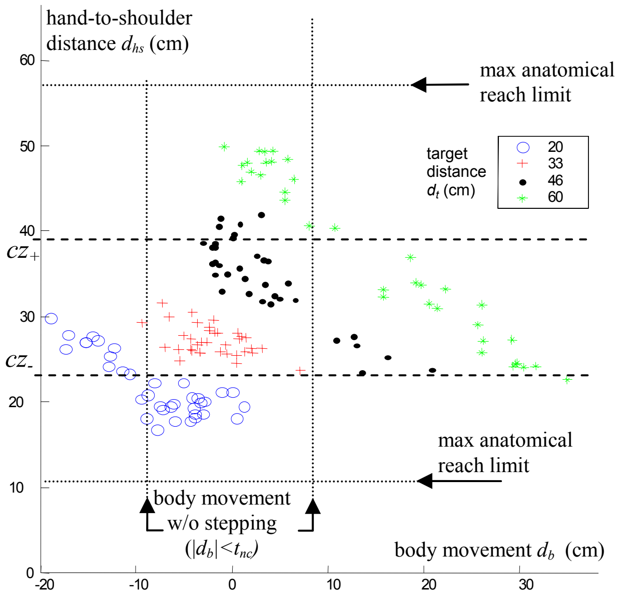

Figure 3: Plotted in this figure is the hand-to-shoulder distance over body movement for four target distances at -30° azimuth (reaching to the right). The sum d_b+d_{hs} roughly equals the target distance (minus the tracker-to-fingertip offset d_{tf}). The comfort zone for d_{hs} is defined as $cz_- \le d_{hs} \le cz_+$. We found cz_- = 23cm and cz_+ = 38cm, but note the additional tracker-to-fingertip offset d_{tf} = 7cm.

The participants' body positions stabilized shortly after the hands had reached the target (within 500ms of movement onset). Thereafter, very little motion of hand and body was observed until the end of the trial. Let d_b be the body movement component along the vector from coordinate system origin to target location, that is, the distance between the initial position of the shoulder and the shoulder's position at time t_E, the time at the end of each trial. Negative values for d_b indicate a movement backwards, away from the target.

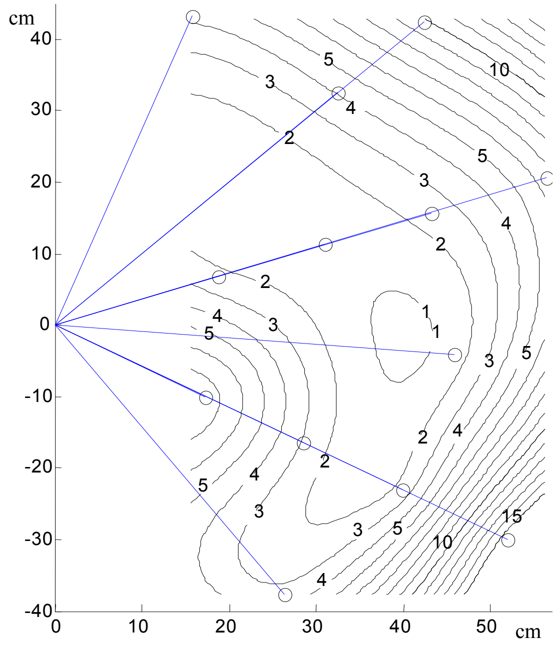

Figure 4: Shown above are "isocomfort" contour lines for medians of absolute body movement $|d_b|$, in cm. The rays and the coordinate system are the same as in Figure 1.

Let d_{hs} be the distance between hand tracker and shoulder at time t_E, the end of the trial. Figure 3 shows the negative linear relationship between d_{hs} and d_b, visible in the diagonal arrangement of the data for each target distance d_t: Either the hand reaches further towards the target (larger d_{hs}) and the compensating body movement d_b is smaller, or vice versa. Some participants chose to use the compensating motion for target distances $d_t \in \{20,46,60\}$, reflected in data points to the left and right of the range of body movement they can make without compensating stepping, $|d_b|<t_{nc}$ (vertical threshold lines). This indicates that these target distances are outside the participant's comfort zone, while the target distance d_t = 33cm is apparently very comfortable. It remains to be noted that $d_{hs}+d_b+d_{tf} = d_t$ does not hold in all cases because d_{hs} is only an absolute distance and no directional vector, and because d_b depends on the exact initial shoulder location.

Another important observation is that the hand-to-shoulder distances d_{hs} that are assumed after stepping are again within a tight range. This can be observed in data points to the left and right of the vertical t_{nc} threshold lines: These data points are confined to within the two dashed *horizontal* lines. The explanation is that the comfort zone of reaching gestures is defined in a reference frame relative to the participant's body, and translates along with her as she moves through space. In this way, as the participant steps to close in on a target that was nearly out of reach, the comfort zone displaces in a world reference frame but remains unchanged in a body reference frame. Again, we can confirm this property by analyzing the spread of the hand locations for only trials in which the participant actually moved.

The central region in Figure 4, about 35-45cm from the shoulder joint, is clearly visible as the region of target locations that evoke the least compensational body movement (1cm isoline). The entire area at this radial distance around the shoulder is also highly preferred: The median body movement was less than 2cm (2cm isoline). In fact, the variation in compensational motion for d_t = 46cm is not significant across different angles (p=0.46). The standard deviation for $|d_b|$ (around 4cm, not shown) confirms uniformity for all participants in this area.

Results were consistent throughout the repetitions and showed a high significance in the target distance parameter (p<0.001). Individual participants' physical arm lengths, actual maximum reaching distances, and actual median reaching distances were not significantly correlated with body movement. Comfort instead seems to be personal preference and/or habit. No significant difference was found between 5 and 20 second trials (p=0.60).

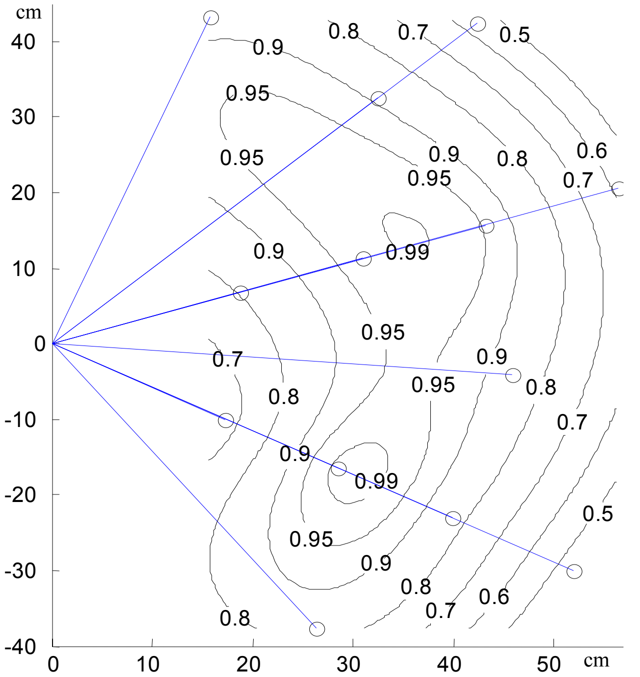

Figure 5: Percentage of trials with absolute body movement under the no-step threshold ($|d_b|<t_{nc}$). The rays and coordinate system are the same as in Figure 1.

DISCUSSION

Our findings correspond to recommendations on workspace design (Grandjean, 1969). Using a recently developed score system (Chung et al., 2002), arm motions necessary to reach all target locations in our experiment would provoke arm-joint discomfort scores from 1 to 8, but by permitting compensating motion, no participant was observed adopting postures with a score higher than 1. This shows that our results are in line with Chung's as well because a score of 1 indicates no experienced discomfort.

The characteristics of the comfort definition (Kölsch et al., 2003) however allow our data to quantify comfort in previously uncharted terrain: We can measure different comfort levels where users persistently report "no discomfort". Figure 5 shows the percentage of users that employed compensating motion to reach for targets at the respective locations. This corresponds to the participants' *comfort zone for hand/arm postures*. Designers that strive to build comfortable gesture interfaces should use it to determine what percentile of the population will experience their intended interface use as comfortable.

This study differs from prior art in the following ways. First, the participants had to sustain only the weight of their limbs and no additional weight. Second, we measured an objective quantity as opposed to traditional questionnaire-based data. Third, most human factors work focuses on actual, adopted positions. Owing to the definition of comfort, this study determined postures that do not elicit posture *changes*, thus reducing the risk potential inherent in *unanticipated* postures.

We did not collect data with discomfort questionnaires primarily because it is essential to the comfort definition that participants are oblivious to the study objective, which would have been an impossible feat with explicit questions about their discomfort. Furthermore, we did not expect the data from questionnaires to deviate in resolution or result from previous studies.

User interfaces that utilize both hands provide many benefits over single-handed interaction (Hinckley et al., 1998; Pierce et al., 1999). The comfort zone for the non-dominant hand is expected to resemble the mirrored image of the comfort zone for the dominant hand. It is expected to be different however when both hands are used concurrently. The comfort zone for hand gestures out of the horizontal plane (Chaffin, Andersson, 1984) is of future interest as well as supinated postures (palm up) versus prone postures (palm-down), the latter allowing non-strain interaction further away from the body (Tichauer, 1978).

The importance of the comfort zone is illustrated by the keyboard. Its intended use pattern (hands suspended in the air above it) lies outside the comfort zone because resting the palms on the desk is more comfortable. The increased pressure on the median nerve in the rested wrist however can cause repetitive strain injuries. Novel interfaces should therefore be evaluated for comfort or they expose users to risk-fraught, unanticipated use patterns.

We presented a fine-grained, two-dimensional comfort function, defined over a horizontal area in front of the body. Researchers and designers of hand gesture tasks can readily make use of these results which are particularly well suited to novel human-computer interface domains such as virtual reality environments. To accommodate most people, the bulk part of the interaction should occur within a tight comfort zone.

ACKNOWLEDGMENTS

We thank all participants in the user study, Andreas Engberg for his assistance with software development (Pope et al., 2001) and Stephen Pope for providing use of the facilities and equipment.

REFERENCES

1. Buxton, W., Fiume, E., Hill, R., Lee, A. and Woo, C. Continuous Hand-Gesture Driven Input. *Proceedings of Graphics Interface '83*, 9th Conference of the Canadian Man-Computer Communications Society, Edmonton, 191-195, 1983.
2. Chaffin, D. B. Localized Muscle Fatigue – Definition and Measurement. *Journal of Occupational Medicine 15(4),* 346-354, 1973.
3. Chaffin, D. B., Andersson G. B. *Journal of Occupational Biomechanics*. John Wiley & Sons, 1984.
4. Chung, M. K., Lee, I., Kee, D., and Kim, S. H. A Postural Workload Evaluation System Based on a Macro- postural Classification. *Human Factors and Ergonomics in Manufacturing, 12(3),* 267-277, 2002.
5. Cutler, R. and Turk, M. View-based Interpretation of Real-time Optical Flow for Gesture Recognition. *Proc. 1998 IEEE Conference on Automatic Face and Gesture Recognition*, 1998.
6. Fikes, T. G. *System Architecture Analysis for Reaching and Grasping*. University of California, Santa Barbara, PhD Thesis, 1993.
7. Fitts, P. M. The information capacity of the human motor system in controlling the amplitude of movement. *Journal of Experimental Psychology 47*, 381-391, 1954.
8. Grandjean, E. Fitting the task to the man. An Ergonomic Approach. Taylor & Francis Ltd, London, 1969.
9. Hinckley, K., Pausch, R., Goble, J. C., and Kassell, N. F. A Survey of Design Issues in Spatial Input. *Proc. ACM Symposium on UIST*, 213-222, 1994.
10. Hinckley, K., Pausch, R., Proffitt, D., and Kassell, N. F. Two-handed virtual manipulation. *ACM Transactions on Computer-Human Interaction (5) 3*, 260-302, 1998.
11. Kee, D. A method for analytically generating three-dimensional isocomfort workspace based on perceived discomfort. *Applied Ergonomics, 33(1),* 51-62, 2002.
12. Kölsch, M. and Turk, M. Keyboards without Keyboards: A Survey of Virtual Keyboard Implementations. SIMS, 2002, at http://www.create.ucsb.edu/sims/Proceedings.html.
13. Kölsch, M., Beall, A. and Turk, M. An Objective Measure for Postural Comfort. In *Proc. HFES 47th Annual Meeting (this publication)*, 2003.
14. Pausch, R. and Williams, R. D. Tailor: Creating Custom User Interfaces Based on Gesture. *Proc. 3rd ACM SIGGRAPH Symposium on User Interface Software and Technology*, 1990.
15. Pierce, J. S., Stearns, B., and Pausch, R. Two Handed Manipulation of Voodoo Dolls in Virtual Environments. *Symposium on Interactive 3D Graphics*, 141-145, 1999.
16. Pope, S. T., Engberg, A., Holm, F. The Distributed Processing Environment for High-Performance Distributed Multimedia Applications. Proc. 2001 IEEE Multimedia Technology and Appl. Conf., 2001.
17. Rosenbaum, D. A., Meulenbroek, R. J., Vaughan, J., Jansen, C. Posture-Based Motion Planning: Applications to Grasping. *Psychological Review (108) 4*, 709-734, 2001.
18. Salvendy, G. *Handbook of Human Factors and Ergonomics*. 2nd edition. John Wiley & Sons, 1997.
19. Tichauer, E. R. The Biomechanical Basis of Ergonomics. John Wiley & Sons, 1978.
20. Wiker, S. F., Langolf, G. D., and Chaffin, D. B. Arm Posture and Human Movement Capability. *Human Factors 31(4)*. 421-441, 1989.
21. Woodson, W. E. Human Factors Design Handbook, 2nd edition, McGraw-Hill Professional, 1992.