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Objectively Determining Comfortable Lumbar Support in Task Seating

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The Human Performance Institute at Western Michigan University (WMU) conducted a laboratory study to determine the location and magnitude of support that a user requires for his/her lower back while sitting in a task chair. For this research study, a test chair and a method of gathering and measuring valid data were developed. The Haworth patented test chair allowed users to adjust support in the lower back region. It was then decided that the subjects would participate in three separate trials occurring over a 3-5 day timeframe. The amount of desired support was considered (and measured) at the point when the participant stated that no more adjustments were desired on the chair for two consecutive adjustment periods. Results show that approximately 70% of the participants self-selected asymmetrical lower back support. Nearly one out of four participants selected double the support on one side of their lower back versus the other side. This study may serve as motivation for designers to rethink what users desire in low back support.

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Introduction

Chair design and evaluation have been prevalent in the ergonomic literature for 50 years. Despite investigations using radiography[1], pressure mapping[2], electromyography[3], and human kinematics[4], the relationship between these objective measures, subjective reports of comfort, and their relationship to chair features remain an enigma. A review of literature reveals many seating studies that compare chair seat size[5], shape[6], or design[7]. Many of these studies use small sample sizes and relatively sophisticated technologies to collect copious amounts of data, from which the investigators then attempt to determine statistical correlations between various chair features and subjective ratings of comfort. This approach has been met with limited success and very few studies report any relevant statistical findings that can be of practical use to chair manufacturers.

Lumbar support is considered paramount in designing a comfortable task chair. The design of the lumbar support is usually motivated by the idea that to be comfortable it is imperative to preserve the curve in the low back (i.e., low back lordosis). It is widely understood that lumbar lordosis decreases[8] as the angle between the trunk and hip approaches 90°, as in an erect sitting posture. Unfortunately, the relationship between low back lordosis and subjective feelings of comfort are largely unknown. Nevertheless, today's lumbar supports are being designed to move vertically and increase/decrease firmness as per an individual's requirement. Thus, the impetus for this study was not to conform to the traditional approaches for the designing of low back rests, but rather allow the user to determine what is comfortable and appropriate. More specifically, the objectives of this study were to design and conduct a laboratory experiment to determine, objectively, the location and magnitude of support an individual desires in the low back.

Methodology

To meet the objectives of this study, two formidable challenges had to be overcome. First, an experimental chair that would allow for an unprecedented degree of adjustability in the low back region had to be designed. Second, a protocol, that ensured that data collected from the experimental chair was of appropriate quality, had to be developed.

Experimental Chair

To determine the appropriate support (magnitude and location) that any given participant may desire in the low back region, an experimental chair was constructed (Figure 1). This patented test chair is equipped with an array of 35 spring-loaded diodes, (Figure 2) which can be adjusted to support the low back region. The participants had the ability to adjust the forces on the springs (while in the seated position) as per their subjective requirements, by using an electric screwdriver via remote control. Covering the diodes was a FSA pressure mapping system (FSA Industrial Seat and Back Systems, Verg Inc., USA). Two separate pressure maps covered the seat pan and the seat back.

Figure 1. Experimental chair and testing environment setup.

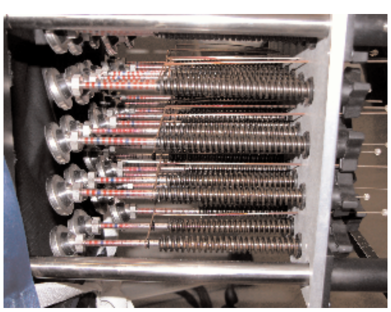


Figure 2. Side view of thirty-five spring-loaded diodes.

Experimental Protocol

Theoretical Basis

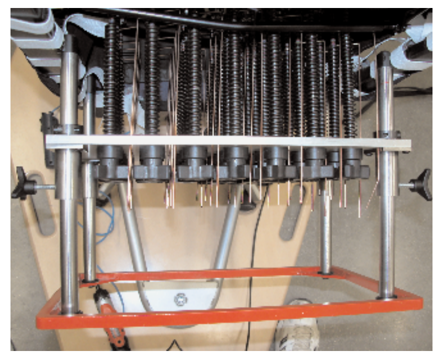
The theoretical framework for this research is embedded in a branch of psychology known as psychophysics. In general, the psychophysical approach is concerned with human sensations associated with external physical stimuli. Within ergonomics, psychophysical methods have been used to quantify subjective tolerance to occupational stress. This approach has been widely used in determining acceptable weight limits for manual material handling problems[9] and acceptable frequency (repetition) for upper extremity work[10]. Like those studies, this investigation made use of the method of adjustment. The resulting protocol encouraged the participants to methodically increase or decrease the amount and location of back support desired over the testing period. A participant's desired low back support was considered the point at which the participant did not want to proceed with additional adjustments.

Experimental Testing Procedure

This study took place in the Human Performance Institute at Western Michigan University (WMU). Upon receiving consent from the Human Subjects Institutional Review Board at WMU, an adjustable workstation holding a computer monitor, a document holder, and an adjustable keyboard were set up in the testing room. The monitor was adjusted so that it was in line with the seated participant's eye level. The keyboard was then adjusted so that it was at the elbow height of each participant. The document holder was mounted at eye height and placed in the same plane as the monitor, and on the dominant eye side of the participant. A footrest was also provided to the participants, allowing the participant to position their feet in an ergonomically accepted position. All adjustments conformed to BSR/HFES 100[11].

The participants in the study consisted of 61 males and 64 females. Applicants were selected based on height (between 5th to 95th percentile for females and males respectively), weight (between 5th to 95th percentile for females and males respectively), and no evidence of historical back problems.

Each participant completed three trial periods. During each trial, the diodes were initially set to an extreme position (fully extended or fully retracted). Figure 3 presents two overhead views of the diodes which illustrate the fully extended and fully retracted positions. The fully extended position refers to the adjustment of a diode to have full contact with the participant's back while the fully retracted position implies that a diode does not come into contact with the participant's back. At the beginning of the first trial, each diode was set to an extreme position according to one of two patterns, chosen at random. Once the diodes were set, a baseline pressure map of the seat back and seat pan were recorded and participants were required to complete a chair comfort questionnaire[12], a comfort and discomfort seating questionnaire[13], and a modified body part discomfort scale (discomfort levels for specified regions of the back – "back map")[14].



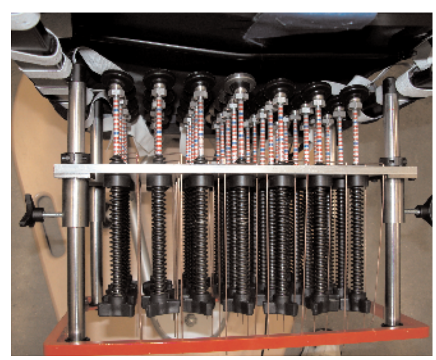


Figure 3. Overhead views showing all diodes in the fully extended position (above) and the fully retracted position (below).

The participants were then asked to perform a typing task for 5 minutes. At the end of the 5-minute task, the participant completed a subjective rating questionnaire and back map questionnaire. The participant was then asked to sit in the erect position while adjusting each of the diodes (using an electric screwdriver equipped with a remote control) to a position the participant required for low back support. Once completed, the participant resumed the typing task for 5 minutes. At the end of the fifth minute of this task period, pressure map readings of the seat pan and seat back were recorded for eight seconds (at ~ 6 frames per second) with the participant sitting in the erect position. The same subjective questionnaires were repeated and the diodes were again adjusted based on the participant's low back support requirements. The process of typing for 5 minutes followed by questionnaires and diode adjustments was repeated until there were two periods where the participant did not require additional diode adjustments.

Following the second period of no adjustments, the participant was asked to sit in the erect position for five minutes while a final series of 8-second pressure map samples were collected, one sample at the beginning of each minute. A final set of subjective questionnaires were then administered. Upon completion of the questionnaires, the participant was requested to leave the testing room for 20 minutes. During the 20-minute break, the investigators recorded the force and displacements for all diodes. The diode positions were then set for trial 2 using the other extreme starting pattern.

In trial 2, the participant was asked to sit in the test chair and the participant's seat position was checked to verify that it was similar to the seat position employed by the participant in trial 1. Once the seat position was verified, a baseline pressure map of the seat pan and seat back were recorded. The participant was then asked to complete the same testing regime as in trial 1. Figure 4 graphically depicts the testing regimen for trials 1 and 2.

A third trial occurred 3-5 days after trials 1 and 2. It was the objective of trial 3 to determine if a participant desired similar low back support several days later. As in the earlier trials, the participants were seated in the test chair with the diodes in an extreme position pattern (randomly chosen) and asked to type for 5 minutes. The adjustment period and typing sequence protocol followed in trial 3 was the same as in trials 1 and 2.

Results

Subjects

Table 1 presents the anthropometric dimensions of the 125 participants (subjects) in this study.

Protocol Testing

Prior to describing the participants' preference in low back support, it was necessary to create aggregate, standardized, and composite pressure maps[15] to compare groups of participants to one another. From the aggregate pressure maps it was then possible to compare a participant's results from trial 1 to trial 2 and from trials 1 and 2 to trial 3. Recall, if the psychophysical regime was appropriate, the results in the last testing periods should be similar (Figure 5). Comparing individual pressure map readings of trial 1 to trial 2 by location revealed that on average 91% of the pressure map readings were within 15 mmHg. To put this into perspective the tip of the finger has a pressure sensitivity of approximately 15 mmHg[16] and capillary occlusion is typically cited to be 32 mmHg[17]. To have 91% of the pressure cells within 15mmHg suggests that the methodology is appropriate and performing well. Furthermore, it was determined that when comparing the aggregate mean pressure map readings of trial 1 and 2 with the readings from trial 3 (the trial where participants came back to the laboratory several days later and repeated the testing regime), 86% of the pressure map readings were within 15 mmHg. Again, this suggests that participants were consistent in their opinions of how much and where they desired low back support.

Pressure Mapping Findings

Figure 5 depicts the composite pressure map for all the participants in this study. It should be noted that the higher the composite score, the higher the participant agreement of standardized magnitude and location of pressure. In a composite map, a value of *one* corresponds to a map location in which *all* subjects in the map have their maximum contact pressure and a value of *zero* corresponds to a map location in which *no* subject has any contact. The most fascinating point of this composite pressure map is what you do not see – i.e., you do not see a uniform shape. This finding tends to support Yun et al.[18] who found that uniformity of the pressure distribution, particularly in the low back was statistically correlated to local *discomfort* in a study on car seats.

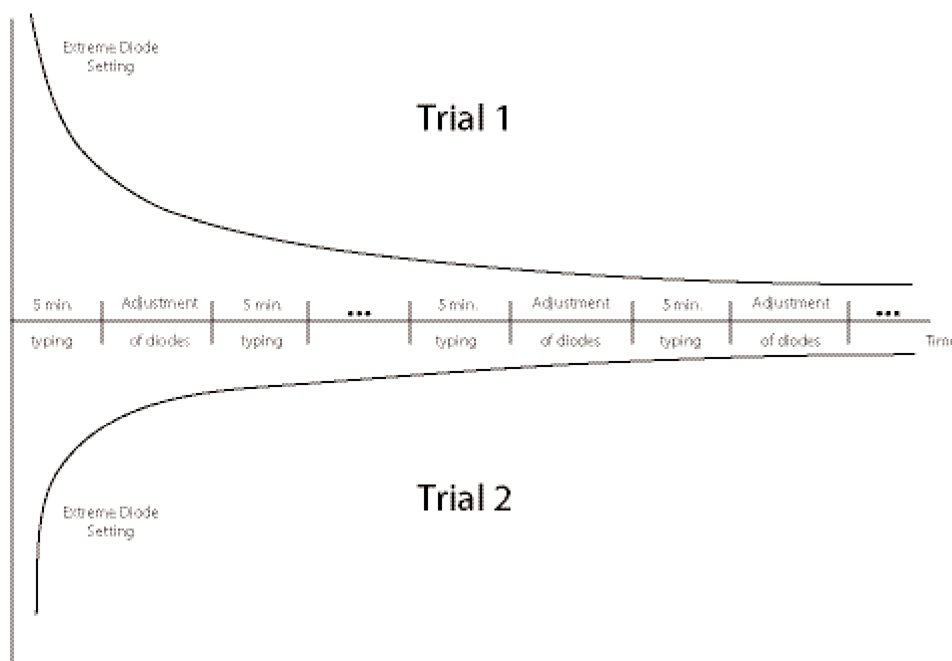


Figure 4. Experimental psychophysical protocol for trials 1 and 2.

While not pictured here, the composite maps partitioned by gender are different and non-uniform. The differences in the male and female maps may be due to anthropometric differences between the subjects or it could be a gender difference. At this point, the underlying cause for the apparent difference is unknown but under investigation.

Figure 6 depicts the comparison of the sum of the contact pressures on the left side of the low back to the right side of the low back. If the two sums were equal, the data points would fall on the line in the center. Reviewing this graph suggests that many participants self-selected asymmetrical support in the low back. Further investigation revealed that approximately 70% of the participants self-selected support which was at least 20% greater on one-side versus the other. In fact, it was determined that 45% of the participants had self-selected more support on the left side (left side dominant), 25% of the participants had self-selected more support on the right side (right side dominant), and 30% of the participants were considered symmetrical in their selection of support (less than a 20% difference between the left and right sides).

Figure 7 depicts the degree to which the participants self-selected asymmetrical low back support. Degree of asymmetry was measured in terms of the percent difference in the support of one side versus the other. For example, the first category in Figure 7 (20% or greater) includes all participants whose percent difference was at least 20%. Interestingly, approximately 1 out of every 4 participants desired support on one side which was at least twice that of the other side (100% or greater).

Figures 8 and 9 depict the degree to which males and females self-selected asymmetrical low back support. For males at the 20% or greater support level, it was determined that 38% selected the left side for more support, 29% selected the right, and 33% selected symmetrical support. For the females at the same level, 53% self-selected more support on the left, 20% self-selected more support on the right, and 27% preferred symmetrical support. Note that the proportion of men and the proportion of women who selected more contact pressure on the right and left were not similar. Originally, it was hypothesized that the participant's "side dominance" (side with the greater support) was associated with hand

Measurement	Female (n = 64) Mean (Standard Deviation)	Male (n = 61) Mean (Standard Deviation)
Age (years)	29.6 (10.8)	28.1 (10.2)
Height (mm)	1645.9 (76.1)	1748.4 (89.2)
Weight (kgs)	66.0 (12.0)	75.2 (14.8)
Hip Height (mm)	871.2 (56.7)	901.8 (80.9)
Hip Breadth (mm)	401.1 (38.4)	384.9 (60.4)
Waist Breadth (mm)	302.0 (40.0)	327.0 (97.1)
Sitting Height Erect (mm)	829.4 (79.0)	868.8 (108.8)
Elbow Height (mm)	226.2 (54.1)	238.8 (89.3)
Elbow Breadth (mm)	408.3 (51.9)	453.8 (72.9)
Popliteal Length (mm)	471.1 (34.2)	483.3 (32.7)
Popliteal Height (mm)	414.3 (29.0)	448.9 (32.5)
Shoulder Breadth-Bi-acromial (mm)	335.7 (28.5)	385.3 (42.7)
Shoulder Breadth-Bi-deltoid (mm)	417.8 (29.4)	467.9 (39.7)

Table 1. Anthropometric measures for all participants by gender.

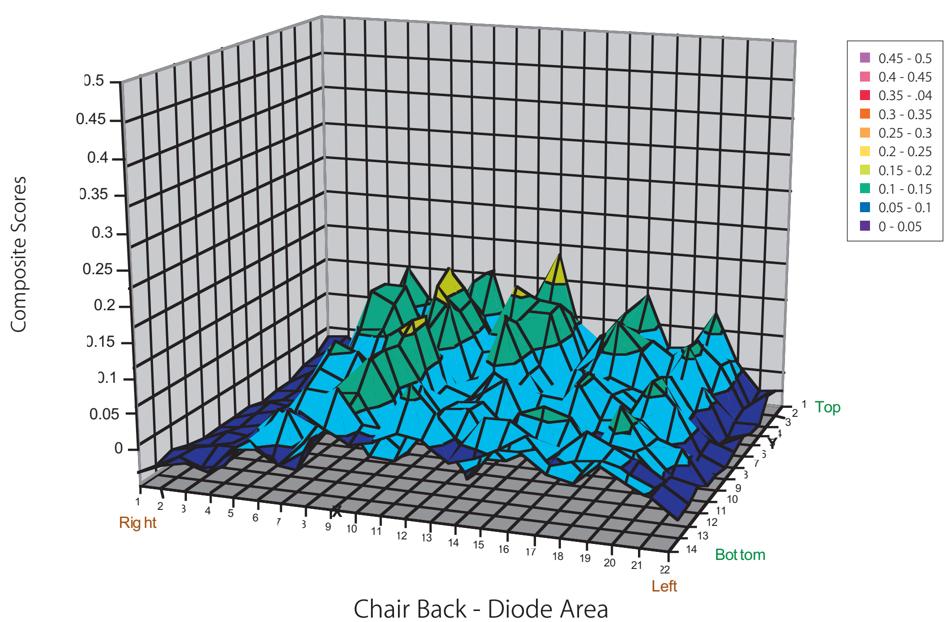


Figure 5. Composite pressure map for all participants (n = 125) in diode area. (Note: The higher the composite score the higher the subject agreement of standardized magnitude and location of pressure.)

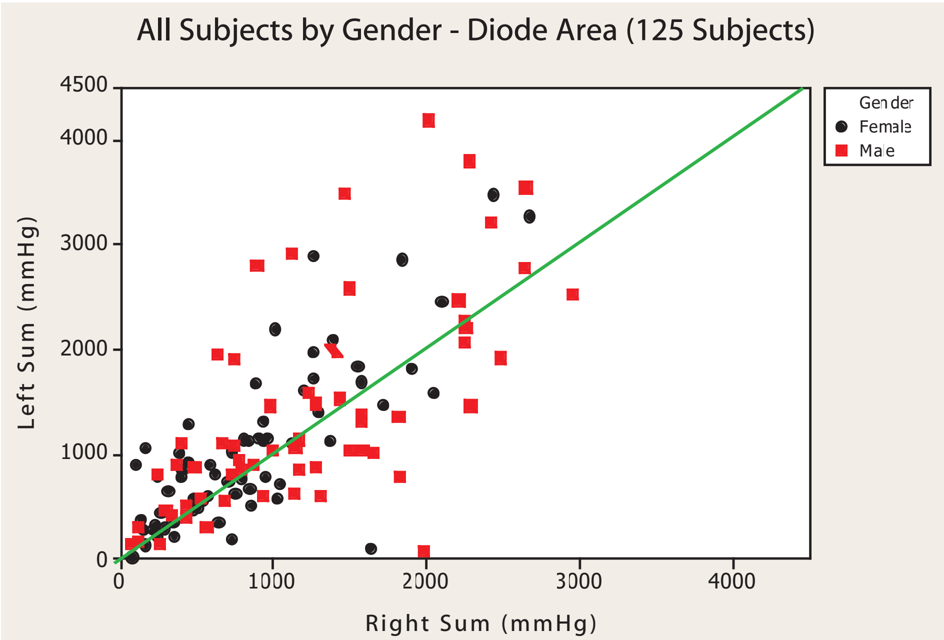


Figure 6. Left side sum of contact pressures vs. right side sum of contact pressures for all participants (n = 125).

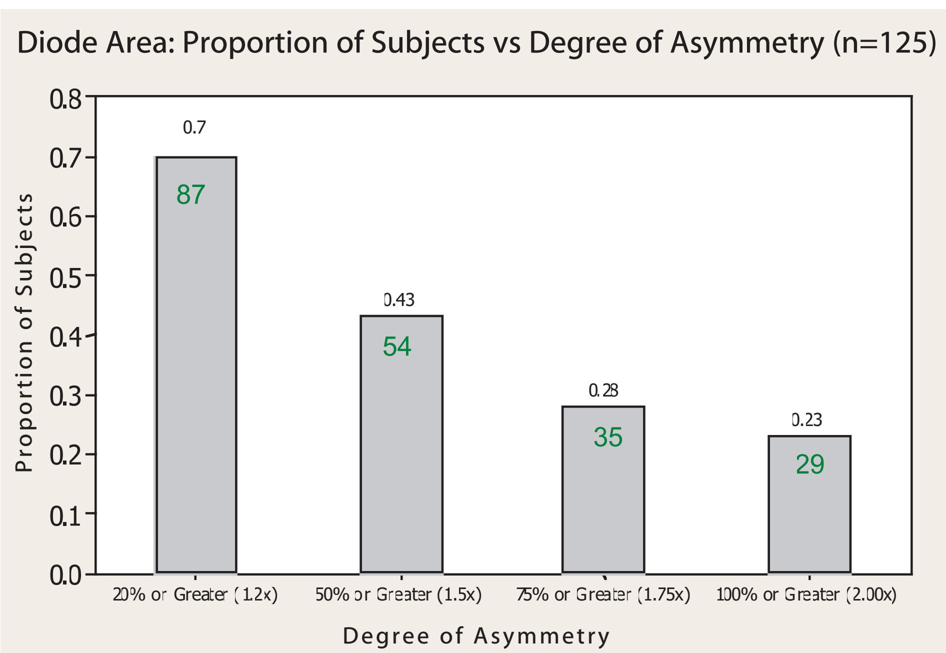


Figure 7. Proportion of all participants selecting a given degree of desired asymmetric support. (Note: the numbers within the bars correspond to the number of participants that are in the category.)

dominance or eye dominance. Further testing revealed no statistical correlation between side dominance and either hand or eye dominance. Other hypotheses are currently under investigation.

Closing Remarks

This study was created to take a new look at the traditional approach to designing a low back support. By creating an experimental procedure and test chair with an unprecedented amount of adjustability in the low back region, participants were able to self-select the magnitude and location of the low back support they desired. From this endeavor it has been learned that participants, when given an opportunity to self-select their own low back support, tend to select support which was not uniform across the low back region. In fact, it has been determined that approximately 70% of the 125 participants in this study, self-select asymmetrical low back support that was at least 20% greater on one side versus the other. Additionally, nearly 1 out of 4 participants self-selected support on one side which was at least twice that of the other side.

This investigation represents a critical review of a small segment of a task chair. The relationship between the low back support and seat pan using the new methodology developed in this study is unknown. Future work will investigate this relationship as well as the underlying mechanisms which explain the behaviors exhibited in this endeavor. It is the hope that the culmination of this research will aid chair manufacturers in building a better seating experience for users.

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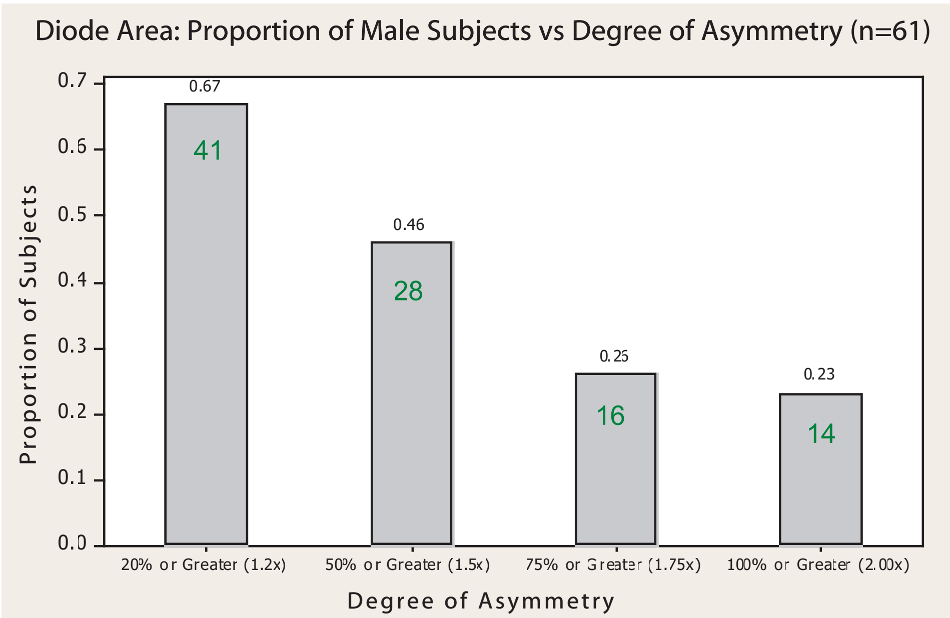

Figure 8. Proportion of male participants selecting a given degree of desired asymmetric support. (Note: the numbers within the bars correspond to the number of participants that are in the category.)

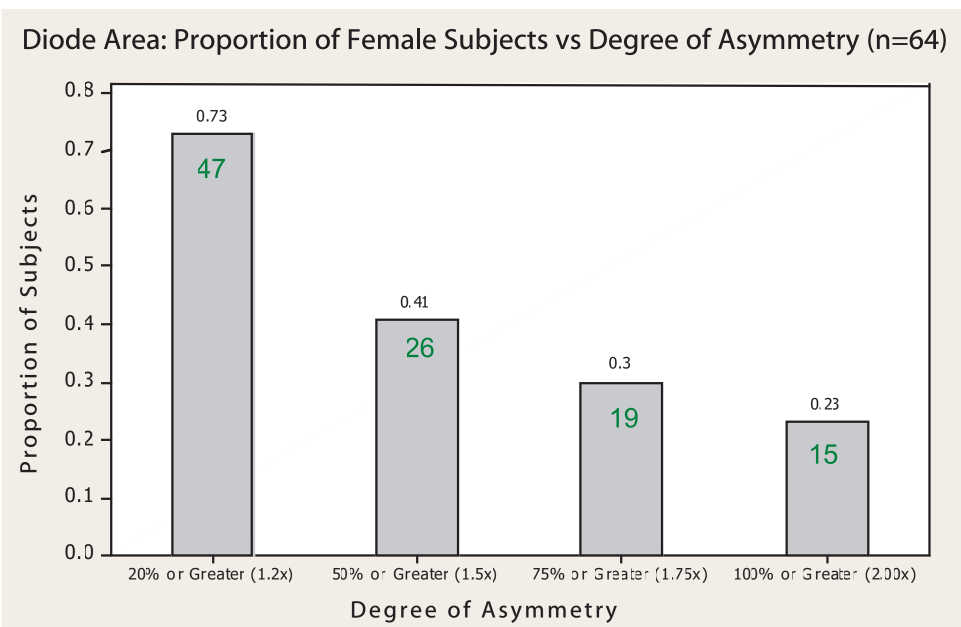

Figure 9. Proportion of female participants selecting a given degree of desired asymmetric support. (Note: the numbers within the bars correspond to the number of participants that are in the category)

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