2019

FROM BREAST PUMP TO BEST PUMP: A HUMAN-CENTERED EVALUATION

Rachel L. Bartels
University of Rhode Island, rbartels05@gmail.com

FROM BREAST PUMP TO BEST PUMP: A HUMAN-CENTERED EVALUATION

BY

RACHEL L. BARTELS

A THESIS SUBMITTED IN PARTIAL FULLFILMENT OF THE

REQUIREMENTS FOR THE DEGREE OF

MASTER OF SCIENCE

IN

SYSTEMS ENGINEERING

UNIVERSITY OF RHODE ISLAND

2019

MASTER OF SCIENCE THESIS

OF

RACHEL BARTELS

APPROVED:

Thesis Committee:

Major Professor Gretchen A. Macht

Valerie Maier Speredelozzi

Diane DiTomasso

Nasser H. Zawia
DEAN OF THE GRADUATE SCHOOL

UNIVERSITY OF RHODE ISLAND
2019

Abstract

Mothers can experience breastfeeding challenges, and the breast pump is often at the center**.** Existing literature outlines the range of mothers' negative experiences with breast pumps, though there is a gap in which breast pump characteristics are important to mothers. Identifying which breast pump characteristics (i.e., *portability, ease of use, low-weight, fast milk extraction, comfortability, low-noise, discreet*) are important to breast pumping mothers, and whether or not this importance varies between mothers who do or do not work outside of the home will help identify user needs. Collecting user needs informs future breast pump designs in a user-centered design process. A survey collected information on mothers' experiences with breast pumps and which breast pump characteristics mothers considered important**.** Summary statistics were analyzed for mothers who did and did not work outside the home, and Latent Class Analysis (LCA) was used to determine whether there were possible groupings between the importance of these characteristics. Summary statistics indicated that mothers considered all seven breast pump characteristics important except for *discreet*. The only characteristic found as statistically significantly different between mothers of different work statuses was *portability*. LCA identified a two-class model with mothers' age as a significant covariate. Mothers' work status was not a significant covariate but did predict class membership when considered as a grouping variable in conjunction with mothers' age. Breast pumping mothers' needs differ beyond their work status, and collecting and considering these different needs is vital to creating redesigns that improve mothers' breast pumping experience.

Acknowledgements

First, I'd like to thank my advisor, Dr. Gretchen Macht, for all of her help and guidance during the process of completing this thesis. She has mentored, guided, and advised me from the beginning of my interest in systems engineering, human factors, and user-centered design, and has helped me transform this interest into a fulfilling career.

I would equally like to thank Dr. Maier Speredelozzi and Dr. DiTomasso for their help and encouragement in the completion of this work. Without their guidance, this work would not have been possible.

I would also like to thank Mike Galuska for his important contributions to the initial stages of this body of work.

Lastly, I would like to thank my family for their love and support, and especially my mother, Dr. Gloria Faye Boudreaux-Bartels. Without her example, unwavering love, support, and endurance with an uncomfortable breast pump, I would not be here today.

Preface

This thesis is written in manuscript format. The manuscript has been prepared for submission to the *Journal of Human Lactation* using APA formatting with a word limit of 3500 words. At the time of submission of this thesis to the University of Rhode Island's Graduate School, this paper has not yet been submitted to the journal for review. This paper will be submitted by Fall 2019.

Table of Contents

Abstract ……………………………………………………………………………..ii

Acknowledgements …………………………………………………………...iii

Preface …………………………………………………………………………...iv

List of Figures ………………………………………………………………...vi

List of Tables ………………………………………………………………...vii

Manuscript ………………………………………………………………………1

Appendix A: Breast Pump Survey ……………………………………………...29

Appendix B: Detailed Results …...……………………………………………...37

Appendix C: R Studio and SAS Code ..………………………………………...45

List of Figures

Figure 1: 95% Confidence intervals for odds ratios indicating *Younger* (higher birth year) group was predictive of membership in Wanting Everything class (Latent Class 2) …………….21

List of Tables

Table 1: Descriptive and Demographic Characteristics of the Sample ………………12

Table 2: Percentage of Mothers that Rated Each Breast Pump

Characteristic as Important ……………………………...………………16

Table 3: Class membership probabilities (γ-estimates) and item response

probabilities (ρ-estimates) for 2-class model for response *Important*………17

Table 4: Two-Class LCA Model for Levels of Breast Pump Characteristic

Importance ………………………………………………………………18

Table 5: Three-Class LCA Model for Levels of Breast Pump Characteristic

Importance ………………………………………………………………18

Table 6: Four-Class LCA Model for Levels of Breast Pump Characteristic

Importance ………………………………………………………………18

Table 7: Five-Class LCA Model for Levels of Breast Pump Characteristic

Importance ………………………………………………………………19

Table 8: Model Selection Tools for Baseline LCA Models ……………………...….19

Table 9: Class Membership Probabilities in 2-class Model with Mothers'

Working Status as a Grouping Variable …………………………………...22

Table 10: Class Membership Probabilities in 2-class Model with Mothers'

Age and Working Status as a Grouping Variable ………..………………...22

Introduction

The manuscript has been prepared for submission to the *Journal of Human Lactation* using APA formatting with a word limit of 3500 words. This paper will be submitted to the journal by Fall 2019.

Manuscript

BACKGROUND

Breastfeeding is widely recognized as the preferred way to feed and nourish infants. The American Academy of Pediatrics (AAP) recommends breastfeeding for at least the first year of an infant's life, and the World Health Organization (WHO) encourages continuation until two years or longer with complementary foods (World Health Organization, 2019; "Breastfeeding and the Use of Human Milk", 2012). The long-term benefits of breastfeeding to the infant (e.g., stronger immune systems, fewer ear infections, lower rates of heart disease and diabetes) are well established (DiTomasso & Paiva, 2017). Breastfeeding benefits also extend to the mother; studies show a reduced risk of ovarian and breast cancer (Hildebrand, Gapstur, Campbell, Gaudet & Patel, 2013; Su, Pasalich, Lee & Binns, 2013). Importantly, a negative breastfeeding experience is predictive of depressive symptoms in the postpartum phase (Brown, Rance & Bennett, 2015). Thus, while there are comprehensive benefits to a positive, productive breastfeeding relationship between mother and infant, there are often challenges to building and maintaining this relationship. At the nexus of these challenges often lies the human-machine interaction between lactating mother and the breast pump.

A breast pump is a Class I (manual) or Class II (electric) medical device that allows lactating mothers around the world to express and collect their breast milk for future use (Eglash & Malloy, 2015). Surveys show that the majority of breastfeeding mothers prefer electric breast pumps over manual breast pumps or hand milk expression (Clemons & Amir, 2010). Studies show that most breastfeeding mothers in the United States (U.S.) now feed their infants bottled human milk expressed from breast pumps (Felice & Rasmussen, 2015; Labiner-Wolfe, Fein, Shealy & Wang, 2008). Specifically, a longitudinal U.S. survey that followed about 2,000 mother-infant pairs from 2005 to 2007 revealed that 92% of breastfeeding mothers pumped milk at some point in the first year postpartum (Fein et al., 2008). Breast pumping allows breastfeeding mothers to stimulate, extend and/or maintain their capability and effectiveness of extracting their milk faster than manual expression (Eglash & Malloy, 2015; Rasmussen & Geraghty, 2011). Ability to extend or maintain expressing milk quickly is important for women who return to work outside of the home, deal with complications of breastfeeding (e.g., oral thrush, engorgement), care for premature or ill infants, and encourage partner or caregiver participation in feeding (Eglash & Malloy, 2015). Research findings have indicated, however, that significant problems exist with breast pumps, particularly when it comes to comfort, experience, and usability of these devices, which may cause women to end breastfeeding earlier than they had otherwise planned (World Health Organization, 2019; Brown et al., 2015; Dietrich Leurer & Misskey, 2015; Hurst, Engebretson & Mahoney, 2013; Labiner-Wolfe et al., 2008).

Interviews with new mothers showed mothers' attitudes and perceptions towards pumping and its related tasks (e.g., sanitization) to be widely negative (Avishai, 2004; Felice et al., 2017; Hurst et al., 2013). Many women resented the time spent at the breast pump, while in direct contrast, mothers considered feeding at the breast well-spent bonding time with their infant (Avishai, 2007; Felice et al., 2017). In a qualitative analysis of the breast pump experiences of over 1100 women, hundreds of women reported feeling distress, anxiety, pain, and isolation while using a breast pump, which supports the literature (Clemons & Amir, 2010; D'Ignazio, Hope, Michelson, Churchill & Zuckerman, 2016; Flaherman, Hicks, Huynh, Cabana & Lee, 2014; Qi, Zhang, Fein, Wang & Loyo-Berrios, 2014; Tucker, Wilson & Samandari, 2011). The top negative words associated with the use of a breast pump included, "hate," "pain," and "difficult" (D'Ignazio et al., 2016). In addition to emotional and physical distress, the literature describes that mothers find pumping milk to be both labor-intensive and time-consuming (Avishai, 2004, 2007; D'Ignazio et al., 2016; Felice et al., 2017). Lack of usability and resultant excessive time commitments are exacerbated when breast pumping mothers work outside of the home. To quote one breast pumping mother who works outside of the home, "the setup is a hassle. Getting the tubes set up, getting everything together, doing it, putting it back, washing it. From start to finish, it takes about 20 minutes… I'm right in the middle of something. Or I can't schedule meetings." (Avishai, 2004). Additionally, mothers are often embarrassed by the distinct look and noise of their breast pumps in the workplace environment (Avishai, 2004; Spitzmueller et al., 2015).

With literature reporting widespread negative experiences with breast pumps, it is essential to understand and consider mothers' comfort and usability of current breast pump designs. This will inform breast pump design changes that will substantially improve the mother-infant breastfeeding relationship, leading to lasting benefits for both parties. A proven method to improve usability and user experience in product design is the user-centered design process. The user-centered design (UCD) process is an evidence-based, iterative approach that considers the end-user's needs, perspectives, and experience to inform the design of a product or system (D'Ignazio et al., 2016; McCurdie et al., 2012; Norman, 2013; "User-Centered Design Basics | Usability.gov", 2019). User- or human-centered design inverts the traditional human-machine relationship by suggesting that technologies must adapt to match humans instead of humans adapting to technologies (D'Ignazio et al., 2016). More specifically, UCD is a cyclical approach that seeks to identify and understand users and their needs, and meet these needs through design iterations ("User-Centered Design Basics | Usability.gov", 2019). The UCD process has proven beneficial across multiple domains as it identifies challenges early in the design process allowing for quicker solutions, avoids poorly defined system requirements, improves performance by reducing number of user errors, and results in products that actually meet user's needs ("Benefits of User-Centered Design | Usability.gov.", 2019). The literature outlining mothers' negative experiences with breast pumps accentuates the opportunity for applying a user-centered design process to redesign breast pumps that improve usability and the mother's comfort.

The female body has long been cross-culturally considered taboo, which experts argue has directly limited the development of women's health (Almeida, Comber & Balaam, 2016; Rossmann, 2008). In the last eight years, there has been a movement in the field of user-centered design to be more inclusive of women's issues, known as "feminist design" (Bardzell & Bardzell, 2010). This means not only promoting women's active participation in the design process through designing, providing (often overlooked) user perspectives, and beyond, but earnestly investigating the domain of women's health issues in order to understand and design for opportunities in this space (Buckley, 1986; Rossmann, 2008). The breast pump is a prime product for redesign via the application of a feminist design philosophy. With little to no consideration for the experiences of the women who use breast pumps, the design has evolved little beyond a technology that "gets the job done" (D'Ignazio et al., 2016). Incorporating women's experiences and keeping women's health at the forefront of design are necessities to providing adequate, equitable care globally. In this way, feminist design is a vehicle to bring women's health, intimate care, experiences, and needs into prominence.

The literature documents that breast pumping mothers experience both emotional and physical issues with breast pumps which can negatively impact the mother-infant breastfeeding relationship. However, there is an established gap in the literature around what pumping mothers want, need, and desire when it comes to breast pumps. In a user-centered product design process, this is a critical first step – evaluating the needs of the target user groups. In a feminist product design process, determining what is important to mothers about breast pumps informs where the focus should be when redesigning breast pumps that empower mothers and respect their experience. This paper aims to fill this gap in the literature by asking mothers directly what characteristics are important to them in a breast pump. This user-centered design approach will help bring breast pumps out from the shadows of the past and explode into an equitable future. The research presented here seeks to answer two specific research questions: (1) How important are the breast pump characteristics of *portability, ease of use, low-weight, fast milk extraction, comfortability, low-noise* and *discreet* to breast pumping mothers? and (2) Are there significant differences in the importance of these breast pump characteristics to breast pumping mothers who work outside of the home versus breast pumping mothers who do not work outside of the home?

METHODS

Data Collection

A 19-item questionnaire surveyed lactating mothers to gain insights into their experiences associated with breast pumps. To formulate critical questions, market research gathered information on commercially available breast pumps and a literature review established an initial understanding of the issues women may experience with breast pumps. The survey's design and questions went through multiple iterations that were corroborated by industry experts, such as the South County Hospital lactation consultants. Once the IRB was approved (HU1617-125), the consent form and survey questions were facilitated on SurveyMonkey® (see Appendix A). In order to reach a difficult population of current lactating mothers, the link was posted publicly on Facebook, specifically on the South County Hospital New Mothers' Support Group page.

Sample

The survey received 352 responses between March and July in 2017. Eighty-seven respondents indicated they had not used a breast pump (at all, or for their most recent baby), so they were omitted from the analysis. One additional respondent indicated she was uncomfortable speaking English; thus, the response to the in-

English survey was excluded. These removals resulted in an analytic dataset of n=264 survey respondents. Table 1 outlines the sample characteristics.

Table 1. Descriptive and Demographic Characteristics of the Sample

Descriptor	No. (%)
Breast pumping mothers	264 (100%)
Age	
Maternal age, mean ± sd (range)	34 ± 4 (23-48)
Age 20-24	2 (0.8%)
Age 25-29	25 (9.5%)
Age 30-34	124 (47%)
Age 35-39	84 (32%)
Age 40-44	4 (1.5%)
Age 45-49	2 (0.8%)
Education	
Completed graduate school	138 (52%)
Completed college	101 (38%)
Completed some college	24 (9%)
Completed high school degree	1 (0.4%)
Work Status	
Currently work outside of the home (WOH)	210 (79%)
Currently do not work outside of the home (NWOH)	54 (21%)
Breast pump manufacturer and model	
Medela Pump-In-Style	154 (58%)
Medela Freestyle	32 (12%)
Spectra S2	18 (7%)
Other brands (e.g. Ameda, Avent, Hygeia, Platex, Freemie)	60 (23%)

Dependent variables

The dependent variables were the self-selected importance levels of seven breast pump characteristics (i.e., *portability, ease of use, low weight, fast milk extraction, comfortability, low noise, discreet*) to breastfeeding mothers. Survey question 7 asked mothers to independently rate the importance of each characteristic using a five-point Likert scale that ranged from (1) “Unimportant,” (2) “Somewhat unimportant,” (3) “Somewhat important,” (4) “Important,” and (5) “Very important.”

Independent variables

The independent variable was whether respondents worked outside of the home (survey question 4). After reviewing respondents' comments, three responses were adjusted based on misinterpretations of the question. These three edits resulted in 209 (79%) respondents who work outside the home (WOH), and 55 (21%) respondents who do not work outside the home (NWOH).

Covariates

Demographic characteristics of mothers' work status, age, education level, and manufacturer and model of their breast pump were evaluated as covariates in the statistical analyses. Additionally, demographic characteristics were used as grouping variables in the latent class analysis.

Statistical Analysis

Before beginning statistical analyses, the seven breast pump characteristics were tested for collinearity, meaning one characteristic would predict or explain another requiring omission. No characteristics were found to be collinear (Appendix B); thus, all characteristics were included in further analyses.

Summary statistics were used to determine, overall, which breast pump characteristics were important to mothers. The five-point Likert scale of importance in Question 7 was dichotomized into "Little to no importance" (Likert levels 1, 2 and 3) or "Important" (Likert levels 4 and 5). Percentages then determined the importance of characteristics to the analytic dataset of breast pumping mothers (n=264), WOH mothers (n=209), and NWOH mothers (n=55).

This was purposeful and volunteer sampled data with no targeted sample other than breast pumping mothers. Skewness and kurtosis values of importance for each characteristic showed that the data were non-normal, and non-parametric tests were used throughout, with an alpha value of 0.05 (skewness: *portability*: -1.27, *ease of use*: -1.02, *low weight*: -0.39, *fast milk extraction*: -1.29, *comfortability*: -1.49, *low noise*: -0.21, *discreet*: -0.02; kurtosis: *portability*: 4.57, *ease of use*: 2.99, *low weight*: 2.79, *fast milk extraction*: 3.76, *comfortability*: 4.23, *low noise*: 2.53, *discreet*: 2.28). Kruskal-Wallis pairwise comparison tests determined whether there were statistically significant differences between the importance of these seven breast pump characteristics between WOH and NWOH mothers (Kruskal & Wallis, 1952).

To further explore whether differences in the importance of breast pump characteristics exist between WOH and NWOH mothers latent class analysis (LCA) was employed. LCA is a statistical method of identifying hidden groups of individuals based on their responses to a set of observed categorical variables. LCA estimates two functional parameters: γ-parameters, probabilities of membership to a specific class, and ρ-parameters, item-response probabilities conditional on class membership (Lanza, Collins, Lemmon, & Schafer, 2007; Lanza, Tan, & Bray, 2013; Miaskowski et al., 2015). A sequence of models was fit with increasing numbers of classes, and various model selection tools were considered in conjunction with the selection of the optimal model. These tools included the likelihood-ratio G^2 statistic (compares expected to observed response pattern proportions), Akaike's Information Criterion (AIC), and Bayesian Information Criterion (BIC) (Akaike, 1974; Schwarz, 1978). A smaller AIC and BIC indicates a better fitting model. Another essential tool is the

Bootstrap Likelihood Ratio Test (BLRT), which tests the hypothesis that a model with one additional class is required to describe the data (Collins, Fidler, Wugalter, & Long, 1993). Other important considerations for selecting the model include maximum likelihood estimation and model interpretability. Maximum likelihood estimation ensures the resulting parameter estimates correspond to the maximum likelihood solution (i.e., highest log-likelihood value of the likelihood function) instead of a "local" maximum (Dziak & Lanza, 2015). Model interpretability means that each class should be distinguishable from all others, no class should be trivial in size, and it should be possible to assign a meaningful title to each class (Lanza et al., 2007).

After selecting the best-fitting, appropriate model, the model was expanded to include covariates and grouping variables independently. LCA with covariates extends the model to include predictors of class membership, and LCA with grouping variables is a model in which the γ-parameters and ρ-parameters are influenced by membership in an observed group (Lanza et al., 2007). Initial analyses were conducted using R 3.5.1. LCA analyses were conducted using the PROC LCA command in SAS 9.4 (see Appendix C for R and SAS code).

RESULTS

Summary Statistics

Summary statistics (see Table 2) suggest that the majority of all mothers, WOH mothers, and NWOH mothers consider each breast pump characteristic important, except for *discreet* (33.3%, 33.0%, and 34.5%, respectively). Further, only slightly greater than half of the surveyed mothers considered *low weight* (53.4%, 50.1%, and 63.6%, respectively) and *low noise* (52.3%, 51.7%, and 54.5%, respectively) important.

Table 2: Percentage of Mothers that Rated Each Breast Pump Characteristic as *Important*

Breast pump characteristic	**Percentage of all mothers that rated characteristic as *Important*, mean(sd)**	**Percentage of WOH mothers that rated characteristic as *Important*, mean(sd)**	**Percentage of NWOH mothers that rated characteristic as *Important*, mean(sd)**
Portability	86.0%, 4.3(.84)	89.0%, 4.4(.78)	74.5%, 3.93(.96)
Ease of use	97.3%, 4.62(.54)	97.2%, 4.61(.55)	98.2%, 4.69(.50)
Low weight	53.4%, 3.55(1.01)	50.1%, 3.50(1.03)	63.6%, 3.73(.89)
Fast milk extraction	89.8%, 4.53(.70)	90.9%, 4.54(.69)	85.4%, 4.49(.74)
Comfortability	95.1%, 4.67(.57)	95.7%, 4.67(.56)	92.7%, 4.65(.62)
Low noise	52.3%, 3.62(.98)	51.7%, 3.61(1.01)	54.5%, 3.67(.88)
Discreet	33.3%, 3.13(1.21)	33.0%, 3.12(1.22)	34.5%, 3.16(1.15)

74.5% of NWOH mothers reported that *portability* of a breast pump is important to them, as compared to 89.0% of WOH mothers. Kruskal-Wallis results indicate that *portability* is a statistically significantly smaller percentage between NWOH and WOH (p = 0.0002). No other characteristic importance ratings between WOH and NWOH mothers were statistically significantly different.

LCA Baseline Model

A series of models with one to five latent classes were fit based on responses of importance. Additional classes were not considered as classes became trivial in size. The γ-parameters and ρ-parameters were considered per model. Starting with the two-class model, Table 3 shows the γ-parameter and ρ-parameter estimates.

Table 3: Class membership probabilities (γ-estimates) and item response probabilities (ρ-estimates) for 2-class model for response *Important*

Breast pump characteristic *Class membership probability (standard errors)*	**Latent class 1** *0.4527 (0.0486)*	**Latent class 2** *0.5473 (0.0486)*
Portability	0.8604 (0.0329)	0.8594 (0.0298)
Ease of Use	0.9671 (0.0166)	0.9788 (0.0121)
Low weight	0.3757 (0.0486)	0.6651 (0.0404)
Fast milk extraction	0.8511 (0.0342)	0.9363 (0.0207)
Comfortability	0.9003 (0.0284)	0.9925 (0.0075)
Low noise	0.0000 (0.0034)	0.9550 (0.0680)
Discreet	0.0620 (0.0450)	0.5577 (0.0423)

Interpreting Table 3 indicates that 45% of respondents are expected to belong to Latent Class 1, with practically no probability (0%) of considering *low noise* an important characteristic in a breast pump. Conversely, 55% of respondents are expected to belong to Latent Class 2, with a very high probability (95%) of considering *low noise* important. Further, Table 3 indicates members of both classes have a very high probability (90% and 99%, respectively) of considering *comfortability* an important breast pump characteristic.

Appendix B outlines parameter estimates for the remaining models. In order to better visualize item-response probabilities, characteristics were marked with a checkmark (✓) if there was a high probability of an *Important* response within a class (≥ 60%), a double dash (--) if there was a 50-59% probability, and cells were left blank if there was a low probability of an *Important* response (< 50%). Tables 4 through 7 use these visual indicators to graphically display the importance of breast pump characteristics to each latent class of mothers in the two- through five-class models.

Table 4: Two-Class LCA Model for Levels of Breast Pump Characteristic Importance

Breast pump characteristic *Class membership probability*	**Latent class 1** *45%*	**Latent class 2** *55%*
Portability	✓	✓
Ease of Use	✓	✓
Low weight		✓
Fast milk extraction	✓	✓
Comfortability	✓	✓
Low noise		✓
Discreet		--

KEY: ✓ = Important to large majority of class (≥ 60%); -- = Important to 50-59% of class; (blank) = Important to minority of class (< 50%).

Table 5: Three-Class LCA Model for Levels of Breast Pump Characteristic Importance

Class membership probability	**Latent class 1** *15%*	**Latent class 2** *52%*	**Latent class 3** *33%*
Portability	--	✓	✓
Ease of Use	✓	✓	✓
Low weight		✓	
Fast milk extraction	✓	✓	✓
Comfortability	✓	✓	✓
Low noise		✓	
Discreet		--	

KEY: ✓ = Important to large majority of class (≥ 60%); -- = Important to 50-59% of class; (blank) = Important to minority of class (< 50%).

Table 6: Four-Class LCA Model for Levels of Breast Pump Characteristic Importance

Class membership probability	**Latent class 1** *(7%)*	**Latent class 2** *(35%)*	**Latent class 3** *(15%)*	**Latent class 4** *(43%)*
Portability	✓	✓	✓	✓
Ease of Use	✓	✓	✓	✓
Low weight		✓		
Fast milk extraction	✓	✓	✓	✓
Comfortability	✓	✓	✓	✓
Low noise		✓	✓	
Discreet		--	✓	

KEY: ✓ = Important to large majority of class(≥ 60%); -- = Important to 50-59% of class; (blank) = Important to minority of class (< 50%).

Table 7: Five-Class LCA Model for Levels of Breast Pump Characteristic Importance

	Latent class 1	**Latent class 2**	**Latent class 3**	**Latent class 4**	**Latent class 5**
Class membership probability	*(16%)*	*(9%)*	*(7%)*	*(38%)*	*(29%)*
Portability	✓	✓	--	✓	✓
Ease of Use	✓	✓	✓	✓	✓
Low weight					✓
Fast milk extraction	✓	✓	✓	✓	✓
Comfortability	✓	✓	✓	✓	✓
Low noise		✓			✓
Discreet		✓			✓

KEY: ✓ = Important to large majority of class (≥ 60%); -- = Important to 50-59% of class; (blank) = Important to minority of class (< 50%).

In addition to the γ-parameters and ρ-parameters per model, model selection tools were considered to identify the final model (see Table 8).

Table 8: Model Selection Tools for Baseline LCA Models

No. of classes	**Likelihood ratio, G^2**	**Degrees of freedom (df)**	**AIC**	**BIC**	***p* from BLRT**
1	68.31	120	182.31	207.34	N/A
2	58.02	112	88.02	141.66	0.01**
3	48.63	104	94.63	176.87	0.82
4	31.18	96	93.18	204.03	0.08
5	19.94	88	97.74	237.40	0.38

*NOTE: *p ≤ 0.05, **p ≤ 0.01, ***p ≤ 0.001, AIC=Akaike's Information Criterion, BIC=Bayesian Information Criterion, BLRT=Bootstrap Likelihood Ratio Test*

The AIC and BIC values are lowest at the two-class model, suggesting that this model is the best fit among these models; however, AIC and BIC bias towards smaller models based on their equations, thus exploring G^2 and BLRT is required. The drop in G^2 relative to degrees of freedom provides an improvement in fit for the two-class model. The four-class model was considered with a borderline significance of BLRT (p=0.08), but identification plots indicated convergence on a local log-likelihood maximum instead of the global, highest log-likelihood value (see Appendix B).

Finally, the only significant outcome of the BLRT occurred from the one-class to two-class model (p=0.01), confirming the selection of the two-class model. Inspecting the parameter estimates from the two-class model suggests that the two classes are distinguishable and nontrivial.

One group of breast pumping mothers does not consider *low weight*, *low noise*, or *discreet* to be important characteristics of a breast pump (Latent Class 1), and the other group considers all seven breast pump characteristics important (Latent Class 2). The two-class model was chosen as the final, baseline model, and the classes were titled "Form Follows Function," and "Wanting Everything," respectively.

LCA with Covariates

Mothers' working status, age, education level, and breast pump model were used as covariates on the two-class model. Age was bifurcated by birth year at the median (1983), with the *Older* group including those born in the year 1982 and before, and the *Younger* group including those in the year 1983 and later. Age was found to be a significant covariate (p=0.0106), while mothers' working status, education level, and breast pump model were not (p=0.6577, p=0.5615, and p=0.5950, respectively). Odds ratio plots (95% confidence interval, see Figure 1) show that the *Younger* group has higher odds of membership in the Form Follows Function class (noted in Figure 1 as "Class 2") relative to the Wanting Everything class. A significant covariate is indicated in Figure 1 by the fact that the confidence interval (rectangle) does not overlap with the y-axis value of 1; hence illustrating Age as a significant covariate.

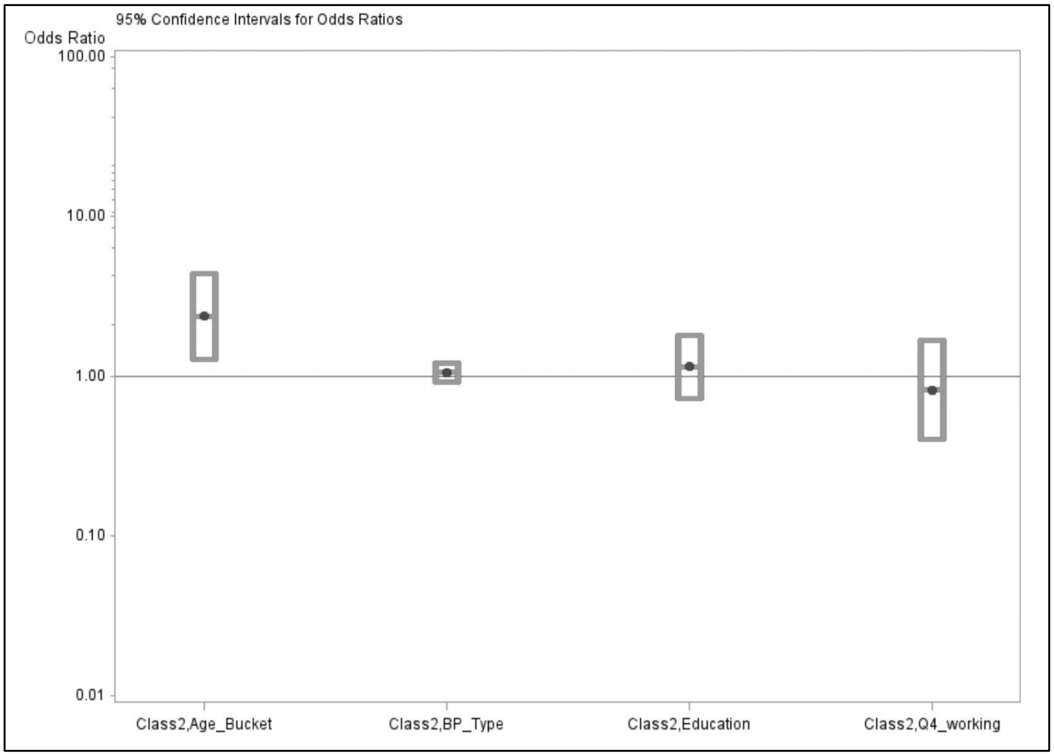


Figure 1. 95% Confidence intervals for odds ratios indicating *Younger* (higher birth year) group was predictive of membership in Form Follows Function class ("Class 2")

LCA with Grouping Variables

The two-class baseline LCA model was explored to include observed groups as grouping variables. To test for measurement invariance between groups, the model was first fit with free ρ-parameter estimation, and then with restrictions that equate the ρ-parameters across groups. The model fits were compared and were not found to be significantly different (*p*=0.6845), which provides evidence that measurement invariance holds and indicates classes have the same meaning for each group. First, mothers' working status was included as a grouping variable with two levels: WOH and NWOH. Second, as mothers' age was found to be a significant covariate, mothers age in addition to working status was included as a grouping variable with four levels: WOH-Older, WOH-Younger, NWOH-Older, NWOH-Younger.

The optimal two-class model with mothers' working status as a grouping variable yielded the γ-estimates shown in Table 9.

Table 9: Class Membership Probabilities in 2-class Model with Mothers' Working Status as a Grouping Variable

	Form Follows Function	**Wanting Everything**
WOH	0.4876	0.5124
NWOH	0.4379	0.5621

NOTE: WOH=working outside of the home, NWOH=not working outside of the home.

These γ-estimates indicate that there is almost an even probability that members of the WOH and NWOH groups belong to either of the two latent classes. The baseline two-class model with mothers' age in addition to working status as a grouping variable yielded the γ-estimates shown in Table 10.

Table 10: Class Membership Probabilities in 2-class Model with Mothers' Age and Working Status as a Grouping Variable

	Form Follows Function	**Wanting Everything**
WOH-Older	0.4306	0.5694
WOH-Younger	0.5481	0.4519
NWOH-Older	0.1301	0.8699
NWOH-Younger	0.6366	0.3634

NOTE: WOH=working outside of the home, NWOH=not working outside of the home.

Table 10 illustrates that when mothers' age is considered jointly with their working status, there are substantial differences in class membership probabilities. While *Older* and *Younger* WOH mothers have almost an even probability of belonging to either Form Follows Function or Wanting Everything, *Older* NWOH mothers have an 87% chance of belonging to Wanting Everything, and *Younger* NWOH mothers have a 64% chance of belonging to Form Follows Function. These results indicate that membership in the two identified latent classes, while predicted by age, depends not solely on age, but on the combination of mothers' age and working status.

DISCUSSION

These results suggest that there are two distinct user groups of mothers in this sample who consider different breast pump characteristics important. The Form Follows Function group is solely focused on a breast pump's functionality, thus non-functional aspects of the pump (*low weight, low noise, discreet*) are considered unimportant. The Wanting Everything group considers each of the seven listed characteristics important in a breast pump, which contrasts with the summary statistics results indicating *discreet* was considered unimportant. Further, results indicate that membership in these groups is informed not by mothers' working status or age alone, but in fact by the two together. This provides evidence that mothers' needs vary for more complex reasons than simply whether or not they work from home. Similarly, the fact that the latent class analysis revealed further information regarding the importance of breast pump characteristics than the summary statistics suggests that quickly categorizing mothers based on their work status or another demographic characteristic is inaccurate for capturing mothers' breast pump needs.

The sample population reported similar breast pump experiences to the experiences described in the literature. Mothers reported nipple pain (48%), nipple damage (14%) and general discomfort and pain when using a breast pump (49%). Mothers also reported feeling that breast pumping takes too long (79%) and that the pump is difficult to clean (43%) which directly correlates to the literature. This similarity between sample population experiences and experiences outlined in the literature further supports the validity of these two identified user groups. Identifying the different needs of mothers and sorting into accurate user groups, beyond simply demographic characteristics, will enable redesigns of breast pumps that address those user needs. Literature suggesting the benefit of individualizing breast pump recommendations to mother-infant dyads supports this conclusion (Meier, Patel, Hoban, & Engstrom, 2016).

Limitations

The survey did not ask mothers to rank breast pump characteristics from least to most important, which would have indicated what characteristic was most important to mothers, and did not allow mothers' free response. Also, the survey did not explicitly ask mothers whether this was their first infant, which could have been more of a predictor of breast pump experience than mothers' age.

Additionally, responses of importance were dichotomized in order to address scarcity at the 1 and 2 Likert levels. Expanding the surveyed population could resolve this scarcity and allow for the Likert levels to be analyzed individually, which could potentially alter the number and distribution of latent classes.

Further, this sample population was significantly skewed. While the sample had a slightly higher percentage of WOH mothers compared to the U.S. population (79% and 70%, respectively), the main reason for the skewness was education level (DeWolf, 2017). In this sample, 99.6% of respondents completed at least some college and higher, with 39% completing college and 52% completing graduate studies. This is in direct contrast of about 58% of mothers completing at least some college and higher, about 21% completing college, and about 11% completing graduate studies in the U.S. (IPUMS-USA, 2016). Thus, this sample does not represent the larger U.S. population.

Further research must be conducted in order to identify user groups and user needs of breast pumping mothers globally. Additionally, other characteristics of breast pumps such as price must be considered in future redesigns. However, identifying two user groups in such a skewed population suggests the possibility of identifying numerous additional user groups with varying user needs in the larger population.

CONCLUSION

Identifying user needs is an important first step in a user-centered redesign of breast pumps. Advancing breast pump technology with considerations for mothers' comfort, usability, and preferences also carries forward the field of feminist design. By asking mothers directly what is important to them in a breast pump and considering mothers as user groups beyond simply demographic characteristics or working status, this paper contributes directly to this body of work. Redesigning breast pumps to meet the needs of different user groups can help alleviate many of the negative experiences mothers undergo with breast pumps which can play a key role in prolonging the beneficial mother-infant breastfeeding relationship.

ACKNOWLEDGEMENTS

Special thanks to Dr. Lisa Harlow, a behavioral science Professor at the University of Rhode Island, who advised on the statistical approach for this work. Further, special thanks to Elizabeth Collins and Jill Fagre, South County Hospital Lactation Consultants, as well as Michael Galuska, Franshelyne Torres, and Daniela Oliveira deAlmeida, undergraduate researchers, for their assistance with questionnaire development and research. Finally, special thanks to Ana Rodriguez Rivera for continuing this important work.

References

Almeida, T., Comber, R., & Balaam, M. (2016). HCI and intimate care as an agenda for change in women's health, In *Proceedings of CHI Conference on Human Factors in Computing Systems*. May 7-12, 2016, San Jose, CA.

Akaike, H. (1974). A new look at the statistical model identification. *IEEE Transactions on Automatic Control*, *19*, 716–723.

Avishai O. (2004). At the pump. *Journal of the Association for Research on Mothering*, *6*, 139-149.

Avishai O. (2007). Managing the lactating body: The breast-feeding project and privileged motherhood. *Qualitative Sociology*, *30*, 135-152. doi:10.1007 /s11133-006-9054-5

Bardzell, S. (2010). Feminist HCI: Taking stock and outlining an agenda for design, In *Proceedings of CHI 2010:HCI For All*, April 10-15, 2010, Atlanta, GA, USA

Bardzell, S., & Bardzell, J. (2010). Towards a feminist HCI methodology: Social science, feminism, and HCI, In *Proceedings of CHI 2010: HCI For All,* April 10-15, 2010, Atlanta, GA, USA

Benefits of user-centered design | Usability.gov. (2019). Retrieved from https://www.usability.gov/what-and-why/benefits-of-ucd.html

Breastfeeding and the use of human milk. (2012). *Pediatrics*, *129*, e827-e841. doi:10 .1542/peds.2011-3552

Brown, A., Rance, J., & Bennett, P. (2015). Understanding the relationship between breastfeeding and postnatal depression: The role of pain and physical difficulties. *Journal Of Advanced Nursing*, *72*, 273-282. doi:10.1111/jan .12832

Buckley, C. (1986). Made in patriarchy: Toward a feminist analysis of women and design, *Design Issues*, *3*(2), 2-14.

Clemons, S., & Amir, L. (2010). Breastfeeding women's experience of expressing: A descriptive study. *Journal of Human Lactation*, *26*, 258-265. doi:10.1177 /0890334410371209

Collins, L. M., Fidler, P. L., Wugalter, S. E., & Long, J. D. (1993). Goodness-of-Fit testing for latent class models. *Multivariate Behavioral Research, 28*, 375-389. doi:10.1207/s15327 906mbr2803_4

DeWolf, M. (2017). 12 stats about working women. Retrieved from https://blog.dol .gov/2017/03/01/12-stats-about-working-women

Dietrich Leurer, M., & Misskey, E. (2015). "Be positive as well as realistic": A qualitative description analysis of information gaps experienced by breastfeeding mothers. *International Breastfeeding Journal*, *10*(1), 10. doi:10 .1186/s13006-015-0036-7

D'Ignazio, C., Hope, A., Michelson, B., Churchill, R., & Zuckerman, E. (2016). A feminist HCI approach to designing postpartum technologies: "When I first saw a breast pump I was wondering if it was a joke.". In *Proceedings of CHI Conference on Human Factors in Computing Systems*. San Jose, CA.

DiTomasso, D., & Paiva, A. (2017). Neonatal weight matters: An examination of weight changes in full-term breastfeeding newborns during the first two weeks of life. *Journal of Human Lactation*, *34*(1), 86-92. doi:10.1177/0890334417722508

Dziak, J. J., & Lanza, S. T. (2015). SAS graphics macros for latent class analysis users' guide (Version 2.0.1). University Park: The Methodology Center, Penn State. Retrieved from http://methodology.psu.edu

Eglash, A., & Malloy, M. (2015). Breastmilk expression and breast pump technology. *Clinical Obstetrics And Gynecology*, *58*, 855-867. doi:10.1097/grf.0000000000000141

Fein, S., Labiner-Wolfe, J., Shealy, K., Li, R., Chen, J., & Grummer-Strawn, L. (2008). Infant feeding practices study II: Study methods. *Pediatrics*, *122*(Supplement 2), S28-S35. doi:10.1542/peds.2008-1315c

Felice, J., & Rasmussen, K. (2015). Breasts, pumps and bottles, and unanswered questions. *Breastfeeding Medicine*, *10*, 412-415. doi:10.1089/bfm.2015.0107

Felice, J., Geraghty, S., Quaglieri, C., Yamada, R., Wong, A., & Rasmussen, K. (2017). “Breastfeeding” without baby: A longitudinal, qualitative investigation of how mothers perceive, feel about, and practice human milk expression. *Maternal & Child Nutrition*, *13*, e12426. doi:10.1111 /mcn.12426

Flaherman V. J., Hicks K. G., Huynh J., Cabana M. D., Lee K. A. (2014). Positive and negative experiences of breast pumping during the first 6 months. *Maternal and Child Nutrition*, *12*, 291-298. doi:10.1111/mcn.12137

Goodall, P. (1983). Design and gender. In *The block reader in visual culture*. Abingdon, UK: Routledge.

Hildebrand, J., Gapstur, S., Campbell, P., Gaudet, M., & Patel, A. (2013). Recreational physical activity and leisure-time sitting in relation to postmenopausal breast cancer risk. *Cancer Epidemiology Biomarkers & Prevention*, *22*, 1906-1912. doi:10.1158/1055-9965.epi-13-0407

Hurst, N., Engebretson, J., & Mahoney, J. (2013). Providing mother's own milk in the context of the NICU. *Journal of Human Lactation*, *29*, 366-373. doi:10.1177 /0890334413485640

IPUMS-USA. (2016). U.S. Census data for social, economic, and health research: Mother's education level. Retrieved from https://iecam.illinois.edu /characteristics/education/mothers-education/

Kruskal, W. H., & Wallis, W.A. (1952). Use of ranks in one-criterion variance analysis. *Journal of the American Statistical Association, 47*, 583-621.

Labiner-Wolfe, J., Fein, S., Shealy, K., & Wang, C. (2008). Prevalence of breast milk expression and associated factors. *Pediatrics*, *122*(Supplement 2), S63-S68. doi:10.1542/peds.2008-1315h

Lanza, S. T., Collins, L. M., Lemmon, D. R., & Schafer, J. L. (2007). PROC LCA: A SAS procedure for latent class analysis. *Structural Equation Modeling, 14,* 671-694.

Lanza, S. T., Tan, X., Bray, B. C. (2013). Latent class analysis with distal outcomes: A flexible model-based approach, *Structural Equation Modeling: A Multidisciplinary Journal, 20*(1), 1-26. doi:10.1080/10705511.2013.742377

McCurdie, T., Taneva, S., Casselman, M., Yeung, M., McDaniel, C., Ho, W., & Cafazzo, J. (2012). mHealth consumer apps: The case for user-centered design. *Biomedical Instrumentation & Technology*, *46*(s2), 49-56. doi:10.2345 /0899-8205-46.s2.49

Meier, P. P., Patel, A. L., Hoban, R., Engstrom J. L. (2016). Which breast pump for which mother: An evidence-based approach to individualizing breast pump technology. *Journal of Perinatology, 36*, 493-499. doi:10.1038/jp.2016.14

Miaskowski, C., Dunn, L., Ritchie, C., Paul, S. M., Cooper, B., Aouizerat, B. E., Alexander, K., Skerman, H., Yates, P. (2015). Latent class analysis reveals distinct subgroups of patients based on symptom occurrence and demographic and clinical characteristics. *Journal of Pain and Symptom Management, 50*(1), 28-37. doi:10.1016/j.jpainsymman.2014.12.011

Norman, D. (2013). *The design of everyday things.* New York City, NY: Basic Books.

Qi ,Y., Zhang, Y., Fein, S., Wang C., & Loyo-Berrios, N. (2014). Maternal and breast pump factors associated with breast pump problems and injuries. *Journal of Human Lactation*, *30*, 62–72. doi:10.1177/0890334413507499

Rasmussen, K., & Geraghty, S. (2011). The quiet revolution: Breastfeeding transformed with the use of breast pumps. *American Journal of Public Health*, *101*, 1356-1359. doi:10.2105/aj ph.2011.300136

Rossmann, J. S. (2008). Built to spec? The vaginal speculum as a case study of inadequate design. *Ambidextrous*, 47–49.

Schwarz, G. (1978). Estimating the dimension of a model. *Annals of Statistics, 6,* 461–464.

Spitzmueller, C., Wang, Z., Zhang, J., Thomas, C., Fisher, G., Matthews, R., & Strathearn, L. (2015). Got milk? Workplace factors related to breastfeeding among working mothers. *Journal of Organizational Behavior*, *37*, 692-718. doi:10.1002/job.2061

Su, D., Pasalich, M., Lee, A., & Binns, C. (2013). Ovarian cancer risk is reduced by prolonged lactation: A case-control study in southern China. *The American Journal of Clinical Nutrition*, *97*, 354-359. doi:10.3945/ajcn.112.044719

Tucker C. M., Wilson E. K., & Samandari G. (2011). Infant feeding experiences among teen mothers in North Carolina: Findings from a mixed methods study. *International Breastfeeding Journal*. *6*(14), 1-11. doi:10.1186/1746-4358-6-14

User-centered design basics | Usability.gov. (2019). Retrieved from https://www.usability.gov/what-and-why/user-centered-design.html

World Health Organization. (2019). *Breastfeeding*. Retrieved from http://www.who.int/topics/breastfeeding/en/.

Appendix A: Breast Pump Survey

THE UNIVERSITY OF RHODE ISLAND COLLEGE OF ENGINEERING

Breast Pump Survey

Consent Form

Dear Participant

You have been invited to take part in the research project described below. If you have any questions, please feel free to contact Dr. Diane Thulier (401) 874-5327 or Dr. Gretchen Macht (macht@uri.edu and (401) 874-2243, the people mainly responsible for this study. Alternatively, contact SIS Lab members Michael Galuska (michael_galuska@my.uri.edu) or Franshelyne Torres (ftorres@my.uri.edu) for additional questions.

The purpose of this study is to determine the opinions of women on breast pumps, with the intention of using it to inform engineers. Responses to these items will be collected through an electronic survey.

YOU MUST BE AT LEAST 18 YEARS OLD to be a participant in this research project.

If you decide to take part in this study, your participation will involve filling out a questionnaire pertaining to your experience with breastfeeding and breast pumping, as well as demographic questions.

Your participation should take about 5-7 minutes in total.

The possible risks or discomforts of the study are minimal. They do not extend beyond those you would experience in everyday life.

Although there are no direct benefits of the study, your answers will help engineers design breast pumps that better suit the wants and needs of all women.

Your part in this study is anonymous. This means that your answers to all questions are strictly private. No one else can know if you participated in this study and no one else can find out what your answers were. Scientific reports will be based on group data and will not identify you or any individual as being part of this project.

The decision to participate in this research project is up to you. You do not have to participate and you can refuse to answer any question, or exit the survey at any time.

Participation in this study is not expected to be harmful or injurious to you. However, if this study causes you any injury, you should contact Dr. Diane Thulier or Dr. Gretchen Macht at the University of Rhode Island.

If you have other concerns about this study or if you have questions about your rights as a research participant, you may contact the University of Rhode Island's Vice President for Research and Economic Development, 70 Lower College Road, Suite 2, URI, Kingston, RI, (401) 874-4328.

You are at least 18 years old. You have read the consent form and your questions have been answered to your satisfaction. Your filling out the survey implies your consent to participate in this study.

By selecting yes, you agree to all the terms provided above.

Thank you,

Dr. Diane Thulier and Dr. Gretchen Macht

THE UNIVERSITY OF RHODE ISLAND
COLLEGE OF ENGINEERING

Breast Pump Survey

1. Have you used a breast pump?

- ◯ Yes
- ◯ No

THE UNIVERSITY OF RHODE ISLAND COLLEGE OF ENGINEERING

Breast Pump Survey

2. How often did your most recent baby breastfeed? (Please fill in the blank)

When I am home with the baby, he/she usually breastfeeds _____ times daily.

If I take the baby to work with me, he/she usually feeds ____ times daily.

Number of minutes for an average feeding: ____.

3. Did you use a breast pump for your most recent baby?

- Yes
- No

If you answered "No," please indicate why you didn't use a breast pump.

4. Are you currently working outside the home?

- Yes
- No

If you answered "Yes," how soon after birth did you go back to work? If you answered "No," do you plan to work outside of the home during your child's infancy?

5. What are your reasons for using a breast pump? (select all that apply to your most recent baby)

- ☐ Premature or sick baby
- ☐ Nipple pain or damage
- ☐ Breast engorgement
- ☐ Concern about milk supply
- ☐ Concern about infant weight-loss
- ☐ Flat or inverted nipples
- ☐ Work outside the home
- ☐ So that partner can feed the baby
- ☐ Other (please specify)

6. How often did you use a breast pump for your most recent baby?

When home with the baby, I usually pump ____ times daily.

When at work outside the home, I usually pump ____ times daily.

7. In your opinion, how important are the following breast pump characteristics? (if you do not wish to list an additional breast pumping characteristic, select "Unimportant" for "Other")

	Unimportant	Somewhat Unimportant	Somewhat Important	Important	Very Important
Portability	○	○	○	○	○
Ease of use	○	○	○	○	○
Low-weight	○	○	○	○	○
Fast milk extraction	○	○	○	○	○
Comfortability	○	○	○	○	○
Low-noise	○	○	○	○	○
Discrete	○	○	○	○	○

8. How satisfied were you with your current most recently used breastpump?

Strongly Dissatisfied	Dissatisfied	Neutral	Satisfied	Strongly Satisfied
○	○	○	○	○

9. In the previous question, what pump are you referring to?

- ◯ Ameda Purely Yours Carry All
- ◯ Ameda Purely Yours Ultra
- ◯ Avent Double Electric Comfort
- ◯ Avent Single Electric Breast Pump
- ◯ Simplisse Dr. Brown's
- ◯ Evenflo Single Pump
- ◯ First Years Double Electric MI Pump
- ◯ First Years Double Quiet Expressions
- ◯ Hygeia EnJoye LBI
- ◯ Medela Pump in Style
- ◯ Medela Freestyle
- ◯ Medela Symphony
- ◯ Playtex
- ◯ Whisper Wear
- ◯ Spectra S1
- ◯ Spectra S2
- ◯ Spectra Dew 350
- ◯ Limerick PJ's Bliss
- ◯ Limerick PJ's Comfort
- ◯ Lansinoh SmartPump
- ◯ Lansinoh Signature Pro Double Electric
- ◯ Freemie Freedom Hands Free Electric Pump
- ◯ If your pump is not listed, please list it below:

10. How likely are you to try another breast pump in the future?

Very Unlikely	Unlikely	Neutral	Likely	Very Likely
◯	◯	◯	◯	◯

What is the reason for your selection?

11. At times I have experiences the following:

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
Difficulty expressing milk	◯	◯	◯	◯	◯
Producing too little milk when *pumping*	◯	◯	◯	◯	◯
Feeling self-conscious when pumping in public	◯	◯	◯	◯	◯
Feeling uncomfortable in my workplace when pumping	◯	◯	◯	◯	◯

12. At times I feel that:

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
Breast pumping takes too long	◯	◯	◯	◯	◯
My pump makes too much noise	◯	◯	◯	◯	◯
My pump is too heavy to carry	◯	◯	◯	◯	◯
My pump is difficult to clean (i.e., washing and sanitation)	◯	◯	◯	◯	◯
My pump is difficult to assemble	◯	◯	◯	◯	◯
My pump has too many parts	◯	◯	◯	◯	◯
My pump does not fit my breasts well	◯	◯	◯	◯	◯

13. I have experienced the following when using a breast pump:

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
Nipple pain	◯	◯	◯	◯	◯
Nipple damage	◯	◯	◯	◯	◯
Discomfort or pain	◯	◯	◯	◯	◯
Bleeding	◯	◯	◯	◯	◯
Bruising	◯	◯	◯	◯	◯
Too much suction	◯	◯	◯	◯	◯
Breast distortion	◯	◯	◯	◯	◯

If you experience something not described by this question, please list it below.

14. In your opinion, what is a reasonable amount to pay for a double electric breast pump? (assuming US whole dollars)

15. Do you feel that discomfort is a necessary part of using a breast pump?

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
◯	◯	◯	◯	◯

16. I would describe my breast size as:

- ◯ Small
- ◯ Medium
- ◯ Large

17. What year were you born in?

18. What is your highest level of education?

- ◯ Some High School
- ◯ High School Diploma
- ◯ Some College
- ◯ College
- ◯ Graduate School

19. I feel comfortable understanding and speaking English.

◯ Yes

◯ No

Appendix B: Detailed Results

Table B.1: Test for collinearity: Correlation table

	Q7_port	Q7_ease	Q7_weight	Q7_fast	Q7_comfort	Q7_noise	Q7_discrete
Q7_port	1.00	0.25	0.22	-0.04	-0.03	0.02	0.09
Q7_ease	0.25	1.00	0.19	0.09	0.25	0.11	0.20
Q7_weight	0.22	0.19	1.00	0.16	0.16	0.30	0.26
Q7_fast	-0.04	0.09	0.16	1.00	0.21	0.16	0.21
Q7_comfort	-0.03	0.25	0.16	0.21	1.00	0.23	0.21
Q7_noise	0.02	0.11	0.30	0.16	0.23	1.00	0.53
Q7_discrete	0.09	0.20	0.26	0.21	0.21	0.53	1.00

Table B.2: Test for collinearity: Significance table

	Q7_port	Q7_ease	Q7_weight	Q7_fast	Q7_comfort	Q7_noise	Q7_discrete
Q7_port		0.0000	0.0004	0.5046	0.6218	0.7481	0.1508
Q7_ease	0.0000		0.0018	0.1673	0.0000	0.0875	0.0010
Q7_weight	0.0004	0.0018		0.0081	0.0087	0.0000	0.0000
Q7_fast	0.5046	0.1673	0.0081		0.0006	0.0076	0.0006
Q7_comfort	0.6218	0.0000	0.0087	0.0006		0.0002	0.0008
Q7_noise	0.7481	0.0875	0.0000	0.0076	0.0002		0.0000
Q7_discrete	0.1508	0.0010	0.0000	0.0006	0.0008	0.0000	

Table B.3: One-class LCA Model: Parameter Estimates (Response Category 1 = Little to no importance, Response Category 2 = Important)

```
                              1-class model - bifurcated

                    Parameter Estimates

Class membership probabilities: Gamma estimates (standard errors)
Class:                      1
                       1.0000
                      (0.0000)

Item response probabilities: Rho estimates (standard errors)
  Response category  1:
Class:                      1
  Q7_port     :        0.1402
                      (0.0214)
  Q7_ease     :        0.0265
                      (0.0099)
  Q7_weight   :        0.4659
                      (0.0307)
  Q7_fast     :        0.1023
                      (0.0186)
  Q7_comfort  :        0.0492
                      (0.0133)
  Q7_noise    :        0.4773
                      (0.0307)
  Q7_discrete :        0.6667
                      (0.0290)

  Response category  2:
Class:                      1
  Q7_port     :        0.8598
                      (0.0214)
  Q7_ease     :        0.9735
                      (0.0099)
  Q7_weight   :        0.5341
                      (0.0307)
  Q7_fast     :        0.8977
                      (0.0186)
  Q7_comfort  :        0.9508
                      (0.0133)
  Q7_noise    :        0.5227
                      (0.0307)
  Q7_discrete :        0.3333
                      (0.0290)
```

Table B.4: Three-class LCA Model: Parameter Estimates (Response Category 1 = Little to no importance, Response Category 2 = Important)

```
                              3-class model - bifurcated

                         Parameter Estimates

Class membership probabilities: Gamma estimates (standard errors)
Class:                     1           2           3
                      0.3308      0.2063      0.4628
                    (0.0681)    (0.0693)    (0.0474)

Item response probabilities: Rho estimates (standard errors)
  Response category  1:
Class:                     1           2           3
  Q7_port     :       0.0513      0.2862      0.1384
                    (0.0428)    (0.0841)    (0.0321)
  Q7_ease     :       0.0002      0.0536      0.0333
                    (0.0016)    (0.0352)    (0.0168)
  Q7_weight   :       0.0397      0.7880      0.6269
                    (0.0883)    (0.1763)    (0.0484)
  Q7_fast     :       0.0233      0.1248      0.1487
                    (0.0241)    (0.0539)    (0.0332)
  Q7_comfort  :       0.0002      0.0187      0.0980
                    (0.0019)    (0.0196)    (0.0278)
  Q7_noise    :       0.0503      0.0389      0.9789
                    (0.0490)    (0.0947)    (0.0497)
  Q7_discrete :       0.4216      0.4603      0.9343
                    (0.0610)    (0.0900)    (0.0336)

  Response category  2:
Class:                     1           2           3
  Q7_port     :       0.9487      0.7138      0.8616
                    (0.0428)    (0.0841)    (0.0321)
  Q7_ease     :       0.9998      0.9464      0.9667
                    (0.0016)    (0.0352)    (0.0168)
  Q7_weight   :       0.9603      0.2120      0.3731
                    (0.0883)    (0.1763)    (0.0484)
  Q7_fast     :       0.9767      0.8752      0.8513
                    (0.0241)    (0.0539)    (0.0332)
  Q7_comfort  :       0.9998      0.9813      0.9020
                    (0.0019)    (0.0196)    (0.0278)
  Q7_noise    :       0.9497      0.9611      0.0211
                    (0.0490)    (0.0947)    (0.0497)
  Q7_discrete :       0.5784      0.5397      0.0657
                    (0.0610)    (0.0900)    (0.0336)
```

Table B.5: Four-class LCA Model: Parameter Estimates (Response Category 1 = Little to no importance, Response Category 2 = Important)

4-class model - bifurcated

Parameter Estimates

Class membership probabilities: Gamma estimates (standard errors)

Class:	1	2	3	4
	0.4221	0.1390	0.0822	0.3567
	(0.0680)	(0.0691)	(0.0886)	(0.0613)

Item response probabilities: Rho estimates (standard errors)

Response category 1:

Class:	1	2	3	4
Q7_port :	0.1252	0.2984	0.2632	0.0673
	(0.0375)	(0.1135)	(0.1517)	(0.0314)
Q7_ease :	0.0002	0.0002	0.3182	0.0001
	(0.0028)	(0.0029)	(0.3473)	(0.0010)
Q7_weight :	0.6140	0.9490	0.7158	0.0437
	(0.0549)	(0.1345)	(0.1629)	(0.1101)
Q7_fast :	0.1643	0.1581	0.0042	0.0298
	(0.0412)	(0.0805)	(0.0262)	(0.0209)
Q7_comfort :	0.1075	0.0274	0.0011	0.0002
	(0.0329)	(0.0298)	(0.0095)	(0.0014)
Q7_noise :	0.9756	0.0395	0.5483	0.0427
	(0.0661)	(0.1102)	(0.1829)	(0.0471)
Q7_discrete :	0.9266	0.3283	0.9883	0.4169
	(0.0406)	(0.1993)	(0.0404)	(0.0609)

Response category 2:

Class:	1	2	3	4
Q7_port :	0.8748	0.7016	0.7368	0.9327
	(0.0375)	(0.1135)	(0.1517)	(0.0314)
Q7_ease :	0.9998	0.9998	0.6818	0.9999
	(0.0028)	(0.0029)	(0.3473)	(0.0010)
Q7_weight :	0.3860	0.0510	0.2842	0.9563
	(0.0549)	(0.1345)	(0.1629)	(0.1101)
Q7_fast :	0.8357	0.8419	0.9958	0.9702
	(0.0412)	(0.0805)	(0.0262)	(0.0209)
Q7_comfort :	0.8925	0.9726	0.9989	0.9998
	(0.0329)	(0.0298)	(0.0095)	(0.0014)
Q7_noise :	0.0244	0.9605	0.4517	0.9573
	(0.0661)	(0.1102)	(0.1829)	(0.0471)
Q7_discrete :	0.0734	0.6717	0.0117	0.5831
	(0.0406)	(0.1993)	(0.0404)	(0.0609)

Table B.6: Five-class LCA Model: Parameter Estimates (Response Category 1 = Little to no importance, Response Category 2 = Important)

5-class model - bifurcated

Parameter Estimates

Class membership probabilities: Gamma estimates (standard errors)

Class:	1	2	3	4	5
	0.3590	0.3068	0.1020	0.1452	0.0870
	(0.0798)	(0.0544)	(0.0412)	(0.0717)	(0.0599)

Item response probabilities: Rho estimates (standard errors)

Response category 1:

Class:	1	2	3	4	5
Q7_port :	0.0023	0.0683	0.3364	0.3215	0.4255
	(0.0138)	(0.0352)	(0.1130)	(0.1413)	(0.2398)
Q7_ease :	0.0002	0.0001	0.0002	0.1812	0.0006
	(0.0027)	(0.0010)	(0.0030)	(0.1050)	(0.0078)
Q7_weight :	0.5043	0.0269	0.9519	0.6597	0.9556
	(0.0931)	(0.0788)	(0.1406)	(0.1377)	(0.1290)
Q7_fast :	0.1718	0.0176	0.1605	0.0026	0.2115
	(0.0510)	(0.0230)	(0.0819)	(0.0180)	(0.1235)
Q7_comfort :	0.0512	0.0001	0.0341	0.0005	0.3122
	(0.0372)	(0.0013)	(0.0384)	(0.0046)	(0.1686)
Q7_noise :	0.8432	0.0108	0.0151	0.5776	0.9865
	(0.1130)	(0.0310)	(0.0484)	(0.1498)	(0.0416)
Q7_discrete :	0.8735	0.3612	0.1127	0.9934	0.9947
	(0.0483)	(0.0752)	(0.2331)	(0.0253)	(0.0207)

Response category 2:

Class:	1	2	3	4	5
Q7_port :	0.9977	0.9317	0.6636	0.6785	0.5745
	(0.0138)	(0.0352)	(0.1130)	(0.1413)	(0.2398)
Q7_ease :	0.9998	0.9999	0.9998	0.8188	0.9994
	(0.0027)	(0.0010)	(0.0030)	(0.1050)	(0.0078)
Q7_weight :	0.4957	0.9731	0.0481	0.3403	0.0444
	(0.0931)	(0.0788)	(0.1406)	(0.1377)	(0.1290)
Q7_fast :	0.8282	0.9824	0.8395	0.9974	0.7885
	(0.0510)	(0.0230)	(0.0819)	(0.0180)	(0.1235)
Q7_comfort :	0.9488	0.9999	0.9659	0.9995	0.6878
	(0.0372)	(0.0013)	(0.0384)	(0.0046)	(0.1686)
Q7_noise :	0.1568	0.9892	0.9849	0.4224	0.0135
	(0.1130)	(0.0310)	(0.0484)	(0.1498)	(0.0416)
Q7_discrete :	0.1265	0.6388	0.8873	0.0066	0.0053
	(0.0483)	(0.0752)	(0.2331)	(0.0253)	(0.0207)

Figure B.7: One-class LCA Model: Frequency distribution of log-likelihoods for multiple starting values indicating convergence on **global maximum** (e.g. highest log-likelihood value)

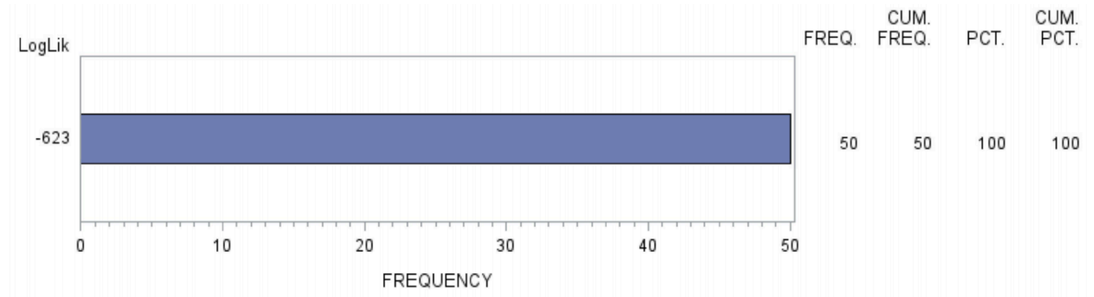


Figure B.8: Two-class LCA Model: Frequency distribution of log-likelihoods for multiple starting values indicating convergence on **global maximum** (e.g. highest log-likelihood value)

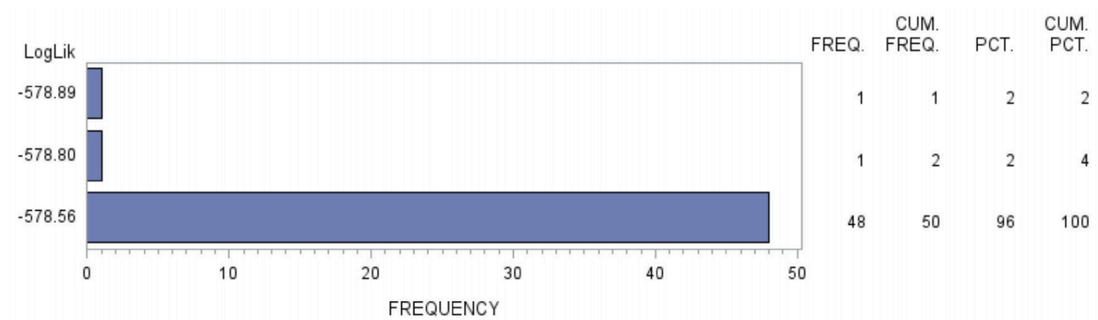


Figure B.9: Three-class LCA Model: Frequency distribution of log-likelihoods for multiple starting values indicating convergence on **local maximum**, not global maximum

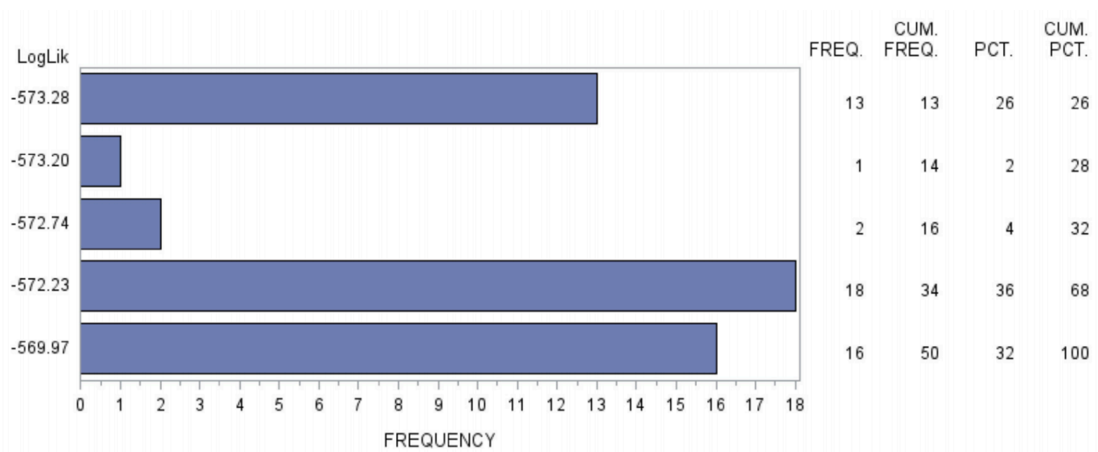


Figure B.10: Four-class LCA Model: Frequency distribution of log-likelihoods for multiple starting values indicating convergence on **local maximum**, not global maximum

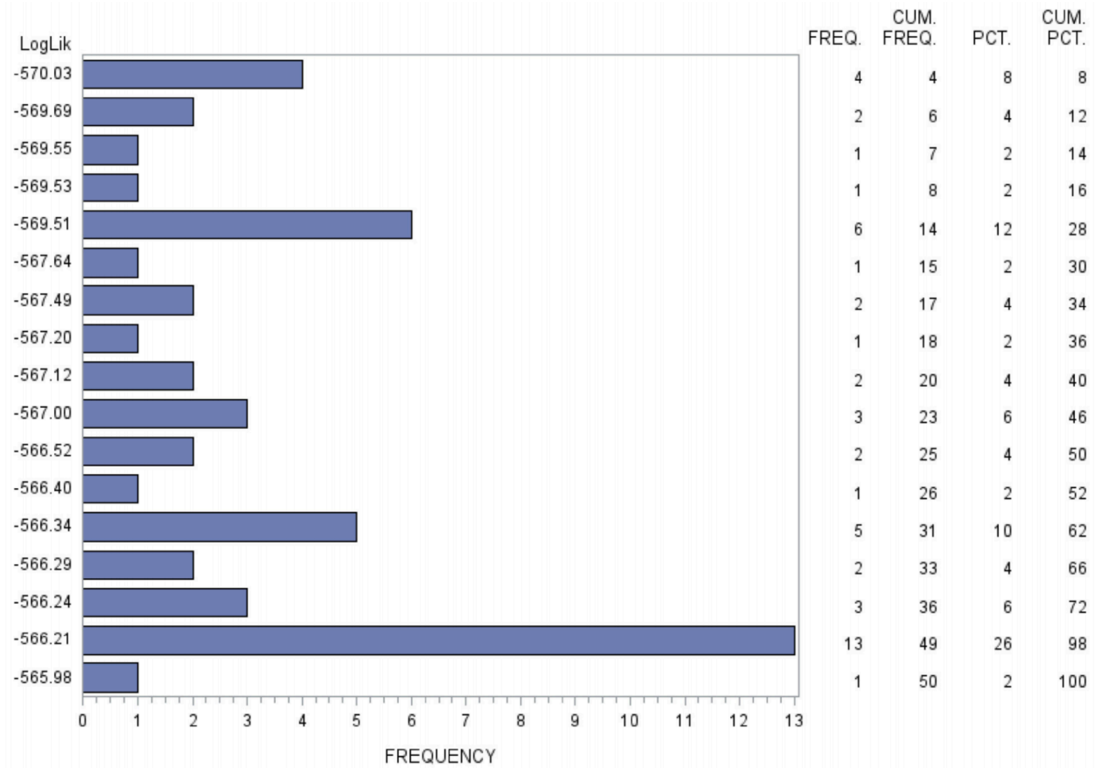
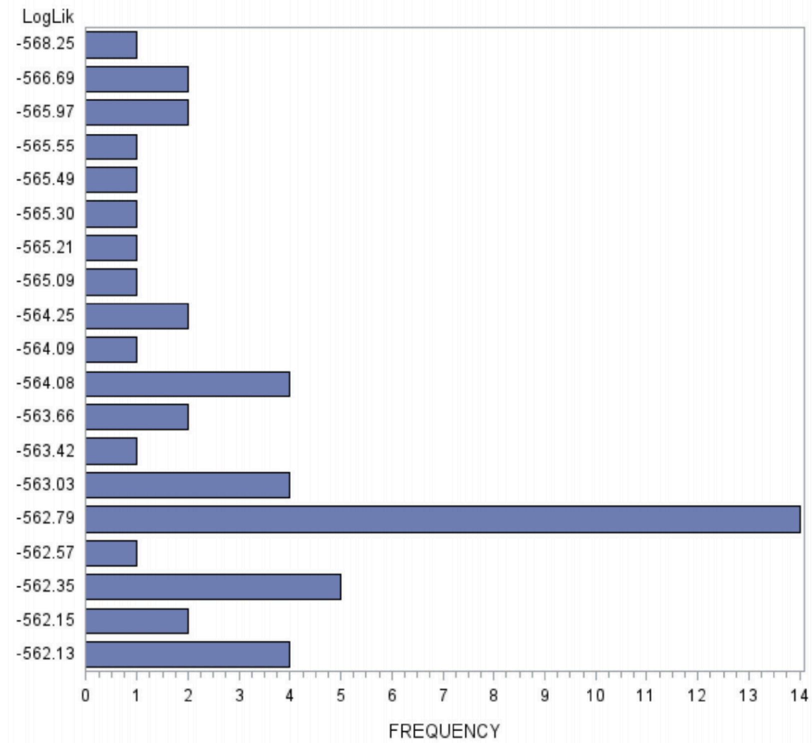


Figure B.11: Five-class LCA Model: Frequency distribution of log-likelihoods for multiple starting values indicating convergence on **local maximum**, not global maximum



LogLik	FREQ.	CUM. FREQ.	PCT.	CUM. PCT.
-568.25	1	1	2	2
-566.69	2	3	4	6
-565.97	2	5	4	10
-565.55	1	6	2	12
-565.49	1	7	2	14
-565.30	1	8	2	16
-565.21	1	9	2	18
-565.09	1	10	2	20
-564.25	2	12	4	24
-564.09	1	13	2	26
-564.08	4	17	8	34
-563.66	2	19	4	38
-563.42	1	20	2	40
-563.03	4	24	8	48
-562.79	14	38	28	76
-562.57	1	39	2	78
-562.35	5	44	10	88
-562.15	2	46	4	92
-562.13	4	50	8	100

Appendix C: R Studio and SAS Code

R 3.5.1 code

````
title: "MS thesis - BP data analysis"
output: html_notebook
---

##Libraries
```{r}
library(mclust)
library(skimr)
library(ggforce)
library(ggplot2)
library(Hmisc)
library(stats)
library(devtools)
library(moments)

install_github("vqv/ggbiplot")

library(ggbiplot)

##Check for colinearity
```{r}
dataQ7 <- data[,11:17]

  Q7rr_corr <- rcorr(as.matrix(dataQ7), type="spearman")
  Q7rr_corr
```
##Kruskal-Wallace - compare WOH and NWOH on 7 chars
```{r}
kruskal.test(Q7_port ~ Q4, data=data)
kruskal.test(Q7_ease ~ Q4, data=data)
kruskal.test(Q7_weight ~ Q4, data=data)
kruskal.test(Q7_fast ~ Q4, data=data)
kruskal.test(Q7_comfort ~ Q4, data=data)
kruskal.test(Q7_noise ~ Q4, data=data)
kruskal.test(Q7_discrete ~ Q4, data=data)
```
````
````

SAS 9.4 code

```
/* ENTIRE DATASET WTIH 5 LEVELS FOR LIKERTS*/
PROC LCA DATA=BPDATA.BPDATA;
NCLASS 5;
ITEMS Q7_port Q7_ease Q7_weight Q7_fast Q7_comfort Q7_noise Q7_discrete;
CATEGORIES 5 5 5 5 5 5 5;
SEED 861551;
RUN;

PROC LCA DATA=BPDATA.BPDATA;
TITLE2 '2-class model';
NCLASS 2;
ITEMS Q7_port Q7_ease Q7_weight Q7_fast Q7_comfort Q7_noise Q7_discrete;
CATEGORIES 5 5 5 5 5 5 5;
SEED 861551;
RUN;

PROC LCA DATA=BPDATA.BPDATA;
TITLE3 '3-class model';
NCLASS 3;
ITEMS Q7_port Q7_ease Q7_weight Q7_fast Q7_comfort Q7_noise Q7_discrete;
CATEGORIES 5 5 5 5 5 5 5;
SEED 861551;
RUN;

PROC LCA DATA=BPDATA.BPDATA;
TITLE3 '2a-class model';
NCLASS 2;
ITEMS Q7_port Q7_ease Q7_weight Q7_fast Q7_comfort Q7_noise Q7_discrete;
CATEGORIES 5 5 5 5 5 5 5;
SEED 861551;
RHO PRIOR = 1;
RUN;

PROC LCA DATA=BPDATA.BPDATA;
TITLE3 '3a-class model';
NCLASS 3;
ITEMS Q7_port Q7_ease Q7_weight Q7_fast Q7_comfort Q7_noise Q7_discrete;
CATEGORIES 5 5 5 5 5 5 5;
SEED 861551;
RHO PRIOR = 1;
RUN;

PROC LCA DATA=BPDATA.BPDATA;
TITLE3 '2-class model - bifurcate';
```

```
NCLASS 2;
ITEMS Q7_port Q7_ease Q7_weight Q7_fast Q7_comfort Q7_noise Q7_discrete;
CATEGORIES 2 2 2 2 2 2 2;
SEED 861551;
RHO PRIOR = 1;
RUN;
*immediately above does not work - SAS detects that there are 5 levels for Q7_port
etc;

/*BIFURCATED DATA*/
PROC LCA DATA=RBTHESIS.JANBPDATABIREV OUTEST=est1
OUTPARAM=par1;
TITLE3 '1-class model - bifurcated';
NCLASS 1;
ITEMS Q7_port Q7_ease Q7_weight Q7_fast Q7_comfort Q7_noise Q7_discrete;
CATEGORIES 2 2 2 2 2 2 2;
SEED 861551;
*RHO PRIOR = 1;
RUN;
PROC LCA DATA=RBTHESIS.JANBPDATABIREV OUTEST=est2
OUTPARAM=par2;
TITLE3 '2-class model - bifurcated';
NCLASS 2;
ITEMS Q7_port Q7_ease Q7_weight Q7_fast Q7_comfort Q7_noise Q7_discrete;
CATEGORIES 2 2 2 2 2 2 2;
SEED 861551;
*RHO PRIOR = 1;
RUN;

PROC LCA DATA=RBTHESIS.JANBPDATABIREV OUTEST=est3
OUTPARAM=par3;
TITLE3 '3-class model - bifurcated';
NCLASS 3;
ITEMS Q7_port Q7_ease Q7_weight Q7_fast Q7_comfort Q7_noise Q7_discrete;
CATEGORIES 2 2 2 2 2 2 2;
SEED 861551;
*RHO PRIOR = 1;
RUN;

PROC LCA DATA=RBTHESIS.JANBPDATABIREV OUTEST=est4
OUTPARAM=par4;
TITLE3 '4-class model - bifurcated';
NCLASS 4;
ITEMS Q7_port Q7_ease Q7_weight Q7_fast Q7_comfort Q7_noise Q7_discrete;
CATEGORIES 2 2 2 2 2 2 2;
SEED 861551;
```

```
*RHO PRIOR = 1;
RUN;

PROC LCA DATA=RBTHESIS.JANBPDATABIREV OUTEST=est5
OUTPARAM=par5;
TITLE3 '5-class model - bifurcated';
NCLASS 5;
ITEMS Q7_port Q7_ease Q7_weight Q7_fast Q7_comfort Q7_noise Q7_discrete;
CATEGORIES 2 2 2 2 2 2 2;
SEED 861551;
*RHO PRIOR = 1;
RUN;

%INCLUDE "C:\Users\BP Data\Documents\LcaBootstrap.sas";

%LcaBootstrap(null_outest=est1, alt_outest=est2, null_outparam=par1,
alt_outparam=par2, n=2000, num_bootstrap=99, num_starts_for_null = 20,
num_starts_for_alt=20,cores=1);
%LcaBootstrap(null_outest=est2, alt_outest=est3, null_outparam=par2,
alt_outparam=par3, n=2000, num_bootstrap=99, num_starts_for_null = 20,
num_starts_for_alt=20,cores=1);
%LcaBootstrap(null_outest=est3, alt_outest=est4, null_outparam=par3,
alt_outparam=par4, n=2000, num_bootstrap=99, num_starts_for_null = 20,
num_starts_for_alt=20,cores=1);
%LcaBootstrap(null_outest=est4, alt_outest=est5, null_outparam=par4,
alt_outparam=par5, n=2000, num_bootstrap=99, num_starts_for_null = 20,
num_starts_for_alt=20,cores=1);

/*-----adding nstarts-----*/
PROC LCA DATA=RBTHESIS.JANBPDATABIREV OUTEST=est1
OUTPARAM=par1 OUTSEEDS=seed1;
TITLE3 '1-class model - bifurcated';
NCLASS 1;
ITEMS Q7_port Q7_ease Q7_weight Q7_fast Q7_comfort Q7_noise Q7_discrete;
CATEGORIES 2 2 2 2 2 2 2;
SEED 861551;
*RHO PRIOR = 1;
NSTARTS 50;
RUN;
PROC LCA DATA=RBTHESIS.JANBPDATABIREV OUTEST=est2
OUTPARAM=par2 OUTSEEDS=seed2;
TITLE3 '2-class model - bifurcated';
NCLASS 2;
ITEMS Q7_port Q7_ease Q7_weight Q7_fast Q7_comfort Q7_noise Q7_discrete;
CATEGORIES 2 2 2 2 2 2 2;
SEED 861551;
```

```
*RHO PRIOR = 1;
NSTARTS 50;
RUN;
PROC LCA DATA=RBTHESIS.JANBPDATABIREV OUTEST=est3
OUTPARAM=par3 OUTSEEDS=seed3;
TITLE3 '3-class model - bifurcated';
NCLASS 3;
ITEMS Q7_port Q7_ease Q7_weight Q7_fast Q7_comfort Q7_noise Q7_discrete;
CATEGORIES 2 2 2 2 2 2 2;
SEED 861551;
RHO PRIOR = 1;
NSTARTS 50;
RUN;

PROC LCA DATA=RBTHESIS.JANBPDATABIREV OUTEST=est4
OUTPARAM=par4 OUTSEEDS=seed4;
TITLE3 '4-class model - bifurcated';
NCLASS 4;
ITEMS Q7_port Q7_ease Q7_weight Q7_fast Q7_comfort Q7_noise Q7_discrete;
CATEGORIES 2 2 2 2 2 2 2;
SEED 861551;
RHO PRIOR = 1;
NSTARTS 50;
RUN;

PROC LCA DATA=RBTHESIS.JANBPDATABIREV OUTEST=est5
OUTPARAM=par5 OUTSEEDS=seed5;
TITLE3 '5-class model - bifurcated';
NCLASS 5;
ITEMS Q7_port Q7_ease Q7_weight Q7_fast Q7_comfort Q7_noise Q7_discrete;
CATEGORIES 2 2 2 2 2 2 2;
SEED 861551;
RHO PRIOR = 1;
NSTARTS 50;
RUN;
%INCLUDE "C:\Users\BP Data\Documents\LcaGraphicsV2.sas";
%IdentificationPlot(SeedsDataset=seed1);
%IdentificationPlot(SeedsDataset=seed2);
%IdentificationPlot(SeedsDataset=seed3);
%IdentificationPlot(SeedsDataset=seed4);
%IdentificationPlot(SeedsDataset=seed5);

%ItemResponsePlot(ParamDataset=par1);
%ItemResponsePlot(ParamDataset=par2);
%ItemResponsePlot(ParamDataset=par3);
%ItemResponsePlot(ParamDataset=par4);
```

```
%ItemResponsePlot(ParamDataset=par5);


 /*---COVARIATES---*/
PROC LCA DATA=RBTHESIS.JANBPDATABIREV OUTEST=est2
OUTPARAM=par2 OUTSEEDS=seed2 OUTSTDERR=std2;
TITLE3 '2-class model - bifurcated - covariates, class 1 as ref';
NCLASS 2;
ITEMS Q7_port Q7_ease Q7_weight Q7_fast Q7_comfort Q7_noise Q7_discrete;
CATEGORIES 2 2 2 2 2 2 2;
COVARIATES Q4_working Education Age_Bucket BP_Type;
REFERENCE 1;
SEED 861551;
RHO PRIOR = 1;
NSTARTS 50;
RUN;
%OddsRatioPlot(ParamDataset=par2, StdErrDataset=std2);

PROC LCA DATA=RBTHESIS.JANBPDATABIREV OUTEST=est4
OUTPARAM=par4 OUTSEEDS=seed4;
TITLE3 '4-class model - bifurcated - covariate Q4, class 1 as ref';
NCLASS 4;
ITEMS Q7_port Q7_ease Q7_weight Q7_fast Q7_comfort Q7_noise Q7_discrete;
CATEGORIES 2 2 2 2 2 2 2;
COVARIATES Q4_working;
REFERENCE 1;
SEED 861551;
*RHO PRIOR = 1;
NSTARTS 50;
RUN;
/*directly above doesn't run*/

/*---GROUPS---*/
/*grouping with Q4*/
PROC LCA DATA=RBTHESIS.JANBPDATABIREV OUTEST=est2
OUTPARAM=par2 OUTSEEDS=seed2 OUTSTDERR=std2;
TITLE3 '2-class model - bifurcated - Q4 as grouping variable, params estimated
freely';
NCLASS 2;
ITEMS Q7_port Q7_ease Q7_weight Q7_fast Q7_comfort Q7_noise Q7_discrete;
CATEGORIES 2 2 2 2 2 2 2;
GROUPS Q4_working;
GROUPNAMES Yes No;
*MEASUREMENT groups;
SEED 861551;
RHO PRIOR = 1;
```

```
NSTARTS 50;
RUN;

PROC LCA DATA=RBTHESIS.JANBPDATABIREV OUTEST=est2
OUTPARAM=par2 OUTSEEDS=seed2 OUTSTDERR=std2;
TITLE3 '2-class model - bifurcated - Q4 as grouping variable, meas invar imposed
across groups';
NCLASS 2;
ITEMS Q7_port Q7_ease Q7_weight Q7_fast Q7_comfort Q7_noise Q7_discrete;
CATEGORIES 2 2 2 2 2 2 2;
GROUPS Q4_working;
GROUPNAMES Yes No;
MEASUREMENT groups;
SEED 861551;
RHO PRIOR = 1;
NSTARTS 50;
RUN;

/*grouping with Q4 + Age buckets*/
PROC LCA DATA=RBTHESIS.JANBPDATABIREV OUTEST=est2
OUTPARAM=par2 OUTSEEDS=seed2 OUTSTDERR=std2;
TITLE3 '2-class model - bifurcated - Q4+Age as grouping variable, params estimated
freely';
NCLASS 2;
ITEMS Q7_port Q7_ease Q7_weight Q7_fast Q7_comfort Q7_noise Q7_discrete;
CATEGORIES 2 2 2 2 2 2 2;
GROUPS GROUP2;
GROUPNAMES YesOld YesYoung NoOld NoYoung;
*MEASUREMENT groups;
SEED 861551;
RHO PRIOR = 1;
NSTARTS 50;
RUN;

PROC LCA DATA=RBTHESIS.JANBPDATABIREV OUTEST=est2
OUTPARAM=par2 OUTSEEDS=seed2 OUTSTDERR=std2;
TITLE3 '2-class model - bifurcated - Q4+Age as grouping variable, meas invar
imposed across groups';
NCLASS 2;
ITEMS Q7_port Q7_ease Q7_weight Q7_fast Q7_comfort Q7_noise Q7_discrete;
CATEGORIES 2 2 2 2 2 2 2;
GROUPS GROUP2;
GROUPNAMES YesOld YesYoung NoOld NoYoung;
MEASUREMENT groups;
SEED 861551;
RHO PRIOR = 1;
```

```
NSTARTS 50;
RUN;

/*grouping with Education*/
PROC LCA DATA=RBTHESIS.JANBPDATABIREV OUTEST=est2
OUTPARAM=par2 OUTSEEDS=seed2 OUTSTDERR=std2;
TITLE3 '2-class model - bifurcated - Edu as grouping variable, params estimated
freely';
NCLASS 2;
ITEMS Q7_port Q7_ease Q7_weight Q7_fast Q7_comfort Q7_noise Q7_discrete;
CATEGORIES 2 2 2 2 2 2 2;
GROUPS Education;
GROUPNAMES HSDiploma SomeCollege College GradSch;
*MEASUREMENT groups;
SEED 861551;
RHO PRIOR = 1;
NSTARTS 50;
RUN;

PROC LCA DATA=RBTHESIS.JANBPDATABIREV OUTEST=est2
OUTPARAM=par2 OUTSEEDS=seed2 OUTSTDERR=std2;
TITLE3 '2-class model - bifurcated - Edu as grouping variable, meas invar imposed
across groups';
NCLASS 2;
ITEMS Q7_port Q7_ease Q7_weight Q7_fast Q7_comfort Q7_noise Q7_discrete;
CATEGORIES 2 2 2 2 2 2 2;
GROUPS Education;
GROUPNAMES HSDiploma SomeCollege College GradSch;
MEASUREMENT groups;
SEED 861551;
RHO PRIOR = 1;
NSTARTS 50;
RUN;

/*grouping with Age*/
PROC LCA DATA=RBTHESIS.JANBPDATABIREV OUTEST=est2
OUTPARAM=par2 OUTSEEDS=seed2 OUTSTDERR=std2;
TITLE3 '2-class model - bifurcated - Age Bucket as grouping variable, params
estimated freely';
NCLASS 2;
ITEMS Q7_port Q7_ease Q7_weight Q7_fast Q7_comfort Q7_noise Q7_discrete;
CATEGORIES 2 2 2 2 2 2 2;
GROUPS Age_Bucket;
GROUPNAMES Old Young;
*MEASUREMENT groups;
SEED 861551;
```

```
RHO PRIOR = 1;
NSTARTS 50;
RUN;

PROC LCA DATA=RBTHESIS.JANBPDATABIREV OUTEST=est2
OUTPARAM=par2 OUTSEEDS=seed2 OUTSTDERR=std2;
TITLE3 '2-class model - bifurcated - Age Bucket as grouping variable, meas invar
imposed across groups';
NCLASS 2;
ITEMS Q7_port Q7_ease Q7_weight Q7_fast Q7_comfort Q7_noise Q7_discrete;
CATEGORIES 2 2 2 2 2 2 2;
GROUPS Age_Bucket;
GROUPNAMES Old Young;
MEASUREMENT groups;
SEED 861551;
RHO PRIOR = 1;
NSTARTS 50;
RUN;

/*---SEPARATE DATASETS - WOH---*/
PROC LCA DATA=RBTHESIS.WOH OUTEST=west1 OUTPARAM=wpar1
OUTSEEDS=wseed1;
TITLE3 '1-class model - WOH';
NCLASS 1;
ITEMS Q7_port Q7_ease Q7_weight Q7_fast Q7_comfort Q7_noise Q7_discrete;
CATEGORIES 2 2 2 2 2 2 2;
SEED 861551;
*RHO PRIOR = 1;
NSTARTS 50;
RUN;
PROC LCA DATA=RBTHESIS.WOH OUTEST=west2 OUTPARAM=wpar2
OUTSEEDS=wseed2;
TITLE3 '2-class model - WOH';
NCLASS 2;
ITEMS Q7_port Q7_ease Q7_weight Q7_fast Q7_comfort Q7_noise Q7_discrete;
CATEGORIES 2 2 2 2 2 2 2;
SEED 861551;
*RHO PRIOR = 1;
NSTARTS 50;
RUN;
PROC LCA DATA=RBTHESIS.WOH OUTEST=west3 OUTPARAM=wpar3
OUTSEEDS=wseed3;
TITLE3 '3-class model - WOH';
NCLASS 3;
ITEMS Q7_port Q7_ease Q7_weight Q7_fast Q7_comfort Q7_noise Q7_discrete;
CATEGORIES 2 2 2 2 2 2 2;
```

```
SEED 861551;
RHO PRIOR = 1;
NSTARTS 50;
RUN;

PROC LCA DATA=RBTHESIS.WOH OUTEST=west4 OUTPARAM=wpar4
OUTSEEDS=wseed4;
TITLE3 '4-class model - WOH';
NCLASS 4;
ITEMS Q7_port Q7_ease Q7_weight Q7_fast Q7_comfort Q7_noise Q7_discrete;
CATEGORIES 2 2 2 2 2 2 2;
SEED 861551;
RHO PRIOR = 1;
NSTARTS 50;
RUN;

PROC LCA DATA=RBTHESIS.WOH OUTEST=west5 OUTPARAM=wpar5
OUTSEEDS=wseed5;
TITLE3 '5-class model - WOH';
NCLASS 5;
ITEMS Q7_port Q7_ease Q7_weight Q7_fast Q7_comfort Q7_noise Q7_discrete;
CATEGORIES 2 2 2 2 2 2 2;
SEED 861551;
RHO PRIOR = 1;
NSTARTS 50;
RUN;
%INCLUDE "C:\Users\BP Data\Documents\LcaGraphicsV2.sas";
%IdentificationPlot(SeedsDataset=wseed1);
%IdentificationPlot(SeedsDataset=wseed2);
%IdentificationPlot(SeedsDataset=wseed3);
%IdentificationPlot(SeedsDataset=wseed4);
%IdentificationPlot(SeedsDataset=wseed5);

%ItemResponsePlot(ParamDataset=wpar1);
%ItemResponsePlot(ParamDataset=wpar2);
%ItemResponsePlot(ParamDataset=wpar3);
%ItemResponsePlot(ParamDataset=wpar4);
%ItemResponsePlot(ParamDataset=wpar5);

%INCLUDE "C:\Users\BP Data\Documents\LcaBootstrap.sas";

%LcaBootstrap(null_outest=west1, alt_outest=west2, null_outparam=wpar1,
alt_outparam=wpar2, n=2000, num_bootstrap=99, num_starts_for_null = 20,
num_starts_for_alt=20,cores=1);
```

```
%LcaBootstrap(null_outest=west2, alt_outest=west3, null_outparam=wpar2,
alt_outparam=wpar3, n=2000, num_bootstrap=99, num_starts_for_null = 20,
num_starts_for_alt=20,cores=1);
%LcaBootstrap(null_outest=west3, alt_outest=west4, null_outparam=wpar3,
alt_outparam=wpar4, n=2000, num_bootstrap=99, num_starts_for_null = 20,
num_starts_for_alt=20,cores=1);
%LcaBootstrap(null_outest=west4, alt_outest=west5, null_outparam=wpar4,
alt_outparam=wpar5, n=2000, num_bootstrap=99, num_starts_for_null = 20,
num_starts_for_alt=20,cores=1);

 /*---Covariates---*/
PROC LCA DATA=RBTHESIS.WOH OUTEST=west2 OUTPARAM=wpar2
OUTSEEDS=wseed2 OUTSTDERR=wstd2;
TITLE3 '2-class model - WOH - covariates, class 1 as ref';
NCLASS 2;
ITEMS Q7_port Q7_ease Q7_weight Q7_fast Q7_comfort Q7_noise Q7_discrete;
CATEGORIES 2 2 2 2 2 2 2;
COVARIATES Education Age_Bucket BP_Type;
REFERENCE 1;
SEED 861551;
RHO PRIOR = 1;
*BETA PRIOR = 1;
NSTARTS 50;
RUN;
%OddsRatioPlot(ParamDataset=wpar2, StdErrDataset=wstd2);

/*---SEPARATE DATASETS - NWOH---*/
PROC LCA DATA=RBTHESIS.NWOH OUTEST=nest1 OUTPARAM=npar1
OUTSEEDS=nseed1;
TITLE3 '1-class model - NWOH';
NCLASS 1;
ITEMS Q7_port Q7_ease Q7_weight Q7_fast Q7_comfort Q7_noise Q7_discrete;
CATEGORIES 2 2 2 2 2 2 2;
SEED 861551;
*RHO PRIOR = 1;
NSTARTS 50;
RUN;
PROC LCA DATA=RBTHESIS.NWOH OUTEST=nest2 OUTPARAM=npar2
OUTSEEDS=nseed2;
TITLE3 '2-class model - NWOH';
NCLASS 2;
ITEMS Q7_port Q7_ease Q7_weight Q7_fast Q7_comfort Q7_noise Q7_discrete;
CATEGORIES 2 2 2 2 2 2 2;
SEED 861551;
*RHO PRIOR = 1;
NSTARTS 50;
```

```
RUN;
PROC LCA DATA=RBTHESIS.NWOH OUTEST=nest3 OUTPARAM=npar3
OUTSEEDS=nseed3;
TITLE3 '3-class model - NWOH';
NCLASS 3;
ITEMS Q7_port Q7_ease Q7_weight Q7_fast Q7_comfort Q7_noise Q7_discrete;
CATEGORIES 2 2 2 2 2 2 2;
SEED 861551;
RHO PRIOR = 1;
NSTARTS 50;
RUN;

PROC LCA DATA=RBTHESIS.NWOH OUTEST=nest4 OUTPARAM=npar4
OUTSEEDS=nseed4;
TITLE3 '4-class model - NWOH';
NCLASS 4;
ITEMS Q7_port Q7_ease Q7_weight Q7_fast Q7_comfort Q7_noise Q7_discrete;
CATEGORIES 2 2 2 2 2 2 2;
SEED 861551;
RHO PRIOR = 1;
NSTARTS 50;
RUN;

PROC LCA DATA=RBTHESIS.NWOH OUTEST=nest5 OUTPARAM=npar5
OUTSEEDS=nseed5;
TITLE3 '5-class model - NWOH';
NCLASS 5;
ITEMS Q7_port Q7_ease Q7_weight Q7_fast Q7_comfort Q7_noise Q7_discrete;
CATEGORIES 2 2 2 2 2 2 2;
SEED 861551;
RHO PRIOR = 1;
NSTARTS 50;
RUN;
%INCLUDE "C:\Users\BP Data\Documents\LcaGraphicsV2.sas";
%IdentificationPlot(SeedsDataset=nseed1);
%IdentificationPlot(SeedsDataset=nseed2);
%IdentificationPlot(SeedsDataset=nseed3);
%IdentificationPlot(SeedsDataset=nseed4);
%IdentificationPlot(SeedsDataset=nseed5);

%ItemResponsePlot(ParamDataset=npar1);
%ItemResponsePlot(ParamDataset=npar2);
%ItemResponsePlot(ParamDataset=npar3);
%ItemResponsePlot(ParamDataset=npar4);
%ItemResponsePlot(ParamDataset=npar5);
```

```
%INCLUDE "C:\Users\BP Data\Documents\LcaBootstrap.sas";

%LcaBootstrap(null_outest=nest1, alt_outest=nest2, null_outparam=npar1,
alt_outparam=npar2, n=2000, num_bootstrap=99, num_starts_for_null = 20,
num_starts_for_alt=20,cores=1);
%LcaBootstrap(null_outest=nest2, alt_outest=nest3, null_outparam=npar2,
alt_outparam=npar3, n=2000, num_bootstrap=99, num_starts_for_null = 20,
num_starts_for_alt=20,cores=1);
%LcaBootstrap(null_outest=nest3, alt_outest=nest4, null_outparam=npar3,
alt_outparam=npar4, n=2000, num_bootstrap=99, num_starts_for_null = 20,
num_starts_for_alt=20,cores=1);
%LcaBootstrap(null_outest=nest4, alt_outest=nest5, null_outparam=npar4,
alt_outparam=npar5, n=2000, num_bootstrap=99, num_starts_for_null = 20,
num_starts_for_alt=20,cores=1);

 /*---Covariates---*/
PROC LCA DATA=RBTHESIS.NWOH OUTEST=nest2 OUTPARAM=npar2
OUTSEEDS=nseed2 OUTSTDERR=nstd2;
TITLE3 '2-class model - NWOH - covariates, class 1 as ref';
NCLASS 2;
ITEMS Q7_port Q7_ease Q7_weight Q7_fast Q7_comfort Q7_noise Q7_discrete;
CATEGORIES 2 2 2 2 2 2 2;
COVARIATES Education Age_Bucket BP_Type;
REFERENCE 1;
SEED 861551;
RHO PRIOR = 1;
*BETA PRIOR = 1;
NSTARTS 50;
RUN;
%OddsRatioPlot(ParamDataset=npar2, StdErrDataset=nstd2);
```