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Christopher J. Garneau and Matthew B. Parkinson
U.S. Army Research Laboratory, Human Research and Engineering Directorate, Aberdeen Proving Ground, MD 21005, USA
Engineering Design, Mechanical Engineering and Industrial Engineering, The Pennsylvania State University, University Park, PA 16802, USA
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Considering just noticeable difference in assessments of physical accommodation for product design

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aU.S. Army Research Laboratory, Human Research and Engineering Directorate, Aberdeen Proving Ground, MD 21005, USA; bEngineering Design, Mechanical Engineering and Industrial Engineering, The Pennsylvania State University, University Park, PA 16802, USA

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Configuring products or environments for the size of their human users requires the consideration of several characteristics of the target user population, including body dimensions (anthropometry) and preferred interaction. Users are both adaptable and imperfect observers, which often makes it difficult for them to distinguish between candidate designs. This insensitivity is described by a concept called ‘just noticeable difference’, or JND. This paper presents an implementation of JND modelling and demonstrates how its use in the sizing of products or environments for target user populations can improve expected performance. Two facets of this problem are explored: (1) how experimental measures of JND for dimensional optimisation tasks may be obtained, and (2) how measures of JND may be included in models of user–device interaction for both adjustable and discretely sized products and the assumptions required. A case study demonstrating the collection and modelling of JND for a simple univariate problem is also presented.

Practitioner Summary: Since people are adaptable and imperfect observers, there exists a ‘just noticeable difference’ that can be considered when designing products and environments. When JND is modelled for a target population, less variability in design dimensions due to physical user requirements may be necessary. This paper considers JND in quantitative simulations of population accommodation.

Keywords: just noticeable difference (JND); designing for human variability (DfHV); user sensitivity; anthropometry; physical accommodation

1. Introduction

Configuring characteristics of a product or environment to meet the physical requirements of users is a task that requires designers to consider quantitative measures of the user population’s variability. In dimensional optimisation, the size of the device is configured to best accommodate the range of body sizes (or anthropometry) of the target user population. This is usually achieved with adjustability on one or more dimensions of the device, multiple discrete sizes or both. Accommodation is a key performance metric and is generally specified as the percentage of target users able to use or fit a candidate design in a desired way. Design for Human Variability (DfHV) is the area of research concerned with methods for optimising user–product interaction, which is achieved by modifying parameters of the design of products and environments to suit target population attributes. These attributes include anthropometry, user behaviour and factors influencing these such as demographics and age. This paper explores user sensitivity to product configuration as an additional source of variability.

Anthropometry-independent user preference has been posited as a component of human variability that moderates the physical interaction between user and device. In other words, it is often the case that some variability in user preference is not correlated with anthropometry. In Garneau and Parkinson (2009), aggregate user preference was modelled using experiments involving a sample of representative users interacting with a prototype device. Comparisons indicate that models that account for anthropometry-independent preference yield design configurations that are more robust to variability in the way users interact with a product (Garneau and Parkinson 2011).

Accommodation is often considered to be a binary state, wherein users are considered to be accommodated or disaccommodated with no intermediate compromise. However, such treatment ignores two possible scenarios: (1) users may experience some amount of acceptable disaccommodation without noticing, or (2) there may be several optimal configurations or a range of optimal accommodation for a particular user. Either situation implies the existence of a measurable deviation from a nominal value that is not detectable as disaccommodation to the user. This measure is called the just noticeable difference, or JND, in psychophysics literature. Its inclusion in assessments of physical accommodation has been considered previously (Pheasant 2006) and leads to more accurate assessments of user–device interaction.
The objective of this paper is to explore user sensitivity to disaccommodation via the JND and DfHV paradigms. Specifically, the paper explores methods for both measuring and including JND in stochastic models representing physical user interaction with products and environments.

1.1. Just noticeable difference and related literature

Experiments beginning in the mid-nineteenth century explored the concept of sensory thresholds, the amount of a stimulus above which an experience will be noticed. Sensory thresholds are measured as absolute thresholds and difference thresholds. The absolute threshold is defined as the smallest amount of stimulus energy necessary to produce a sensation; the difference threshold is defined as the change in stimulus required to produce a JND in the sensation (Gescheider 1984). Sensory thresholds may be directly measured for many types of individual stimuli targeting one of the senses – for example, the frequency of a sound or the weight of an object.

Standardised experimental psychophysical methods that test for sensory thresholds have been developed. Since humans are imperfect observers and stimuli contain variability, thresholds are typically defined as the stimulus value perceptible in 50% of trials. The traditional means for determining sensory thresholds include the method of constant stimuli, the method of limits, the up-and-down method and the method of adjustments (Gescheider 1984). While assumptions and efficiency for each method differ, all of the methods determine thresholds by presenting participants with a variety of stimuli and asking the participant to identify which stimuli, or difference between stimuli (i.e. JND), are perceptible.

Applications of sensory threshold measurements may be found in many areas. For instance, sensitivity to pressure on the skin in the area of the ischial tuberosity has been studied with respect to comfort while sitting (Goossens, Teeuw, and Snijders 2005). JNDs in auditory stimuli have been investigated among cochlear implant patients (Aronson et al. 1994). JND in visual acuity finds many applications in displays and image processing – for example, in the design of a nuclear power plant display (Rantanen and Goldberg 1996), for enhancing perceptibility of images on a dim LCD display (Huang et al. 2008) and for guiding creation of watermarks for digital images (Niu et al. 2010). For thermal stimuli, JND has been measured to guide the design of a control procedure for a room air conditioner (Lee et al. 1998). For tactile stimuli, JND has been measured to evaluate slip at the fingertips (Salada et al. 2004) and high-frequency vibratory feedback in tactile displays (Pongrac 2008). In Weir et al. (2007), the ability of both novice and expert designers to discriminate between two trunk postures was assessed. This was achieved by presenting images of people in different postures and assessing whether the designer could discern a difference. In Hsia and Drury (1986) and Heath et al. (2011), measures of JND find application in tool handle design.

A common application for DfHV methodologies is vehicle design, and several studies have explored JND in this context. In Hoffman and Joubert (1968), experiments measured the ability of drivers to perceive changes in vehicle handling variables, measuring the JND for the parameters of steering ratio, stability factor and response time. In Mansfield and Griffin (2000), both absolute and difference thresholds for automobile seat vibration were measured. In Southall (1985), JND was examined to determine discrimination among clutch pedal resistance; in Giacomin and Mackenzie (2001), JND was considered to determine sensitivity to gearshift resistance. Walker, Stanton, and Young (2006) investigated driver sensitivity to various non-visual stimuli to quantify the effect of such stimuli on situational awareness. Kyung and Nussbaum (2009) examined driving posture and comfort in an experimental study to formulate recommendations for driving posture to be used with digital human models; the results considered participants’ ratings on criteria for comfort and discomfort.

Britt and Nelson (1976) explore incorporating a measure of JND in product design to improve the user experience. This goal is investigated from a marketing perspective by posing the question ‘how much must a product be improved before consumers notice the difference and choose it over competing brands?’ The study offers examples that explore the trade-off between design optimisation and noticeability. In one example, the weight of a suitcase is the product metric under consideration; incremental improvements in weight must exceed a certain percentage of the original weight or the consumer will likely not notice the difference. The authors point out that any design resources expended to improve product performance within this threshold would have been largely wasted on the improvement since few users would notice the change.

1.2. Goals of the present work

Broadly, the goal of this paper is to explore including measures of JND in the optimal sizing of products or environments for target user populations. Two facets of this problem are explored: (1) how experimental measures of JND for dimensional optimisation tasks may be obtained, and (2) how measures of JND may be included in models of user–device interaction.
2. Methodology

Since there are two main goals of this work, the methodology is divided into two corresponding sections: (1) measuring JND and (2) including JND in design processes.

2.1. Experimentally measuring JND for dimensional optimisation tasks

2.1.1. Population models and virtual fitting

One strategy for conducting experiments that capture user interaction is to sample a sufficiently large number of representative users and perform statistical analysis to determine the desired range of variability in the design variable (which then determines adjustability or configuration of discrete sizes). This is called a population model. An alternative is to correlate body measures with a user’s preferred device configuration (e.g. their selected size or preferred setting). Linear regression may then be used to model a population’s preferred interaction with a product. Extending this model to include a measure of anthropometry-independent preference may be achieved by retaining a measure of residual variance in the regression model for the population. Using the results of this model with a large sample of representative anthropometry (e.g. 1000 sets of measures) yields a virtual fitting trial (Garneau and Parkinson 2009). Results of the virtual fit may be used to determine desired range of variability by retaining the desired portion of population response (e.g. 950 of the 1000 points for 95% accommodation).

The virtual fitting process considers a measure of anthropometry-independent preference across a population, but not for individuals within it. That is, while individual deviations from linear behaviour of a population are considered, each individual is considered to be either strictly accommodated or strictly disaccommodated with no allowance for their sensitivity or satisfaction.

2.1.2. Just noticeable difference in experiments for product design

JND may be thought of as an individual’s sensitivity to their preferred setting. A user’s interaction with many products simultaneously stimulates many senses; for example, an automobile interior stimulates visual, olfactory, tactile and auditory stimuli. JND in this context may be thought of as the user’s aggregate response to these multiple interacting stimuli.

Classic techniques for measuring JND were discussed in the Introduction. The method of constant stimuli is considered here. In this method, a standard stimulus and comparison stimulus are presented and participants are asked whether there is a perceptible difference between the two (Gescheider 1984). A key assumption of this concept is that there exists an unchanging standard stimulus to which all other stimuli are compared to measure perceptible difference. Classically, normality in the given responses is assumed so that the cumulative distribution follows an ogive shape and frequency follows a normal curve. The method of constant stimuli was chosen for this paper because it most efficiently models user response for DfHV analyses; this method is explored further in the following section.

2.1.3. Explicit standard stimulus

There are two ways in which the ‘standard stimulus’ may be interpreted in the context of developing experiments for dimensional optimisation in DfHV. The first is a direct application of traditional JND measurement techniques – a user is presented with a given size or product setting as the standard, and then several alternate sizes or configurations are presented in a methodical fashion to determine the degree to which the user notices a difference for each comparison. In this paper, this method is referred to as the explicit standard stimulus method because users are explicitly presented with two stimuli to compare. To find both the mean preferred product configuration and the deviation about this mean, two separate experiments are required.

Figure 1 shows two typical psychometric functions for such an experiment and a normal distribution showing the probability of subjective equality. Subjective equality represents the condition under which a participant would consider the comparison stimulus to be greater than (or less than) the standard stimulus 50% of the time. In other words, the participant is unable to distinguish the comparison stimulus from the standard stimulus.

To measure JND, deviation from subjective equality is considered. It is common to consider 50% JND – that is, in an experiment conducted multiple times with a single participant, 50% JND is the interval within which half of the participant’s responses lie. This condition requires that the proportion of the participant’s ‘greater than’ responses to total responses lie in the range of 0.25–0.75 (equivalently, the proportion of participant’s ‘less than’ responses will vary between 0.75 and 0.25; see Figure 1). It is important to note that the area under half of the normal curve for 50% JND equals \(0.5/2 = 0.25\), corresponding with a \(z\)-score of 0.674. This area is shaded in Figure 1.
2.1.4. Implicit standard stimulus

A second strategy for measuring JND is to perform an experiment that attempts to measure the user’s mean preferred behaviour and then describes the distribution of responses that result. In this paper, this method is referred to as the implicit standard stimulus method. In contrast to the explicit standard stimulus approach, only a single experiment is needed. Study participants are required to make several determinations of their preferred size or setting, beginning from different initial conditions. A key assumption of this method is a rethinking of the standard stimuli – in this technique, a user compares each possible configuration of the device to their internal standard. When the device configuration (the comparison stimuli) aligns with the user’s implicit ideal (the standard stimuli), subjective equality is achieved, represented by the peak on the normal distribution.

Determining JND for the population using an implicit standard stimulus is a two-step process (using the results from one experiment). First, JND is calculated for individuals in the population in the standard way – for a 50% JND criterion, JND is $0.674 \sigma$ ($z = 0.674 \sigma$ for $P = 0.5$) for the distribution of each user’s response. This generates a distribution of JND, which is characterised by mean $\bar{JND}$ and standard deviation $s_{JND}$. Assuming a typical model of user behaviour, both of these distributions are normal.

2.1.5. Choosing a strategy

Consider a simple application of each technique wherein a user is asked to evaluate the seat height of an office chair for optimal comfort. In the explicit standard stimulus method, the researcher first asks the user to determine their preferred seat height by moving the chair up and down throughout its adjustable range. Once a preferred height is determined, the researcher conducts a second experiment to measure the user’s sensitivity to this height (JND) across several trials by slightly altering the preferred height by random and varying amounts. The researcher asks the user to indicate the trials for which they notice a difference between these alterations and their preferred height. The user makes comparisons between their perceived comfort of their stated preferred height (standard stimulus) and the comfort attained by deviations about this height (comparison stimuli).

In the implicit standard stimulus method, the researcher conducts only one experiment and asks the user to determine their preferred seat height over several trials. Between each trial, the chair is randomly positioned to a new starting condition to avoid bias effects. The researcher notes each preferred seat height, which will typically differ by a small amount. The user makes comparisons between their internal notion of comfort (standard stimulus) and the comfort attained by each chair height configuration (comparison stimuli).

Each technique has advantages and disadvantages. Use of an explicit standard stimulus adheres to classical psychometric experimentation methods that provide participants with a clear difference between the standard and comparison stimuli. However, the complete modelling of user interaction would require two experiments, one for mean preferred behaviour and a second for sensitivity (JND). Furthermore, JND may be a function of product size or configuration; the JND distribution would likely change as users are presented with various configurations as the standard
stimuli. Use of an implicit standard stimulus resolves these issues and enables efficient modelling of user preference. These things considered, the second strategy considering an implicit standard stimulus more accurately and efficiently represents user behaviour using only one experiment. This strategy will be used in the remainder of this paper.

2.2. Modelling JND in quantitative simulations

The preceding discussion sets the foundation for appropriately collecting and interpreting data describing JND for individual users. As Figure 1 shows, each individual user is assumed to have a unique sensitivity profile given by a normal distribution with a certain standard deviation from the mean. However, not all users’ sensitivities will be equal – each individual has their own JND. It is important to consider this variation across the population as well. As noted in the previous section, it is reasonable to assume that JND across a population of users will follow a normal curve, as shown in Figure 2. In this figure, users at the left tail of the distribution are very sensitive to small perturbations about their mean preferred value and thus have a small JND. Conversely, users at the right tail are not very sensitive and have a larger JND. Some curves showing the probability of subjective equality (PSE) are shown as small distributions with thin lines for several points across the population sensitivity distribution (large distribution with thick line).

The concepts illustrated by Figures 1 and 2, along with the virtual fit methodology previously used for solving DfHV dimensional optimisation tasks, provide the necessary framework to model user–device interaction considering aggregate user preference and individual user sensitivity. This better models user behaviour where accommodation is not a binary state, and permits the designer to specify solutions to a given level of sensitivity (e.g. 50% JND) for an experimentally derived distribution of representative user responses. A brief overview of the virtual fit methodology is described next, followed by a description of the additional steps necessary to integrate measures of JND.

2.2.1. Virtual fitting with binary accommodation

The virtual fit method may be divided into a four-part process to quantitatively model user–product interaction (Parkinson and Reed 2006), as enumerated next. The following description assumes that only one measure of anthropometry is correlated with the preferred device parameter to measure user behavior, but the method may be extended to multivariate anthropometry where the benefit of considering JND may be amplified.

1. User behaviour is captured through user trials wherein participants of known anthropometry interact with a prototype that models the full range of user interactions – this is called a preference study.

2. User-selected device preference and anthropometry are modelled for the population using linear regression. If the outcome measure for preference is known to be strongly correlated to a specific measure of anthropometry, that specific measure may be used in the regression; otherwise, the regression may be performed with stature or BMI. In robust analyses, the residual variance is included as a stochastic component representing aggregate population preference unrelated to anthropometry (Garneau and Parkinson 2009). This is reflected in Equation (1), where $O$ is...
the outcome measure, $A$ is a measure of anthropometry, $c$ and $b$ are linear regression slope and intercept, and $N(0, s_{\text{regression}})$ indicates a normal distribution with a mean of 0 and a standard deviation $s_{\text{regression}}$ equal to the RMSE of the regression:

$$O = cA + b + N(0, s_{\text{regression}}).$$  \hfill (1)

(3) The regression model is applied to a large virtual population that mirrors the statistical properties of the target user population. In other words, the device preference for each virtual person in a large virtual population is described by the regression.

(4) Estimates of accommodation are made by excluding a certain number of individuals at the tails of the virtual population. For instance, for 95% accommodation of a 1000-member population interacting with a univariate product, 25 people with the most extreme preferred configurations are excluded from the virtual population. Figure 3 shows the results of the virtual fitting process for a 1000-member virtual population.

2.2.2. Virtual fitting with JND

Including user sensitivity (JND) modifies three steps in the virtual fitting process. First, user sensitivity must be captured in the preference study. According to the discussion from the previous section, this may be achieved by requesting that each participant perform the experiment several times to yield a distribution of responses for each participant (the implicit standard stimulus strategy). Second, in the analysis this sensitivity may be included in the virtual fitting model by placing a distribution of responses about each virtual person’s mean preferred response. Equation (2) modifies Equation (1) by adding an additional term that models individual user sensitivity: $N(JND, s_{\text{JND}})$ represents a normal distribution with mean $JND$ and standard deviation $s_{\text{JND}}$ for the JND distribution of the population. Third, estimates of accommodation must be modified to consider some slight disaccommodation within the JND of users in the population – this step is discussed in greater detail next. Figure 4 shows a representation of JND in the preference study and the virtual population.

$$O = cA + b + N(0, s_{\text{regression}}) + N(JND, s_{\text{JND}}).$$  \hfill (2)

In the virtual fitting process with binary accommodation, the final step is to perform statistical analysis on the large virtual population. For instance, if accommodation of individuals with the central 95% of responses is desired, the central 950 responses by users in the 1000-member population may be retained; the 25th and 975th responses determine limits (representing the 2.5th and 97.5th percentiles).

If JND is considered in the virtual fitting process, the estimation must be modified to allow for some disaccommodation within the threshold of noticeability. Figure 5 illustrates the effect of considering JND for accommodation estimation. The arrows show how users’ responses are treated for accommodation estimation; users with responses above the mean are shifted within the lower limit of their JND and users with responses below the mean are shifted within the upper limit of their JND. Once each person has been shifted according to their JND, then the selections of the central portion (e.g. 95%) of users may be retained to determine limits. The outcome is a resulting decrease in required range in the design variable. This outcome is to be expected intuitively because the design strategy permits some amount of what would be considered disaccommodation under a model not considering JND.

Figure 3. Virtual fit method with no measure of user sensitivity (JND).
Note: A preference study (Figure 3a) is used to generate a large virtual population (Figure 3b).
2.2.3. Comparing anthropometry-independent preference with JND

Both anthropometry-independent preference and JND – represented by normal distributions $N(0, s_{\text{regression}})$ and $N(JND, s_{\text{JND}})$ in Equation (2) – represent uncertainty in user response. If one of the uncertainties dominates, it may be appropriate to neglect the other component, saving time during subsequent experimentation and analysis. Consider the following three scenarios, paired with an illustrative example:

1. $s_{\text{regression}} < JND$. The effect of anthropometry-independent preference and JND both contribute meaningfully to the model and are of approximately the same magnitude.

   Users of an office chair might prefer a mean seat height of 40 cm; users’ average preferences differ with other users of the same size by a standard deviation of 1 cm and users’ own preferences also differ from trial to trial within 1 cm on average.

2. $s_{\text{regression}} \gg JND$. The effect of anthropometry-independent preference dominates; users are very sensitive to slight differences in the outcome measure and so JND may be neglected.

   Users of an office chair might prefer a mean seat height of 40 cm; users’ average preferences differ with other users of the same size by a standard deviation of 1 cm and users’ own preferences differ from trial to trial within only 0.1 cm on average.

3. $s_{\text{regression}} \ll JND$. The effect of user insensitivity dominates; users are not sensitive to slight differences in the outcome measure and so anthropometry-independent preference may be neglected. If the magnitude of JND is

Figure 4. Virtual fit method with a measure of user sensitivity (JND).
Note: A preference study (Figure 4a) that also measures JND is used to generate a large virtual population (Figure 4b). Each virtual person is associated with a distribution of selected device parameter as shown.

Figure 5. Virtual population with JND shown for a few randomly selected people.
Note: The arrows show how users’ responses are treated for accommodation estimation. This modification results in less required overall range.
much greater than the total variability due to the correlation between anthropometry and the preferred parameter, the entire regression with anthropometry may also be neglected.

Users of an office chair might prefer a mean seat height of 40 cm; users’ average preferences differ with other users of the same size by a standard deviation of 1 cm and users’ own preferences differ from trial to trial within a much larger 10 cm on average.

Figure 6 compares these scenarios. Identifying the relative magnitude of the respective uncertainties early in the testing and evaluation phase would guide designers in their analyses.

3. Case study

The method discussed in this paper could be applied to a wide variety of products or environments in which users’ physical size is a consideration in the design of the artefact. Suppose a designer wants to solve a simple univariate problem: determine height and range of saddle height (the design variable) so that 95% of users can comfortably sit on an upright exercise cycle seat (see Figure 7). The authors have considered this problem before in an experimental study with a virtual fit methodology (Garneau and Parkinson 2009, 2011). A first step is to conduct a preference study with a sample of users...
riding a prototype. Each person’s preferred seat height is noted across several trials. A regression model – including JND – is developed relating seat height to users’ stature:

\[ H = 0.5S + 20 + N(0, 30) + N(25, 5). \]  

(3)

Applying Equation (3) to 1000 male statures from the 1988 U.S. Army Anthropometric Survey (ANSUR, Gordon et al. 1989) yields the virtual population shown in Figure 8. The constants shown in Equation (3) are similar to values obtained from actual experiments (e.g. Garneau and Parkinson 2011); in practice, the designer would conduct their own experiment to determine constants appropriate for their target demographics and usage.

In addition to the stature and preferred saddle height of the virtual population, Figure 8 denotes ranges in saddle height required for various accommodation criteria. Each of these criteria is described next, in order of greatest to least required range:

1. **100% range (pref)**. This range is constructed by determining the maximum and minimum preferred saddle height for the entire population taking into account anthropometry-independent preference (but without considering JND). This solution is non-optimal – the required range for 100% accommodation is typically expensive (e.g. in terms of cost, material or space restrictions).
2. **100% range (JND)**. This range is constructed by determining the maximum and minimum preferred saddle height for the entire population, with an added allowance for JND that reduces required adjustability.
3. **95% range (pref)**. This range is constructed by determining the maximum and minimum preferred saddle height for 95% of the population. Anthropometry-independent preference is considered in this solution, but not JND.
4. **95% range**. This range is constructed by determining the maximum and minimum saddle height for 95% of the population, without regard to anthropometry-independent preference or JND. This range considers only the linear part of Equation (3).
5. **95% range (pref + JND)**. This range is constructed by determining the maximum and minimum preferred saddle height for 95% of the population, considering anthropometry-independent preference and with an added allowance for JND.

A designer might choose to accommodate the specified ranges using either adjustability or discrete non-adjustable sizes. As shown in Figure 7, an adjustable solution is desired for this study. Including both anthropometry-independent preference and JND components in the virtual fit model may be appropriate because \( s_{\text{regression}} \) and \( \text{JND} \) are of the same order of magnitude. Adjustment limits accommodating the central 95% of the population considering both \( s_{\text{regression}} \) and \( \text{JND} \) are 852–971 mm. Results for other accommodation strategies are shown in Figure 8.

![Figure 8. Interaction of a virtual population with an exercise cycle.](image)

Note: Respectively, ranges are shown for 100% accommodation, 100% accommodation considering JND, 95% accommodation considering anthropometry-independent preference only, 95% accommodation considering mean response and 95% accommodation considering both JND and anthropometry-independent preference. Note that the solutions including JND require a smaller range of the design variable than those that omit it.
One important observation from Figure 8 is that the required range in saddle height to achieve 95% accommodation is appreciably less for the results considering both anthropometry-independent preference and JND (range: 852–971 mm), as opposed to the solution that considers only anthropometry-independent preference (range: 827–996 mm). For this problem, the solution considering neither form of sensitivity (marked ‘95% range’) achieves similar results to the solution that considers both forms of sensitivity (marked ‘95% range (pref + JND)’), but this results from the specific constants used in Equation (3). This will not always be the case.

4. Discussion

This paper makes several important contributions to methods for modelling user accommodation for physical/spatial optimisation and extends other concepts developed within the DHV paradigm. First, the definition of JND, how to capture it via user studies and how to model it in analyses of physical accommodation are explored. Second, the effect of considering JND in the model outcome – and when it is appropriate to include or neglect JND – is demonstrated. Third, a case study is presented that illustrates how to capture and model JND for a simple univariate design problem.

Given the assumptions of this paper, considering JND in product design, with respect to accommodating users’ physical size requirements, will result in products that either (1) require less variability in the design dimensions given a fixed design accommodation target or (2) accommodate more users given a fixed range of variability. Such outcomes are generally beneficial for many stakeholders. Analyses considering JND allow designers to make more informed trade-offs between the range of the design variable required for target accommodation and the noticeability or benefit of additional range. Considering JND in quantitative models yields a more robust solution that considers individual user sensitivity.

4.1. Adjustability versus discrete sizes

Considering JND in virtual assessments of population accommodation might aid designers in choosing between a strategy that makes use of adjustable product settings or discrete sizes of a product. The relative magnitudes of $s_{\text{regression}}$ and $\text{JND}$, as discussed in Section 2.2.3, would be a factor in this decision. If $s_{\text{regression}}$ dominates, then adjustability may be more appropriate than discrete sizes. This observation makes sense intuitively – if users are very sensitive to slight perturbations in the design dimension(s), then adjustability may better satisfy users because product setting(s) could be very finely tuned. Conversely, if $\text{JND}$ dominates, then discrete sizes may offer cost savings over adjustability while not lessening user accommodation, so long as the differences between design dimensions among sizes are less than JND for the population.

4.2. Discussion of assumptions

In this paper, normality is assumed for distributions of user preference (i.e. anthropometry-independent preference and JND). Usually, JND is modelled in a normal distribution (Gescheider 1984), as pictured in Figure 1. In a situation where people are free to make unconstrained choices, their selections are indeed likely to be distributed normally. However, for products with physical adjustability, users’ choices are not truly unconstrained – there exist limits to the size or configuration. When users are unable to select their desired choice because of device limitations, they are said to be censored.

In real-world design problems where censoring is possible, assuming that some behaviour is characterised by a non-normal distribution may be a more appropriate design assumption. For instance, suppose a designer must specify adjustability for an automobile seat track. Users may be more sensitive to disaccommodation as they near the steering wheel or rear of the seat track. The shape and statistics (mean, standard deviation) of their JND distribution will likely change as a function of seat location. This will affect accommodation assessment via virtual fitting.

The discussion and case study in this paper consider univariate problems (i.e. models include only one measure of anthropometry). However, the methods may be extended to consider multivariate anthropometry. Measuring JND for multivariate problems may prove particularly beneficial for multivariate costing. If users are more sensitive to one factor or design dimension than another, designers may choose to address only the critical dimensions or at least change their solution strategy. For instance, consider that a designer is revisiting the seat track design problem, but in addition to fore-aft adjustability, they must consider seat height. A preference study may reveal similar correlations on both design dimensions. However, if JND is much smaller (more sensitive) for fore-aft adjustability than seat height, the designer may determine that a seat with fixed height will yield accommodation identical to a seat with adjustable height. The problem may then be treated as a much simpler univariate one.

By considering sensitivity (JND), it is possible to specify a permissible level of dissatisfaction for a given portion of the population. Stated another way, including sensitivity when modelling user behaviour enables the designer to estimate how likely users around the tails of a virtual population will be to notice their disaccommodation. However, a designer must
choose a criterion for JND – 50% is a common choice. Selecting different criteria will affect results. For instance, 25% JND is about $0.3 \times 50\%$ JND and 75% JND is about $1.7 \times 50\%$ JND. Tighter criteria (smaller percentages) will ensure that more of the target population will not notice being disaccommodated, but will effectively increase required adjustability. Future studies might look at the correlation between JND criteria and performance for a given solution.

5. Conclusion

This paper has introduced JND as a consideration in the design of products’ spatial configuration for accommodating the physical requirements of their users. Some considerations for modelling JND, such as its experimental measurement and application, have been addressed in this paper. The authors’ previous ‘virtual fit’ methodology has been augmented in the present work to include JND. In addition to anthropometry-independent preference across a population, JND may be considered a measure of individual user sensitivity that may be modelled in quantitative simulations. The results of this paper show that including JND decreases required variation in the products’ design dimension(s), in general.

Future work should investigate additional facets of including JND in quantitative models of physical accommodation. Specifically, using JND as a decision-making tool for multivariate costing problems and the effect of censoring and a non-normal distribution on the modelling of JND should be considered. Additionally, future studies might consider different levels of sensitivity (JND) in their accommodation estimates as an additional parameter for a given solution.

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