

An Objective Measure for Postural Comfort

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ABSTRACT

Biomechanics determines the physical range in which humans can move their bodies. Human factors research delineates a subspace in which humans can operate without experiencing musculoskeletal strain, fatigue or discomfort.

We claim that there is an even tighter space which we call the *comfort zone*. It is defined as the range of postures adopted voluntarily – despite the availability of other postures. We introduce a measurable, objective foundation for comfort, which was previously assumed equivalent to the absence of discomfort, a subjective quantity.

Interfaces designed outside a user’s comfort zone can prompt the adoption of alternative use patterns, which are often less favorable because they trade off the unnoticeable potential of injury for comfort. Designing interfaces within the limits of comfort zones can avert these risks.

Keywords

Comfort zone, postural discomfort, biomechanical workload

INTRODUCTION

Not surprisingly, simply taking the envelope of human capabilities (e.g. [4, 8, 15, 17]) into consideration during user interface design does not guarantee that it will be used in the intended way. Users might prefer an alternative use pattern that they subjectively experience to be more convenient, but which might cause musculoskeletal strain or physical injuries not immediately apparent to the user. If instead the use pattern is designed to match a *comfortable* way to operate the interface, then the likelihood that the user will adopt alternative strategies is naturally reduced.

We propose a method that aides interface designers to stay within these more subtle limits of comfort and preference. We define the *comfort zone* as a range of postures or motions that are voluntarily adopted – as opposed to those that are avoided if an alternative posture is possible. The extent of this zone can be assessed by objective measures, alleviating the need for user questionnaires.

DISCOMFORT, FATIGUE – AND COMFORT?

The human state of feeling along the “comfort dimension” can roughly be classified into states of comfort, discomfort, fatigue, and pain. Table 1 summarizes the following subsections: Figure 1 plots how these feelings can be experienced across a 2D space at a certain point in time.

feeling \ measure	comfort	discomfort		fatigue
		unaware	aware	
direct	no	no	BPD (RPE)	EMG
indirect	no	this paper	posture shifts	RPE, perform.
objective	no	this paper	posture shifts	EMG, perform.
subjective	absence of discomfort		BPD (RPE)	RPE

Table 1: Which and how various states along the comfort dimension can be measured. BPD stands for Body Part Discomfort [6], RPE the Rate of Perceived Exertion in the Borg scale [2], EMG are electromyographic signals [3]. For example, EMG is a direct and objective measure for fatigue, and BPD is a subjective method for direct ascertainment of aware discomfort. “Direct” refers to measurement methods that can detect the feeling as such, while “indirect” methods have to rely on measuring a secondary effect caused by the feeling.

Discomfort

Discomfort is usually assessed with questionnaires to the study participant, for example with the Body Part Discomfort (BPD) scale (Corlett et al. [6]). Participants repeatedly indicate uncomfortable body parts on a body chart and rate the severity of discomfort. Drury et al. [7] added the BPD Frequency (total number of body parts with some discomfort) and BPD Severity (mean severity of discomfort of body parts with some discomfort) to the questionnaire.

In addition to the subjective nature of the results, the questioning continuously raises the discomfort issue with the participant, potentially exaggerating receptiveness to discomfort. Questionnaires are also incapable of determining a low-grade or unaware feeling of discomfort.

Several studies ([1], [9], [12]) observed that the frequency of postural shifts of not work-related body parts correlates to the participants’ perceived discomfort, which comes closer to employing an objective method to measure discomfort. Kee [10] built a human-physics model to compute surfaces of uniform discomfort based on perceived discomfort. He had collected subjective discomfort data which can now be used for purely observational discomfort estimation [5].

Fatigue

Fatigue is a stronger sensation than discomfort. The Borg scale [2] is frequently used to rate overall body exertion. Borg found a logarithmic relationship between achieved

power on a treadmill and the participant's Rate of Perceived Exertion (RPE). The RPE is obtained with a questionnaire on a scale of 6-20, some numbers having a descriptive name, ranging from "Least Effort" to "Maximal Effort". Because the boundary between discomfort and fatigue is somewhat fluid, the RPE is sometimes used to rate discomfort as well.

Fatigue can be objectively witnessed by a loss of functionality, e.g. as a decrease in accuracy or speed of movement. Pan et al. [14] suggest that performance variability is directly related to fatigue and boredom effects. Another method uses physiological measures: nervous electromyographic (EMG) signals to the muscles (Chaffin [3]). Other studies however found little or even adverse correlation between EMG frequency shifts and subjective fatigue [13], particularly for low postural loads.

As a rough guideline established from empirical data, it is generally accepted (e.g. [6]) that when muscular exertion remains below 15% of the maximum voluntary contraction the participants do not experience fatigue and performance does not decrease over time.

Comfort

Postural comfort is most often defined as the absence of discomfort. Discomfort in return is based on subjective data, making comfort a subjective quantity (e.g. Kee [10]). We endeavor to show how behavioral methods can be used for comfort assessment as well.

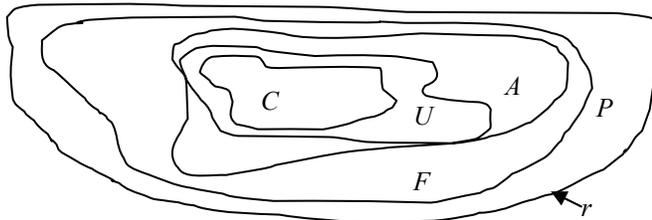


Figure 1: Conceptual view of comfort areas in a physical space at a particular time. r depicts the anatomically possible range, P the range in which pain is experienced, F the range of fatigue but without pain, A the range of discomfort the participant is aware of, U the range that is not comfortable but the participant is unaware of the discomfort, and C the range of complete comfort.

Temporal Effects

The aware feeling of discomfort and the areas in which it is felt increase over time [9, 14]. While we have not conducted research on comfort longevity, we suggest that the area of unaware discomfort shrinks with time and the participant becomes aware of the discomfort, but that the boundary to the comfort zone remains untouched (compare Figure 1). If in fact the entire area of unaware discomfort diminished asymptotically, i.e. U was "eaten up" completely by an expanding A , this would constitute an alternative way to define the comfort zone.

Regardless, postural changes might be a necessary alleviation for problems associated with static postures, even those within the comfort zone.

OPERATIONAL DEFINITION OF COMFORT

This section describes the steps that lead to a measurable indication of postural comfort, which is a subspace of the full base range of the physically possible. The main concept is to allow for compensation for uncomfortable postures through alternative motions or postures and to measure under what conditions the compensation takes over. Comfort is defined as the set of postures that can be adopted and motions that can be performed without eliciting these secondary motions. A person is in a state of postural comfort if there is not, and likely will not arise, a (possibly unaware) desire to compensate. Comfort can therefore not be measured directly or by means of questioning the participant.

1. Base: Specified is an *object under investigation* ("OI", a body part or joint) for which a comfortable sub range of positions is to be determined during execution of a certain task. Select a *base range* of the OI's possible positions, which can be either the anthropomorphically feasible range (i.e. the physical reach limit for example), or it can be an ergonomically sensible range (for example the maximum non-fatiguing reach) for this body part or joint.

2. Compensation: A way to adjust the OI must be identified such that the OI can assume any location within its full base range without hampering task execution. This *compensation* can either be another body part or joint that can substitute for the movement of the OI, or it can be a way to adjust the experiment settings. An example for compensation by another body part is sideways (around the longitudinal axis) head rotation (OI) that can be compensated for by full-body rotation around the same axis. An example for adjusting experiment settings would be an alternative for head rotation in the horizontal axis (OI), e.g., when performing a visual display terminal task (VDT task, reading on a monitor). A monitor that can be rotated around the body's horizontal axis would qualify as a device that can compensate for the head's rotation. Care must be taken to choose a compensation that does not require considerable effort from the participant. That is to say, it is important that these alternatives are not anthropomorphically more "expensive" than the adoption of an uncomfortable posture.

3. Comfort Zone: We will determine the comfort zone by an experiment where the participants are free to use both the OI and the compensation as they desire. We design a set of tasks such that, if compensation was not permitted, areas in the base range of OI's positions have to be adopted at sufficient sample density. Then we allow for compensation and observe which sub-range of the OI's positions is still adopted, and which complementary region is compensated for by the secondary motion or posture. This boundary delineates the *comfort zone* which is the main result of the procedure. Frequently, a second range can be observed: the positions assumed by the OI after compensating motion. Strictly speaking, this range is independent of the comfort zone. However, we generally expect it to fall within the

limits of the comfort zone. This in fact validates and reinforces the result of the comfort zone. This phenomenon was observed in an experiment [11], confirming our theory of a comfortable interaction range.

DISCUSSION

While our definition of comfort clearly describes how to measure a quantity, the relationship between this quantity and (dis)comfort is not inherent. In other words, the comfort zone, defined as the area of the most comfortable motions/postures for a given task, does not predicate an absolute measure of well-being. Further experiments have to be designed to study this relationship. For the purpose of evaluating biomechanical postures with respect to their relative sustainability however our definition delivers the desired results: Users within their comfort zone are unlikely to change into other postures.

There are two main innovations of our method for comfort measurement. First, as participants are naïve to the study's purpose, we can expect that demand characteristics of the study itself do not play a significant role in influencing the results. In fact, the method measures an objective quantity in contrast to traditional questionnaire-based data collection methods. An important contribution of such behavioral methods is their isolation from the conscious, cognitive strategies of individuals. They can detect discomforts that have not yet risen to the user's awareness or even those that are cognitively impenetrable. Second, most human factors work is targeted towards decreasing the risk for musculoskeletal injuries resulting directly from an actual, adopted position during task performance. Our work however aims at finding postures that do not motivate the desire to *change* posture, thus eliminating the risk of *unanticipated* postures.

Collecting questionnaire-based user discomfort data during comfort assessment must be met with caution since it is essential that participants are oblivious to the study objective. Intermittent data collection is therefore prohibitive. Post-experiment data collection either includes recall of past discomfort feelings – an arguable feat – or experiment re-execution with interlaced evaluation, which again would interfere with the participants' naivety towards the purpose of the compensational motion. Furthermore, the information gathered with conventional methods is too coarse for a meaningful comparison because it does not go beyond aware feelings.

Example 1: A potential experiment could include displaying text at locations around the head and have the participants read it aloud. For some locations, the participants will be more likely to turn their head towards the text without moving their bodies (the comfort zone), and for other locations they will compensate for extreme head rotations by rotating their entire bodies.

Example 2: A comfortable arm/hand reaching posture 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 others will not. The *comfort zone* is the range of targets which elicits little or no trunk motion.

We conducted this experiment for gestures in the transverse (horizontal) plane at about stomach height [11]. Our findings correspond to recommendations on workspace design (primarily [8], also [3, 16]). The measured comfort zone is a true subspace of the area with score 1 according to Chung et al. [5], which is the area of no experienced discomfort (Figure 1, range *U*). Our method and the results in our study go further as they add resolution to an area that was previously indistinguishable.

Example 3: The intended use pattern of keyboards is with the hands suspended in the air above the keyboard. Yet it is more comfortable to rest the palm on the device or the surface in front of it. This however increases pressure on the median nerve in the wrist, which can cause repetitive strain injuries such as the carpal tunnel syndrome. One must therefore avoid designing interfaces prone to creating similar problems, i.e. those that are uncomfortable to use in their intended way and prompt users to find more comfortable yet injury-prone ways to perform the interaction.

CONCLUSIONS

The proposed method allows for assessment of postural comfort. We determine the comfort zone by measuring compensating motion that allows participants to freely pick a comfortable posture range with the body part under scrutiny. Our method does not rely on acquisition of subjective data. Instead, it is entirely objective and allows for participants that are naïve to the study purpose.

Staying within the comfort zone of a user averts the risk of users adopting alternative use patterns that appear more comfortable, yet which are often less favorable because they trade off the unnoticeable potential of injury for comfort.

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