AN ABSTRACT OF THE DISSERTATION OF

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Robert B. Stone

This work explores a framework for the gathering and analysis of information rich customer needs, with the goal of informing inclusive product design practice. The goal is to be able to provide information and experience to designers so that they can better understand the needs of exceptional users and include those needs in the early stages of design, making inclusive products easier and less expensive to design, produce and use. Human subjects testing is conducted to test a key aspect of the framework – that of a surrogate experience for general users as a valid proxy for eliciting needs similar to an exceptional user set. For this, both users with actual motion restrictions and general users wearing a motion restriction simulation suit (to provide an exceptional user-like experience) are included in this study to provide customer needs for a product set and mobility characterization data.

The framework provided by this research enables designers to collect and classify the customer needs produced during elicitation activities, and connect those needs with the users' functional capabilities and other information, making the needs useful for informing inclusive design. The interconnected data set is used to examine comparisons between user types and experience and other aspects of user functionality to provide evaluations for the surrogate experience. Both the customer needs and their categorizations are examined across multiple dimensions as well as additional connections to user activity and experience. Most importantly, validations of the collection methods and the surrogate experience are performed.

The research findings detail how functional capability metrics from the occupational therapy field are added into a motion restriction simulation study to enhance the available data

and enable future correlation searches. This dissertation covers the methodology of the selection process for the new metrics along with their implementation into the research procedure and the types of considerations and constraints involved. It provides a detailed description of the motion restriction simulation suit as well as the data collection procedures.

This dissertation also includes a discussion of how a recent customer needs ontology is applied to a set of needs gathered for six different manually operated household products. A modification to the original customer needs ontology is proposed and analyzed. The coding of the collected needs sets serves as a validation for the usage and adaptation of the ontology. The different structures and emphases of the ontology as well as ontology code coverage for this particular type of customer need set and products are discussed. Insights on how the ontology can be helpful for future developments are noted results.

The overall conclusion is that significant insight into exceptional users is gained, even with the limitations noted in this data set. By identifying so much interconnection, many aspects of niche design can be investigated that support a broader approach to design for exceptional users. That investigation is reported here, and subsequent avenues of investigation are suggested.

Gathering Information Rich Customer Needs for Inclusive Product Design

by
Jessica Armstrong

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I understand that my dissertation will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my dissertation to any reader upon request.

Jessica Armstrong, Author

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Chapter 1: Introduction

1.1 Research Motivation:

The motivation for this research is that currently, designers who wish to perform inclusive design lack proper guidance on how to gather a valid and thorough set of customer needs specifically for the purpose of inclusive design (that is, designing for as wide a variety of user abilities as possible). Designing for specific subgroups of users requires knowledge of the needs of those users as well as guidance for how best to use that knowledge. The main gap that we are addressing is the gap in designers' experience - namely how they determine customer needs for different users. Once valid customer needs information is obtained and confirmed, designers can use existing inclusive design guidelines, existing modular product and product family techniques, and their existing prior design knowledge to create usable solutions. The framework provided by this research ensures that designers will be able to easily classify and connect the customer needs produced during customer needs gathering with the users' functional capabilities and limitations. Knowledge of how each of the informational aspects that are being brought together by this research informs design is expected to be of great help in bridging the existing knowledge gap and performing inclusive product and system design with lower effort.

One growing niche market is persons with disabilities. This represents 12.6% of the overall American population [1] that can be better served with future products designed with a more complete understanding of their needs. Additionally, the upward trend in disabilities [2] and the lack of accompanying increases in accommodations [3] means the importance of inclusivity will only increase with time. The increase in activist groups and government regulations for the rights of people with disabilities has raised the importance of making products that integrate their needs along all facets of life [4]. Even setting aside the ethical and legal rationales for the inclusion of people with disabilities, there is the economic benefit of targeting a wider consumer base, and the potential for a positive marketing effort.

As a good example of how inclusive design is used to extend the usefulness of an item to larger segments of potential users, take a moment to think about who would be served by including the needs of people with motion restrictions into the design of manually operated products. Including the needs of people with disabilities (permanent restrictions) would also benefit people with temporary limitations (injuries, or environmentally or situationally imposed

restrictions). Almost everyone has been injured at one point in their life, which resulted in some kind of restriction in their movements. Even if it only lasts a short time, they find that the products that have served them well under normal circumstances, do not work under the new circumstances. Making products that accommodate exceptional users, such as people with motion restrictions, will assist everyone, for those inevitable points in their life when they are also exceptional.

Thus, as noted above, this research has the potential to assist a significant number of people. On the user side, it will assist exceptional users (a term that includes persons with disabilities, and persons with temporary movement restrictions), and it will increase the usability for general users. On the engineering side, it will assist designers who want to understand exceptional users thoroughly and quantitatively, it will assist engineers in communicating consistently about a variety of users, it can help identify modular product techniques which reduce the cost of inclusive products, and it will assist product developers in their front end design processes by providing procedures and guidelines for discovering and incorporating inclusive considerations. Academically, it will help advance the concepts of inclusive and empathic design, as well as user measurement and classification, and customer needs gathering and classification and analysis.

There are many markets that consist of users with non-typical needs or abilities as compared to the general population (again, I will refer to these as exceptional users), and persons or products that must operate in non-typical conditions (we will refer to these as extreme environments). Design for these markets is often approached as a niche effort rather than from the perspective of inclusion. The design of these products is often characterized by one-off or small run production and is generally significantly more expensive than products intended for a broader population. Therefore, the use of economies of scale possible through modular product design and the incorporation of inclusive considerations early in the design process are expected to allow inclusive products to be made less expensively and more easily as part of a product family.

It is known that the cost of design changes increases significantly the later in the product design cycle they are made, as depicted in Figure 1, based on [5, 6]. Therefore, treating inclusive design as an integrated and upfront activity, rather than an afterthought or an add on, can result in lower design and product cost. Also shown in Figure 1, the effectiveness of making those

inclusive choices would be much higher if made in the early stages of the product design cycle. Information that can inform those design decisions will increase the effectiveness of the inclusive design and the resulting products. Therefore, this research endeavors to provide information that can push inclusive consideration into the upfront design stages. It works to fill a gap in the knowledge and practice of customer needs collection.

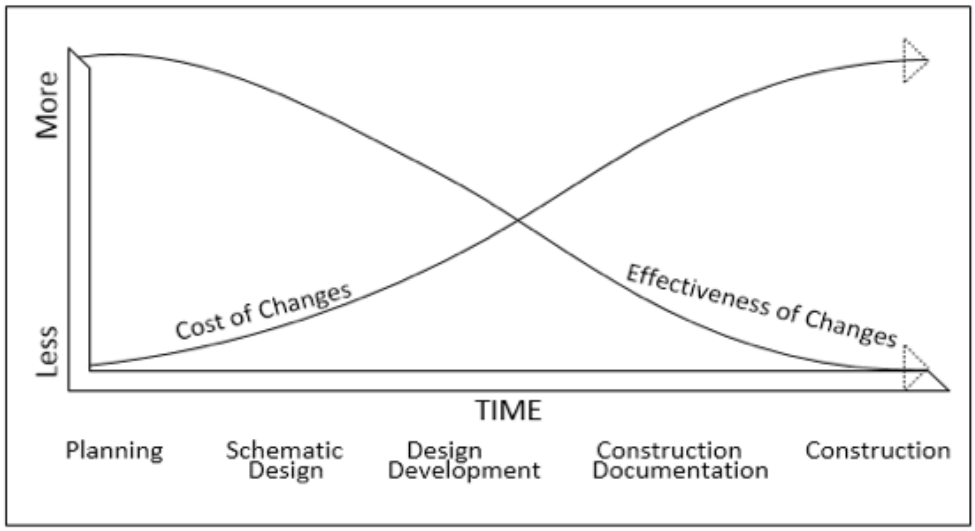


Figure 1: Effectiveness and Cost of Design Changes as the design cycle progresses. [5,6]

Developing the knowledge of customer needs to allow for the proper use of inclusive design techniques and information, products can be made which are more useful to a wide range of users, as well as the intended niche. In this research, the use of surrogate experiences will be investigated as a means of allowing customer needs for niche population sub-groups to be gathered more easily. Additionally, the framework developed by this research, can provide information and guidance to designers who wish to perform thorough informative investigations. The expected result is an improved ability to produce products that offer value to exceptional customers and profitability to the producer.

To summarize, general design methods are good for general purpose design problems – those problems where designers have some level of personal experience or adjacent experience, even if it is just knowledge of other products. General design methods as formulated do not always offer adequate design guidance for markets where the users are not as well understood or where the products must operate in extreme environments. In these cases, the designer lacks

experience with or information about the customers and/or environment. The reported research in this document seeks to alleviate this issue.

1.2 Research Questions:

This research is, at its core, an exploration of how to assist designers in performing inclusive design, by incorporating lessons from customer needs extraction and analysis. This research is expected to allow designers to synthesize and leverage existing design methodologies and principles, including the economies of scale provided by a typical product family design approach, to provide products for exceptional users and extreme environments more easily. It will also allow designers to translate their existing knowledge and bring them closer to inclusive design, through the use of surrogate experiences and categorization frameworks.

This research builds on, and significantly extends, user-centric design methods, function-based design, inclusive product families, and modular product design. This research seeks to relate customer needs statements and user functional limitations in a way that provides information about inclusive product design actions. Classifications of user functioning provide a rich body of knowledge for determining, using, and applying concepts of function as it applies to both users and products. Customer needs categorization analysis also allows for more informed design decisions in later stages of the design process.

As this research represents an exploratory study, its purpose is to determine if and how information on the customer needs of exceptional users can be discovered and incorporated. A valid outcome of this research is the answer "no, it is not possible," i.e., there are not easy generalizable techniques to translate general design knowledge and methods for niche design. However, I believe that the framework created in this study will provide a useful method for gathering inclusive customer needs, which contain and connect a variety of information that will allow designers to perform more data-driven inclusive design. At the very least it will make the customer need (CN) collection process more structured and repeatable.

This leads to the fundamental research questions of this dissertation:

"Can we bridge the gap in designers' experience with exceptional users and environments through surrogate experiences?" and "How do we gather information rich customer needs that will be useful for future inclusive design decisions?"

Specific outcomes of this research include: 1) a validated surrogate customer needs gathering technique; 2) a usage context for the classification of customer needs; 3) a perspective on the connectivity potential between user functioning and customer needs 4) a framework for the collection and management of different informational aspects and 5) preliminary relationships and information necessary for an inclusive modular product design approach.

1.3 Intellectual Merit and Broader Impacts:

The research reported here transforms engineering design practice by creating knowledge and methods that will fundamentally shift the philosophical context and definition of inclusive and niche design. Rather than attempt to design an entire product for a general user/environment, or a niche user/environment, it is preferable to design for both using the same body of knowledge and techniques, with only a guided shift in designer thinking. This research recognizes that both users and producers must be included as inclusive design stakeholders to achieve a high volume of inclusive design practice. It recognizes that with an intelligent identification of the base platform that satisfies all users' needed functionality and the differentiating modules that address specific needs of the exceptional user, and the tradeoffs between the needs of different user subsets, better products will result. It further recognizes that modification and translation of existing knowledge leads to flexibility in designers' ability to perform good work, in varied areas, with a lower effort barrier.

The research creates new knowledge and relationships that quantitatively indicate required product function based on a user's functional limitations from a variety of sources. By adding occupational therapy (OT) metrics for user functional limitations and applying classifications from the World Health Organization's International Classification of Functioning (ICF) throughout, the results are more quantitative, generally applicable, and understandable as tools for inclusive design. By directly connecting functional limitation as the source of the customer needs, the results are more easily translated into decisions under different design techniques.

Combining this research with the existing body of inclusive design principles and guidelines that evaluate the outcome of an inclusive design effort, the proposed work builds the

fundamental foundation for the broad practice of inclusive design and extends it to other considerations commonly involved in niche design.

The fundamental contribution and focus of this research is broader impact. This is done by creating knowledge to better serve currently underserved populations. Discovering approaches for enhancing standard design allows those who wish to design for less well-known user groups to be able to do so with much less effort than currently. Lowering the effort burden of niche design, and inclusive design, has a broad impact on the overall engineering design field.

Furthermore, the validation of empathic simulation techniques provides a useful tool for the broader community to use for customer needs gathering and user understanding. Presentation of the motion restriction simulation suit and the connected data set from this research provides additional design tools to the community. Additional efforts to commercialize both the suit and the data sets in the future will assist in its acceptance as a widely useful design tool.

Broader impacts are immediately achieved through core integrated research activities that include working directly with persons with disabilities. This activity provides immediate impact and extension of the research to a community with limited exposure to engineering research. The benefits of product platform for inclusive products offer economic viability that is expected to lead to more inclusive product offerings.

Additionally, including undergraduates engineering students in the research as active agents, allows them to gain exposure to the "human quality of life improvement" aspect of engineering often not emphasized in the typical undergraduate curriculum. Extending this context, because this research provides surrogate and empathic experiences to designers, it can perform the same gap filling function for those already in the industry.

1.4 Nomenclature:

CN = Customer Need = The phrase describing a need based on customer statements. For this study these needs were derived from statements made during participants' product interactions and take the form Product Should Blank or Product Should Not Blank.

Code = The numerical value assigned to the need based on the definitions of the categories. A full code is a string of numbers.

Raters = The people who assigned the codes to the needs.

Taxonomy = Techniques for the classification of objects into ordered categories. For this study each Taxonomy has a purpose based on the types of information commonly found in customer needs which it classifies.

Ontology = The combination and ordering of taxonomies to create a full classification of the informational content of customer needs. Our study uses 4 different taxonomies.

Needs Set = the list of customer needs (CNs) derived from the participants' use of each product or product pair.

PMR = People with actual motion restrictions (it is a matter of semantics that we no longer use the term disabilities since the context for the work has increased)

SSU = Surrogate Suit Users = the people wearing the second version of the suit who participated during the current round of testing.

PWD = People with Disabilities = the participants with disabilities from the Master's work. (At that stage the focus was on disabilities, rather than general restrictions so it is still accurate for this group)

FSU = First Suit Users = the people in the Master's study who wore the first version of the disability simulation suit.

EU = Exceptional Users

GU = General Users

Ptags = Product Tag = The Tag given to each customer needs statement separated by which product elicited the need.

Ctags = Combined Tag = The tag given to the CN when the product lists are combined into product pairs to match the masters work (list by pair).

Exp1 = Surrogate Experience 1 = The study from my Master's work, performed in 2014.

Exp2 = Surrogate Experience 2 = The study described in this paper for my Phd work.

JO=Jar Opener Pair Set from original experiment Exp1.

CO=Can Opener Product Pair Set from original experiment Exp1.

GP = Garlic Press Product Pair Set from original experiment Exp1.

SGP= the straight style garlic press product from current experiment Exp2.

CGP= the curved style garlic press product from current experiment Exp2.

TJO= the jar opener with twisting action product from current experiment Exp2.

BJO= the black jar opener product from current experiment Exp2.

RCO= the regular style can opener product from current experiment Exp2.

WCO= the white can opener product from current experiment Exp2.

The names, abbreviations and pictures of these products are presented in Table 1.

Table 1: Products used in the Study

Product	Standard garlic press	Kuhn Rikon® garlic press	Kuhn Rikon® jar opener	OXO jar opener	Swing-A-Way® Portable can opener	Zyliss Swiss Innovation® can opener
Abbreviation	SGP	CGP	TJO	BJO	RCO	WCO
Type	Exclusive	Inclusive	Inclusive	Exclusive	Exclusive	Inclusive
Picture						

C=Can Opener Product Pair Set from EXP2.

J=Jar Opener Product Pair Set from EXP2.

G=Garlic Press Product Pair Set from EXP2.

OT = Occupational Therapy = “the only profession that helps people across the lifespan to do the things they want & need to do through the therapeutic use of daily activities(occupations)” [199]

ROM= Range of Motion

9HPT = Nine Hole Peg Test = commonly used test of fine motor dexterity skills

BBT= Box and Blocks Test = commonly used test of gross motor dexterity skills

Chapter 2: Literature Review

This section is intended to provide information about the fields that provide knowledge for the proposed research. As most of the fields being discussed are established disciplines, with large bodies of literature, only the relevant topics are reviewed here. It will cover the general design process, inclusive design, empathic design, exceptional user simulation, relevant schemes for classifying user functionality, customer needs coding, and product family/platform design.

2.1 The Design Process:

The Design process moves from Need to Function to Form. This is described in [9, 10, 11] and can be seen well in the design cycle chart from [12] presented in Figure 2.

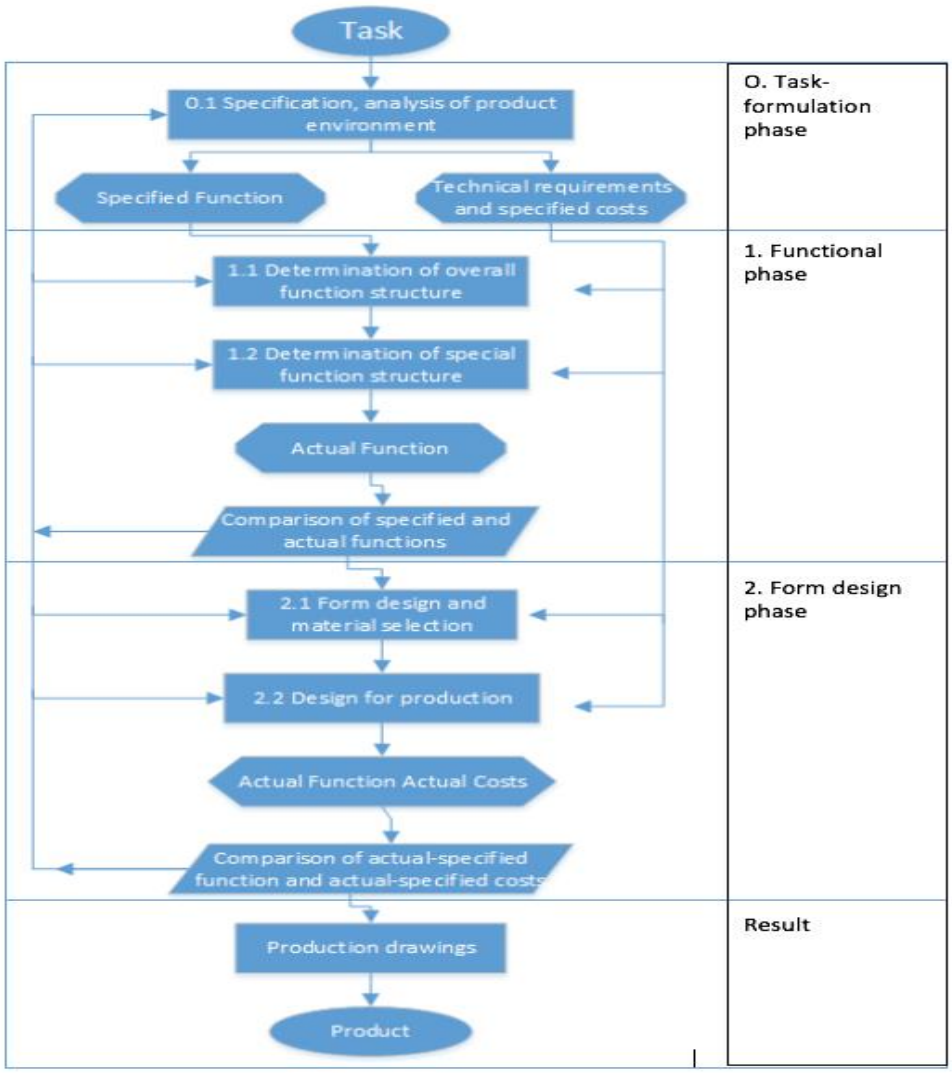


Figure 2: The Roth Design Phases recreated from illustration in the Pahl and Beitz text [9]

There are many other ways to breakdown and present the design cycle. The specific steps and divisions varies depending on which subfield is followed. Another example is presented in Figure 3, which was derived from [13, 10].

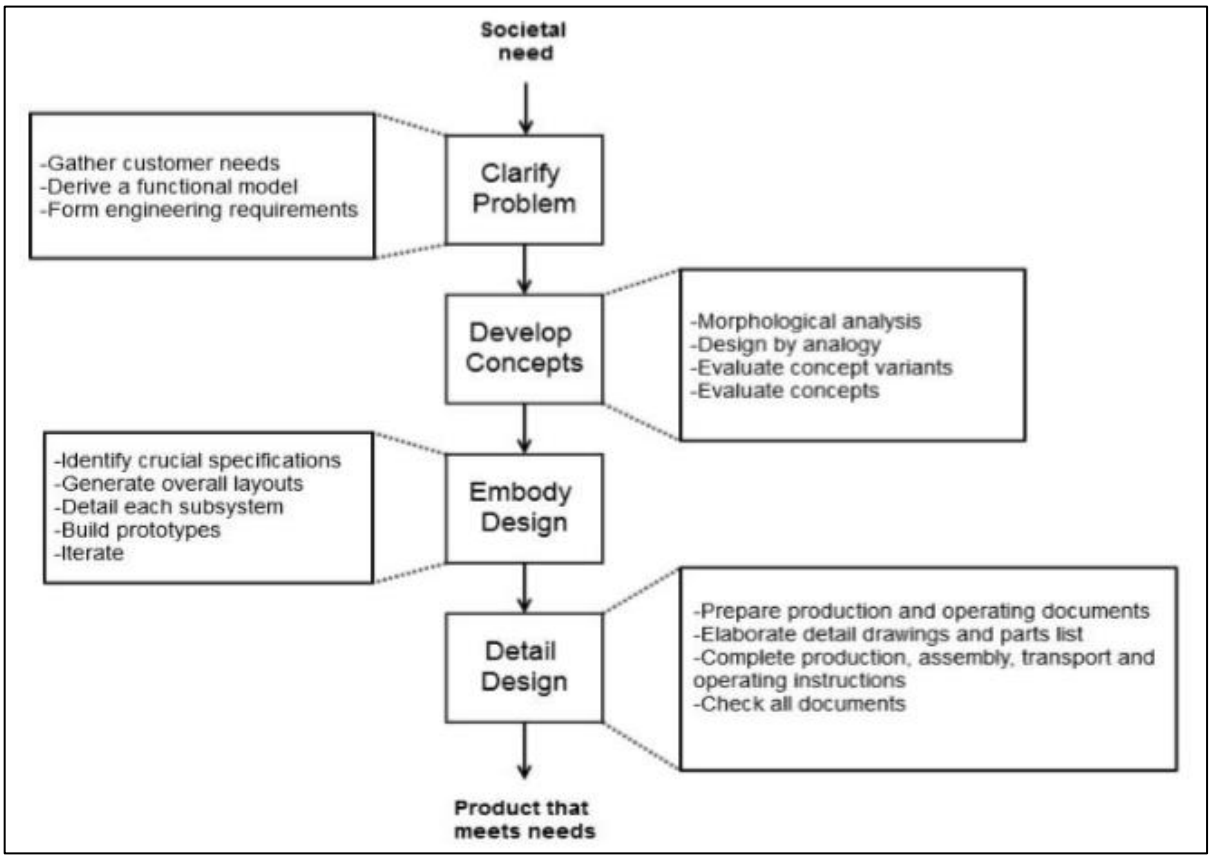


Figure 3: The Design Process [13,10]

For a sampling of different types of design cycles used for educational purposes see [14].

What is common to all processes, is that it begins with needs discovery. After that, it moves on to determining the necessary product functions. Then, the cycle moves on to how to accomplish the functions, then again moves on to design details that focus on such ideas as materials and manufacturing.

As stated in [15], "Whatever the stage we are concerned with at a particular time, [the product design] specification is our basic reference." Many choices are involved in what to include, and to what detail level, in the specifications, as shown in Figure 4 from [15] and the Checklist for drawing up specifications in Table 2 from [12].

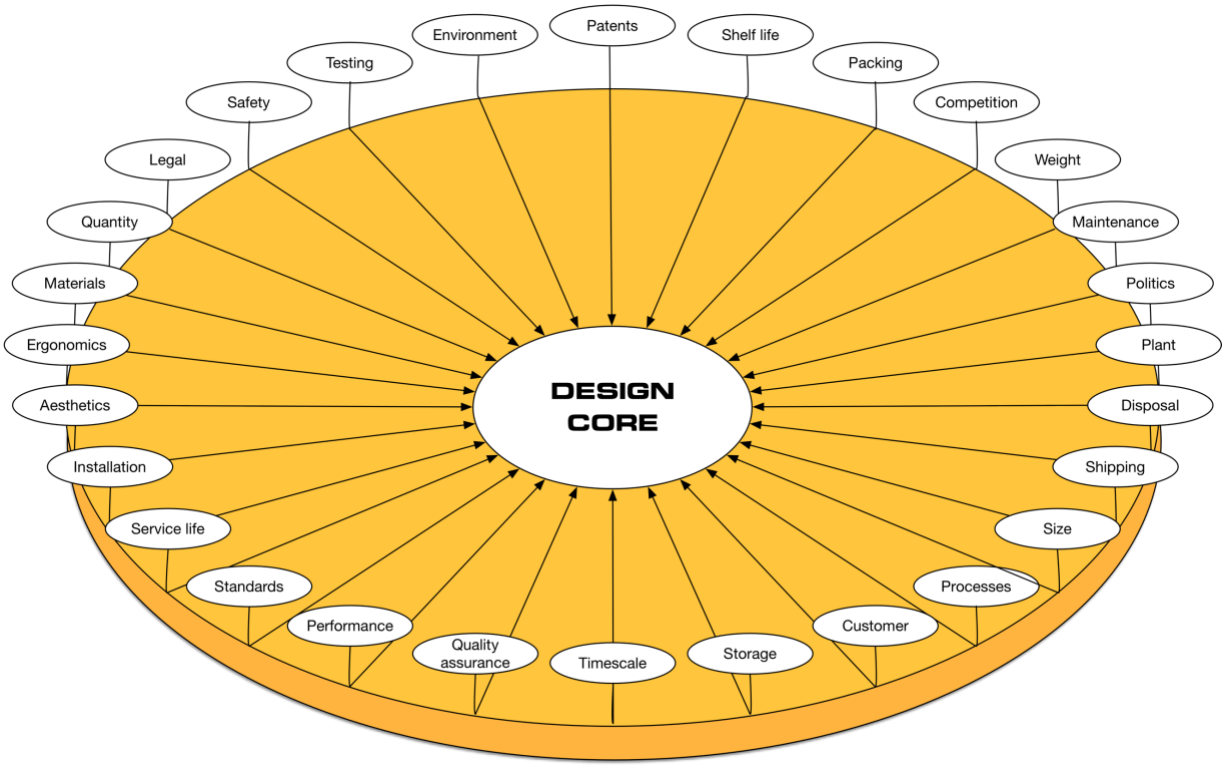


Figure 4: Elements of a Product Design Specification recreated from [15]

Table 2: A Specification Checklist from [12]

Main Headings	Examples
Geometry	Size, height, breadth, length, diameter, space requirements, number, arrangement, connection, extension.
Kinematics	Type of motion, direction of motion, velocity, acceleration.
Forces	Direction of force, magnitude of force, frequency, weight, load, deformation, stiffness, elasticity, inertia forces, resonance.
Energy	Output, efficiency, loss, friction, ventilation, state, pressure, temperature, heating, cooling, supply, storage, capacity, conversion.
Material	Flow and transport of materials. Physical and chemical properties of the initial and final product, auxiliary materials, prescribed materials (food regulations, etc.)
Signals	Inputs and Outputs form display, control equipment.
Safety	Direct protection systems, operational and environmental safety.
Ergonomics	Man-machine relationships, type of operation, operating height, clearness of layout, sitting comfort, lighting, shape compatibility.
Production	Factory limitations, maximum possible dimensions, preferred production methods, means of production, achievable quality and tolerances, wastage.
Quality Control	Possibilities of testing and measuring, application of special regulations and standards.
Assembly	Special regulations, installation, siting, foundations.
Transport	Limitations due to lifting gear, clearance, means of transport (height and weight), nature and conditions of dispatch.
Operation	Quietness, wear, special uses, marketing area, destination (for example, sulphutous atmosphere, tropical conditions).
Maintenance	Servicing intervals (if any), inspection, exchange and repair, painting, cleaning.
Costs	Maximum permissible manufacturing costs, cost of tools, investment and depreciation.
Schedules	End date of development, project planning and control, delivery date.

In engineering practice, once a set of design specifications have been formed, the rest of the engineering efforts are fairly straightforward and prescribed. The majority of the engineering knowledge is in the end phases of the process, in which specifications are forwarded to engineers for measurement, detailing and manufacturing. There is a smaller knowledge base in regards to how best to accomplish the early stages of design. However, since the needs collection influences the entire process [16], and the resulting product, it is of particular importance to generate high quality CNs.

Various research efforts on how to accomplish early design phase tasks [17, 18, 19] and how to incorporate typically later stage considerations early [20-25] is currently underway.

This research focuses on the customer needs generation stage, and it adds knowledge about what analyses can be performed to ensure that the resulting customer needs information can be useful for performing inclusive design.

2.2 Inclusive Design:

Inclusive design is defined by the British Standards Institute [26] as "The design of mainstream products and/or services that are accessible to, and usable by, as many people as reasonably possible ... without the need for special adaptation or specialized design." Focusing on the second part of this statement, this research works to create methods whereby engineers can use common techniques to create inclusive products. Other terms that are used to denote goods and services with similar goals, but slightly different focuses in their approaches, include universal design, accessible design, design for all and barrier-free design. The term inclusive design is used in this research.

Good overviews of inclusive design can be found in The Universal Design Handbook [27], Handbook of Human Factors for the Older Adult [28], and Handbook of Human Factors [29]. The University of Cambridge website The Inclusive Design Toolkit [30] provides details on the goals of inclusive design and other resources. One of the major foundations of the field of inclusive design is the works of Clarkson [31, 32, 33, 8]. The main challenge for inclusive design is implementation rather than motivation or interest in producing inclusive products. Designers who are convinced of the benefit still, have a hard time knowing where to start the process.

The landscape of inclusive design literature is vast and contains significant coverage of historical and social context. There exist many other guidelines and resources for inclusive *architecture* design such as [34-40]. This far surpasses what is available for inclusive *product*

design. As an example, of the 69 chapters in The Universal Design Handbook [41], 36 chapters focus on the history of inclusive design, the rationale behind it, legal issues, documentation of workshops, or similar discussions and 24 chapters provide descriptive guidelines and quantitative requirements for inclusive architectural design. Only nine chapters contain guidelines, case studies, or other content that provides detailed insight or design guidance into inclusive product design. Insight can be gained from applying architectural inclusive design principles to inclusive consumer products as in [42, 43], but the process is by no means straightforward.

Research teams from around the world have worked to address this gap [44-51]. Despite the efforts of groups like these, there is little in the way of a prescriptive approach to inclusive design with more detail than simply broad design objectives [52]. Additionally, though creating modular products that minimize modification to become inclusive is a recognized approach to inclusive design, specific knowledge and methods to do it do not exist [32]. Methods that allow the design of inclusive products that offer value to the user and profitability to the producer have yet to be thoroughly developed. Part of this research work includes filling these voids in the spaces of inclusive design methods and connecting them to niche product design.

A team of researchers organized through The Center for Universal Design at North Carolina State University has compiled seven principles of universal design [44] that have been well received by designers in a range of disciplines. They provide high level guidance as through evaluation aids rather than product design aids. As they have stated "…the practice of design involves more than consideration for usability. Designers must also incorporate other considerations such as economic, engineering, cultural, gender, and environmental concerns in their design processes [44]." This thought process is a driving force or our research in that we are trying to help designers expand their thinking into unfamiliar areas, ideally with a minimum of hassle.

The Center for Inclusive Design and Environmental Access at the University of Buffalo contains an active group of researchers that focus on inclusive design [45, 47, 48]. A team of researchers at the University of Cambridge has produced implementable results for inclusive design [32, 33, 49, 50, 51, 53]. Their focus has been in modeling user groups, creating product assessment methods, and extending the needs of inclusive design to modern product design processes. Despite the efforts of groups like these and inclusive design being an active research, fundamental work applicable to product design is still sparsely populated.

Inclusive design is more of an objective than a systematic design approach. There is little in the way of a prescriptive approach to inclusive design with more detail than simply broad design objectives [52]. Additionally, though creating modular products that minimize modification to become inclusive is a recognized approach to inclusive design, specific knowledge and methods to do it do not exist [32]. Methods that allow the design of inclusive products that offer value to the user and profitability to the producer have yet to be thoroughly developed. Part of our proposed work includes filling a void in the space of inclusive design methods.

The challenge for inclusive design is implementation rather than motivation or interest in producing inclusive products. Designers have a hard time knowing where to start the process. This work is partially addressing the gap in implementation by providing a framework for designers to follow, which should yield a large and useful set of information to inform inclusive design. This framework has the flexibility to be added to and adapted, as necessary, for each individual design situation.

2.3 Empathic Design:

Empathic design has been approached from many different angles, making it a somewhat nebulous field. Though it is recognized as beginning with Spark [54], it has gone in many different directions [55, 56]. Empathic design has many different emphases in its definitions through the reviewed literature. Empathic research strategies incorporate shared language and collaboration, applied ethnography and empathic modeling in order to work with the user to better understand the 'why' aspects of the golden circle [57, 58]. Empathic design is researchers and designers attempting to move towards understanding of the end user experience as part of human centered design [59]. "Empathic design is embedded in recent user-centered approaches where information on future users is collected from their everyday life to generate insights for designers" [60].

Empathic design can be used in any field, but the specifics of the application will differ based on where it is used. Research into developing empathy [61], identifying situations where it is effective in industry [62], and use in process design (e.g., the less obvious example of investigating the pelvic exam process) [63] represent the diversity of the field.

Much work has been done to identify methods and tools for performing empathic design [60, 63-67]. There are three basic structures for empathic design, in three stages and seven steps [68]. The main class of literature uses empathic design methods to perform designs, but other research uses other design related methods to inform and extend empathic design [69, 70].

Better product development is found to result from interactions between designer and customer, indicating that employing empathic research strategies early in the education of designers will enhance their awareness of others when they design [71]. It has also been shown that empathic design methods used in concept generation positively influences the originality of resulting concepts, without changing the quality or feasibility [72].

Therefore, empathic design techniques provide a good option for closing the gap in understanding between designers and users. This work serves to add to the confirmation of the usefulness of empathic techniques. By exploring how to provide a valid empathic experience to designers, this work can directly increase their awareness and internalization of the needs of exceptional users. This work is providing one easy tool and process for understanding the effects of physical limitations on product interaction, and needs expression.

2.4 Simulation Suits:

In order to collect data on the needs of exceptional users with upper extremity physical restrictions, empathic design concepts have been used to create a physical restriction simulation suits to solicit surrogate needs from persons without restrictions [73-77]. Though testing with the target population is still very important, simulation is a useful way to expand the potential participant pool. Collecting customer needs from persons with physical movement restrictions can be logistically difficult and time consuming for both researcher and participant. Physical simulation allows any individual willing to participate to become a useful research subject for studies into the needs of people with physical restrictions.

For information on the design of the motion restriction simulation suit see the original work by Adam Raher [77]. In creating the motion restriction suit for Oregon State University, several possibilities, including the Third-Age Simulation Suit used by Boeing, were considered before the suit design was finalized [77]. Four relevant full body simulation suits were examined. Several generations of the AGNES age simulation suits created by the AgeLab team at MIT [78] were examined as well as the GERT suit by Produkt + Projekt Design [79]. These focused on

recreating the hardships of elderly persons. The first substantial simulation suit is the "Third Age Suit" developed in 1990 by Ford Motor Company [80]. The main goal of that suit is to offer engineers a deeper and more accurate understanding of the difficulties encountered by elderly people during driving tasks.

Several shortcomings were discovered with each of these designs [77]. Since they are not form fitting, use of these suits by smaller participants is difficult and unreliable. Also, the fact that no finger restriction was provided was their main disadvantage. Other products were investigated that concentrated on the area of loss of finger function.

Simulation gloves from Cambridge University [81] used plastic strips to impede movement while people flex and extend their fingers, with Velcro attachments adding adjustability. The Arthritis simulation glove from Georgia Tech University [82] was another prototype for finger restriction. These reduce dexterity through wiring placed on the fingers; however, this is not an adjustable feature. These options also contained drawbacks. They were too large or too uncomfortable to be reasonable for use on study participants. They would not allow the actions that participants need to perform as part of the OSU studies.

The OSU suit design is unique in three main ways: adjustability to fit many different participants, new finger restriction mechanisms, and improved elbow and shoulder restrictions. It is composed of multiple wearable devices, designed so that there are no hard limits on range of motion. Rather, resistance to both flexion and extension increases the difficulty of movements of the upper extremities. The suit is pictured in Figure 5 to provide a visual description. The OSU suit focused on providing upper extremity limitations in a consistent, reliable, cost effective manner.

Figure 5: Original OSU Motion Restriction Simulation Suit

The suit has been preliminarily validated as a data collection and educational tool [73-75]. It provides a simple way to gather exceptional user needs. Using this suit, designers and others will be able to easily experience and understand the issues faced by people whose motions are restricted or slowed. Combine this with information regarding exceptional users (EU) customer needs (CNs), gathered from various research, and a powerful method for advancing inclusive design is gained.

The specific form of the motion restriction simulation suit was motivated by a desire to limit the scope of the project and control the provided limitations so that the methodology can be validated.

2.5 Classification Schemes:

The proposed research relies on a variety of classification methods to make sure that our research data is standardized enough to be useful in any follow-up work. This includes the World Health Organization (WHO) International Classification of Functioning, Disability and Health (ICF), and various metrics from the field of Occupation Therapy. In this research, we limit our scope to product usage challenges that are related to users' upper extremity physical limitations.

2.5.1 Function Classification in Engineering Design:

As design methods have matured, effort has focused on structuring and systemizing design, including the early concept synthesis stage [11, 83-87]. Common to these structured design methods is approaching the design problem in terms of the functions that the artifact must perform. After establishing the functional needs, a form or morphology is synthesized that provides the needed functions.

The functional basis [88] is a lexicon describing product function. It contains engineering flows categorized into three primary classes of materials, signals, and energy and then further specified with secondary and tertiary categories, and engineering functions categorized into eight primary classes, along with secondary and tertiary classes. It also enables quantitative design by analogy [89]. It continues to gain increasing acceptance as the preferred representation and lexicon for functional modeling [83, 90] and has been independently verified as applicable in representing product function [91-94].

While this work may not involve specific use of the functional basis, the idea of presenting data in a generalizable and easily understandable and transferable manner, as the functional basis does for product function, is a key aspect of our research.

2.5.2 International Classification of Functioning:

The WHO has created the ICF [95]. Rather than classify based on some illness or condition, the ICF is based on the recognition that disability is better understood as some loss, or other significant deviation in body function or structure that limits activity or participation. Individuals with the same condition can have different functional limitations. Similarly, individuals with the same functional limitation may have different conditions.

The primary objective of the ICF is to provide a unified, standard, and well-defined lexicon describing health and health-related states by defining components of health and wellbeing [95]. The ICF provides a systematic organizing scheme and coding rules for putting human functional limitations in terms of an alphanumeric code.

The ICF has been used for a range of health applications correlating the specific links between conditions and function limitations [96]. It has been used to explore connections between functional limitations and high-level participation such as working [97]. Numerous

other applications include its use as a framework for collecting and analyzing health data, identify patient problem areas, and evaluate the quality and results of patient care [98]. Initial research applying the ICF to product design to formally represent product-user interaction [9, 13, 42, 43, 98, 99, 100] has had positive results. These show that the ICF provides a natural and accurate representation of user function in the context of their interaction with a designed artifact. By incorporating the ICF into this work, we explore it as a tool to bridge gaps and connect understanding between design information and user function.

2.5.3 Occupational Therapy Metrics:

The occupational therapy field provides an opportunity for extending inclusive design research since the "primary goal of occupational therapy is to enable people to participate in the activities of everyday life" according to the World Federation of Occupational Therapists [101]. Occupational and Physical Therapists assess an individual's physical functions in order to recommend treatments. Occupational therapy (OT) has insights and useful general metrics for measuring user functions that directly apply to inclusive design research and data collection. The Rehabilitation Measures database [102] is an extensive list of different OT measurement techniques organized with criteria for comparison.

There are numerous options for ability assessment, most of which are not applicable to our testing situations. Although a large portion of the available testing and screening procedures focus on recovery or improvement metrics, the present research requires a method of evaluating capacity at a distinct point in time. Also, many of the options are subjective assessments, either on the part of the patient, or the evaluator. While there is value in subjective testing, quantitative comparisons are of more use when attempting to develop broadly applicable methods. This also applies to tests that are commonly used and have normative data available to enable easy comparison. Therefore, OT metrics that will be singular, quantitative and normative are of interest.

The motivation for using OT metrics in this work is that it allows additional connections with external studies and large sets of information about human functioning. The use of OT metrics provides a level of quantitative understanding not usually associated with customer needs. It will assist in the development of design specifications, and product modularity and tradeoff information.

2.6 Customer Needs:

This section includes background on the collection and classification of customer needs. Customer needs are the backbone of engineering design practice and this research and as such should be gathered with care and analyzed carefully.

2.6.1 Customer needs backgrounds:

Customer needs are the driving force behind product design. Products that meet the needs and wants of its customers are more desirable, praised and purchased. Successful design processes start with gathering information to assemble a thorough list of customer needs as a first step [10, 11, 13, 83]. Whether it is a specialty product for a few people, or a mass-produced product meant for millions of consumers, the customer comes first in successful products and processes [11, 13]. Customer statements can be gathered using a number of different methods, which produce a variety of outcomes [103]. These outcomes can be analyzed to create a list of customer needs. Creating the customer needs list involves translating information from customer need statements [10, 11, 83]. This is a crucial step in the process because, once the customer needs list is finalized, the engineering requirements are generated from this list.
Understanding needs is a key stage in the design process as it gives designers an understanding of their current customer data [11, 83, 104, 105, 106]. The Kano Model is one of the most popular methods of analyzing customer needs, which examines the needs in terms of the functionality of a product versus the satisfaction that it brings to the customer [107]. Ulwick's work found that customer needs typically appear as four different types of data: solutions, specifications, needs, and benefits [106]. Categorizations of existing needs gathering approaches are not mutually exclusive or exhaustive.

2.6.2 Nix Customer Needs Ontology:

Given that customer needs gathering is the first, and it can be argued, the most important step in design, and given that it has been shown to be beneficial for designers to analyze and categorize customer needs before proceeding with design, in 2017, Anthony Nix worked to group together the current literature and research on needs categories into the customer needs ontology, which is made up of taxonomies with independent categories that cover the entire

spectrum of possible types of customer needs. [103, 108] The research by Nix formulated an ontology to provide a mathematical basis-like description of the customer need space [103].

The process for ontology development was to code customer need examples from design texts needs across the proposed taxonomies and then examine both the resulting needs and the process to determine if changes were needed. Through five trials, changes were made and definitions for the categories were refined. For example, if a customer need was encountered that did not fit into any of the existing categories in the ontology, the team determined whether a new category was required, or a combination of other categories, or an expansion of a definition. [103, 108]

This resulted in the final version of the Nix ontology, which can be viewed in Appendix B. The ontology consists of 5 taxonomies (Who, What, Message, Innovation and Target), each with their own set of subcategories, two to eight categories in each, shown in the Appendix B. Definitions for each term are thorough and included in [103]. The Who taxonomy addresses who the customer need is intending to satisfy. The stereotypical customer need is about the user. But they are not the only stakeholders in product development. The What taxonomy covers the main part of the customer need, and it is the largest of the five taxonomies, with eight categories containing information on what the need is addressing. The Message taxonomy relates to Ulwick's work on customer outcomes [106], capturing what message is being conveyed by the need. The Innovation taxonomy measures how innovative the need is for the customer [109]. The Who taxonomy deals with the person or stakeholder that the need is intended for and consists of user, purchaser, manufacturer, seller, and investor categories. The What taxonomy is the main body of the ontology, dealing with what the needs is about. It contains eight categories; main function, supporting function, environment, human factors, aesthetic, performance, safety, and features. The Message taxonomy deals with what message the need conveys and consists of solution, specification, objective, and constraint. The Innovative taxonomy deals with how innovative the statement is, and consists of basic, direct, exciting, and unbeneficial. The Recipient taxonomy deals with what percentage of the population the need affects, and was split into two categories, general and niche. The breakdown of the categories by percentage of the population in the Recipient taxonomy is easily changed to accommodate more granular distinctions based on the situation the user of the ontology wishes to investigate. This looks at the customer population or segment of the market that would benefit from this need being

achieved. This is broken into two categories [110]. It was developed such that General needs apply to over 75% of the population and Niche needs are features or functionality that less than 25% of the customer base will use. However, this taxonomy can be easily broken into more discrete categories (such as, affects 10%, affects 25%, affects 50%, affects 100% of users) to fit a design team's preference in this area. General needs are stated by typical users and refer to features or functionality that nearly everyone will expect. Niche needs may manifest as optional extras not crucial to the main function or use of the product or only meet needs of a small segment of the market.

The ontology is presented as a tool that can provide two types of information. Firstly, is a specific categorization of the type of statement that the customer needs statement is. This benefit is gained only if the coding is done accurately and consistently. Secondly, when an entire need set has been coded, you can know how much of the possible types of customer needs you have gathered, and how much more you have gathered of certain types. This can guide designers in their customer needs gathering efforts to ensure complete and useful information for their design decisions. Initial investigation was performed by Nix to determine which types of customer needs gathering activities elicited more and less of different types of ontology codes. It was also investigated how the coverage of the ontology and the types of needs elicited changed over the design process. [103]

2.7 Product Families and Product Platform Design:

A product family is a group of related products based on a product platform [111]. Product family design is a cost-effective way to achieve mass customization by allowing highly differentiated products to be developed from a common platform while targeting products to distinct market segments [13, 112, 113-127]

Products in a module-based product family are created by adding, substituting, and/or removing one or more modules from a common platform [13, 128 -133, 119, 120,122 -127]. In a scale-based product family, products are developed by scaling one or more parameters related to the platform design to satisfy a variety of market niches [127, 134-139].

Two key challenges for product family design include identifying the product family architecture, i.e. what elements are shared and what elements are deleted or added to make unique products; and identifying the precise configuration and parametric instantiation for the

shared elements. Though outstanding issues still remain, the problem of identifying the precise parametric instantiation has received significant attention in the literature [111]. Typically, the challenge is posed as a tradeoff between a parametric configuration optimal for one product in the family and a configuration that works well for the entire product family.

Thus, our product family design focus in this research is to develop methods that focus on the challenge of determining what elements are shared, deleted, or added, to create the product platform and family in the context of an inclusive product family.

Methods for designing modular product architectures for single products has seen significant activity [85, 140,`141]. A module based product family strategy will allow the efficient design and production of inclusive product families.

Specifically, modules for inclusive design are categorized into 1) common, 2) variant, 3) conditional, and 4) unique. Common modules are based on a function and an associated form solution that is common to both the exclusive and inclusive product to become the product family platform. Variant modules solve functions that are common to both exclusive and inclusive products, but differ in required form. Unique modules have differing (or perhaps additional) functions for exclusive and inclusive products. Conditional modules are used to connect exclusive modules to inclusive modules if needed, and are not generally derived at a customer needs level. Conditional modules can be thought of as integrating assistive technology (products that augment a restricted user to use typical products) into the product and designing a product family around it.

The term that we used to refer to both variant and unique modules is differentiating modules. This indicates that either the function or the form will change based on the inclusivity of the product. Different users will have certain needs that differ or conflict, making them unqualified for the common module, but still important for consideration and classification. With information about the customer needs in the Common and Differentiating modules, a complete picture of the product from a modular perspective can be derived.

Similar work on function based product architecture and product families methods has been completed by [141-146]. An important element of these methods is that they illustrate the way in which function-based representations allow different criteria to be considered in module-based product family design.

In the inclusive product family case, breadth of user limitation becomes an important design consideration, and the coupling of customer needs and user activity. By addressing user limitations as the source of module information, more complete product platform design is enabled. The information contained in the data sets provided by this research should be able to inform modular and family design down the road.

2.8 Action Function Diagramming:

Actionfunction Diagraming is about modeling the user and product simultaneously [147, 148]. The user limitations and the functional models of each product are recorded. Information about the product function is stored in a knowledge base [147]. It has been shown that association based rule data mining techniques can be applied to user activity-product function data generated with Actionfunction diagrams [149, 150]. The Actionfunction diagram provides a formal framework for analyzing products, and product pairs, to determine the design changes in a product as the user activities changes due to disability. The procedure for creating Actionfunction diagrams is detailed in [151].

This is one example of past work attempting to explicitly connect user activity and product function. It is also an example of work which utilized ICF terms as a connection avenue. Therefore, it is relevant or our investigations, as a general model of the process of creating useful design guidelines from disparate information types.

2.9 Human Factors:

Human Factors Engineering as a discipline has grown out of efforts during World War 2 to address the new modes of interaction between operators and the complex technological systems. For various accounts of its history see [152-155].

Human Factors considerations are used to improve a wide variety of fields, with research and guidelines focused mainly on specific fields. The phrase ‘Human Factors in ‘Blank’’ is the common modality when looking for guidance. Illustrations of human factors research applied to a narrow field include [156-158]. Each industry has their own focus in the application of the very broad topic of human factors [159]. For example, “Aviation maintenance human factors research has the overall goal to identify and optimize the factors that affect human performance in maintenance and inspection.” [160] As other examples, see the work of the National Center for

Human Factors in Healthcare [161] and The Human Computer Interaction Institute [162]. The Association for Computing Machinery hosts a yearly international conference on human factors in computing [163]. There also are several societies dedicated to the advancement of human factors throughout the world. [157, 164-166]

The term Human Factors is generally used either in conjunction with or interchangeably with Ergonomics. There are different definitions of the field that encompass different emphases. "Ergonomics (or human factors) is the scientific discipline concerned with the understanding of interactions among humans and other elements of a system, and the profession that applies theory, principles, data and methods to design in order to optimize human well-being and overall system performance." `167] "Ergonomics and human factors use knowledge of human abilities and limitations to design systems, organizations, jobs, machines, tools, and consumer products for safe, efficient, and comfortable human use." [168] "Human factors science or technologies are multidisciplinary fields incorporating contributions from psychology, engineering, industrial design, statistics, operations research, and anthropometry." [160] There are different domains of specialization within Human Factors, including physical, cognitive and organizational. [167] Our research will be focusing on the physical aspects.

There are many human factors aspects that could be of use in a data collection and analysis framework like this research. It remains an open avenue of possibility to use specific human factors guidelines as bridges and connectors between customer needs and design. If human factors can be tied *directly* to subsets of the discovered CNs, design would be assisted and informed. The example of this connection that the work tackles specifically, is hand anthropometry and suit fit issues. Many other possibilities exist for future applications as well. In fact, one of the main ontology categories is human factors specific issues, so our framework should streamline these connections.

2.10 Building on Previous Study:

The previous work [73-77] that this work is a direct extension of is now summarized. The original kindred project had the goal of establishing whether or not providing a surrogate experience for the use of manual handheld products, using a disability simulation suit, was possible. The study also examined whether or not the collected customer need data could be

formulated in terms of weight and frequency, and used this formulation to test a modular product design hypothesis.

That study also tested both real persons with upper extremity physical disabilities and general users wearing the disability simulation suit that was created for that purpose. The goal of that work was to validate whether the suit could provide similar outputs from persons with disabilities and persons in the suit. This was also two-fold. There was the mindset piece, of whether the needs of the persons in the suit provided adequate coverage of the needs of persons with disabilities, and the physical aspect of whether the suit was physically restricting people to similar degrees as to match with the persons with disabilities. For this work the physical restriction was compared directly between the PWD group and the FSU group, as well as between the SSU group and external disability study scales.

The results of this work was that FSU participants were providing good coverage of PWD needs, and their information could be considered as adequately representative. It found that the suit was restricting to a higher degree than the measured PWD group, the suit was restricting to a med/severe level according to the external disability scales, and the suit had some reliability issues with the finger mechanisms. It found that formulating the collected information by weight and frequency was easily done, and that there were no significant differences in weight or frequency between user types. Plotting the CNs onto the WvsF space confirmed the hypothesis that the high-weight/high-frequency space contained the common module type needs for non-general users.

2.11 Synthesis:

It was decided that, for the sake of project scope and timeline, many of the ideas provided by this literature would not be included in the initial investigations. Specifically, considerations of modularity were designed into the study protocols, intending to be investigated to inform product family and platform design. Not enough information to be able to make strong conclusions for this avenue was collected, so it has been set aside as future work, for when more information can be added. However, the framework methodology is still able to provide this connection. Given the possibilities indicated by the wide research, the framework was designed in a way to enable future investigations not specifically associated with research tasks. The review of literature indicated a wide range of fields available for connection, each with particular

avenues of helpful information to offer. The goal of this research was partially to try to make some of these connections in an efficient and useful manner. Additional connections to these and other fields will be more useful in the context of design decision making. For the purpose of this study, the decisions are still up to the individual design situation/company, and not under investigation. We are simply preparing a space for those decisions to be made with as complete and useful information as possible.

Chapter 3: Materials and Methods

From the larger research questions introduced in Section 1.2, the overall research approach and context of this work is driven by a set of surrogate needs gathering approaches for exceptional users. Figure 6 posits a spectrum of customer need gathering techniques on a scale of most-to-least accurate. This table is not exhaustive, but presents snapshots of empathic needs gathering techniques that can be deployed to improve the accuracy of needs from a surrogate user set. Narrowing the focus, this work explores the highest fidelity surrogate needs gathering approach of physical simulation. To inform physical simulation, our approach is to identify functional capability metrics that allow the measurement of the surrogate user's performance in a physical simulation suit. With appropriate performance measurements, a physical simulation suit can be calibrated to represent a desired exceptional user population. Specifically, this research is designed to validate the surrogate experience.

	Actual Needs	**Most Accurate Surrogate Needs** →→→			**Least Accurate Surrogate Needs**	
General	Exceptional User (EU)	Physical Simulation	Direct Observations	Mental Model Simulation	Info about EU provided to GU	General User (GU)
	Research Examples					
Exceptional User	Persons with motion restrictions asked to give needs for product	GU in a motion restriction suit	Empathic observation techniques	GU mapping the activities a person with restrictions must do to complete tasks	GU reads information about physical restrictions	GU is asked to give needs for a product
Extreme Environment	Astronaut with EVA experience	GU wearing a spacesuit in a simulated zero-g environment	Reports and interviews on functional issues	GU mapping the activities to complete an EVA task	GU reads info about space suit design considerations	GU is asked to give needs for a product

Figure 6: Surrogate Experience Spectrum

Looking at the larger design spectrum with dimensions of user and environment shown in Figure 7, this work falls within the quadrant of general environment/exceptional user. This is also the quadrant where inclusive design techniques tend to function [7,8]. The general user/general environment quadrant is where standard engineering design tends to reside. The remaining quadrants are beyond the scope of this current work. Future avenues of research will be needed to gain a more complete understanding of those design spaces.

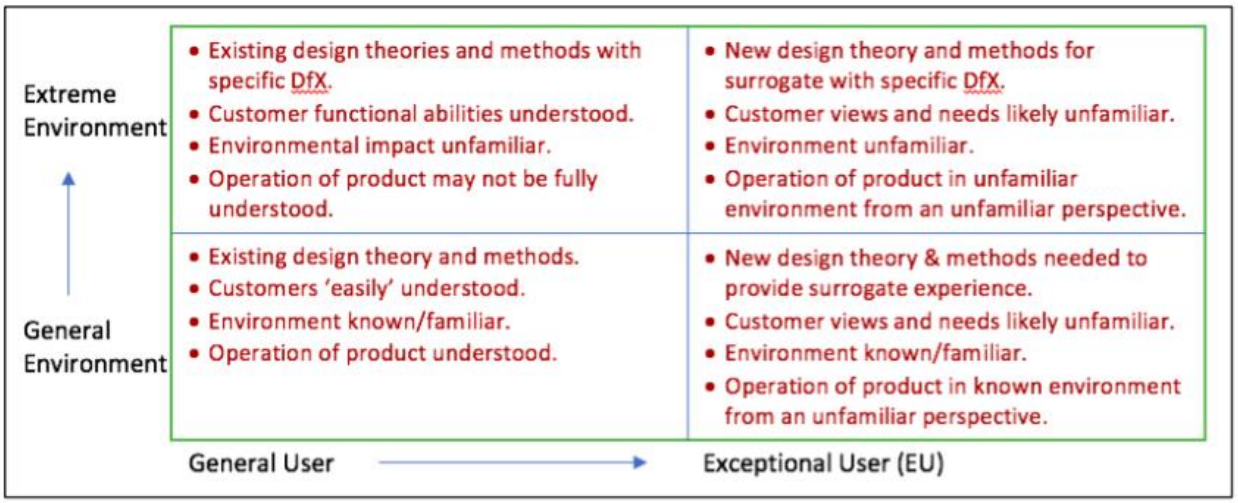


Figure 7: Exceptional User and Environment Spectrums

The remainder of this chapter is divided into eight subsections. In it I will be discussing: i) the formulation of the research questions; ii) the set-up of human subjects testing; iii) the motion restrictions simulation suits; iv) the functional capability metrics; v) the customer needs interpretation process; vi) the ontology coding process; vii) the validation methods; viii) a discussion of the considerations for the selected comparisons and the statistical limitations of the results. Given that this work is best described as an exploratory study, the methods selected were based on collecting a wide array of data, in order to extract meaningful information that would ensure valid comparisons and potential meta-analyses.

To provide grounding for the reader in the framework of this research, an entire process flowchart has been created showing each step in the process, and the informational relationships. This has been divided into two figures in order to be large enough to read and is presented as Figures 8-9 on the next two pages. The framework consists of a few main pieces.

The study set-up involves making several choices about what data you wish to gather and the process and surrogate experience you will be using to gather it. The chart shows occupational therapy (OT) as the only input, since for this work, many of the other factors were predetermined by prior work [73]. In reality, there is also general human factors, the individual design situation and the product types of interest, company priorities and resources, and prior design knowledge.

The data gathering processes are all shown as concurrent interconnected pieces. Data is developed regarding multiple aspects simultaneously and must be carefully tracked. This can be a concurrent or sequential process depending on the needs of the framework's users.

Then it moves onto the data analysis and extracting knowledge from the CN data. In this case, the weights and the Ontology are shown, but additional analysis options can also be applied as needed. Once all the data is together, you can determine if it is adequate across the different dimensions of interest and perform specific validations. Then the validated data can be examined, to find trends and possibilities for informing inclusive design.

An inherent benefit of this framework is the large amount of interconnected data, but this is also a difficulty in that it leads to a complex process, with many decisions points. On these flow charts, the diamonds are decisions, the squares are processes, the parallelograms are data, and the rounded pieces are external information.

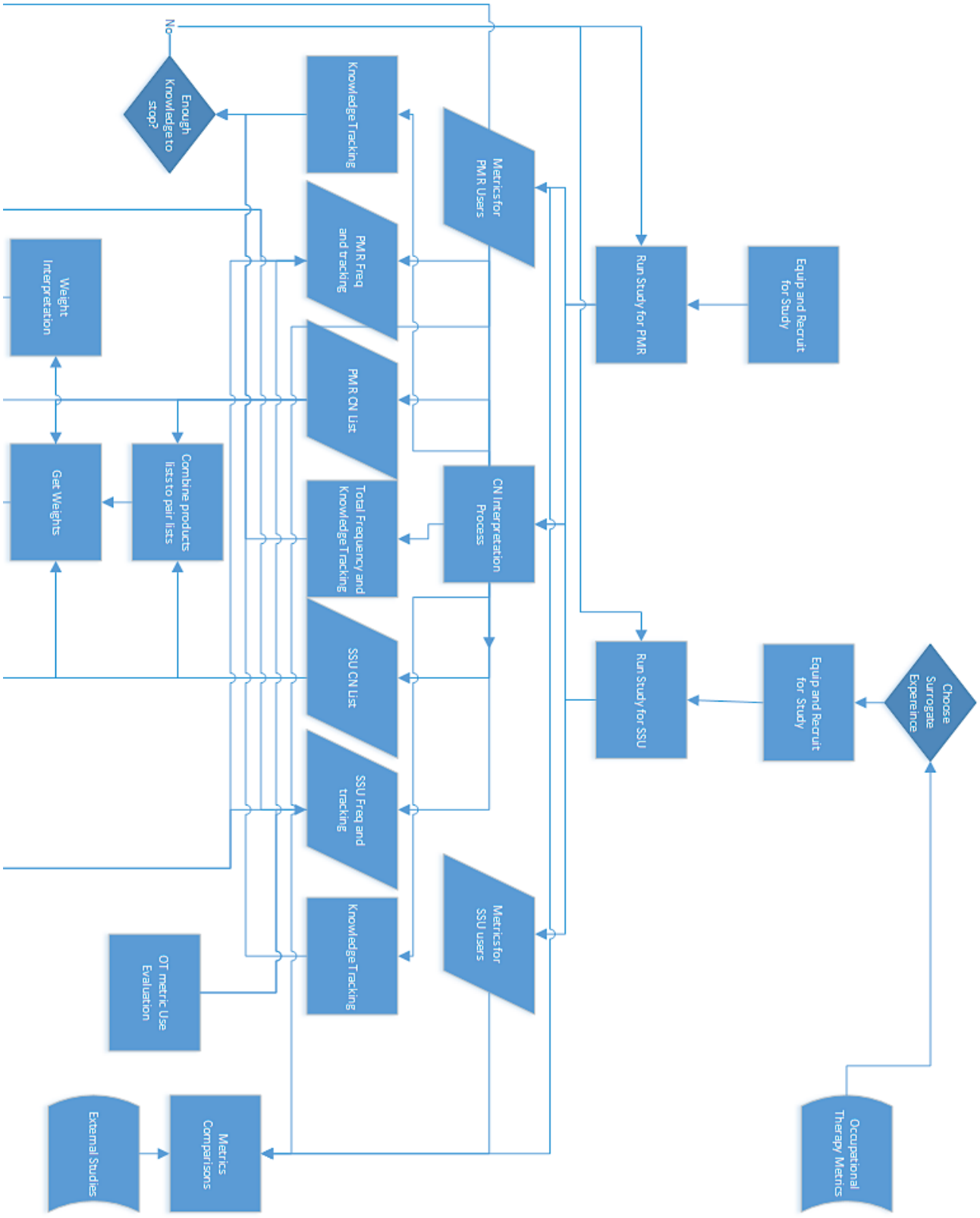


Figure 8: Research Framework Flow Chart Part 1

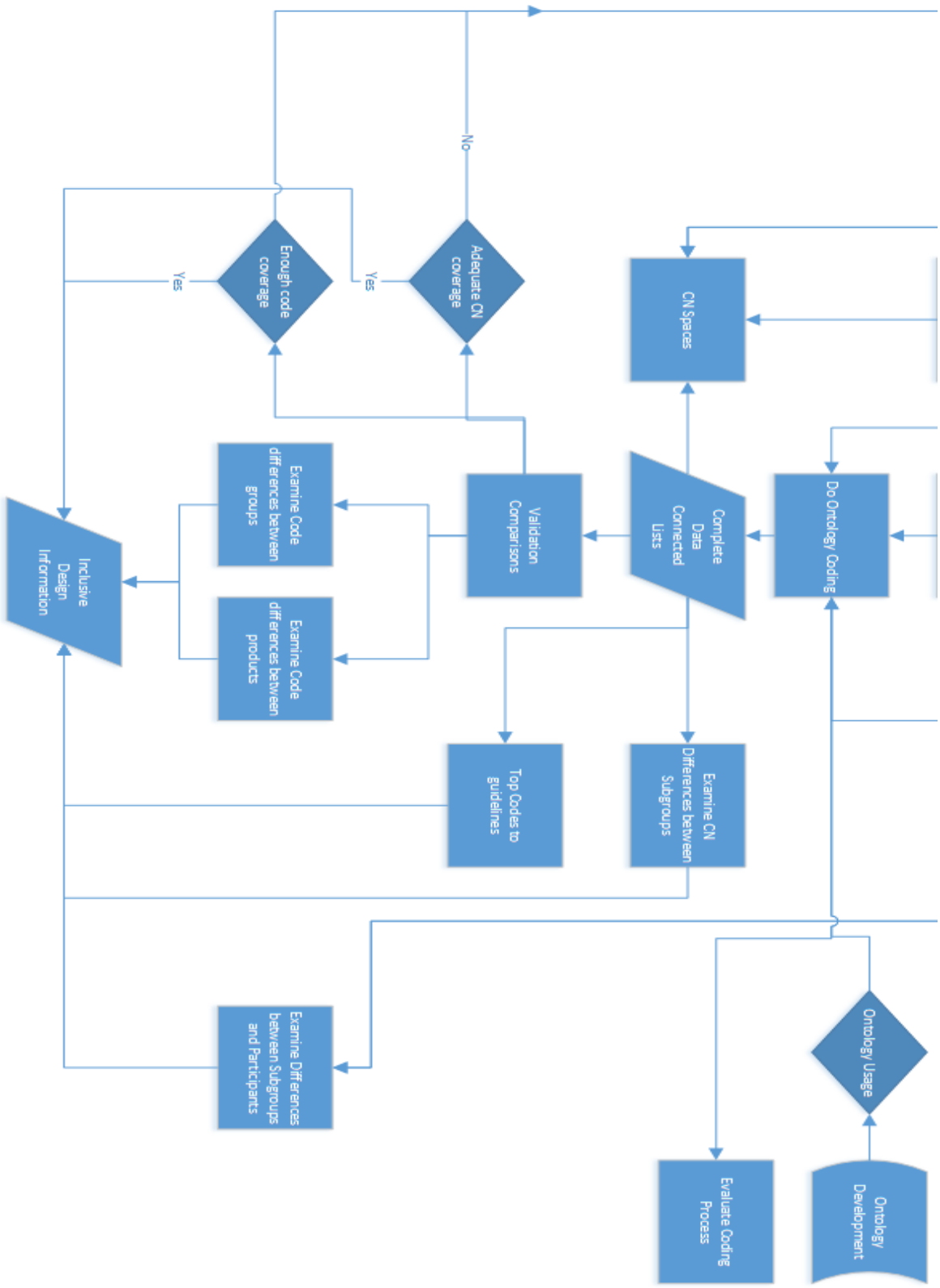


Figure 9: Research Framework Flow Chart Part 2

Given the complexity of the actual research framework I also present a simplified version in Figure 10. This flowchart is a basic representation of the process that was followed during my masters work (Exp1) for the validation of the methodology. The Phd work (Exp2) adds the boxes with the white words, which create the 'information rich CNs' and allows for more complete analyses of inclusive design considerations.

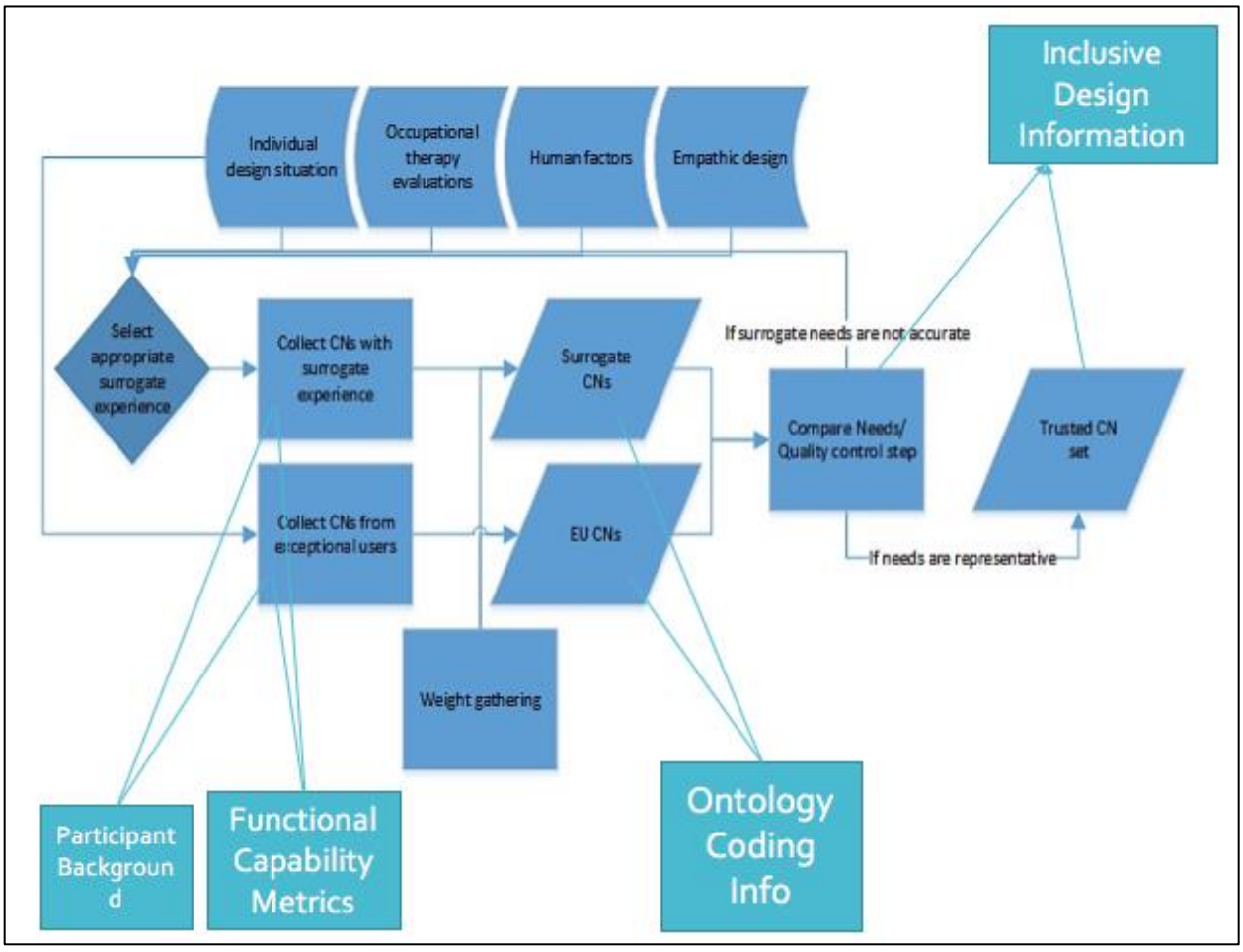


Figure 10: Simplified Framework Flowchart

3.1 Research Questions:

The research questions were introduced in Chapter 1, but here they are discussed and decomposed more specifically. The main questions from Chapter 1 again are: "Can we bridge the gap in designers' experience with exceptional users and environments through surrogate experiences?" and "How do we gather information rich customer needs that will be useful for future inclusive design decisions?".

3.1.1 Validation Questions:

For the surrogate experience bridge, it must be determined whether the experience is eliciting a valid representative customer needs set (CNS). There are two aspects of this for this research:

Q 1.1 Are the surrogate users wearing the suit for the experience eliciting needs that cover more than 50% of the CNs stated by people with actual motion restrictions?

If the answer is yes, then the surrogate users will be considered as acceptable substitutes/extensions of PMR users and the complete needs sets from this study can be used with confidence for developing inclusive products. More than 50% was determined to be an acceptable cut-off level, however higher coverage should result in a better inclusive product and therefore as high a coverage as possible is desired.

If the answer is no, then the suit is not creating the right conditions for participants to serve as an adequate simulation. Changes to the suit or the methodology or other factors of the surrogate experience would need to be made to achieve a better result.

Q 1.2 Are the people wearing the suit exhibiting physical restrictions comparable to motion restricted individuals?

For this question, we are not concerned with having the suit match any particular set of restrictions, because the suit was not designed with a specific disability matching goal in mind. Rather, the aim was to provide general restriction at any level (which could be tuned in the future) in order to elicit valid surrogate CNs that represent a PMR population. The prior use of this suit had it restricting persons who wore it to the medium/severe level [73]. Slight modifications to its design were made to moderate the severity of the disability it was simulating and increase the reliability of its components. With those slight design changes, we do not know where its performance will fall. However, if the suit does not restrict people enough to match mobility performance on any disability scale, then its use as a surrogate tool comes into question. It should be showing that the participants are being restricted in their movements. As part of the exploratory aspect, we wanted to be able to place the general effect of the suit on various functionality spectrums. Therefore, we have several sub questions focusing on suit functionality.

Together these questions address what functional capability impairments the suit is mimicking most accurately.

Q 1.2.1 Where does the suit fall on the three disability scales regarding dexterity from our previous research and how does that compare to the previous version of the suit?

Q 1.2.2 Does the additional OT information allow us to determine the placement and range of restrictions of participants in regards to normal functioning as established by other associated external data sets?

Q 1.2.3 Can the perception of the suit's restriction be determined and a rating assigned based on participant comments?

Also, since it would be optimal to compare all aspects across the two different experiences, for validation, we include an additional question regarding comparison.

Q 1.3 In what ways do the two similar surrogate experience techniques succeed or fail to accurately capture the needs of exceptional users?

3.1.2 Ontology Questions:

To determine if the addition of the customer needs ontology to the study can provide useful ways to connect and analyze information, we consider several sub-questions.

Q 2.1 Is it possible to code this type of customer need data with the CN ontology?

Q 2.2 How should the CN ontology be adapted to apply easily in this research?

Q 2.3 Have we achieved enough accuracy in coding to be confident in the results?

Q 2.4 What does the code coverage look like across various dimensions of the data? (i.e. how many of the possible codes are elicited, what codes are used more/most often, are there important gaps, are the gaps and clusters different for different subgroups, etc.)

Q 2.5 Does the ontology coding provide useful information for making design decisions?

3.1.2 Occupational Therapy Questions:

Several aspects of occupational theory were addressed to determine if the occupational therapy metrics were useful within the bounds of this research. This can be seen throughout several stages of the presented methodology.

Q 3.1 Is the selection and incorporation of the Occupational Therapy metrics and tests appropriate for the study and its goals?

Q 3.2 Is the tracking and connection between OT metrics and CNs manageable?

Q 3.3 Do the OT metrics provide additional options for evaluation or organization of CNs based on functional limitations?

Q 3.4 What additional comparisons and analyses are available by having so much functional capability information available?

Q 3.5 Do the OT metrics provide a clear and encompassing picture of the restrictions of the participants?

Q 3.5.1 Can ICF code/descriptions of participant limitations be developed using only the occupational therapy metrics?

Q 3.5.2 Does the additional OT information allow us to determine the placement and range of restrictions of participants in regards to what is considered 'normal functioning' as established by other associated external data sets?

3.1.3 International Classification of Functioning Questions:

Connecting the ICF to the information in this study could be considered part of the 'examine differences between subgroups and participants' step. These questions address how easily we can create a connection between the ICF and the information obtained by this study.

The classification and functioning questions involve inspection of ICF code descriptions, links to CNs, and participants. These questions are listed below.

Q 4.1 Can ICF code descriptions be assigned based on the content and interpretation of the CN statements?

Q 4.2.1 Can ICF code descriptions of participant limitations be developed using only the occupational therapy metrics?

Q 4.2.2 Can ICF code descriptions of participant limitations be developed using only the descriptions given by participants of their physical disability?

Q 4.3 Does the availability of ICF information inform inclusive design?

Q 4.4 Can the ICF codes/descriptions be used to match the general type of loss of function the suit simulates and note overlap with the loss of function that the persons with disabilities have?

Notice that the Ontology, OT and ICF questions are all quite similar in that at a basic level we are interested in determining 1) if these avenues of information can be incorporated at all, 2) how easy/successful is this incorporation, and 3) what does each aspect show us that might be useful for inclusive design. A good starting point for research into any aspect of future framework changes or additions would be in answering the three basic questions of "If it can be done", "How well" and "What does it show us".

3.1.4 Framework Questions:

Finally, in regards to the practical application of the presented methodology framework, the question is simply whether the framework is useful. This work assessed its potential usefulness in many ways, at different stages of the study. Useful can be defined as both representative and adequate. The question of "whether the framework gathers data that is representative of real users" is answered with the multiple validation aspects from this study, but other external or additional exceptional user validations can be added as needed. The other aspect of adequacy, in terms of 'Has it provided the information needed at certain stages for designers/companies to be able to make the decision to proceed?' can be answered using the following sub-questions regarding the informational comparisons it enables. These also can be added to as more information content is incorporated into the framework as it is adopted and adapted by actual designers for their individual design situation and priorities.

Q 5.1: What useful differences exist in the information content of the customer needs between a general purpose and a niche product?

Q 5.2: What useful differences exist in the information content of the customer needs between an exceptional and surrogate user?

Q 5.3: What useful differences exist in the information content of the customer needs between surrogate experiences?

3.2 Human Studies Set-up:

This section describes the study formulation and administration and how the protocols were chosen and organized. It begins with a discussion of what is the same and different between

this study and the previous study. Then it presents the flowchart and discussion of the aspects of the human subject study.

3.2.1 Study Formulation:

Differences between current and previous study: As this study builds on previous work (completed as part of my Master's thesis and referred to as Exp1), the experimental protocols for Exp2 were kept as close as possible to that work, except where it was important to add or change procedures to test for a more realistic surrogate experience.

The differences in this study are listed below.

1) The addition of the functional capability metrics testing and surveys for background and disability information, in order to acquire more information about participants on a more individual level.
2) The expansion of the recruitment strategies and the addition of undergraduate research assistants and additional resources and training for researchers, in an attempt to get a large number of participants through the research study in a consistent manner. (This time it was also ensured that the testing was able to be mobile, so that people who wanted to participate who were not able to come to our testing facility on campus could still be included.)
3) The added explanations and slight protocol tweaks and removal of the general user product testing to ensure the quality of the statements elicited during testing.
4) The more exacting customer needs interpretation process and the tracking of the product and participant source of the customer needs, in order to identify potential relationships within the customer needs.
5) Modification of the motion restriction simulation suit (suit 2.0) to be differently restrictive than the previous study with respect to finger movement.

The parts of the study that remain the same as previous include: the fact that participants are being video recorded, the fact that participation is strictly voluntary, the products used in the elicitation and the available timeline. Also, the setup of the testing space is basically the same.

The products used in the study were also used in previous work [73]. They were kept for this study because a direct comparison to Exp1 was needed. These three product pairs were the ones that were able to elicit useful/enough information from the previous similar elicitation

process. Each product pair contains one product that was designed inclusively and one that was not. The abbreviation for the products are in the Nomenclature section. Repeating them here they are SGP (the standard garlic press), CGP (the curved garlic press), TJO (the twisting jar opener), BJO (the black jar opener), RCO (the red can opener), WCO (the white can opener). The inclusive products are CGP, TJO, WCO. The participants were not told which was inclusive during the study, though they were told afterword if they asked. Table 3 below shows the products and their names and tags again.

Table 3: Repeat of Product Information

Product	Standard garlic press	Kuhn Rikon® garlic press	Kuhn Rikon® jar opener	OXO jar opener	Swing-A-Way® Portable can opener	Zyliss Swiss Innovation® can opener
Abbreviation	SGP	CGP	TJO	BJO	RCO	WCO
Type	Exclusive	Inclusive	Inclusive	Exclusive	Exclusive	Inclusive
Picture						

3.2.2 Additional Information Collection Details:

Exp2 continues gathering verbal information about participants' disabilities. Each PMR participant is asked to describe their disability in as much detail as they are comfortable with and recorded in what they say. This data can be parsed in different ways, but is not biased by the collection method.

I also continue to ask individuals who wore the suit the question "Do you think that this experience has given you a better understanding of the issues faced by persons with disabilities?" This is an initial metric on the empathic experience we hope the suit is providing. The information contained in their why or why not explanation and their answer will help future research.

For the testing for Exp2, I added a survey of participant backgrounds. This is done for all participants, to see if there are correlations between their experience and the types of needs they

express. This survey collects generic demographics as well as previous experience with inclusive design and persons with disabilities.

I collected standard anthropomorphic information about the hand as well. This data may be useful in the future, as the shape of the hand may have some bearing on its strength or dexterity factors. Since it is easy to collect, it has been included in this round of testing. These measurements include hand length, palm width, grasp circumference, finger length, finger width, finger circumference, and flat reach.

I also added the World Health Organization's Disability Assessment Schedule [170]. It is a 5 minute, 36 question form covering many aspects of functioning. It is "A tool to produce standardized disability levels and profiles"[170], which is what we want. It also provides an easy link with the International Classification of Functioning, Disability and Health [95]. Some of these aspects will have more direct applicability than others but we wanted to capture everything. Having a self-assessment in the study allows participants to express their perception of their disability in a useful quantitative way.

3.2.3 Study Administration:

All human studies activities in this research were approved by the OSU IRB (study approval numbers are #7088 for Exp2 and #5615 for Exp1). The study participants were limited to adults who spoke English with no mental disabilities and no major hearing or sight restrictions. This was done to ensure that all instructions and testing procedures could be understood easily. The PMR group participants needed to have a self-identified upper extremity restriction of some sort. The SSU group participants had to have no upper extremity restrictions. All participants were prescreened to ensure their agreement with being video recorded and physically handled by researchers as necessary for the suit application and functional capability tests. Visibly pregnant women were also restricted from the study since it could not be ensured that application of the back brace portion of the suit would be safe for them.

There are several parts of the study. The most important part is the product interactions. The order of the pieces of the study was controlled so that some were done in a specific order and some were randomized. Surveys were conducted first to ease people into the process. Product interactions were placed before the functional capability metrics to prevent the fatigue, a known to be a variable effect of the suit, from become a confounding factor in the elicitation.

Someone who gets fatigued and has to use the products more worn out than another participant may elicit different needs. (In fact, fatigue effects are one of the issues yet to be explored and are a recommendation for future work) The product interaction order was left up to the participant. The functional capability tests were randomized by the test administrator. A script was provided so that each study could be run the same way and all pieces would be included.

The study process can be seen in the Flow chart below in Figure 11. The blue boxes are those processes that the participants are involved in. The whites boxes are processes completed entirely by the researchers. The diamond is the decision made by the participant as to whether they identify as motion restricted or not.

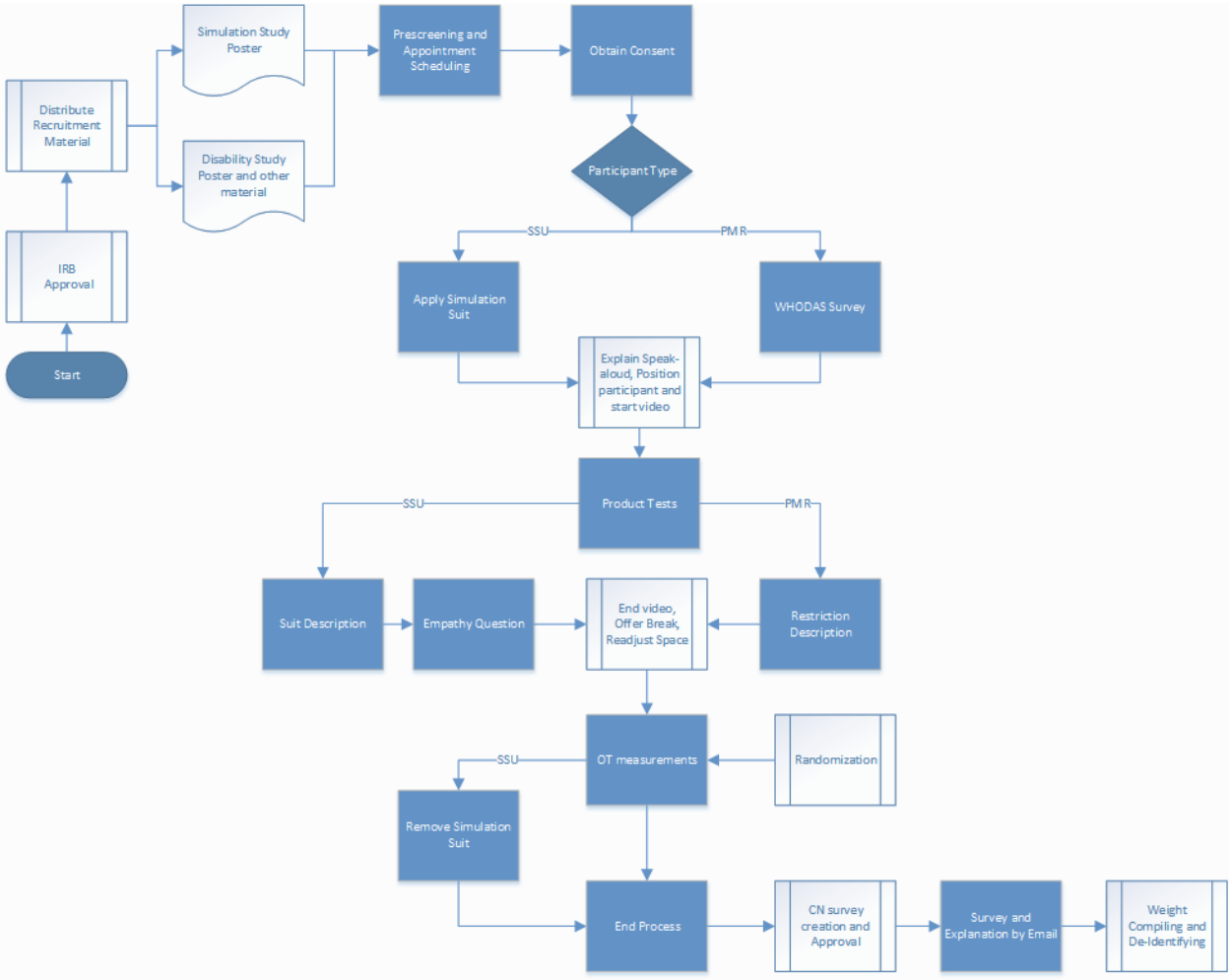


Figure 11: Study Protocol Flow Chart

For the ‘product tests’ box we performed a non-guided speak aloud protocol analysis. This involves the participants using each product one at a time and speaking through their experience. Speak aloud protocol analysis is a standard methodology for analyzing product interactions [171, 172]. The point of the study is to see what needs arise from the product interactions, without biasing or guiding participants. Therefore, as with the previous study, administrators were not allowed to lead or assist participants. Since this was a non-guided elicitation exercise, the only statements test administrators were allowed to make during the video portion were ‘can you elaborate on that’, ‘what do you mean by that’, ‘remember to talk through things’, ‘what are you thinking about’, ‘what are you looking at now’, and other variations on this theme.

After all products had been used, the participants were asked to identify which product out of each pair they preferred and give a quick explanation as to why. They were then asked the ending questions on camera before it was turned off. The end questions for those SSU participants were: “Please explain what you thought of the suit, how were its restrictions and its effects for you?” and “Do you think that doing this study has given you a better understanding of the issues faced by people with disabilities?” For those PMR participants the end question was “Please describe your physical restrictions in as much detail as you are comfortable with”.

In order to effectively capture all information about the product interactions video recording was determined to be the proper methodology. That way when a participant says something like ‘that was hard’ we would be able to see what they were doing and properly translate that into a customer need.

3.3 Motion Restriction Simulation Suit:

In this section I provide a thorough description of the suit so that its particular functionality can be understood. For additional information on the development of the suit, see [74,75,77]. The motion restriction simulation suit restricts only the upper extremities, in order to limit the initial scope of the project and is shown in Figure 12. The suit places restrictions on the motions of the torso, shoulders, elbows, wrists and fingers. For each of the areas, a detailed description of the suit part is given.

Figure 12: Motion Restriction Simulation Suit

3.3.1 Torso:

For the torso part of the disability simulation suit, an Ergodyne Proflex 1051 Mesh Back Support Brace is used. It does not restrict very much but provides awareness of the torso and a good platform for holding other things. The belt also provides the necessary adjustability to accommodate a wide variety of body types and situations. Having the connections over the pelvic bones is a common anatomical reference point that is different for each person and requires unique adjustment for each participant.

Figure 13: Pictures of the Back Brace Portion of the Suit

Figure 14: Double Grommet Belt.

3.3.2 Shoulders:

For the shoulders of the suit, SPRI Dynamic Recovery Light Resistance Flat Bands are fastened from just over the pelvic bones in the back, to the upper arm brace in the middle of the band (detailed in the elbow section), to the front of the participant, on each side. This way the arm cannot move forward, outward or backward (shoulder flexion, extension and abduction) without encountering resistance. It is important to have equal resistance on both sides so adjusting of the front strap connection point to cause this is needed. This is left to the participant to judge. We simply ask them to flap and tell us if one side is tighter than the other. Another important part is to make sure the connection between the arm and the band stays secure so the band does not slip into a non- triangular configuration during movement and a consistent restriction is maintained. This was done by securing the middle of the band into the convenient places in the padding and straps of the elbow brace.

Figure 15: Pictures of the shoulder restriction band. Its actions and connections.

3.3.3 Elbows:

To create the elbow parts of the suit, an Ossur Innovator X Post Op Elbow Brace is modified by replacing the hinge with a rotary damper. The brace provides comfortable attachment to the participant, since it is designed and padded for the purpose of long wear. It provides good adjustability, so that it can be used for a variety of arm sizes. For the restrictive portion, a rotary damper was mounted such that the torque was transferred from the plates of the brace through a shaft to the damper. A miniature rotary damper with an estimated resistive value of 283 in-oz torque was selected because it was the smallest dual direction resistant square insert available at the time. This effectively slows the movement of the arm and provides significant resistance in both flexion and extension. This device did develop a little bit of a delay as time went on. This causes small movements to be accomplished before the damper catches and its

effects kick in. The pin also comes out occasionally. Both of these effects are due to the soft material of the braces being worn down by the harder material of the shaft. This is an easy fix for future suit builds.

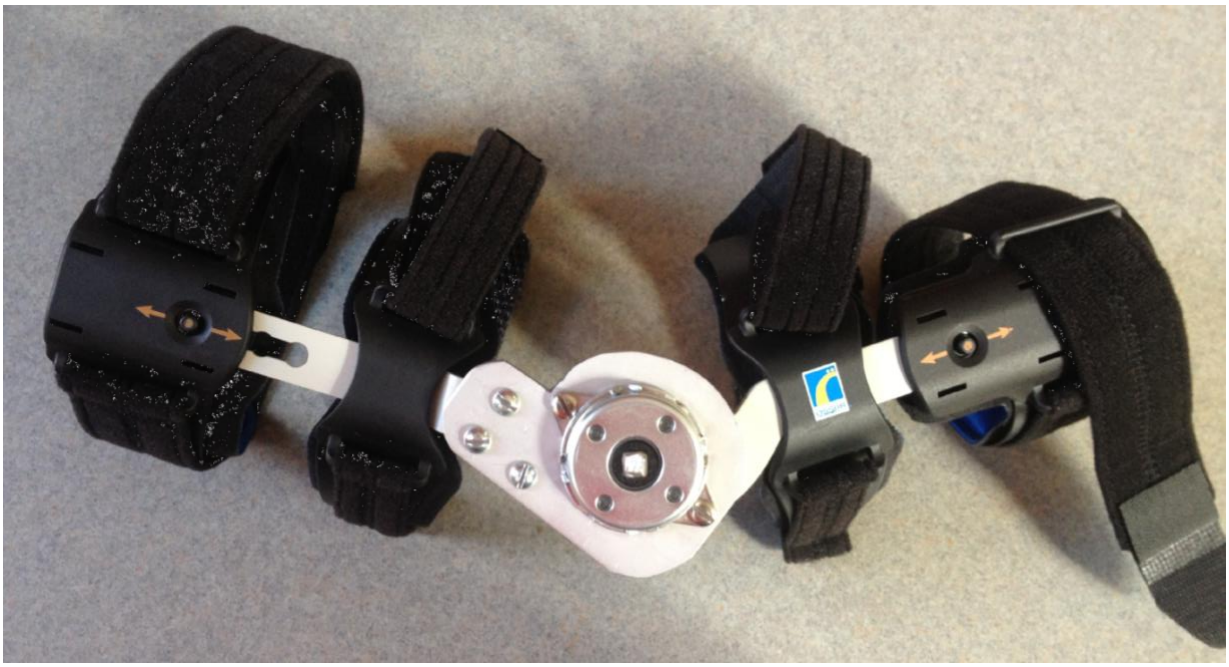


Figure 16: Picture of the rotary damper hinge on the elbow brace

3.3.4 Wrists:

For the wrist parts of the suit, ACE wrist braces were modified by replacing the rigid metal insert, which did not allow any wrist movement, with plastic inserts cut to the same shape, which do allow wrist movement, but provide resistance to flexion and extension. Since different materials will provide different resistance levels, the plastic could be switched out for more specialized testing in the future. The fabric of the braces' sides provides sufficient resistance to lateral deviation. In order to also restrict the twisting motion of the forearm, the edge of the elbow brace is moved toward the end of the arm, so that it is on top of the wrist braces and cinched down, providing some friction and catching during supination and pronation. A more specific rotational restriction option could be adopted in future suit versions.

Figure 17: Wrist Braces with Inserts

3.3.5 Fingers:

The final and most difficult part of the suit is the finger restrictors. The finger restrictors have gone through two designs for the two different rounds of testing (Exp1 and Exp2). The first, used during Exp1, followed the elbow model, with a restricted joint along the side of the finger joint. A wavy washer in the joint provided the restriction. They had custom 3D printed bridges and padding to conform them to the fingers. The devices were held to the finger with double sided Velcro.

Figure 18: Original Finger Restriction Mechanisms

These mechanisms had several problems. The wavy washer provided inconsistent restriction. Some parts of the motion were more inhibited than others. Some days the devices were stiffer than others, and each device was not the same stiffness. This was a problem since the mechanisms do not have an easy way to adjust or calibrate them. They also provided an unintended restriction. Since they had to be mounted between the fingers to align the joints, they caused the persons to be unable to close their fingers together. This did create a significant drop in dexterity, but is not the intended function. These mechanisms also had to be secured quite tightly in order to stay in place. Extra Velcro from the fingers to the wrist brace was required to keep them from riding upwards with movement. This created a potential circulation hazard for participants, and actually prevented its use in one case.

To combat the unintended function, low reliability, and attachment issues, we decided to perform a redesign for the next round of testing. A team of undergraduate research assistants were directed to perform this redesign through prototyping and testing. The goal was to find the simplest method to combat the problems of the original finger restrictors and provide the type of movement restriction desired.

The current model uses NiteIze GearTie reusable rubber twist ties. These are clipped to the wrist brace and wrapped around the fingers. This provides some restriction of all of the finger joints. These ties resist movement in all directions equally, which is part of the goal. If applied properly, they provide good restriction without pinching the participant and without preventing finger closure or tactile interaction with products. The performance of these restrictors is more under control of the research team. Another advantage of this method is that it can be easily extended to the thumb, whereas the original option would have required significant adaptation in order to fit the different form of the thumb. We still do not restrict the thumb for the tests since we have to maintain comparability with the original tests, but this could be added in future studies.

Figure 19: Finger Restriction Mechanisms

3.3.6 Additional Options:

A padded neck brace can also be added if that is a desired restriction, but has been left off for these tests. Additions of headphones and goggles can also be easily applied to add visual and hearing distortion to the simulation. These have also been left out of these tests, so as not to confound the physical data being gathered. Many additional options for studying different restrictions could be added to future versions of the suit. [76] is one example of a study to add essential tremor simulation. Any further restrictions will change the level and type of the surrogate experience the suit provides, and will affect the data resulting from its use. Therefore, additional options should be carefully considered for and studied. It is suggested that the suit remain as simple, modular and size adjustable as possible when making changes.

3.3.7 Suit Application Directions:

Directions and further specifications on the manufacturing of the suit may be requested from the OSU Design Engineering Lab. Direction on the application of the suit are as given below, to mimic the training of the test administrators.

Step 1: Prep (Undo all Velcro, straighten the ties, put the elbow brace extensions correctly (upper all the way out, lower all the way in), check all connections and lay out pieces.

Step 2: Apply back brace and tighten as needed. On skinnier participants the brace can be applied inside out using the inner Velcro pieces to secure it rather than the end Velcro.

Step 3: Apply the belt under the brace with the band connection points over the center of their hip bones and have them secure it in front, tuck the extra away.

Step 4: Put the elbow brace up their arm, have them bend their elbow and line up the hinge with the joint, have them help you hold it in place while you secure the top and third Velcro. Have them remove jackets and bulky clothing. Be careful when adjusting the straps to not pinch their skin and to actually catch the metal rounds. You will have to hold the metal tight with one hand and move the strap with the other hand. Make the straps tight so the brace cannot slide around, but don't cut off circulation.

Step 5: Pick the right sized wrist brace for the size of hand. A good method for this is to know which size fits you best and compare your hand size to theirs.

Step 6: Put the wrist braces on. They will need to remove all watches and rings for the testing.

Step 7: Wrap the ties carefully around the fingers. Going the same way for each, not going along the very back of the knuckle, making sure there is at least one curve per segment, keeping it off the pad of the finger but making sure it engages near the nail, keeping the excess out of the way. Make sure to wrap it tight enough to engage well but not butting off circulation.

Step 8: Move the lower portion of the elbow brace down so that it covers the upper portion of the wrist brace and tighten the strap so that there is friction interference between them.

Step 9: Find the halfway point in the band and secure it under the padding of the second Velcro on the elbow brace, tighten the Velcro, move their arm to the neutral position, secure the other end of the band to the front so tension is even. Have them flap their arms to make sure the sides feel the same.

Step 10: Go over everything for fit, adjusting as needed.

3.4 Functional Capability Metrics:

This section discusses the process of searching for and selecting the functional capability metrics. The resulting selections and their application to the research is discussed as a result.

3.4.1 Selection Criteria:

The occupational therapy field was investigated to determine how it defines capability metrics. I found this to be a good fit for an extension of inclusive design research since the "primary goal of occupational therapy is to enable persons to participate in the activities of everyday life," according to the World Federation of Occupational Therapists [169]. Occupational and physical therapists assess an individual's physical functions in order to recommend treatments. Therefore, I interviewed local practitioners for advice on appropriate

metrics for upper extremity restrictions. Their recommendations were investigated further, and a wider search was also performed. The Rehabilitation Measures database [102] was consulted due to its extensive list of different measurement techniques organized with criteria for comparison that were helpful.

There are numerous options for ability assessment, most of which are not applicable to this study's testing situation. The majority of available testing and screening options focus on recovery or improvement metrics, instead of evaluating capacity at a single point in time, which is the need of calibrating a disability simulation suit. Many of the options are subjective assessments, either on the part of the patient or the evaluator. While there is value in subjective testing, it is less desirable than quantitative comparisons. Tests that are commonly used and have normative data available to enable direct comparison are prioritized.

Specifically, tests that mimic the motions encountered in the product interactions and capture data about all the movements participants perform are desired. For example, if we know that the participants will be doing a twisting motion in the product interaction, there is likely twisting related needs and the chosen functional capability metrics need to capture twisting aspects.

It is also important that any test adopted does not require specialized medical training. For example, when one visits the doctor with joint pain complaints the doctor will generally pull one's limbs and push on various places and asks the patient to push and stretch and tell them when it hurts. This kind of examination creates useful information for the doctor, but is not an option for researchers untrained in extensive medical evaluation. There are many examples of tests of functionality that can only be administered by a trained therapist and are thus avoided. Apart from training, any chosen functional capability test must support consistent data collection across all participants and be relatively easy to administer by multiple researchers.

The tests also need to be easy for the participant to understand, in order to reduce the potential confounding effects of complex instructions, and to maintain participant willingness to continue. Other factors include cost and time to complete, as data collection is to be confined within a two-hour time window.

To summarize, I wanted to select tests that were; low time, low cost, singular (a measurement at only one point in time), quantitative, had normative data, simple to administer, easy to understand, and mimicked the product interaction motions.

3.4.2 Selected Tests:

The selected OT tests are both a material for the larger study and a result for this particular portion of the study. I have included the detail of the tests in the Results section of the paper along with the analysis of how well they functioned for our purposes. But a quick overview is presented here. Two dexterity tests were chosen, one for fine motor skills and one for gross motor skills. A series of strength tests were selected that cover all the motions of the study. And a Range of Motion (ROM) measurement method was devised to easily account for any divergences from normal ROM.

3.5 Customer Needs Interpretation Process:

The customer needs interpretation process consisted of several stages. All stages were performed with a three person team to ensure reliability in the interpreted needs. This team consisted of the main researcher at all times, filled in with two of the undergraduates assistants depending on availability.

The first stage was to have three people sit down and watch a participant video. While watching, they would write down anything that could be interpreted as a customer need from what the participant said or did. They were provided with examples beforehand, such as, if somebody looks at a thing in confusion for a while and says ‘I’m not sure how to work this’, that becomes a customer in need of “product should be easy to understand”. Another example would be someone performing a motion and going ‘oh that’s really hard’ that would become a customer need of “Product should be easy to perform that motion”. After each video the three interpreters would go through their lists and make sure that everybody had a very similar list and discuss the customer needs. If two out of three people identified a need or note a phrase, then the third would be given a chance to dispute or discuss its appropriateness. Following this reconciliation, if two out of three persons still identified the need, it is added to the CN statement list as being said by that participant. Any need statement identified by only one person was discussed to check that is was actually heard or stated or interpreted correctly and either discarded or added to the list if at least two out of three persons agreed to it being valid. This process showed a very high agreement between the interpreters. The interpreters for this process were myself and two of the undergrad research assistants on the project, though which two varied based on availability. These interpreters had to be project members as approved by the IRB to having access to

participant videos, though that restriction was not present for stage two since the information was sufficiently deidentified.

The second stage of customer needs interpretation involved a standard affinity sort [10, 12]. Preparation for this stage involved writing each statement on the list of each participant separately on a sticky note with the participant number in the corner for tracking. Then the three people (myself and two other graduate researchers in the lab) one at a time took each statement off the stack of sticky notes and placed it on the wall into groupings separated by product. This process served both to group similar statements and separate those statements that felt different. For example ‘be easy to turn’ and ‘not be hard to turn’ are the same customer needs statement said by two different people. As with the development of CNs for Exp1, a statement involving form suggestions was kept separate from a more generic function based statement. For example, ‘have an ergonomic shape’ is different than ‘be curved’, and ‘provide good leverage’ is different than ‘turning knobs should be long enough for good leverage’. This process involved some discussion regarding groupings and intentions and also showed high agreement between the interpreters.

Stage three involved taking the group of sticky notes off the wall and determining what exact phrase encompassed all of the statements in that grouping and assigning it a frequency and entering the data into Excel tracking which participant said each statement. Tracking which participant said which statements was an important part of the research methods for this study, which was not part of Exp1, so care was taken at each stage to preserve that information. A different tracking and interpretation methodology would have to be employed if the CN lists were created as the process progressed, rather than with this method of making the lists after study collection had ceased.

An important thing to note is that throughout all three stages of the customer needs interpretation process, each statement was attributed to a particular product. From the very beginning, if they participant said something while holding or using or talking about the curved garlic press that statement was given the tag CGP, and so forth. This was done purposefully so as to be able to compare inclusive and an exclusive product types. This did involve some repeat customer needs, given that a participant who noticed a particular problem with the straight garlic press is likely also going to notice that same issue or remark on the lack of that problem in the curved garlic press, and the need statement will therefore be on both product lists.

Another thing to note is that someone who says ‘this product does this thing very well’ that is the same customer need as someone who says ‘this other product does that same thing quite poorly’. Both statements would result in a customer need of “Product should do this thing well”. If three people say ‘that was hard to turn’ and three others say ‘that was easy to turn’ they would become combined through this process into the CN “Product should be easy to turn” with a frequency of 6. This is unlikely to happen on the same product, so it would be end up as the same CN on both product lists with a frequency of 3. But when combined as described in the next section it would be further obscured. Also, ‘a bit hard to move around’ and ‘very difficult to maneuver’ would be the same CN of “Product should be easy to maneuver”. So information on the amount and placement of positive versus negative style customer needs was lost during this interpretation process.

3.6 Ontology:

Application of the Customer Needs Ontology to the Customer Needs statements acquired during this research was performed as an important aspect of identifying inherent relationships in the data sets. The use of and usefulness of the ontology to this sort of research is one of the questions of this study. This section of the paper describes the process of evolving and applying the ontology as well as the analyses of the process that were performed to see how well it went.

Since the ontology is still a recent contribution to the design research literature, it requires usage to validate and evolve. The more people use it, the better it can become and the more can be known about best practices and application. Knowing more about the kind of process involved in application of the ontology would be helpful. Additional use and review of the ontology to offer additions or corrections, would strengthen the ontology’s ability to span the customer needs space and have mutually exclusive categories. Our use of the ontology to code and analyze customer needs gathered from actual products is doing exactly what was requested in the future work sections of the ontology literature [103]. Its applicability to our data set of customer needs gathered during human subjects protocol analysis during usage of manual products will be determined.

The ontology codes will provide an additional layer of information to our data that helps inform inclusive product design and surrogate experience. For the purpose of this research, use of the ontology helps us find information on what the customer need spaces look like and what

information that can provide in regard to inclusive design, and niche and product platform design. Specifically, we investigate if correlations existed between certain terms of the Customer Need Ontology and types of products or users. It also allows us to map the categories of the ontology into the product family domain which provides additional validation for the product family information that we gained through the weight versus frequencies customer needs space.

3.6.1 Stage One - Ontology Evolution:

The first stage involved attempting to apply the Nix Customer Needs Ontology as written, directly to the customer needs. The first step in this was deciding to not use the 'Who' and the 'Innovation' taxonomies for this study. Given the nature of the customer needs gathering experience, all needs, or basically all needs, were going to be a User category, since users were the ones giving them and they were directed to think in that context. Also given the nature of the needs gathering, and the interpretation step, all information that may have informed innovation (of which there was very little to begin with) was removed when standardized into the CN statement format. Therefore, it would be adding effort for no additional information to code with the 'Who' and almost impossible to code with the 'Innovation' taxonomies. I also renamed the 'Recipient' taxonomy to 'Market' to better reflect the fact that inclusive design research is trying to accommodate everyone, and these categories are simply a measure of how much of the entire possible market a statement covers.

When performing the pilot test for applying the Nix Ontology to our CNs, the experience of trying to decide which codes to apply highlighted an extreme amount of uncertainty and necessitated a reorganization of the What taxonomy. In examining Nix's 'What' taxonomy, most customer needs could be feasibly rated as several categories. Specifically, it was found that many needs had both a functional aspect and a performance aspect in the statement. As an overarching example, "Product Should VERB ADVERB." Given this, as well as the fact that there was no preference order listed for the taxonomy as a whole, either an enormous amount of performance codes would be generated with a large loss of the additional information in the needs regarding product function, or a redefinition would be required. I opted for the redefinition.

It was determined that most of the human factors type needs had performance aspects to them, which follows with the original definition. And also, since safety needs directly override human factors needs, they also tend to have a performance aspect. Device performance needs

have a performance objective but deal with the device itself rather than the human interaction. Therefore, I decided to pull out safety, human factors, and performance from the 'What' taxonomy and create a new 'Performance' taxonomy. This taxonomy is intended to capture how performance based the need was, and across which aspects of performance. This necessitated the addition of one category to the new 'Performance' taxonomy for those needs that do not have performance aspects in them.

Additionally, it was determined that one of the main benefits this review could provide is a complete preference order for the categories. Then, whenever a rater has an uncertainty as to which category an item belongs in, they can use the preference order to make a decision for them. Similar to the original override of safety trumping human factors in the Nix ontology, but more complete. This preference order was discussed and laid out logically for each taxonomy. Raters were given this preference order along with the category definitions when doing the rating for this study. They were instructed, whenever a need seemed to fall into multiple categories or have aspects of multiple categories, to choose the one higher on the list. The thought process is that this would simplify decision making and hopefully created better consistency. The final revised Ontology can be seen in Table 4.

Table 4: Revised CN Ontology

Codes	Name	Description
Market		
1	General	A desirable expectation to most of the users (>75%) in the customer population for this product.
2	Niche	A desirable expectation to a smaller segment (<75%) of the customer population. They may restrict the customer population or only affect power users of the product. May drive a customer to purchase a different similar product because they do not want this capability.
Message		
1	Constraint	A restriction or limitation that will result in a boundary. These different from objectives in that exceeding or not meeting this boundary is not an option. The boundary may or may not be numerical at this phase in the process.
2	Specification	A measurable target value for the product. There are acceptable bounds on both sides of a specification. The target may or may not be numerical at this phase in the process.
3	Objective	An expression of the attributes and behaviors that the client or potential users would like to see in the product.
4	Solution	A specific way to accomplish the "what". They are typically ways a customer envisions a need being solved.
Performance		
1	Safety	How the product may injure/protect the users or other people near it during operation. These needs may sound similar to human factors but when coding safety supersedes human factors. Safety needs may contain performance variables that explain HOW it will enhance the safety of the product.

2	Human Factors	The user interaction with the product. These needs may also contain judgement on user experience or needs for the human experience or performance variables or aesthetic information that explains HOW it will enhance the user experience.
3	Device	The performance objectives of the product (speed, lightness, quickness). These needs typically include adjectives describing product performance and are measurable (possibly after more defining). These are not to be confused with human factors needs where a performance metric directly enhances the user experience. These needs may or may not contain a target or number.
4	None	A need that does not relate to performance. More what the device does, rather than how well.
What		
1	Aesthetics	The visual appearance of the product, including but not limited to color, shape, texture. These needs may relate with the study of the mind and emotions in relation to the sense of beauty with the product.
2	Features	A way to accomplish a function. These needs will not always contain the function being accomplished but will provide information on how it will be accomplished. Solutions (from the Message taxonomy are typically features).
3	Main Function	The main function the product will complete. The function that would be found in a black box model of the device. These needs are directly about the function and NOT how it will be accomplished.
4	Supporting Function	The supporting functions that the device completes. These needs directly describe the function and NOT how it will be accomplished.
5	Environment	The environment(s) the product will be used in. The boundary must contain entire product. This would be the boundary around black box model flows.

3.6.2 Stage Two - Ontology Application:

For the coding for this study, three coders were selected, each with a different level of experience, both in ontology usage and customer needs in general. Rater 1 was the author (Jessica Armstrong). I was experienced in dealing with customer needs in general as well as being a large part of development of this study's customer needs. I was also slightly experienced in using the ontology, having assisted in coding one prior work with it [103]. Rater 2 was Rob Stone, who is very experienced in customer needs in general, but not this study's specific customer needs. He was also somewhat experienced in ontology development, but not previously rated with it. Rater 3 was Marshall Miller, an undergraduate research assistant in the OSU Design Engineering Lab. She was not experienced with coding or the ontology, and had no specific experience with customer needs, but was familiar with the concept in general. Choosing a much lower level of experience for the third rater was done specifically to test if the ontology can be used effectively by a wide range of experience levels and to examine the effect of the difference in experience.

Rater training for this study was minimal. Training consisted of giving the raters the ontology, organized into taxonomies with definitions for each category, and the preference order, with an exceptionally brief explanation and two to three examples of how a customer need would

be coded. Next, the raters were given the datasets and instructed to code the needs for the desired taxonomies. The specific process of how they coded was left up to the raters and not controlled. This aspect will be discussed again later in the paper.

3.6.3 Stage Three - Analysis Determination:

The analyses performed on the data after the raters had coded the needs are as follows:

For each need set, and each individual taxonomy, I looked at what percentage of the need set showed code agreement by all three raters, what percentage was agreed upon by two of three raters, and what percent had no agreement.

I also examined which set of two raters agreed what percent of the time for each taxonomy and each needs set. This allows us to examine how the experience difference of the raters changed the agreement likelihood. If the same two raters agree more often, that tells us about possible experience and/or training requirements for ontology usage. If the raters agreed more often over different parts of the ontology, that tells us how understandable and well defined the categories are and how well separated the taxonomies are.

All analyses were performed on the 6 CN lists for the individual products from all participants from Exp2, the three product pair lists from PWD participants from Exp1 and the three product pair lists from FSU participants from Exp1. That information will be used later for the comparisons of needs elicitation potentials of the surrogate experiences. It also gives us the possibility of making more general conclusions. Conclusions from this study can be related to the application of the ontology to other handheld manual products and their needs.

The information from this study will be applied to an evaluation of the framework for inclusive customer needs gathering and surrogate experience needs elicitation to inform and support inclusive product design.

3.7 Validation Processes:

The specific validation exercises were performed using the same methods as in the previous study [73]. This involved a simple vector projection activity, projecting the SSU list onto the PMR list to see how much of the PMR CNs were covered by the SSUs. The process for doing this consisted of reading through a PMR list, and for each CN, seeing if there is the same, or a very similar CN, on the *accompanying* SSU list. Which needs are covered and which are not

are shown in the ‘Covered” columns of the tables in Appendix G: Persons with Motion Restrictions Customer Needs List.

This activity allowed the development of a piece of information tied to all the CNs, stating whether that need was stated by only participants with motion restrictions (labeled pmr or r), only participants wearing the suit (labeled ssu or s), or both participant types (labeled both or b). This information was carried throughout the data sets and was helpful for the participant type comparisons. It could be used for further analyses in future as well.

The fact that the simple vector projection validation activity could create an entire participant type column of information shows the versatility of the framework. Other analyses or comparisons performed with it are likely to produce additional information that can be added to the set and used for making informed decisions later.

Given the increase in capability information with Exp2 over Exp1, more detailed information could be obtained regarding the placement of participant capabilities across different aspects. Only the Nine Hole Peg Test (9HPT) dexterity information could be compared across the two experiences. But, as stated with the research questions, there are several sets of comparisons performed between Exp2 participants and external data sets regarding different aspects of functioning.

The process for comparing the participant performance to the external studies [173-178, 194] was straightforward. It required processing of the OT metric information into the averages, ranges, and tables that match the external studies’ spectrums. Many of the metrics are normalized based on specific genders and age ranges, which meant comparisons had to remain on an individual participant level, rather than as subgroup combinations. Since the functional capability metrics were all numeric, the comparisons are very simple. Also, given the small size of the data sets, statistical testing for these comparisons was both unnecessary and not recommended.

The last piece of validation is the question of whether the experience is actually developing empathy in the participants. Since one of the goals of the research is to be able to provide a simulation suit which provides an empathic experience, it is important to confirm this as far as we are able.

3.8 Comparison Considerations:

There are many things to consider when choosing how and what to compare in an exploratory study. These are now described.

3.8.1 Differences in the data set structures:

In order to be able to compare the surrogate experience results between Exp1 and Exp2, I had to ensure that the list of customer needs were formulated the same. Therefore, the customer need lists from the two products in the pair were combined to form a product pair list. This process involved deciding whether a statement had a match on the other list and combining the frequencies. For the frequency combining, the frequencies from both product lists were added, while ensuring that the participant tracking didn't duplicate itself. For those CNs where a participant stated that need for both products in the pair that particular participant could only contribute a frequency of one to the total frequency for that CN on the product *pair* list. That way the pair lists could also be normalized using total participant count. For example, rco-24 "Product should be not flimsy" said by one pmr participant (1freq,1pmr,0ssu) and wco-02 "Product should be durable" said by one ssu participant (1freg,0pmr,1ssu), are the same need, but not duplicated by participant. Therefore, they were combined into the pair list CN of C09 "Product should be durable" with a new total frequency of 2 (2freq,1pmr,1ssu).

This process was done by myself, with checks performed by Rob. This process was both assisted and impeded by the fact that the ontology codes had been applied beforehand. In the cases where the need statements were obviously similar, and yet had different codes, it made the decisions more difficult (given that there was known inconsistency in the codes). However, on some where it was uncertain whether the statements were similar the same codes could help confirm it. This process was performed twice, a week or so apart, as a check. There was minimal difference in the results. The third and final combining was done few weeks later and confirmed by Rob Stone on all but 2 CNs. I have confidence that the pair list is accurate and useful. It is presented in Appendix I&J.

3.8.2 Possible and Impossible Statistics:

The statistics consulting services of the OSU statistics department was consulted to determine which, if any, statistical comparisons were possible and recommended, given the data collection methods and results. They determined that, given the fact that each participant was allowed to say whatever they wanted, there are concerns of repeated measures and non-independence of data. Because multiple statements are made by each subject and the order of tests are not controlled the worry that repeated measurements are likely to be dependent, since

one participant can influence their own experience as it moves along, and it would differ greatly between participant. Coupling these issues with the small sample size means any statistical testing would be in violation of a variety of necessary assumptions, and should not be allowed. Inference is not present, and I must stick with descriptive methods.

However, the data can be presented in ways that allows identification of trends. They advised that whenever I present data, it should be at the lowest detail level possible. For example, dot plots with the information source visible such as in Figure 20, rather than charts which aggregate information. Some aggregation is necessary, but should be kept as low as possible and visual comparisons should be made simple, such as showing both subgroups over only one list's taxonomies in Figure 21.

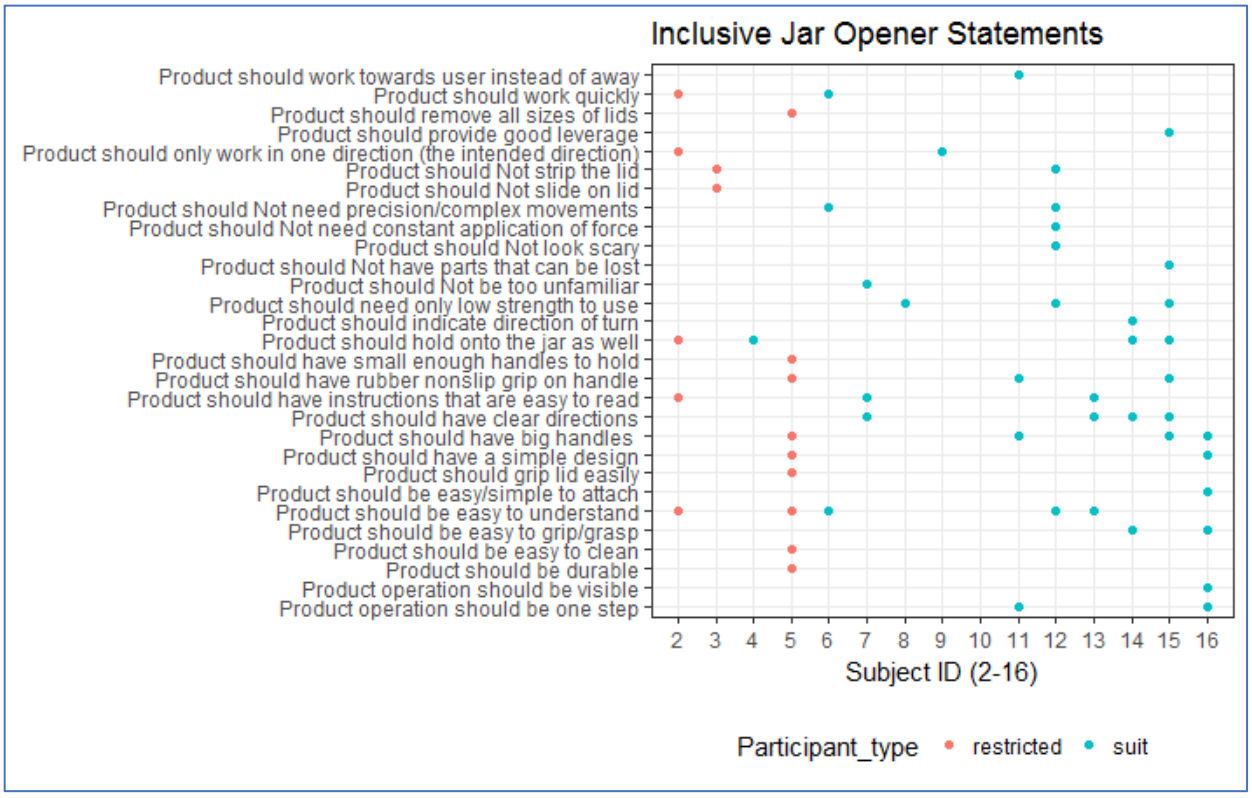


Figure 20: Presentation of Results for Accuracy of Inference

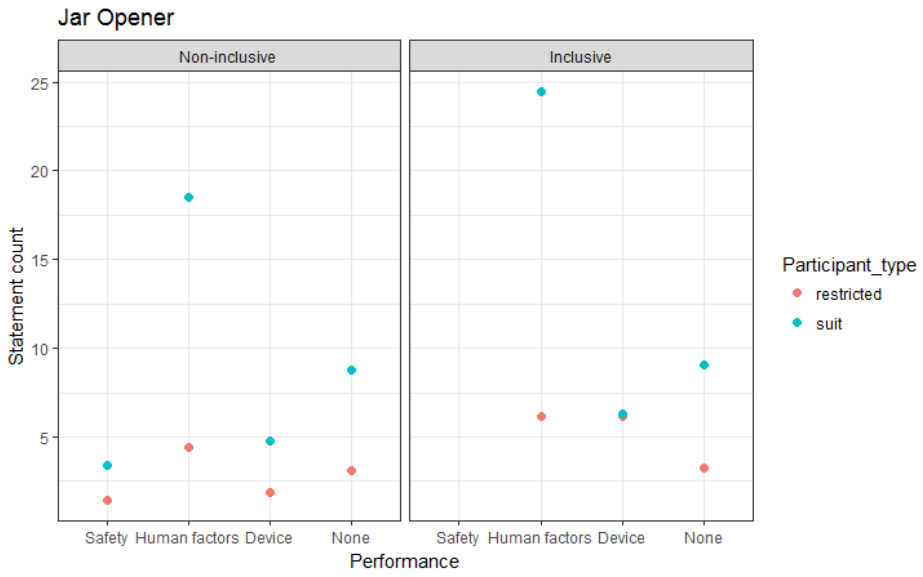


Figure 21: Presentation of Results Options

This had some implications for the planned comparisons for the study. In terms of comparisons using customer need statements, there were some limitations, but the ontology codes could be compared as desired, since their source was more consistent. According to the consultants, descriptive subgroup comparisons would be valid. However, comparing the different products types (inclusive vs exclusive) would be less valid, since it cannot be known whether the identified differences come from the participants or the products. There is an unknown interaction effect present. For this area, only the ontology codes can be compared. Additionally, comparing Exp1 and Exp 2 should be done non-quantitatively and avoiding any joint treatment of data from both studies.

3.8.3 Comparisons:

There are many possible comparisons that could be conducted given the large amount of data in the framework. Results from the planned comparison set, corresponding to research questions 1-5, are presented in Chapters 4-8. Additionally, several serendipitous analyses were possible given relationships observed in the raw data and that is presented in Chapter 9. Other comparisons are left to future work. Given that some comparisons are more useful or more generalizable than others, the users of the framework must make choices in regards to priorities for both design information and specific aspects of interest.

For this study, any comparisons performed between customer needs and another variable was also performed with the ontology code coverage and the same variable, if possible. A sample of the possible comparisons and the impacts on our study is provided in Table 5. This table shows how comparing ‘Variable 1’ vs ‘Variable 2’ could yield ‘Information to be Gained’ and inform ‘RQ’.

There is significant CN space information to be explored, particularly if frequency and weighting information is available. The CN spaces of subgroups are of particular interest for informing differentiating modules.

Table 5: Sample of Comparisons and their meanings.

Variable 1	**Variable 2**	**Information to be Gained**	**RQ**
User Type	CN list	If we are mimicking well	1.1 & 5.2
User Type	Code Coverage	Do different types of people tend towards different types of codes or different spread of code types or	2.4 & 5.2
User Type	Weighting	If there are different priorities	5.2
User Type	Preference	If there are different	5.2
Experience level	Weighting	If experience level affects priorities	5.2
Product Type	CN list	If the difference in usability affecting the elicitation	5.1
Product Type	Code Coverage	Inclusive features may elicit more niche codes or exclusive features may elicit more detailed codes or more human centered codes, or a more focused placement of codes, etc.	2.4 & 5.1
Masters CN list	PhD CN list	What is the difference in the surrogate experience elicitation	1.3 & 5.3
Masters code coverage	PhD code coverage	What is the difference in the surrogate experience in terms of the types of CNs	2.4
Number of CNs stated	Participant Information	What is effecting the amount of elicitation each person does and what are the trends and averages.	5.3
Demographics	CN spaces	What makes the space change	x
User Limitations	CN spaces	What makes the space change	x
Code Coverage	CN lists	Can we create guidelines for design based on which needs and need types are most common	2.4
International Classification of Functioning (ICF)	?	What information from the study connects well to the ICF and how does the ICF info compare across different aspects and what can it show	all of 4
Frequency	Weight	What are the relationships within the needs sets and what is the common module information	x

3.8.4 Data Management:

Another important issue is to put a data management plan in place to make sure that all of the collected data is easily traceable to its source and easily correlated. Since several sets of data will be produced, tracking and mitigating mistakes is key. Developing a process for CN elicitation requires proper documentation and a traceable chain of information. The compilation of the customer needs list was streamlined in order to make correlations to participant limitations possible. Effort was put in beforehand to record data in a way that lessened the need for manual pre-processing of data prior to analysis. Clear documentation of data sets from the different parts and participant types of the project was accomplished. Knowing what information is contained in each part of the data set is important for this research, as well as any other future research wanting to be performed with it.

Chapter 4: Surrogate Experience and Suit Validation Results and Discussion

Moving into study results, this chapter begins with a presentation of results related to the production of customer needs by exceptional and surrogate users as part of the conducted human subjects study. It follows with results related to the validation questions regarding the CNs (Q1.1) and the Suit (Q1.2)

4.1 Human Subjects Study Results:

In order to describe the results of the human subjects testing, this chapter adopts the example format of HFES journal articles such as [187-189]. The range of participants and descriptive statistics on the population pool observed are reported. Limitations arising from problems with the process are discussed. Finally, the knowledge tracking procedures and their results are presented to complete the description of information contained in the study and its sources.

4.1.1 Limitations:

One of the goals of this research was to get a large number of different types of participants to participate so we could develop a large multifaceted data set upon which to base general conclusions. As is the case with human studies, this did not go according to plan. Despite a wide and thorough recruiting effort, this study had less participants than my last one. The low participant count results in a limitation on the generalizability of the observed results. If a trend in this data is observed, the results will be phrased in context of their *possible* meaning for inclusive design.

4.1.2 Participants:

Partial demographic breakdowns for the participant pool are provided in Table 6-7. A total of 17 participants took part in all or part of the experience. Of these participants, 3 provided incomplete or unusable data that needed to be partially or completely discarded. The participant ages ranged from 18-70 years old, with an average age of 30, a median of 25 and a standard deviation of 15.7. The experience level, (the development of which is discussed later), of the participants ranged from 0-15, on a 0-15 scale. The average experience level was 6.5 with a standard deviation of 4.6. There were 11 male and 6 female participants.

There were 5 self-reported PMRs (people with motion restrictions), one of which was discarded completely, one who only provided background and weights, and one whose statements were removed from the PMR CN lists, due to lack of restriction effects during product usage (also discussed later). This makes the PMR group for the CN lists consist of participant 2,3,5. The SSU group consisted of the 11 participants who wore the simulation suit for the study activities, participants 4,6,7,8,10,11,12,13,14,15,16.

Table 6: PMR Group Demographics

PMR	Customer Need List Group (2,3,5)	with 17	with 9	with both
genders	1f/2m	2f/2m	1f/3m	2f/3m
age range	25-65	18-65	25-65	18-65
age avg	48.33	40.75	50	43.6
age med	55	40	55	55
age stdev	20.82	22.78	17.32	20.73
exp range	9-12	9-15	7-12	7-15
exp avg	10.67	11.75	9.75	10.8
exp stdev	1.53	2.5	2.22	3.03

Table 7: SSU Group Demographics

SSU	Participants 4,6,7,8,10,11,12,13,14,15
genders	7m/4f
age range	18-45
age avg	24.45
age med	20
age stdev	8.45
exp range	1-11
exp avg	4.59
exp stdev	3.87

The activities took between 45 minutes and 1.5 hours, depending on the limitations and the elicitation of the participant. Participants chose the order in which to use the products, though the general setup of the experiment was the same across participants.

Further Demographic breakdowns are available if further studies of input factors are desired, but given the small sample set this was not useful at this point, as there were no notable trends.

4.1.3 Knowledge Tracking Activities:

As with Exp 1, knowledge tracking activities following [109] took place. [109] says that knowledge will trail off in a shape such as Figure 22. They say that once the displayed data of # unique CNs starts to flatten out, it is a reasonable time to stop information collections, as more effort involved in obtaining information will result in a limited information gained.

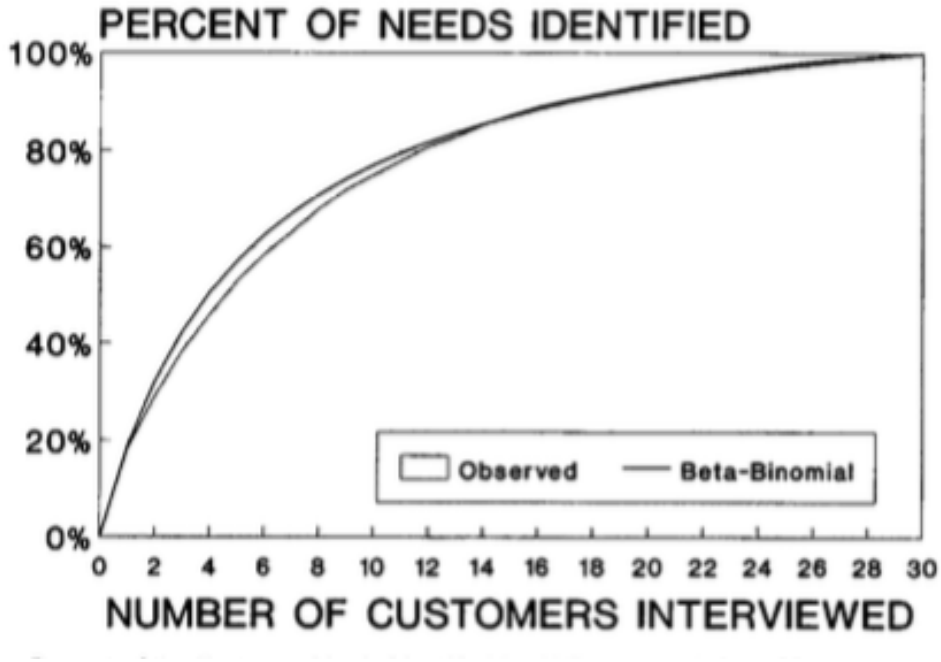


Figure 22: Percent of Customer Needs Identified by N customers as shown by [109]

Knowledge tracking activities were done after data collection ended, since all aggregation and similarity decisions had been made. Care was taken to track what participant(s) stated which needs throughout the study, making it a simple matter to determine the number of unique CNs that came from each participant. Knowledge tracking activities were performed for both the original order of participants, as well as a randomized order, as [109] recommends. This was done for the PMR group, the SSU group, and the whole participant pool. Knowledge tracking was also done for the whole group/data set for the biggest picture possible (complete Exp2). It was also done once using only one product list, to see how a smaller subset of the information changes the graph shape. All of these results showed less asymptotic trends as the data set diminished. The data tables and graphs for the data collected is displayed in the Appendix V&W, but I present the best and worst case scenarios , as well as the Exp2 graphs below.

Table 8: Knowledge Tracking by the Actual Participant Order for All Participants for All Products, i.e. all Exp2.

Participant #	# CNs Stated	# Unique CNs (not stated by previous participants)	knowledge progression = total number of unique CN statements in the set
2	26	26	26
3	16	12	38
4	18	10	48
5	44	31	79
6	14	5	84
7	21	7	91
8	27	11	102
9	10	3	105
10	6	0	105
11	20	6	111
12	31	11	122
13	11	1	123
14	20	5	128
15	47	7	135
16	32	5	140
totals	343	140	

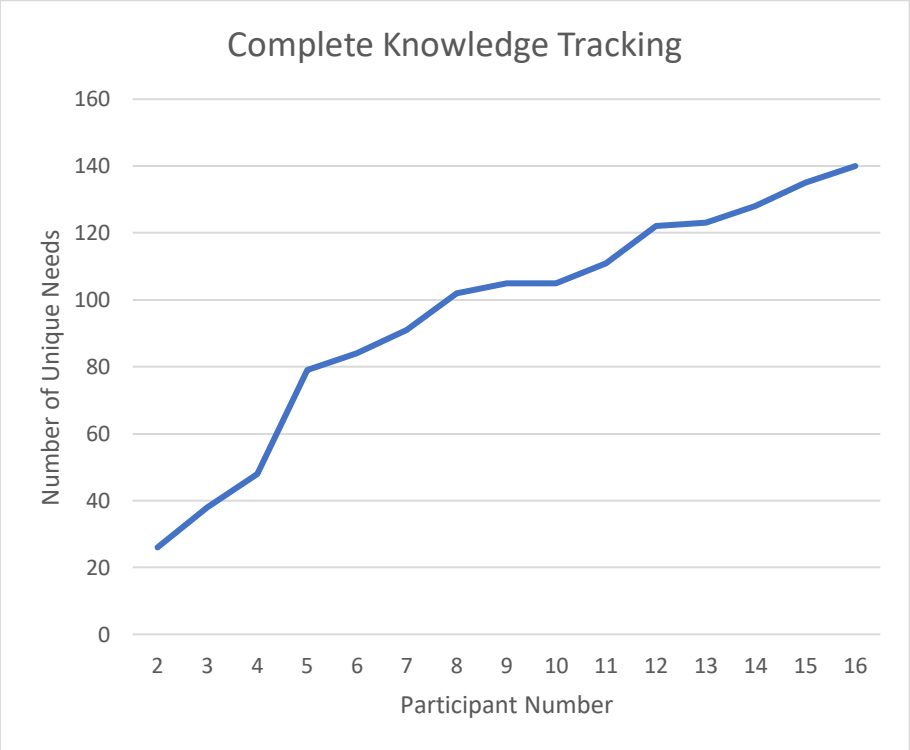


Figure 23: Knowledge Tracking for all Participants for all Products

Table 9: Ideal Knowledge order of PMR Group

PMR Group Entire Study Ideal Order			
Participant #	# CNs Stated	# Unique CNs (not stated by previous participants)	knowledge progression = total number of unique CN statements in the set
5	44	44	44
2	26	18	62
3	16	9	71

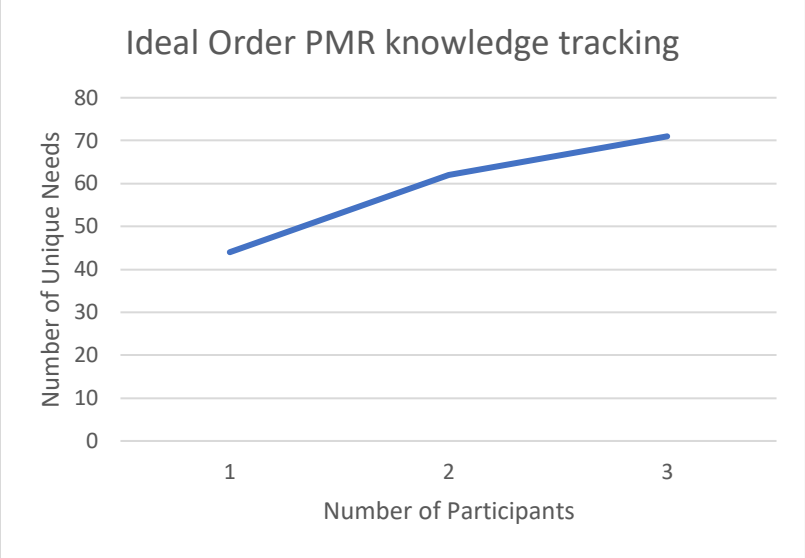


Figure 24: Ideal Order PMR Chart

Table 10: Randomized order for SSU knowledge tracking

SSU Group Entire Study Random Order			
Participant #	# CNs Stated	# Unique CNs (not stated by previous participants)	knowledge progression = total number of unique CN statements in the set
8	27	27	27
4	18	13	40
14	20	11	51
10	6	1	52
11	20	12	64
15	47	19	83
12	31	15	98
16	32	9	107
6	14	3	110
7	21	6	116
13	11	1	117

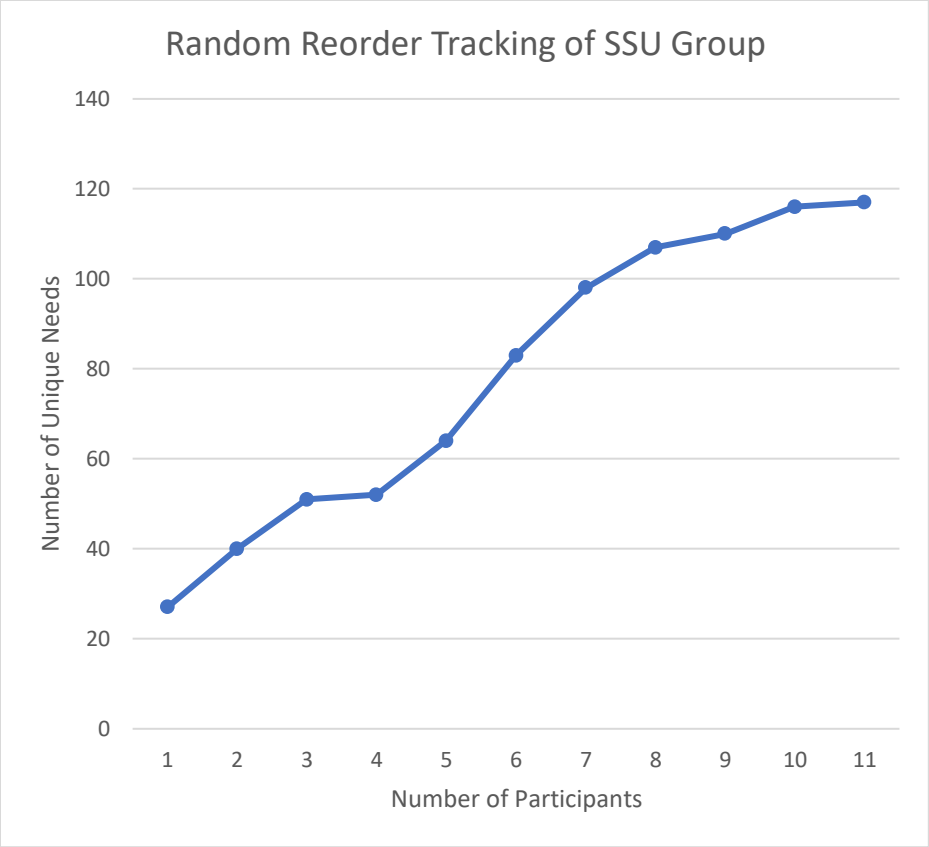


Figure 25: Randomized SSU Tracking

There are a couple of things to notice about the knowledge tracking results.

1) The PMR (people with motion restrictions) group is too small to be creating acceptable coverage of available product knowledge.
2) The SSU (surrogate suit users) group is approaching sufficient saturation.
3) The complete graph is not showing the correct/expected growth shape, it is much more linear, suggesting a change in the type of elicitation produced by this surrogate experience (EXP2) in relation to normal product usage and Exp1.

The PMR information gathered is lacking, as expected, as three participants are not enough to derive a complete picture in terms of the products. Three people are not expected to produce a good consistency of statements, and in fact these three individuals produced little to no overlap in terms of statements made. The lack of overlap in the PMR group shows that our data does not contain a very complete picture of what it looks like to be a person with motion restrictions interacting with these products.

When viewing the reordered SSU group tracking plot, displayed in Figure 25, the number of unique CNs begins to level off at the end. This means that collecting from more surrogate users is unlikely to add many more needs to the data set. This trend is similar to Exp1 in that most lists' knowledge had leveled off by eleven participants (9 to 14) [73].

The fact that we did not reach a good overall turning point (as we did in the last study), does not invalidate the information in the sets, but simply means it is not all encompassing of the available information about the products. It also strengthens our argument that Exp2 (the PhD study experience) is better at getting people to elicit customer needs. Part of the reason for the shape of the knowledge graph is that people in Exp2 state both more, and more diverse, statements compared to Exp1. This indicates that with Exp2 might not have reached the tipping point at 25 people like Exp1 did, but would need to get more people (especially more PMR) before acceptable overlap was occurring. On the other hand, it could also reach the same shape at 25 people but have the turning point placed at an overall higher number of needs. Either result would illustrate both the improvement of procedures in Exp2 and the difficulty in managing a larger information set.

4.2 CN Interpretation Results:

This section will present results mainly in the form of the data that resulted from the process, rather than an analysis of the process. Namely, the breakdowns of the Customer Needs on the various lists are presented. All stages of the CN interpretation process went smoothly and well, as expected. The subsequent interpretation process of combining product lists into product pair lists also was straightforward and without problems. There is also the comparison of the CN breakdown results between Exp1 and Exp2.

The actual CN lists are available in Appendix K. The result of the CN interpretation process was 9 lists of customer needs, 6 individual product lists (SGP, CGP, BJO, TJO, RCO, WCO) and 3 product pair lists (G, J, C). This is the main body of data produced by the framework, the main source of information of use to initiate product design, and the main source of connection between all the additional data pieces (Participant Metrics, Ontology Codes, Frequency and Weight, Participant Type, Etc.).

Table 11-12 show the CN elicitation numbers for both experiences. They show the breakdown and the differences in the number of customer needs elicited for each product and product type and participant type.

Table 11: Customer Need List Breakdown for Exp2

Lists	Number of CNs Total	# CNs from PMR	#CNs from SSU
SGP	25	11	22
CGP	27	12	23
WCO	36	19	28
RCO	29	12	24
BJO	29	14	22
TJO	29	10	24
	group totals	*78*	*143*
G	37	19	33
C	54	29	44
J	48	23	39
	group totals	*71*	*116*
EXP2	175 on 6 product lists /139 on 3 pair lists / 357 total statements	92	265

Table 12: Customer Need List Breakdown for Exp1

Number of CNs by List	Total	PWD	FSU
GP	57	27	30
CO	66	29	37
JO	50	22	28
IT	29	13	16
Exp1	202	91	111

SSU participants in Exp2 were noticeably more vocal in their need statements and produced a larger amount of needs overall. Given that the data set from Exp2 was produced by less people and produced almost as many needs, there is something present in the setup of Exp2 that produces a more detailed elicitation. Part of this difference will be contributed by the individuals involved in the study, but part of it will be inherent in the experience. The reasons behind the Exp2 surrogate experience producing a larger amounts of needs when compared to Exp1 are postulated as follows. The fact that people complete the background survey before they start the interaction with products is likely to have a priming or framing effect [190-193] on participants' mindset. Also, knowing that OT tests will be conducted to measure exactly what participants are and are not capable of doing might cause them to think about those capabilities

and their effects during product interactions. The specific explanation of protocol analysis to the participants in Exp2 likely increased participant competency at protocol analysis causing an increase in their statement output. The lowered restriction of the finger mechanisms of the new suit model likely allows participants to more thoroughly explore the product interactions and to experience and identify more aspects of product functioning and make associated statements. The lowered restriction also is likely to cause less immediate frustration, leading to less tunnel vision on specific difficulties. Future studies would need to be constructed to verify these hypotheses. Tables 13-14 below outline the customer needs produced by each participant and group in both studies, illustrating a difference in the elicitation rates.

Table 13: CN per participant for Exp2

Sum	27	16	19	49	16	22	28	7	23	30	12	23	50	35	9
Participant	2	3	4	5	6	7	8	10	11	12	13	14	15	16	9
Subgroup	pmr	pmr	ssu	pmr	ssu	ssu	ssu	ssu	ssu	ssu	ssu	ssu	ssu	ssu	x

The PMR participants elicited a total of 92 needs, for an average of 30.7 needs per person. The SSU participants elicited a total of 256 needs, for an average of 22.1 needs per person. A total of 366 statements were made during Exp2, for an average of 24.4 statements per person. Removing duplicates, 140 unique CNs were made for the pair lists, for an average of 9.3 unique CNs per participant.

Unfortunately, complete tracking was not performed for Exp1. From the knowledge tracking exercise, we do know the total number of statements for each person, but not which statements for every person.

Table 14: Customer Need Statements by Participant for Exp1

Participant	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
# CN stated	20	22	11	9	13	12	24	19	10	16	13	16	14	19	15	16
Subgroup	fsu	pwd	fsu	pwd	fsu	pwd	fsu	fsu	fsu	fsu	fsu	fsu	pwd	fsu	fsu	fsu

Participant	17	18	19	20	21	22	23	24	25
# CN stated	15	19	9	14	22	12	17	22	9
Subgroup	pwd	pwd	pwd	pwd	pwd	pwd	fsu	fsu	pwd

Including duplicate statements, Exp1 had 388 statements, for an elicitation average of 15.52 statements per person. 231 statements were made by FSU participants for an average of 16.5 statements per participant. 157 statements were made by PWD participants for an average of 14.2 statements.

When looking at just the customer needs lists, with duplicates removed, people wearing the suit elicited a total of 111 CNs, for an average of 7.9 CNs per person. The people with disabilities group elicited 91 CNs, for an average of 8.27 CNs per person. Exp1 in total had 202 CNs, for an average of 8.08 CNs per participant.

From the data in Tables 13-14, it is observed that the main trend is the larger number of the customer needs expressed on a per person basis for Exp2. While Exp1 produced a slightly larger amount of needs overall, this was due to the larger number of participants who undertook the experience. With Exp2 producing almost the same number of needs with only half the amount of people, this indicates that the process change in Exp2 likely caused a significant improvement in the experience, fostering a higher individual needs elicitation rate. Also notice that in Exp1, the motion restricted individuals had a lower elicitation rate than those wearing the suit, but in Exp2 this was reversed. The fact that the higher elicitation group switched between studies is interesting, but with the low participant count in PMR in Exp2, this may be an anomaly rather than a conclusive trend.

4.3 Validation:

This section presents the results of the validation activities. It shows how the suit and the experience is valid across several different dimensions. It answers the research questions Q1.1 and Q1.2.

4.3.1 Validation #1:

The first main result addresses the question: “do participants wearing the motion restriction simulation suit exhibit enough of the needs of people with disabilities to indicate that the experience creating a mindset that produces a valid set of surrogate needs that can inform inclusive design?”, which is a less specific way to say Q 1.1. This is achieved by a simple vector projection – in essence it is akin to going through the PMR list and checking off whether or not each need is present on the SSU list. The tables of the PMR lists in Appendix G showcases this

task on the last column. Then it is a simple percentage calculation. The results for this is below in Table 15.

Table 15: Percent coverage of PMR Needs for all data sets.

Needs List	Percent of the PMR needs also stated by SSU participants
SGP	73
CGP	77
WCO	56
RCO	55
BJO	57
TJO	50
G	84
C	62
J	60

This table shows that we are achieving adequate coverage of the needs of people with motion restrictions across all categories. This table also shows that generally, the coverage of PMR needs increases as you combine more customer needs together. The coverage for the individual product lists for the garlic presses were both in the 70s, but when combined into the G product pair list, the coverage goes up to 89%. The same is true for the other products and their accompanying pairs. The lowest coverage was the inclusive jar opener TJO, but it is still above the 50% cut off that was chosen as being indicative of a valid experience.

4.3.2 Validation #2:

The second validation comparison is for the suit, and there are two main aspects, both exploratory in nature. We first address Q 1.2.1 of "Where does the suit fall on the three disability scales regarding dexterity from our previous research and how does that compare to the previous version of the suit?"

During Exp1 [73] the nine hole peg test (9HPT) data for the participants in the suit were compared to those of external disability studies to determine what level of restriction the suit was providing. These studies include Rheumatoid Arthritis (the RA scale in the table), Parkinson Disease (the Modified Hoehn and Yahr Scale in the table, abbreviated H&Y), and Multiple Sclerosis (the Expanded Disability Status Scale in the table, abbreviated EDSS). [173, 174, 175]

The same procedure was performed for Exp2. The x's in the table show that our study averages are not slow enough to be on the spectrum of RA disability, except in the most extreme restriction group. Table16 shows, from top to bottom, the performance of both hands of, the PWD group, then the FSU group performing the 9HPT as themselves without the suit, then the FSU group in the suit, then the PMR group, then the SSU group, then the participants from Exp2 who were outliers in that they showed a much greater dexterity restriction than any of the others.

Table 16: Placement of the 9HPT data on the disability spectrums described in [173,174,175]

Masters data	**Avg Time (Sec)**	**EDSS**	**H&Y**	**RA**
G1Dom	23.7	2.5-3	1	x
G1ND	26.7	3.3	1-1.5	x
G2ADom	19.5	1	faster	x
G2AND	20.8	1.3	faster	x
G2BDom	28.9	3.5-4	2-2.5	x
G2BND	36	6.3	3	avg match
PhD data	**Avg Time (Sec)**	**EDSS**	**H&Y**	**RA**
PMRDom	20.6	1.25	faster	x
PMRND	24.8	3-3.5	1	x
SSUDom	25.9	3-3.5	1.5-2	x
SSUND	26.8	3-3.5	1-1.5	x
8&10	36.5	6.4	3	avg match

As can be seen from Table 16 comparing the placement of both experiences along the three scales for the external disability studies, there is a discernible difference between the levels of restrictions provided by the first and second suits. The second suit is not as physically restrictive along with the dexterity aspect as the original suit. This is expected given that the version 2.0 suit was modified with the intent of making it less restrictive than the prior Exp1.

This is a good indication, given that the suit was designed in a modular manner, so that in future it could be adjusted or tuned to mimic various disability levels. Stiffer bands and plastic inserts and wires could be used to increase the resistance. Furthermore, some areas of the suit's resistance could be increased, and other areas decreased in order to mimic a particular disability/injury/restriction, for more targeted study in future.

4.3.3 Additional Analysis of the Functioning of the Motion Restriction Simulation Suit:

For Exp2, we also have the ability to compare across other functionality aspects that were not available for Exp1. These comparisons of suit functionality to normative data address Q 1.2.2 "Does the additional OT information allow us to determine the placement and range of restrictions of participants in regards to normal functioning as established by other associated external data sets?" Details on the OT functional capability metrics are contained in Chapter 6, making this a section preliminary positive report on their usage. The amount of comparison and inference possible during these results carry over into chapter 6 to inform the general research question 3.

There are options beyond the 9 hole peg test (9HPT) where normative data is available and statements can be made as to the level of restriction or disability being simulated. Such data is available for Grip strength from [177], Key Pinch norms from [178] and Box and Blocks Test norms from [194]. The spectrum for presenting this information is chosen to be the standard deviations of the data. Each participant is generically identified by gender and decade of age. For each column of test data, the participant's rating is listed as a pair with the first pair being the dominant hand (L or R) and its rating and the second pair being the non-dominant hand and its rating. Definitions for the ratings are at the bottom of each column of test data. Visual breakdowns, such as that in Figure 26-27, for the various restriction levels by tests are provided in the Appendix N, but Table 17 below provides the most compact information.

Table 17: Placement of Metrics on the Spectrums of Normal Functioning on 4 Tests

Participant #	Gender	Age	Type	BBT	9HPT	Grip	Key Pinch
2	m	61-70	pmr	R2-L2	R0-L1	R3-L2	R1-L1
3	f	51-60	pmr	R1-L2	R2-L1	R3-L3	R3*-L3
4	m	20	ssu	R3-L3	R3-L3	R1-L1	R1*-L1*
5	m	21-30	pmr	R2-L3	R0-L3?	R2*-L3	R2*-L3
6	m	19	ssu	R3-L3	R3-L3	R2-L2	R1-L1
7	f	19	ssu	R3-L3	R3-L3	R2-L1	R1*-L1*
8	f	41-50	ssu	L3-R3	L3-R3	L3*-R2	L1-R1*
9	m	51-60	ssu	R2-L1	R0-L1	R2*- ?	R3-L3
10	m	19	ssu	R3-L2	R3-L3	R3-L3	R3*-L3*
11	m	18	ssu	R3-L3	R3-L2	R2-L3	R2-L2
12	f	19	ssu	R2-L3	R3-L3	R2-L3	R1*-R2*
13	f	20-29	ssu	R2-L2	R2-L3	R2-L3	R1*-L1*
14	m	30-39	ssu	R2-L2	R1-L2	R1*-L1*	R3*-L3*
15	m	20-29	ssu	R2-L2	R3-L3	R1-L1	R2*-L1*
16	m	20-29	ssu	R1-L2	R3-L2	R0-L1	R1-L1*
				0= n/a	0= n/a	3*=stronger outside 2SD	3*=stronger outside 2SD
				1= mild = outside 1 SD	1=mild	2*=Stronger within 2SD	2*=stronger outside SD
				2=medium = outside 2 SD	2=medium	1*=Stronger within SD	1*=stronger within SD
				3=Major = outside 3 SD	3=Major	0= normal	0= normal
					outside 1 SD	1=restricted within SD	1=restricted within SD
					outside 2 SD	2=restricted outside SD	2=restricted outside SD
					outside 3 SD	3=restricted outside 2SD	3=restricted outside 2SD

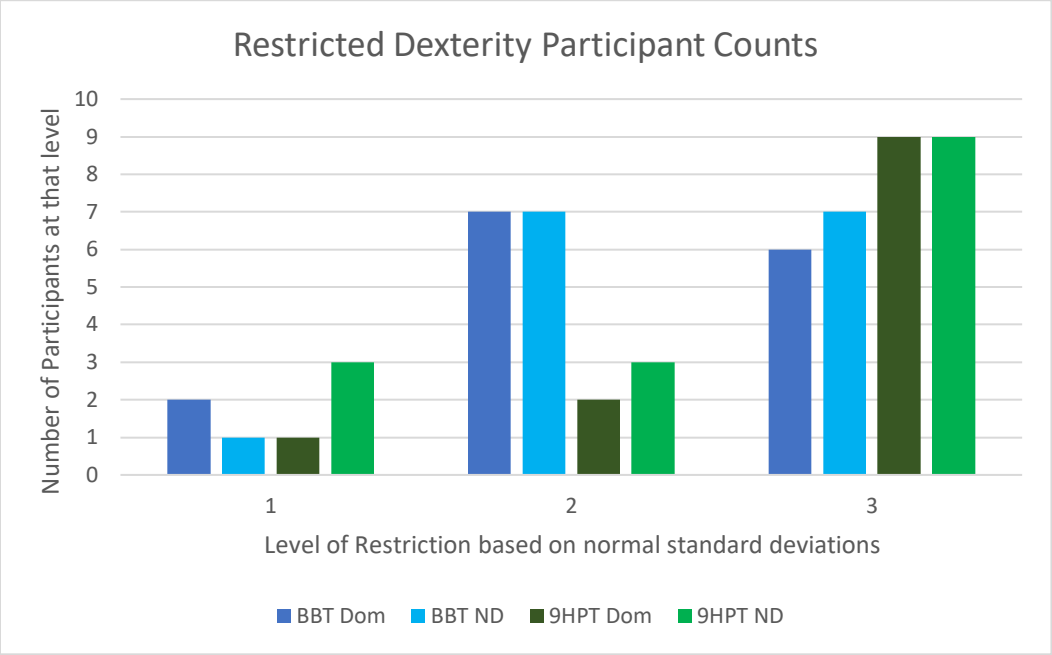


Figure 26: Restriction Count Visualization Example

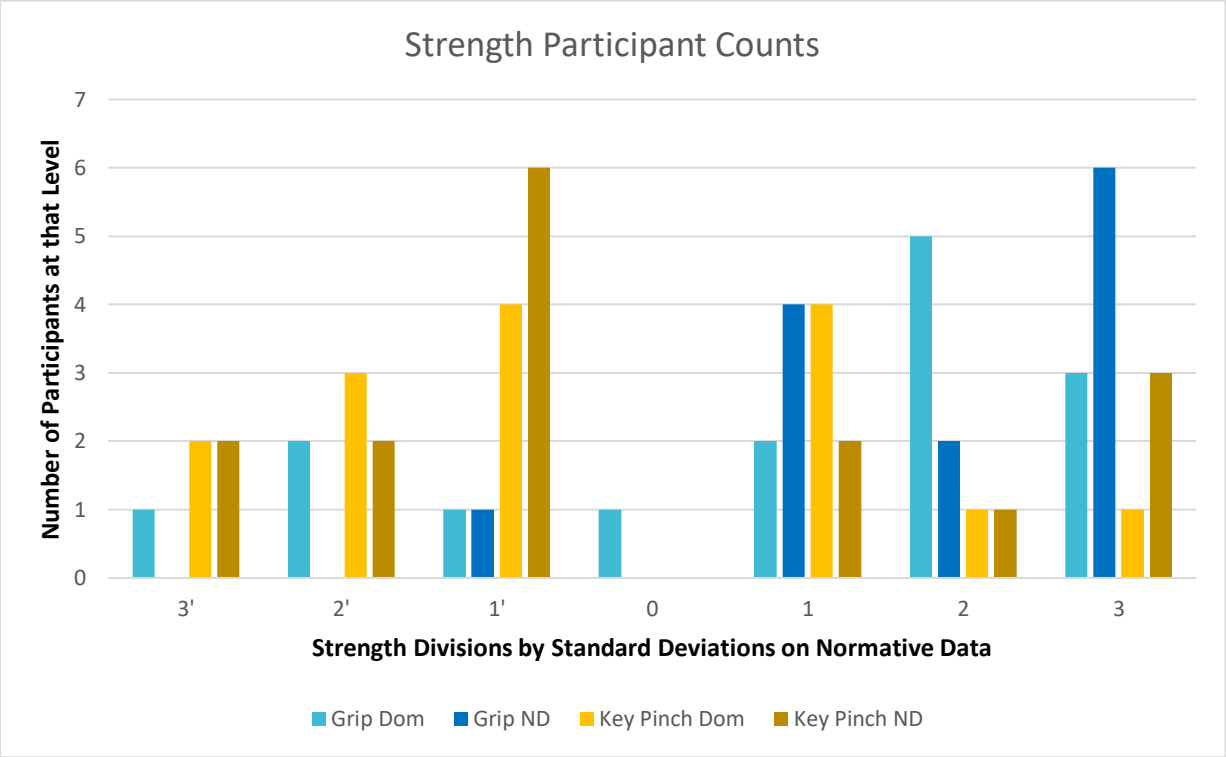


Figure 27: Strength Test Results Chart

The results by subgroup cannot be averaged and then subsequently placed on the spectrum, since the normative data is divided by age/gender. However, once participants have

been assigned a value on the spectrum, these values can be manipulated. If we consider 1 to be mild, 2 to be medium, and 3 to be a major deviation from normal functioning, those numbers can be averaged across groups of interest.

Table 18 below shows the group and subgroup averages for each test. The negative numbers indicate better than average functioning, as linked to the external study data in [176-178, 194]. It is organized by Dominant (Dom or D) and Non-Dominant (NonDom or ND) hand, following the standards of the tests/data.

Table 18: Average Restriction Levels.

	PMR		SSU		EXP2	
	Dom	NonDom	Dom	NonDom	Dom	NonDom
BBT	1.67	2.33	2.43	2.42	2.27	2.4
9PHT	0.67	1.67	2.5	2.58	2.13	2.4
Grip	1.33	2.67	0.75	1.73	0.87	1.93
Pinch	-1.33	2.33	-0.17	-0.67	-0.4	-0.07

From this table several things can be observed.

The key pinch tests are not showing a very high level of restriction, compared to the other tests. The participant groups are exhibiting better than average functioning for the Pinch test, with only 4 participant showing overall restrictions (from the last column of Table 17). This result makes sense, given that there is no thumb restriction in the simulation suit and the key pinch relies primarily on thumb strength.

The grip test is also lower than the dexterity based tests, showing that grip strength is effected less by the suit than dexterity.

Another logical and expected result is the fact that non-dominant hands overall perform worse than dominant hands.

Even after averaging results across groups, the average 9HPT and Grip results still show significant variation.

The most common restriction level across these tests is middle medium.

In addition to examining the “larger picture” provided by aggregating the data, it is always important to consider results on an individual level to avoid mischaracterized generalizations. This makes the main result the fact that there is quite a variability in the

restriction provided, on an individual level. The most common deviation rating number for the participant pool for BBT Dom is 2 and for ND 2 and 3 are equally common, for 9HPT D and ND is 3, for Grip is D is 2 and ND is 3, Pinch D is 1 and ND is -1.

The 9PHT results from this method of examination are in contrast to the other external disability studies. When comparing our 9HPT results to the *normative* data we show high levels of impairment. On the *disability scales*, our results are on the "low" end of the scales, or do not register at all. This showcases the fact that a level of restriction on the 'normal' scale, can seem minor on a 'disability' scale. This speaks further to the fact that subjective and objective measures are different, (which is further discussed in a later section).

The variation between functioning of participants makes sense, since the participants' base functioning will be at play here as well. This suggests that future tuning of the suit will need to start by measuring individual function first. Furthermore, if a particular quantity of restriction or a particular placement of participants in relation to normal is desired in future, examining the starting point of the individual and tuning the suit to match would need to be the procedure.

One limitation in suit functionality analyses for this study is that we cannot say quantitatively what the suit does to each individual. Given that Exp2 did not measure the individual's level of functionality without the suit, we cannot provide the percent restriction on an individual basis like we could with the Exp1 data. However, almost everyone expressed the idea that the suit was restrictive. We created a scale of expressed restrictiveness based on the comments overall and rated each person on it. This is the last column of Table 19. This process could also be done for the videos from Exp1 if further comparison on this score is desired later.

4.3.4 Validation of Empathic Experience

Another analysis for the effect of the suit is whether it is producing empathy in the eyes of the participants. This is done with the empathy question asked at the end of the study protocols for SSU participants. While the results are mixed in their intensity, they are still quite positive. Columns 2 and 3 from Table 19 below was produced by listening to the participant comments and interpreting the message. As would be expected, some participants use stronger words in their answer than others. Some don't actually answer definitively. The explicit answers are from when they actually answer 'yes' or 'no' to the empathy question before proceeding with an explanation. The implicit answers are taken from their general comments/explanations, when

they do not have a clear binary answer first. The perceived difficulty is developed from their comments in answer to the suit functionality question and is discussed later. It is clear that at least 80% of the participants were having an empathic experience. Therefore, the motion restriction simulation suit produces an empathetic response in participants and can be considered as a valid empathic design tool as well.

Table 19: Suit Functionality and Empathy Results

participant	explicit answer	implicit answer	perceived difficulty
4	yes	yes	5
7		yes	4
8	yes		4
10		no	3
11		yes	4
12	yes		5
13		no	2
14	yes		3.5
15	yes		5
16	maybe		3
			scale of 1-5
			1=no perceived impediment
			2=requires adjustment, but still easy to perform tasks
			3=suit provides noticeable impediment, but allows activity
			4=suit contradicts some normal muscle memory motions
			5=use of suit noticeably strains user

4.3.5 Summary

Summarizing the results of this chapter, the suit is producing an experience that mimics a moderate level of restriction or disability. The suit 2.0's modification was successful in that it produces a less severe restriction than the prior Exp1. The variability in the functional capability metric results shows that the suit has the ability to be tuned as needed for future studies. It also shows that the effects of the individual are always present and must be considered further as a confounding variable if it is desired for all participants to achieve a specified level of restriction Finally, it shows how sensitive the situation and experience are to slight variations. Further details on interactions between suit effects are discussed in Chapter 9.

Chapter 5: Ontology Results and Discussion

In this chapter, research question 2's overarching theme of the usefulness of a customer needs ontology to support a more thorough understanding of an exceptional user is examined. Results of the ontology reformulation effort and its application to hand-held inclusive products are presented and discussed (Q2.1, Q2.2, Q2.3). This is followed by the results of using the ontology code coverage as a comparison (Q2.4, Q2.5) between user subgroups (Q5.2) and product types (Q5.1).

5.1 Ontology:

The results are divided into five sections for ease of understanding. I discuss the inter-rater agreement numerical analysis results (§ 5.1.1), the reconciliation process and results (§ 5.1.2), the results of the analysis of which raters agreed more often (titled rater pairings) (§ 5.1.3), the consistency checking (§ 5.1.4), and the difference in rater coding strategies (§ 5.1.5).

5.1.1 Inter-Rater Agreement:

The entire table of the calculated percent agreements is presented in Table 20.

Table 20: Percent agreement table separated by taxonomy, by product, by subset and by number of raters in agreement

three agree	Market	Message	Performance	What	**two agree**	Market	Message	Performance	What	**none agree**	Message	Performance	What
J	50	32	54	18	**J**	50	61	39	71	**J**	7	7	11
C	57	27	43	35	**C**	43	51	41	59	**C**	22	16	5
G	53	43	37	37	**G**	47	43	60	50	**G**	13	3	13
SGP	62	23	27	23	**SGP**	38	73	62	73	**SGP**	4	12	4
CGP	56	30	22	30	**CGP**	44	56	67	63	**CGP**	15	11	7
TJO	52	24	28	34	**TJO**	48	45	59	45	**TJO**	31	14	21
BJO	41	38	21	31	**BJO**	59	41	76	59	**BJO**	21	3	10
RCO	55	31	17	38	**RCO**	45	55	69	55	**RCO**	14	14	17
WCO	44	19	31	36	**WCO**	56	61	58	56	**WCO**	19	11	8
pairs	54	34	44	31	**pairs**	46	52	46	60	**pairs**	15	9	9
prod	51	27	24	32	**prod**	49	55	65	56	**prod**	18	11	11
whole	52	30	31	32	**whole**	48	54	58	58	**whole**	17	10	11

For each CN it was marked if there was agreement for the code between all three raters or only two raters or zero raters. The number of 3/2/0 agreement was counted for each individual need set. This was divided by the number of needs in that set, to get the percent of possible agreement. This was also done for each experience set (the three sets of needs from the product

pairs from the original experience, and the 6 needs sets from individual products from the new experience) and the whole CN set. A significant number of needs were agreed upon by either two or three of the raters. This percent agreement varied somewhat by taxonomy, with certain categories having better averages or higher spreads than others.

Having all three raters agree on less than fifty percent of the needs in a data set only happened in two of the individual products (10/12 data sets) for the Market taxonomy, with three rater agreements happening 52.25% of the time across the entire needs set. The highest agreement percentage was 62% and the lowest was 41%. In the Message taxonomy, the total average agreement was 30%, with a spread of 19-43%. In the Performance taxonomy there was a total rater agreement percentage of 31%, with a spread of 17-54%. Finally, in the What taxonomy there was an average of 32% total agreement, with a spread of 18-38%.

The two rater agreement percentages were higher overall. For the Market, two raters agreed 48% of the time, with a spread of 38-59%. For the Message, two raters agreed 54% of the time, with a spread of 41-73%. For the Performance two raters agreed 58% of the time, with a spread of 39-76%. Lastly, in the What, two raters agreed 58% of the time, with a spread of 45-71%.

No consensus was found a very small amount of the time. Since the Market taxonomy has only two options, it is impossible for none of the raters to agree. This would change if more categories were added. In Message, no consensus was found 17% of the time, with a spread of 4-31%. In Performance, no consensus was found 10% of the time, with a spread of 3-16%. Finally, in the What taxonomy, the average was 11% with a spread of 4-21%.

A lack of consensus only occurred 12.33% of the time for the entire needs list across those taxonomies where it was possible to have no consensus. This was considered very good. Given the fact that the two or three rater agreements covered 87.66 % of the needs, it was deemed acceptable to use those codes with two rater agreements as the final codes. Therefore, reconciling only needed to happen for the CNs with no initial agreement. The high rate of agreement lends confidence to the methodology of applying this ontology to these customer needs.

5.1.2 Reconciliation:

The reconciliation process was done in person over the course of only an hour. The process was: the lead researcher read the need, then voiced their opinion, then the other raters voiced their opinion, and a decision was reached. Sometimes we checked to see what each of the raters had put down as the initial rating, while other times this was not necessary. On some occasions the discussion focused on how the definition of a category informed the code, and how it related to the customer need. Sometimes there was a check for internal consistency, in that we would look up a similar need on a different list and see what it was coded as. For many of the needs that appeared multiple times on the list, sometimes they had a final code already that we could either agree with or change based on the discussion.

A few general points that came out of the reconciliation discussion follow. The constraint category was used if the need states whether or not the product does something or has something – interpreted more as a "does it" or "does it not" category. Deciding if it places a limit on the design seemed like reading too much into it. This may be a suggested definition revision for later. Specification does not have to have the bounds specifically stated in the need if the raters know that the aspects under discussion have easily identified bounds in the data - it can be a specification need. Customer needs tended to have key words that guided the raters towards specific category, such as "easily" implying objective or "handle" implying feature. However, this was not pervasive enough to be made into rules. The 'objective' category may be unfortunately subjective, since the definition contains the word "attribute," which is very different than a performance direction. The definition seemed too broad. This may have been due to the fact that our customer needs had performance aspects to almost everything, therefore most attributes also had a target direction, such as "easily" or "small," which are non-bounded specifications and indicated a target direction for the designer. Therefore, if it is determined that the performance related categories should remain in their own taxonomy, the objective definition will definitely need to be changed to reflect this relationship.

Most of the discussion and most of the uncertainty revolved around the categories and ordering of the Message taxonomy. This makes sense given the numerical evidence discussed earlier. The conclusion is that the Message taxonomy is most in need of definition work.

5.1.3 Rater Pairings:

I performed an analysis on which raters agreed more often. Since there was a built-in difference in raters' experience with both the ontology and customer needs, such analysis helps to inform who can use the ontology more easily and effectively, which is good information for the future. This was done similarly to the percent agreement. It was calculated what percent of the needs of each set each rater pair agreed on. The table of these calculations can be seen in Figure 28.

Rater 3/1	Market	Message	Perform	What
J	82	57	57	54
C	86	35	68	51
G	83	57	53	53
SG	81	50	50	42
CG	81	44	63	48
TJ	83	34	62	52
BJ	76	62	52	41
RC	79	62	52	52
WC	58	33	53	56
pairs	84	48	60	53
products	76	47	55	49
whole	84	48	57	50

Rater 2/1	Market	Message	Perform	What
J	68	46	68	43
C	68	54	54	54
G	63	50	73	57
SG	81	42	54	65
CG	67	56	33	70
TJ	62	31	52	55
BJ	66	41	52	69
RC	69	34	41	59
WC	50	33	44	64
pairs	66	51	64	52
products	65	39	46	64
whole	65	43	52	59

Rater 3/2	Market	Message	Perform	What
J	50	54	75	29
C	59	43	49	59
G	60	67	43	50
SG	62	50	38	35
CG	63	44	37	37
TJ	59	52	28	41
BJ	41	52	34	41
RC	62	52	28	48
WC	42	33	31	44
pairs	57	54	55	47
products	54	47	32	41
whole	55	49	40	44

	Market			Message			Perform			What		
	R3/1	R2/1	R3/2	R3/1	R2/1	R3/2	R3/1	R2/1	R3/2	R3/1	R2/1	R3/2
J	82	68	50	57	46	54	57	68	75	54	43	29
C	86	68	59	35	54	43	68	54	49	51	54	59
G	83	63	60	57	50	67	53	73	43	53	57	50
SG	81	81	62	50	42	50	50	54	38	42	65	35
CG	81	67	63	44	56	44	63	33	37	48	70	37
TJ	83	62	59	34	31	52	62	52	28	52	55	41
BJ	76	66	41	62	41	52	52	52	34	41	69	41
RC	79	69	62	62	34	52	52	41	28	52	59	48
WC	58	50	42	33	33	33	53	44	31	56	64	44
pairs	84	66	57	48	51	54	60	64	55	53	52	47
products	76	65	54	47	39	47	55	46	32	49	64	41
whole	84	65	55	48	43	49	57	52	40	50	59	44

Figure 28: Percent of the needs in each taxonomy agreed on by each Rater Pair, organized two ways.

When looking at the Market taxonomy, Raters 1 and 3 agreed more across all datasets than anything else. In the Message taxonomy, Raters 3 and 1 agreed most often when counting through the highest agreement for each dataset, but when looking at the percent across the whole list, Raters 2 and 3 agreed slightly more. This agreement was lower, and therefore mixed. In the Performance taxonomy, Raters 1 and 3 agreed most often most of the time, but to a lesser extent than in the Market taxonomy. In the What taxonomy however, Raters 1 and 2 agreed most often almost all of the time. This indicates an experience component to the reliability when coding in this category. One of the reasons speculated for these results is that Rater 3 came and asked some clarifying questions to Rater 1, after training and during their process. The other result is that the

message category once again demonstrates its higher uncertainty. The outlier of Rater 2 coding a lot more 2's in the Market taxonomy indicates a different attitude toward the niche field. The examination of the rater differences illustrated the fact that previous rater experience with customer needs and their information and mindset during coding will affect the agreement and should be controlled or taken into account.

5.1.4 Consistency checking:

Each rater expressed during reconciliation the fact that they believed there was some internal inconsistency among their own ratings. This fact was confirmed when looking at the final codes. For example, "be simple" was given the codes 1341 and 1344 (general/objective/none/(safety vs supporting function)). "Have a non-slip surface" was given 1412 and 1442 (general/solution/(constraint vs solution)/features). "Product should work quickly" had 1232 and 1332 (general/(specification vs objective)/device/features). "Product should be usable with only one hand" had both 2122 and 2124 (niche/constraint/humanfactors/(features vs supporting function)). "Product should hold onto the jar" had 1144 and 2444 ((general vs niche)/(constraint vs solution)/none/supportingfunction). "Product should provide feedback that it is secure" had 2424 and 2144 (niche/(solution vs constraint)/(human factors vs none)/supporting function). As you can see, the inconsistencies occurred throughout the taxonomies, not always in the same place, although mostly only one number in the code was inconsistent.

Further examination of where these inconsistencies occurred most often is recommended. This should be done before this ontology is used in future applications of the framework. Deciding on coding and reconciliation procedures prior to ontology applications and knowing the likely consistency effects should be part of the 'ontology choice' flowchart process.

The consistency issues were taken care of through another round of reconciliation, and a third party rater examining the inconsistent codes and recommending choices.

5.1.5 Rater Strategy Difference:

The very different strategies that each rater employed to complete the coding could be contributing to the different aspect of the agreement differences. Coding procedure was not controlled for in this study, but it was discussed. It turns out that all of the raters had very different strategies, with a mix of the possible approaches.

Rater three's strategy was to code each category at a time over one needs set at a time. The rater would read the definition of the last category in the taxonomy, read through one set of needs and mark any that fit that category, then move to the next category up the priority order, go through the need set and mark any that fit that category (making sure to recheck the needs already marked to see if it overrides). They would continue until the taxonomy was complete for that needs set. Then they would repeat with the next Taxonomy until that needs set is completely coded. Then repeat until all the needs sets are coded. The order they did the taxonomies was Market, What, Message, Performance. This was split between 3 sessions with three needs sets coded in one, four in the second, and the last two in the third. They thought the hierarchy was quite helpful. If they had to do it again they said that instead of doing one need set at a time, they would do all 9 needs sets with one category then move on to the next.

Rater one's strategy was to code each taxonomy at a time over all 9 need sets at a time. They read the Market Taxonomy definitions then started at the top of the needs set and read each need and decided what category in that taxonomy it is, code it, move on to next need, go down all 9 need sets. Then they did the Message taxonomy with the same method. Then the Performance, then the What. They took a day break in between each taxonomy, so that it was done in four rating sessions, each session coding the whole needs set. At the end, they did an additional session where they went back through all of the codes where they had marked an uncertainty (either in the form of ? or #? or #/#). These decisions were made in the context of each CN.

Rater two's strategy was to code the four taxonomies for a product and then move on to the next product. The strategy was intended to allow the customer needs for a given product to be fresh in the mind of the rater. At least one product was completely coded in each session, but the overall needs set took four sessions over the course of three days.

5.1.6 Ontology Use Discussions:

We have successfully addressed the research questions Q 2.1 Is it possible to code this type of customer need data with the CN ontology? and Q 2.2 How should the CN ontology be adapted to apply easily in this research? and Q 2.3 Have we achieved enough accuracy in coding to be confident in the results? All of these questions have positive answers.

Over the course of the research, the benefits of reorganizing the ontology were made apparent. Less conflict was present while coding, and while some uncertainty remained, the impression of the ease of the process was higher than with the original organization.
It will be up to future work to determine if this new scheme is more generalizable than the original, or if it is a good match more because of the style of the customer needs statements in this study. Either way, good information will be gained. If it is better overall, then we have achieved the next step in the overall evolution of the ontology. If it is not, then we have still informed the ontology coverage of another customer needs gathering technique. This can be added to the application knowledge for the ontology along with the # techniques from the original development [103].

The most helpful part of the ontology evolution in this research will be the new ordering scheme. Assigning weight and priority to need categories greatly eases the decision process when classifying needs. The priority order also helps foster agreement between raters on needs stated with more complexity.

The ontology organization determined in this study has shown good coding agreement. The fact that only 12% of the 271 needs showed disagreement is encouraging. The new Performance taxonomy and the new What taxonomy had good agreement, and a nice consistent spread.

Of all the categories, the Message taxonomy is most likely to be in need further definition with provided examples, or at the very least of reordering by preference. It was the least consistent taxonomy throughout the different aspects of the coding. This might be due in part to the fact that the coding is colored heavily by the raters' experience with customer needs, with design specification and requirements development, and with design in general. This inherent bias based on experience makes this category significantly less universally applicable, which is snot good since the ontology is meant to be a universal tool. The preference order of the Message categories was the least certain when the ontology was given to the raters, and the discussions demonstrated the lack of an obvious logical hierarchy, such as that in the Performance and the What taxonomies. A suggested reorder would be to go by the order of specificity. Solution is the most specific, telling the designer how to solve the need. Constraint would be the next most specific with the current definition since you must meet the boundary condition. Specification would be the next specific as it puts bounds on a target. Then Objective would be least specific

with either definition (trying to move the design in one direction, or simply identifying attributes with no performance aspect).

Finally, returning to the discussion of the two ways the ontology can help designers. I determined different outcomes for each aspect, as well as a new possible benefit. The first aspect pertains to whether the code for each need is an accurate reflection of the exact type of information and intent contained in the CN statement. It was determined that the new ontology organization provides an acceptable result. However, the remaining uncertainty suggests some level of automation would be beneficial. This can be computer automation or simply a much more rigorous training of raters and prescribed coding procedure. The second aspect pertains to the examination of the needs lists' coverage of the possible ontology space. This aspect remains a useful addition of the ontology, and an additional benefit for the separated Performance and What taxonomy organization. More information about the way the needs are covering the types of information can be provided by examining the needs lists and the different elicitation techniques which use these codes. One additional benefit of ontology usage was also discovered. The raters identified an increase in their personal understanding of the CNs and the customer's views of the product interactions developed during the process of coding. This translates to a benefit for any current product development cycle for which the ontology is used as a tool, as well as any designers' product development and customer needs gathering skills in general. Therefore, even if automation is produced for the coding of CNs for practical application, the process of using the ontology to classify needs will remain a useful teaching and learning tool.

One clear observation I was able to make about the effect of ontology usage was in regards to own my learning. Ontology use did develop my understanding and interpretation of customer need information. I was much more aware of the level of detail and less prone to leeway in my interpretation of similarity after ontology coding experience than I was before. This is well exemplified by the activity of revisiting the similarity determinations for Exp1. The fact that I went back through the similarity matching procedures for the Exp1 data, and came up with a different result than the original process, shows a change in thinking developed by the experience of ontology coding. I did several passes through similarity matching using different mindsets of strictness levels. I also had the impartial third party who had helped with the internal consistency checking for the ontology coding go through and perform the matching as a comparison. Figure 29 below shows part of the Excel file (just the Garlic Press List for PWD

participants for Exp1)to show what that looked like. For each CN on the PWD list I marked whether it had a match on the FSU list for certain (1), under some level of leeway or uncertainty (1?), or definitely did not match to any CNs on the FSU list.

			old				old	new	3rd party
G-2-01	require only small force to squeeze closed	1223	a	G-1-1	have an obvious holder	1321		0	0
G-2-02	be easy to grip/grasp	1322	f	G-1-2	require only modest hand spans	1224	h	1?	0
G-2-03	have large handles	2242	b	G-1-3	not be sloped	2142		0	0
G-2-04	have a large gripping surface	2242		G-1-4	provide stability	1334		0	0
G-2-05	provide force regardless of hand span or mechanism position	1134	q	G-1-5	have a non-slip grip surface	1412	d	1	1
G-2-06	sized appropriately for all hands	1222		G-1-6	parts should align automatically without manual adjustment	1444	i	1	1
G-2-07	accommodate any size garlic clove in compartment / holder	1132	c	G-1-7	be efficient	1334	m	1	1
G-2-08	be easy to pick up	1324		G-1-8	accommodate multiple sizes of garlic	1332	c	1?	1
G-2-09	have a non-slip surface	1412	d	G-1-9	have curved handles	2322		0	0
G-2-10	be simple	1331		G-1-10	prevent user fingers from being caught or squished	1114		0	0
G-2-11	allow one-handed usage	2124	e	G-1-11	be rounded so as not to cut into the hand	1111	p	1	1
G-2-12	transfer energy efficiently	1234		G-1-12	have obvious operation	1321	j	1	1
G-2-13	look simple	1321		G-1-13	have simple garlic insertion method	1324	g	1?	?
G-2-14	have a nice grip	1322		G-1-14	require only low grip force / pressure to close	1223	a	1	1
G-2-15	be easy to insert/load garlic into place	1324	g	G-1-15	have cushy grip surfaces	1422		0	0
G-2-16	feel durable	1321		G-1-16	be lightweight	1232	o	1	1
G-2-17	accommodate small hand spans	2322	h	G-1-17	have a thin grip	2242		0	0
G-2-18	require only low dexterity	1324		G-1-18	be large enough to accommodate both hands	2422	n	1	1
G-2-19	be compact	1332		G-1-19	provide a good grip	1322	f	1	1
G-2-20	provide a mechanical advantage	1133		G-1-20	have a familiar shape	1321		0	0
G-2-21	parts should align automatically without manual adjustment	1144	i	G-1-21	be easy to clean	1325	l	1	1
G-2-22	operation should be obvious / intuitive	1321	j	G-1-22	allow application of uniform pressure	1234	q	0	0
G-2-23	be aesthetically pleasing	1321		G-1-23	only involve one hand	2122	e	1?	0
G-2-24	be easy to maneuver / manipulate	1324	k	G-1-24	be conducive to apply pressure	1324		0	0
G-2-25	be easy to clean	1325	l	G-1-25	have large handles	2242	b	1	1
G-2-26	be efficient (material vs. effort)	1234	m	G-1-26	be easy to manipulate / maneuver	1324	k	1	1
G-2-27	be large enough to allow use of both hands	2422	n	G-1-27	employ pressing rather than squeezing mechanism	1434		0	0
G-2-28	be lightweight	1232	o						
G-2-29	have rounded edges so as not to dig into the hand	1412	p						
G-2-30	fit in the hand comfortably / well	1321							

Figure 29: Sample Exp1 Matching Revisit

Using this data, I could calculate difference levels of matching based on different levels of generosity of interpretation. For this, the 'strict' level is counting all 1?'s as 0's, the 'generous' level is counting all 1?'s as 1's, and the 'mid' level splits the difference. The results of this and the third party interpretation are shown in Table 21 below.

Table 21: Learning Effect on Similarity Determinations

List	percent coverage of PWD needs	OLD	New strict	New generous	New mid	3rd party
GP	55%	55.17%	44.4%	59.3%	51.9%	0.5000
CO	63%	62.96%	20.7%	44.8%	32.8%	0.34483
JO	82%	81.82%	45.5%	68.2%	56.8%	0.59091
	old= Exp1 similarity process	total	total	total	total	
	new= after coding training	66.65%	36.86%	57.42%	47.14%	47.86%

The similarity numbers for the Exp1 Data Lists went down significantly when examined through the lens of ontology coding experience. All results dropped the can opener pair below the acceptable need coverage range of 50%, while only the strict level of interpretation dropped them all below. While this does not necessarily invalidate the results from the previous work, it does indicate that experience level is of particular importance when performing validation calculations.

I will now give several examples of the discrepancies found. There were some obvious similarity changes, and some less obvious ones. For example, the original match between "allow application of uniform pressure" and "provide force regardless of hand span or mechanism position" was obviously no longer true, backed up by the fact that the codes are slightly different (1234 and1134 (the difference being between specification and objective)). The need statements "have a simple garlic insertion method" and "be easy to insert/load garlic into place" which matched for the master's work and are both coded as 1324 (general/objective/humanfactors/supportingfunction), are not precisely similar statements given that simple and easy are, while related, not necessarily solved the same way, and can involve different aspects of product function. Therefore they were marked as uncertain. Additionally, there was the statements "knob should be capable of breaking the seal" and "have a feature to assist with breaking the seal" which are quite related in that the first is, or could be, a detail or solution of the second. However, they are coded as 2434 and 1132 (niche/solution/device/supportingfunction and general/constraint/device/feature) and seemed like quite dissimilar intentions when re-reviewed, so they were marked as uncertain similarity. And finally we still had some obviously similar statements like "remain sharp for a long time" matching " remain sharp for as long as possible" and "have rubber coating" matching "have a rubber gripping surface". Even though they did not have the same codes (1232 vs 1334 (difference between specification vs objective and feature vs supporting function), and 1442 vs 2442 (difference between general and niche)). There is a certain amount of interplay between ontology interpretation and similarity interpretation and this process should be considered during framework use based on the individual design situation.

5.2 Subgroup Comparisons:

This section addresses the answer to research question Q 2.4 and Q 5.2.

There are several aspects across which we can compare the SSU and PMR subgroups; the CN lists, the code coverage, the physical limitations and the elicitation numbers. The first was presented as a validation activity earlier. Currently I will discuss the code coverage, in terms of both full codes and taxonomy breakdowns. All the rest will be discussed as part of other sections.

One issue to examine is, after applying the ontology throughout, what type of difference and similarity there is between the coverage of codes of the different groups. For this, histograms were developed with each subgroups' statements as a data series. Unlike other subgroup comparisons, where it is important to normalize the frequency by the number of people in the group, this frequency is the number of CNs on the lists, created using just the statements of that group, that have a certain code. The codes from both subgroups have been placed on a chart for each product. They have been placed along the horizontal axis of all the needs that were mentioned across all of Exp2 and are shown in Figure 30-35. This enables easier visual comparison. Figures that require specific explanation have discussion immediately after it is displayed. General discussion occurs following the display of all of the histogram figures. These graphs have also been provided in Appendix H in a larger form for easier viewing.

Histograms of Product Lists Separated by Subgroup:

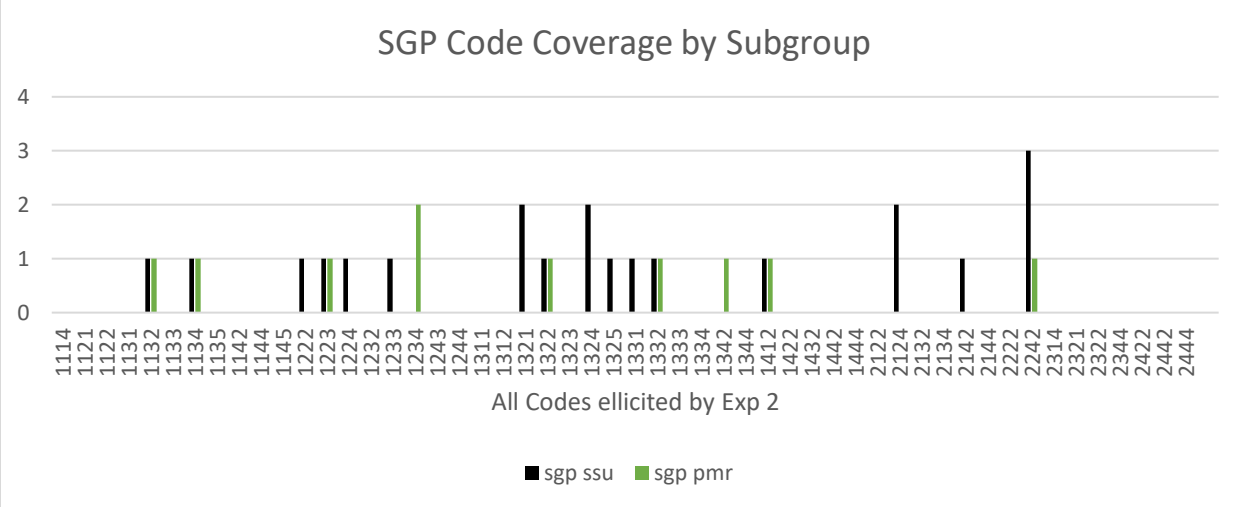


Figure 30: SGP Code Coverage by Subgroup

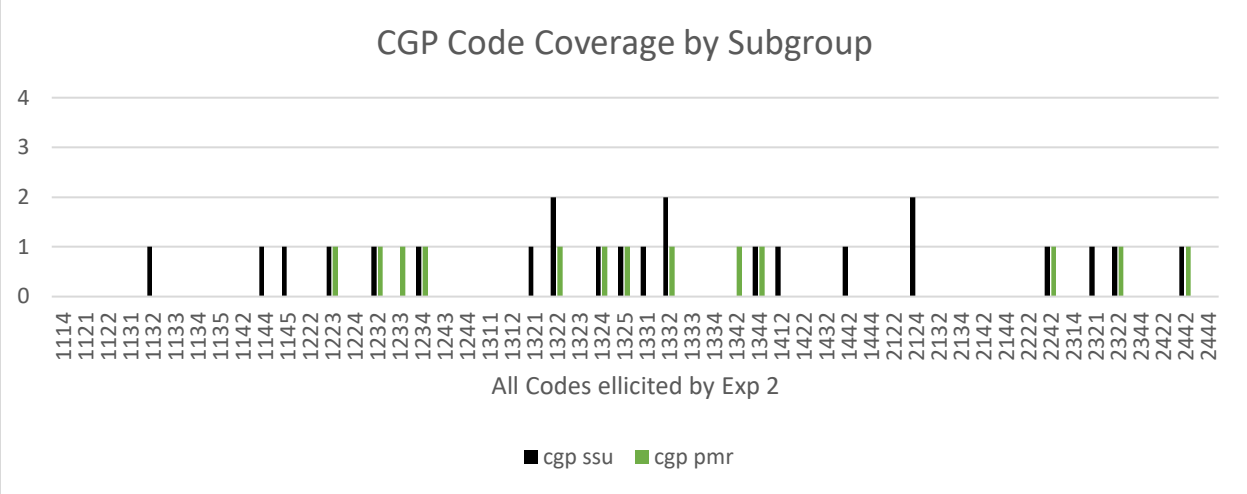


Figure 31: CGP Code Coverage by Subgroup

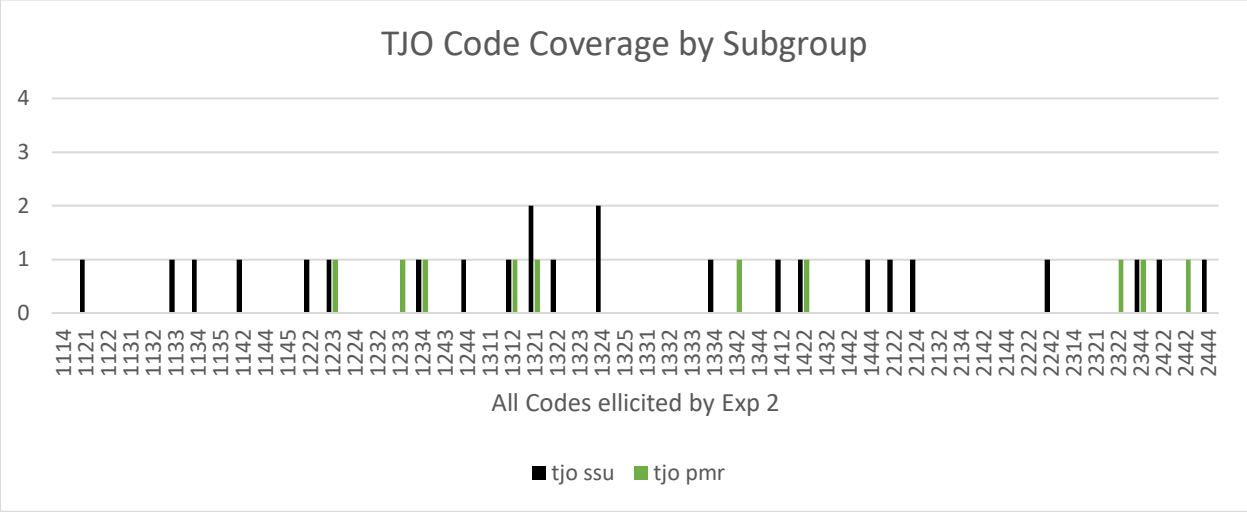


Figure 32: TJO Code Coverage by Subgroup

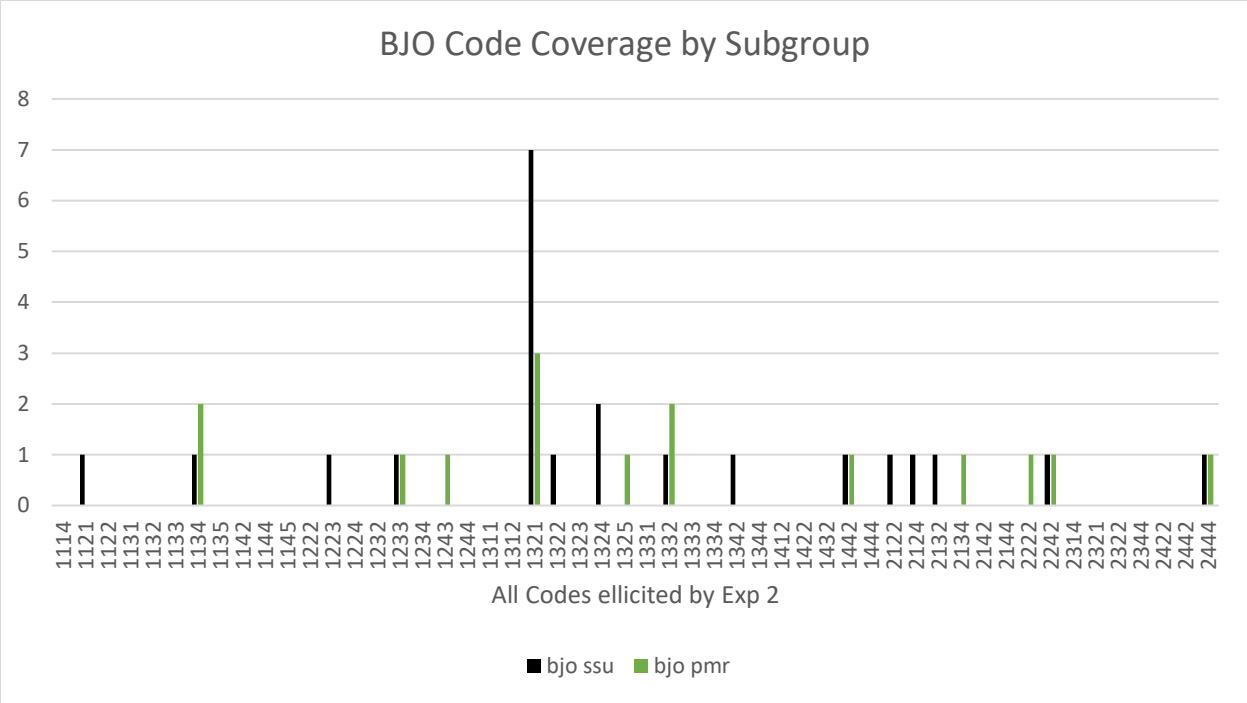


Figure 33: BJO Code Coverage by Subgroup

This product (the Exclusive Jar Opener) has the largest peak of all Exp2, with 7 in SSU and 3 in PMR on Code 1321. The 1321 code is General/Objective/HumanFactors/Aesthetics. This encompasses CNs such as “Be easy to Understand” and “Product should be comfortable to hold” and indicates that the interaction between human factors and aesthetics is significant for design.

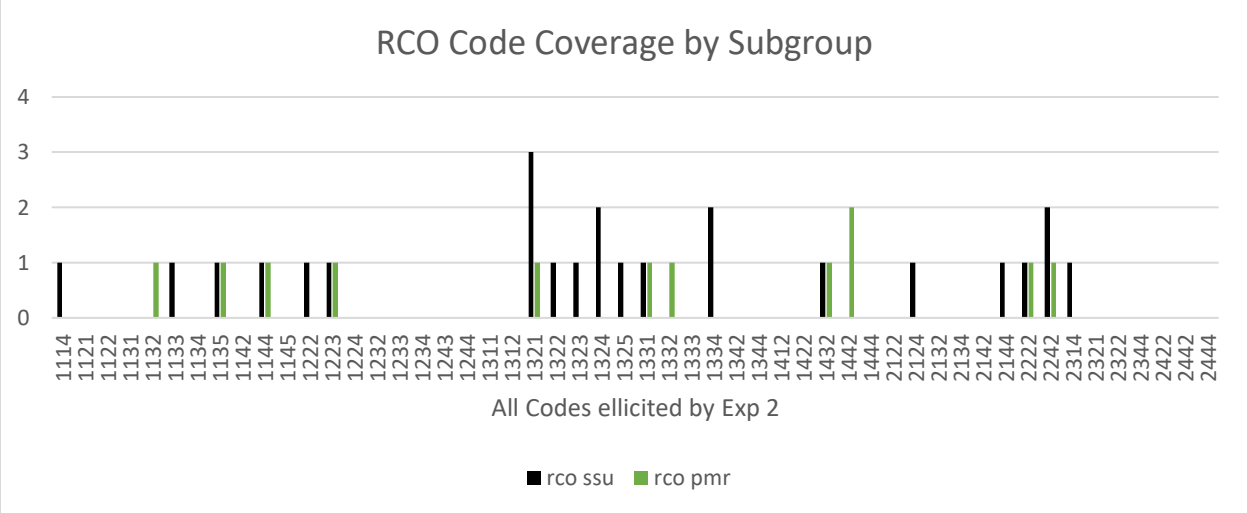


Figure 34: RCO Code Coverage by Subgroup

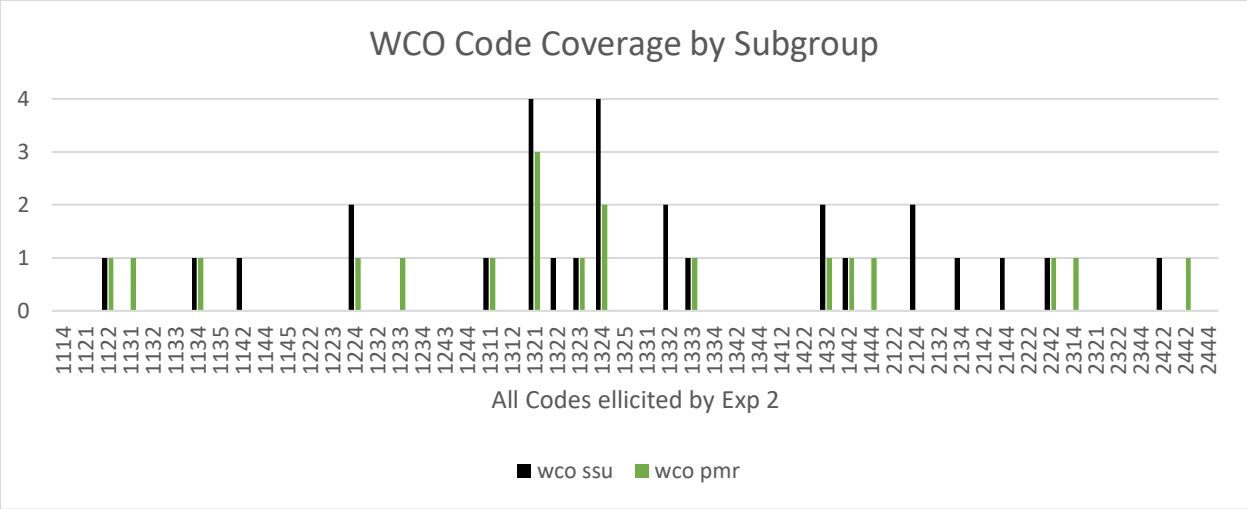


Figure 35: WCO Code Coverage by Subgroup

The SSU participants identified many of the need types that the PMR participants mentioned. The fact that, across the board, the SSU group has also stated most of the codes that the PMR group stated, reinforces the fact that the Exp2 methodology is prompting the surrogate users to find the majority of the needs that the actual exceptional users identify. This serves as a validation step on the code coverage aspect similar to that of the CN coverage aspect from an earlier section.

The data numbers for this is shown in Table 22 below. This table also includes how many SSU additions were made, even though that is not part of the validation, because it is of interest. This is not graphed by Subgroup in the same way as Exp2 since Exp1 separated the lists differently, but the numbers could be obtained in aggregate.

Table 22: Exp2 Codes Coverage and Additions of Interest

Exp2	
% of PMR codes covered by SSU	% of the SSU list only SSU said
72.9	40.7
Counts of PMR covered by SSU	Counts of the SSU list only SSU said
51	46

Additionally, the SSU participants identify need types that the PMR participants do not. This may be due to: 1) the SSU participants' new status as an individual experiencing a restriction or disability (and thus identifying issues that persons who have experienced a

restriction or disability for longer may have learned to overcome and now ignore); or 2) the SSU participants continuing to identify needs from their non-restricted typical experience. In either case, this result is viewed as positive, as it produces a more complete set of customer needs from which a designer may develop a product that performs in an inclusive manner.

One of the main reason associated with an increase in the frequency and coverage of the SSU group is the fact that the SSU group made significantly more CN statements than the PMR group. Adding more statements to a set number of categorical possibilities, by nature, increases the magnitude and breadth of coverage.

Returning to specifics of the codes used by the participants, when there are peaks in the frequency of the code, it tends to occur for codes that are also stated by the PMR group, rather than only an SSU stated code. This occurs in 13 out of 25 peaks, which equals 52% of the time for the whole experience. The peaks in the code frequency will be further discussed in Chapter 5, in a dedicated subsection entitled 'Top Codes.'

Disregarding frequency and focusing solely on code coverage, the amount of matched and unmatched codes and what group they come from is now discussed. The information for this has been collected in Table 23.

Table 23: Subgroup Codes Matching Analysis

Subgroup Code Coverage Amounts and Matches							
Product List	Total Codes Covered	Matched Codes	Codes by only SSU	Codes by only PMR	peak codes by SSU	peak codes by PMR	peak codes Total
SGP	18	7	9	2	4	1	5
CGP	22	11	8	2	3	0	3
TJO	26	6	16	4	2	0	2
BJO	19	7	8	4	2	3	4
RCO	21	8	10	3	4	1	5
WCO	23	11	7	5	6	2	6

The SSU group produced more lone codes in their coverage than the PMR group. The PMR group produced less unmatched codes than they do matched codes. The SSU group produces more unmatched codes than matched codes in 4 out of 6 products. The total number of unmatched codes is higher than the total number of matched codes in (the same) 4 out of 6 products.

As a reminder of what the ontology code numbers mean…

Category	Value	Classification
Market	1	General
	2	Niche
Message	1	Constraint
	2	Specification
	3	Objective
	4	Solution
Performance	1	Safety
	2	Human factor
	3	Device
	4	None
What	1	Aesthetics
	2	Features
	3	Main function
	4	Supporting function
	5	Environment

Figure 36: Ontology Code Naming Reminder

The analysis of where on the code axis they match and where they don't is much more complex an issue. This visual inspection and inference procedure is subjective and produced tentative results.

There are a few ranges of noticeable lack of coverage. The range of 1442-2222 is generally not covered by PMR. This area encompasses the last two general needs of general/solution/none/(features/supporting function) and the beginning of the niche category dealing with all of the niche/constraint needs. That region generally has 2-3 codes by SSU in it. Some of them have PMR gaps covered by SSU in all of the 11##'s (all of the general/constraint codes) and some have that gap at 1323-1331 (general/objective/human factors/main function through general/objective/device/aesthetics), but these are not as consistent, and not always attached to the same product type.

Interestingly, the code 1323(general/objective/humanfactors/mainfunction) is a peak for all but one list and not also stated by PMR for all but two. Also with peaks, the products that peak less, appear to be clustered together on the code space less as well. I would also call the PMR codes shifted to the right slightly in those places where it is not spread evenly.

For more detailed comparisons, the code coverage can be broken down by taxonomy. The finer level of detail provided by individual taxonomy analysis may reveal something hidden

at the full code level. To this end, I now present one product's customer needs lists codes (the RCO – red can opener) that are broken down by taxonomy and subgroup in Table 24 and graphically in Figures 37-40. This has three subgroups, the codes stated by only SSU participants, the codes stated by only PMR participants and the codes stated by both types.

Table 24: Taxonomy Breakdown by Subgroup for RCO

RCO	Subgroup SSU							
	Market		Message		Performance		What	
Code	Percents	Counts	Percents	Counts	Percents	Counts	Percents	Counts
1	75.0%	18	25.0%	6	8.3%	2	12.5%	3
2	25.0%	6	20.8%	5	45.8%	11	29.2%	7
3			50.0%	12	25.0%	6	12.5%	3
4			4.2%	1	16.7%	4	37.5%	9
5							8.3%	2
RCO	Subgroup PMR							
	Market		Message		Performance		What	
Code	Percents	Counts	Percents	Counts	Percents	Counts	Percents	Counts
1	83.3%	10	25.0%	3	0.0%	0	16.7%	2
2	16.7%	2	25.0%	3	25.0%	3	58.3%	7
3			25.0%	3	41.7%	5	8.3%	1
4			25.0%	3	33.3%	4	8.3%	1
5							8.3%	1
RCO	Subgroup Both							
	Market		Message		Performance		What	
Code	Percents	Counts	Percents	Counts	Percents	Counts	Percents	Counts
1	71.4%	5	14.3%	1	0.0%	0	28.6%	2
2	28.6%	2	42.9%	3	42.9%	3	42.9%	3
3			28.6%	2	42.9%	3	14.3%	1
4			14.3%	1	14.3%	1	0.0%	0
5							14.3%	1

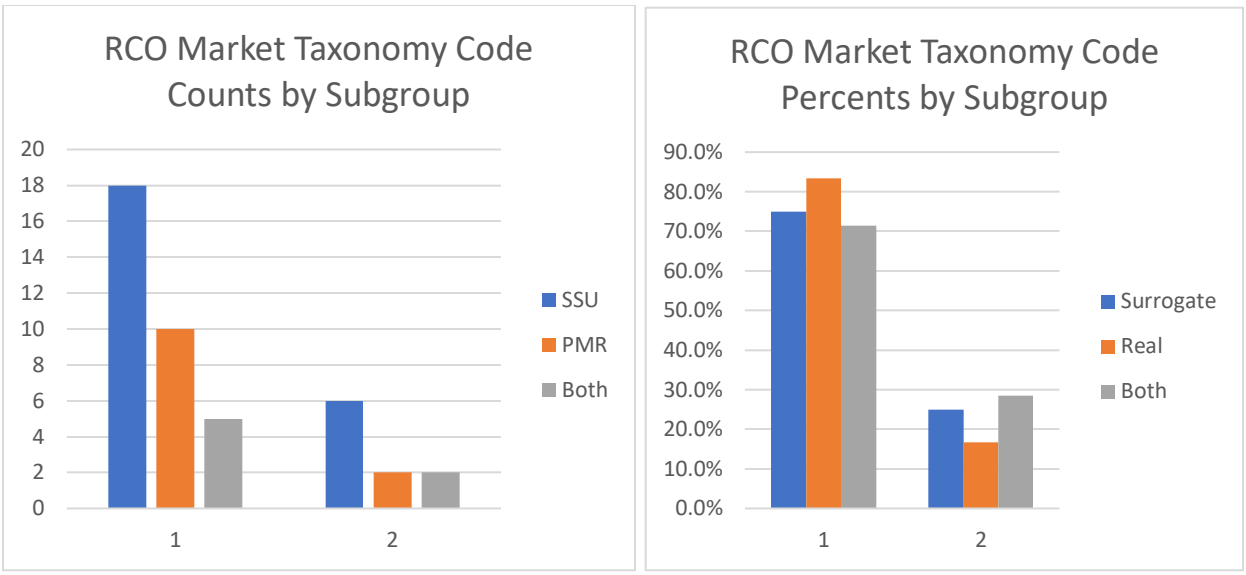


Figure 37: RCO 'Market' taxonomy Graphs

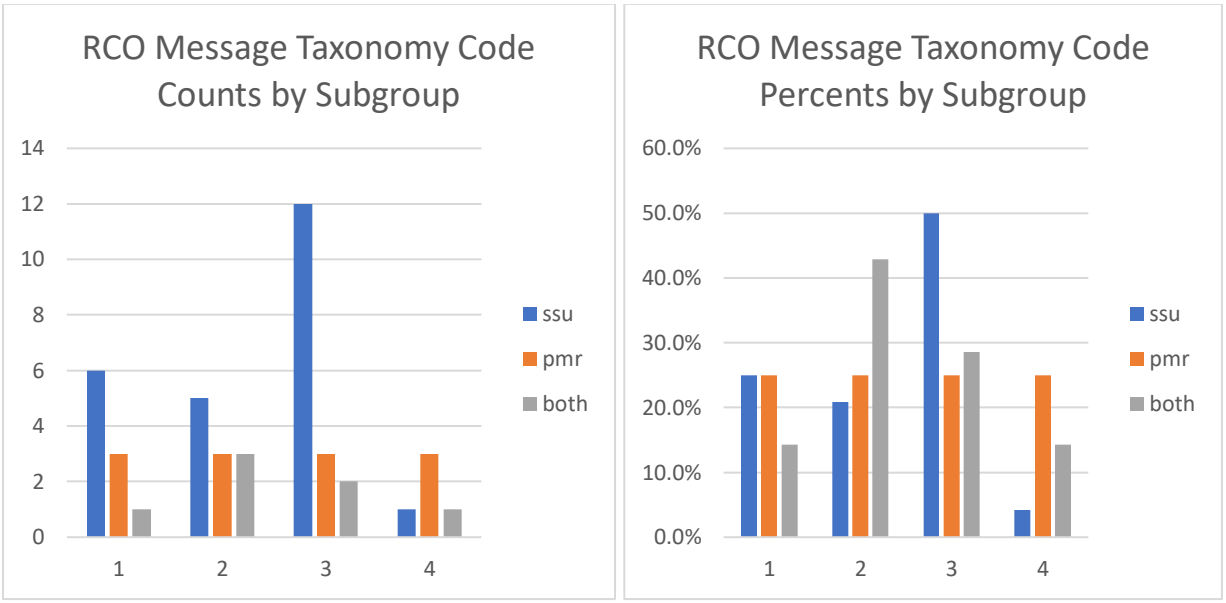


Figure 38: RCO 'Message' taxonomy Graphs

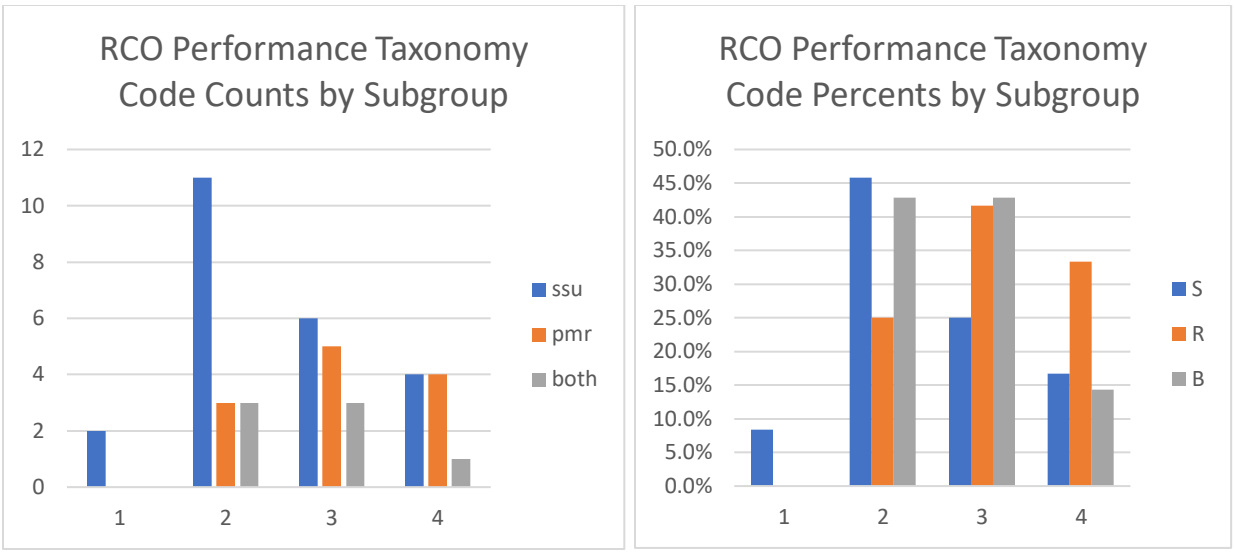


Figure 39: RCO 'Performance' taxonomy Graphs

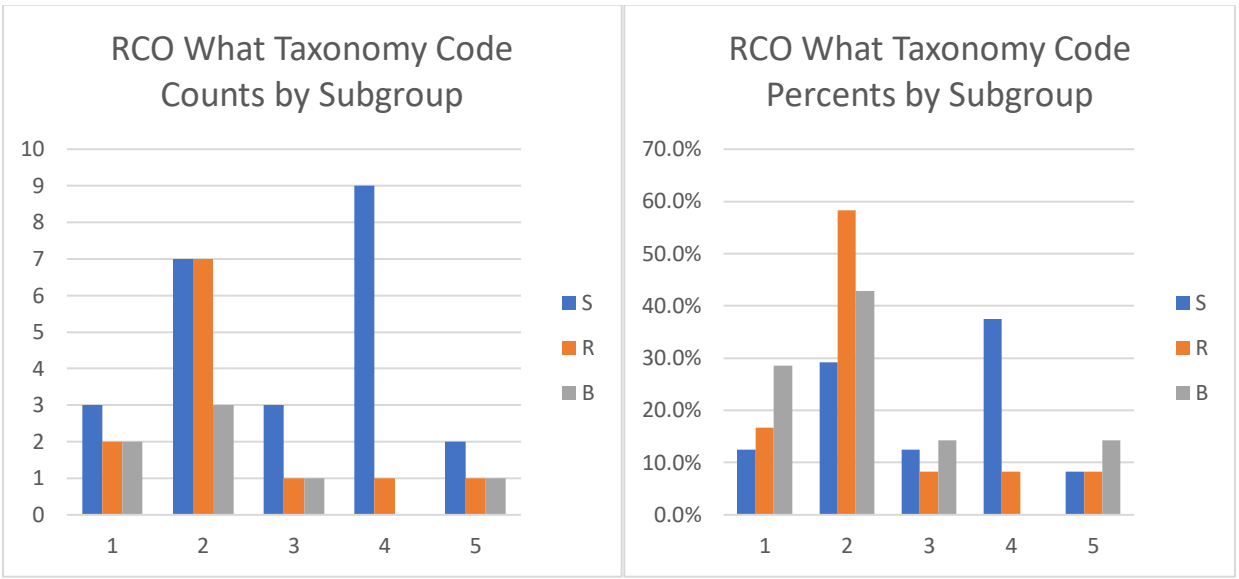


Figure 40: RCO 'What' taxonomy Graphs

These indicate that the highest occurrence code type that the subgroups match on is 1232 or 1222 meaning general/specification/HForDevice/Feature. This indicates that feature specifications of particular importance to all user types, even if the details of those feature specifications may conflict between groups. Both groups are producing the logical 75/25 split in general and niche needs, which backs up the choice of split as still useful for inclusive investigations. Performance is also fairly evenly split between HF and Device, with Device slightly higher is EUs, as is logical. The fact that only SSU noticed safety needs is interesting.

The groups agreed most often on the main function needs, which also makes sense. Also interesting is how SSU noticed that they noticed so many more Supporting function need, and the groups did not overlap at all in which SF needs were identified. This indicates a potentially significant difference in subgroup mindset.

Now it is useful to examine the whole experience to get a better idea of the overall differences in the subgroups. For this, all products' codes were combined for each subgroup, and displayed in Figure 41-42. The fact that SSU covers more than PMR is obvious, even with them not being on the same axis, but they are also plotted on the same axis in Figure 43, for a clearer illustration. The shape of the graphs (apart from the tailing off of the higher frequency shape to the right of the 1321 peak in SSU), seem to be basically the same. Looking specifically at the orange bars in Figure 43 and 45, identifies only two codes that are stated by PMR are not stated by SSU. The SSU group is adding 13 codes, none of which are peaks.

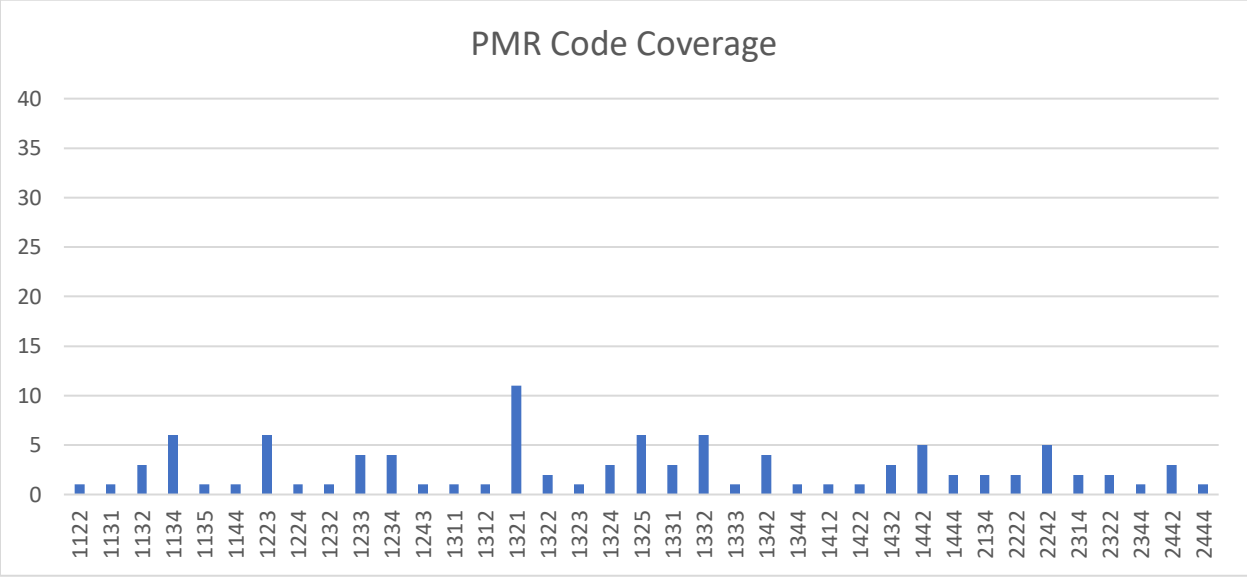


Figure 41: PMR Group Code Coverage for Exp2

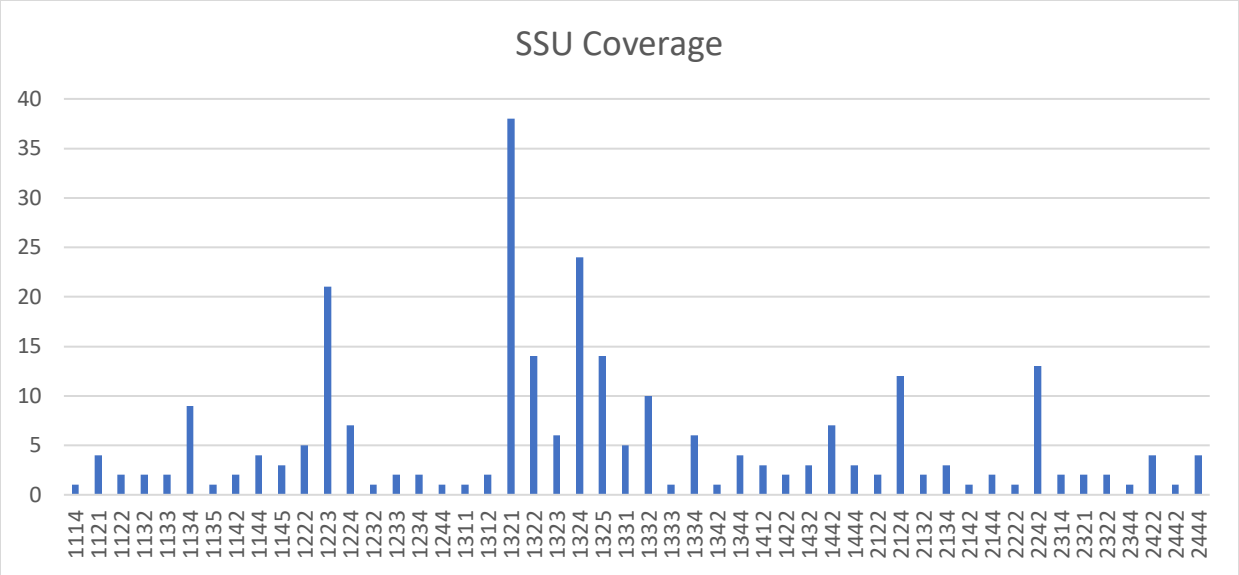


Figure 42: SSU Group Code Coverage for Exp2

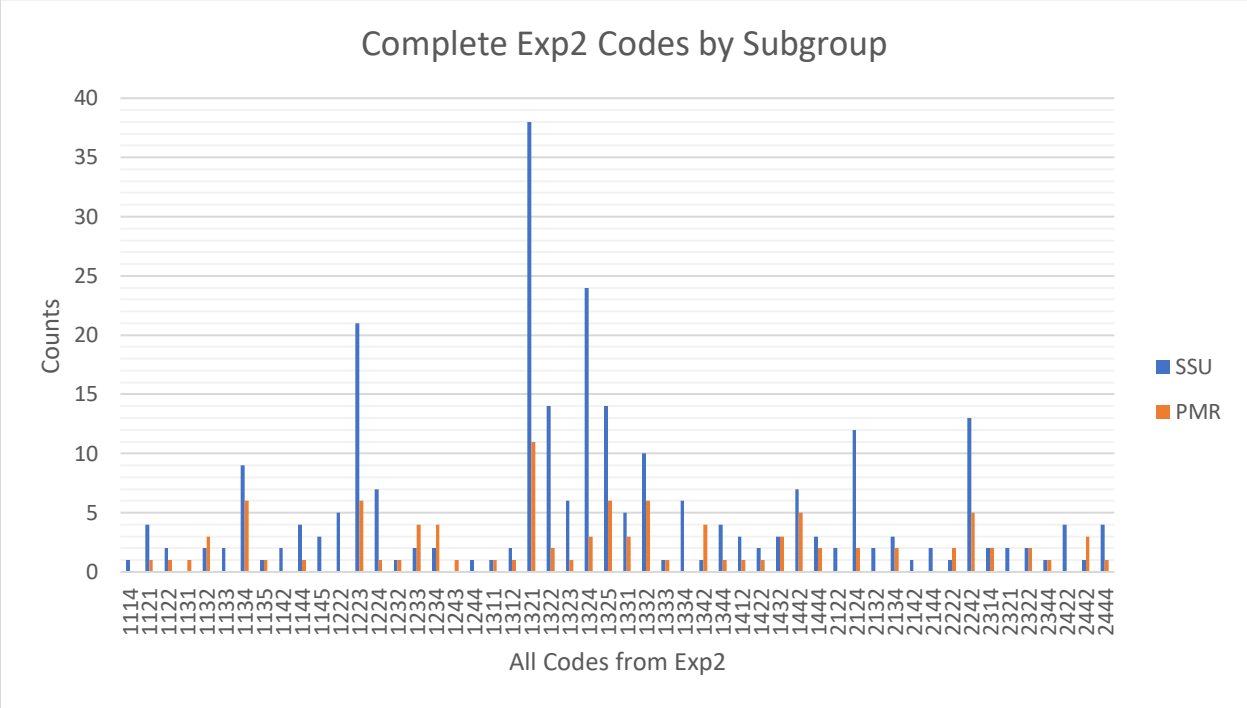


Figure 43: Subgroup Codes on the Same Axis

Now I examine what it looks like when these the coverages are placed on the axis of the complete possible ontology codes. This graph is presented sideways and expanded in Figure 45 in order to have all marks visible. The extra unmatched coverage of the SSU group through the low niche segment is even more obvious on this graph while the other observations become even

less obvious. One notable finding, even with SSU covering more than PMR for this set of products, a large portion of the code space (>50%) is not covered by the current set of customer needs. This is shown more effectively by Figure 44 with the used codes shown by blue line being a minority in the visual space. This could mean that the unused codes in the space are not aligned with inclusive design needs for handheld or hand manipulated manual products. This type of finding can focus the designer on a subset of need types to query from potential customers in order to design an inclusive product.

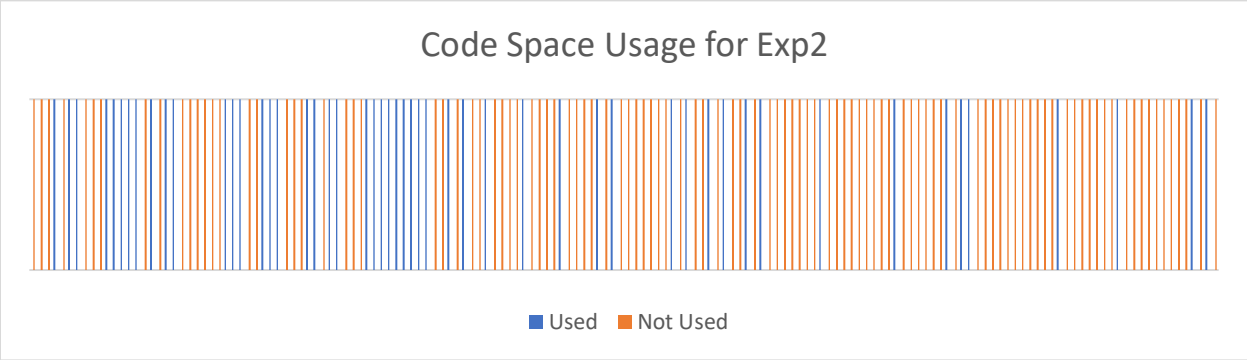


Figure 44: Used and Unused Portions of the Complete Ontology Code Space

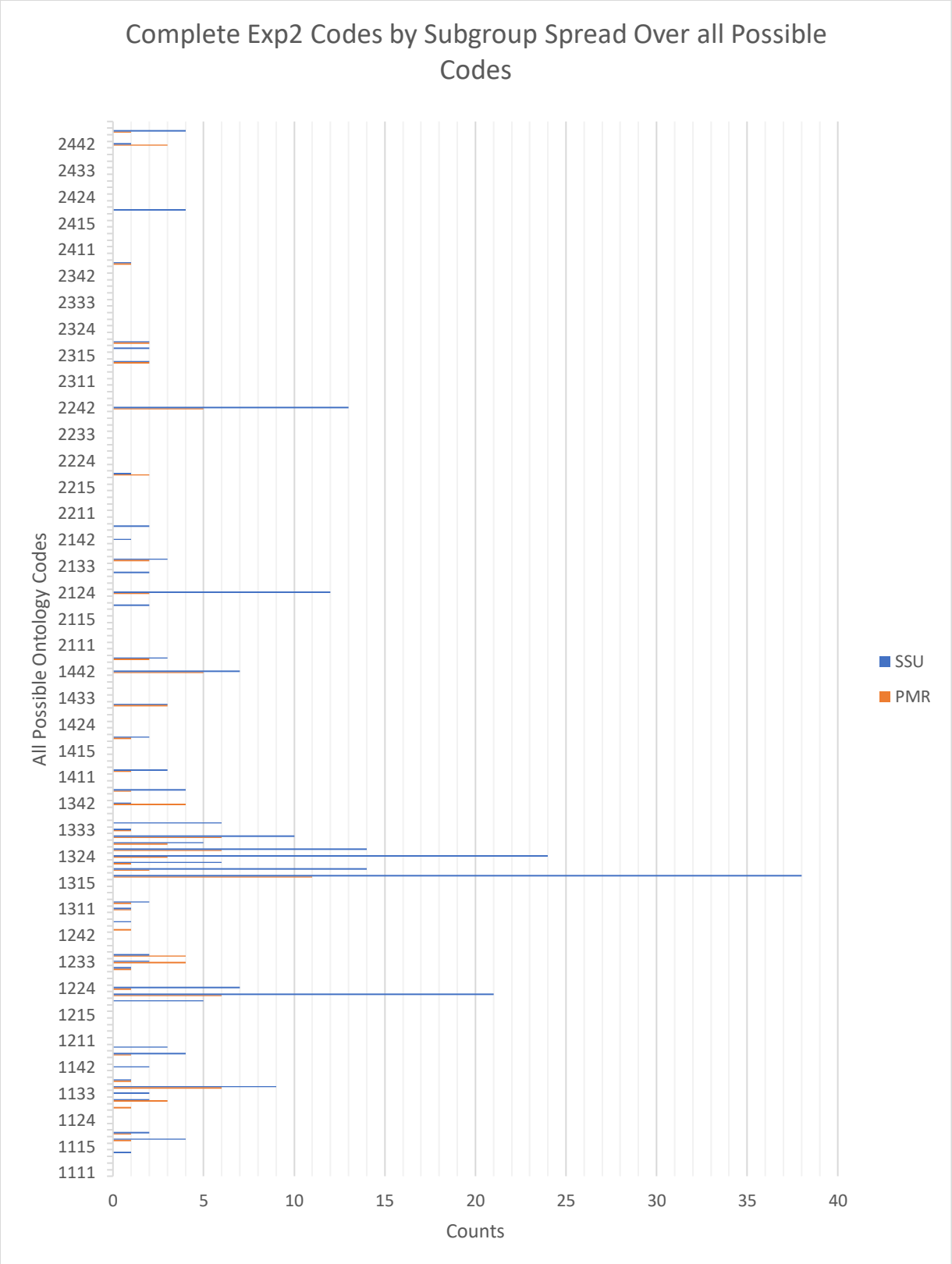


Figure 45: Subgroup Codes on the Complete Axis

5.3 Product Comparisons:

This section addresses the research questions Q 2.4 and Q 5.1. Given the statistical inference limitations discussed earlier, the presented code coverage graphs (complete codes here and top codes in chapter 9) will be the only comparison regarding product type differences. Any other differences found regarding CNs could not be proven statistically or the source of the difference identified.

One noticeable difference in the inclusive versus the exclusive products is their origin. The inclusive products are all from manufacturers in Switzerland. This is not a surprising result given the proliferation of inclusive design in that region as compared to the US. This simple result highlights the motivation for this research and shows its benefit in adding to and proliferating inclusive design.

Graphs detailing the code coverage of the different product types were prepared to be able to perform a visual comparison and are shown in Figures 46-54. These charts are also pictured in a larger format in Appendix H for easier viewing. The BJO list code counts and the TJO list code counts were each used as a data series and placed on the axis of all the codes elicited from Exp2 to create the Jar Opener product comparison graph. This was done for all three product pairs. The subgroup lists for all the product lists were also placed similarly. Having the PMR and SSU breakdowns by product type is important in identifying if potential relationships and interactions between product type and participant type occurs.

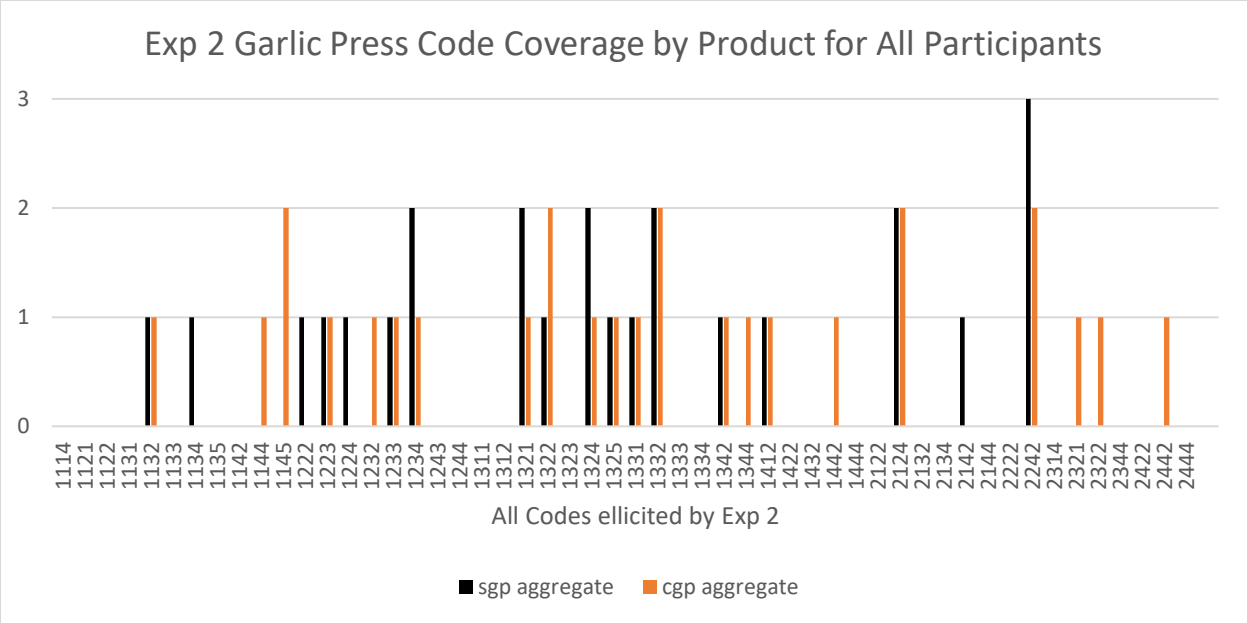


Figure 46: G Code Coverage by Product Over All Participants

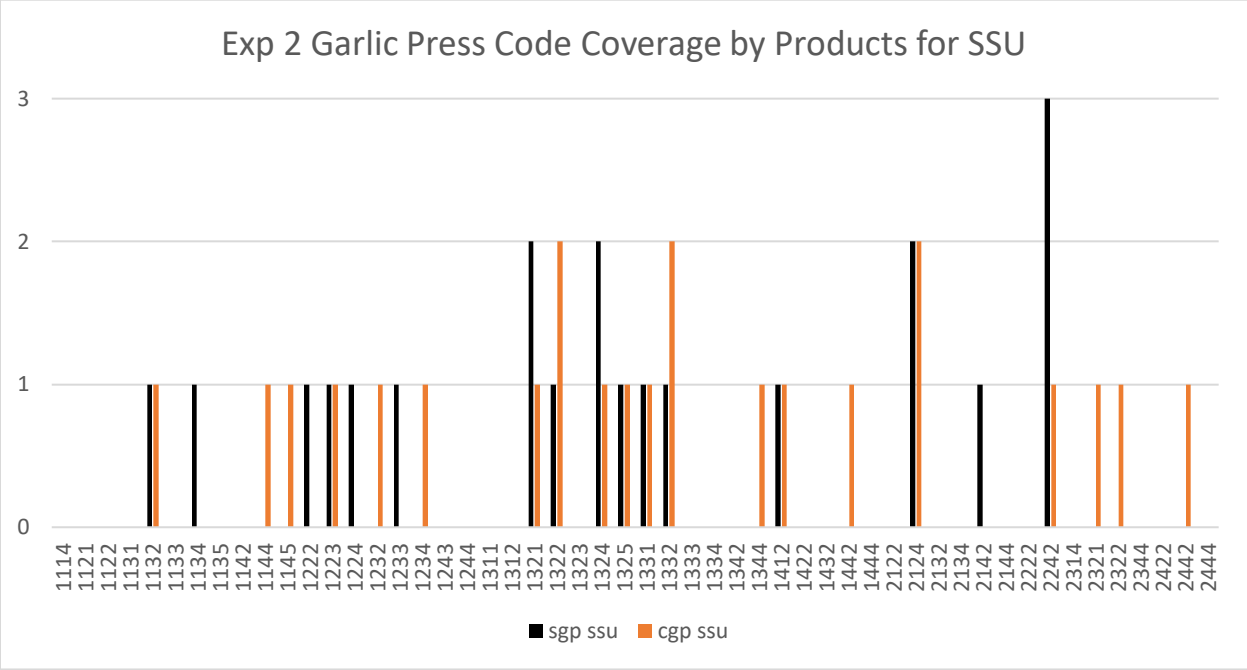


Figure 47: G Code Coverage by Product for SSU

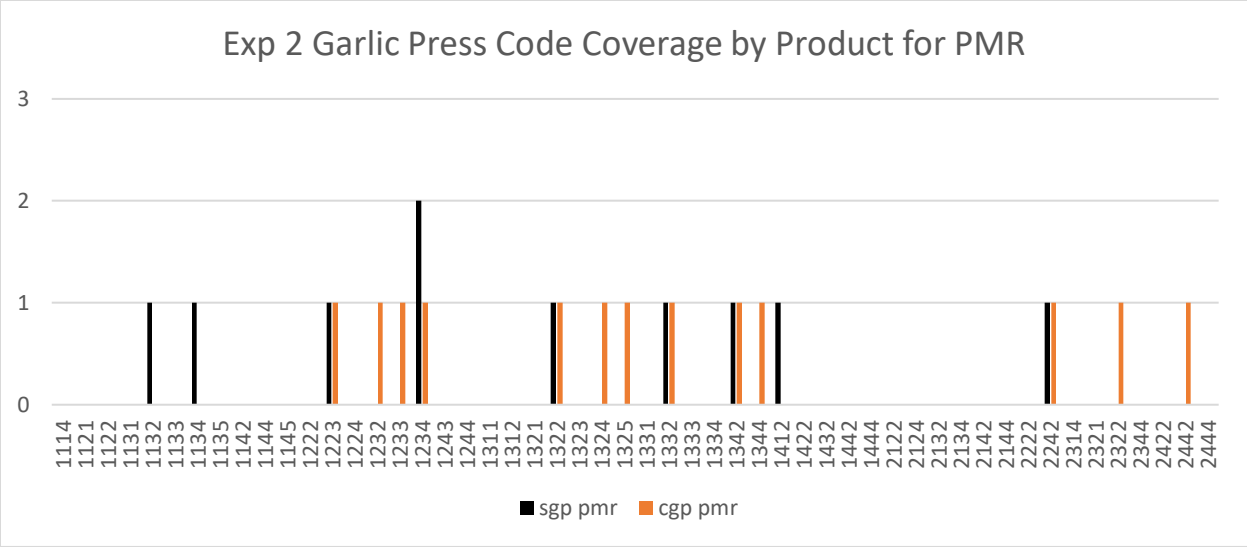


Figure 48: G Code Coverage by Product for PMR

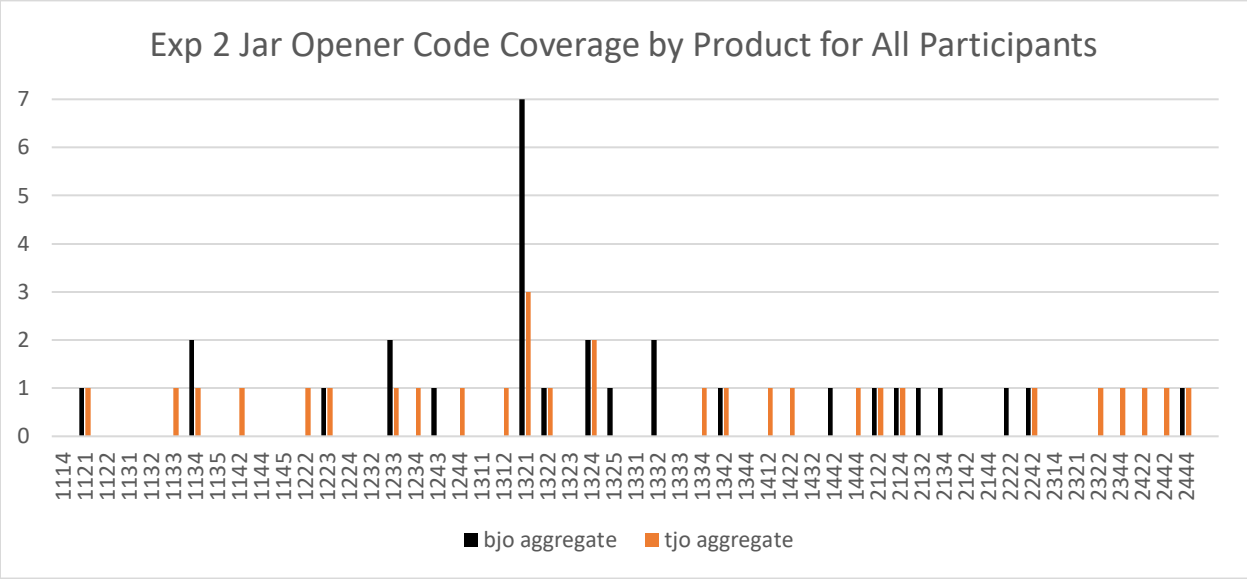


Figure 49: J Code Coverage by Product over all Participants

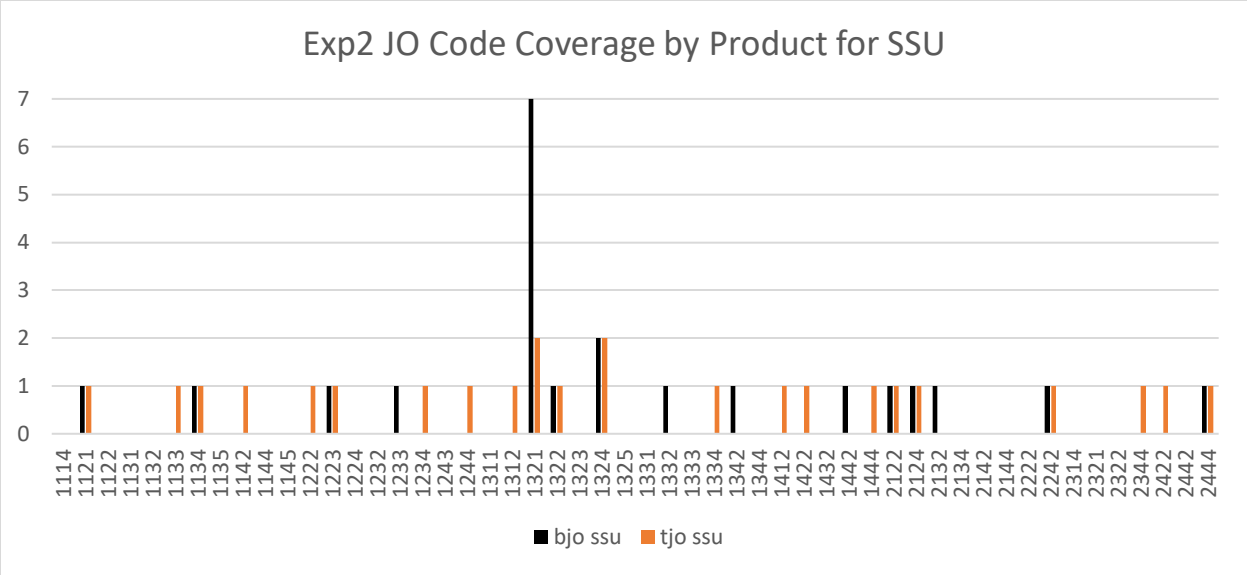


Figure 50: J Code Coverage by Product for SSU

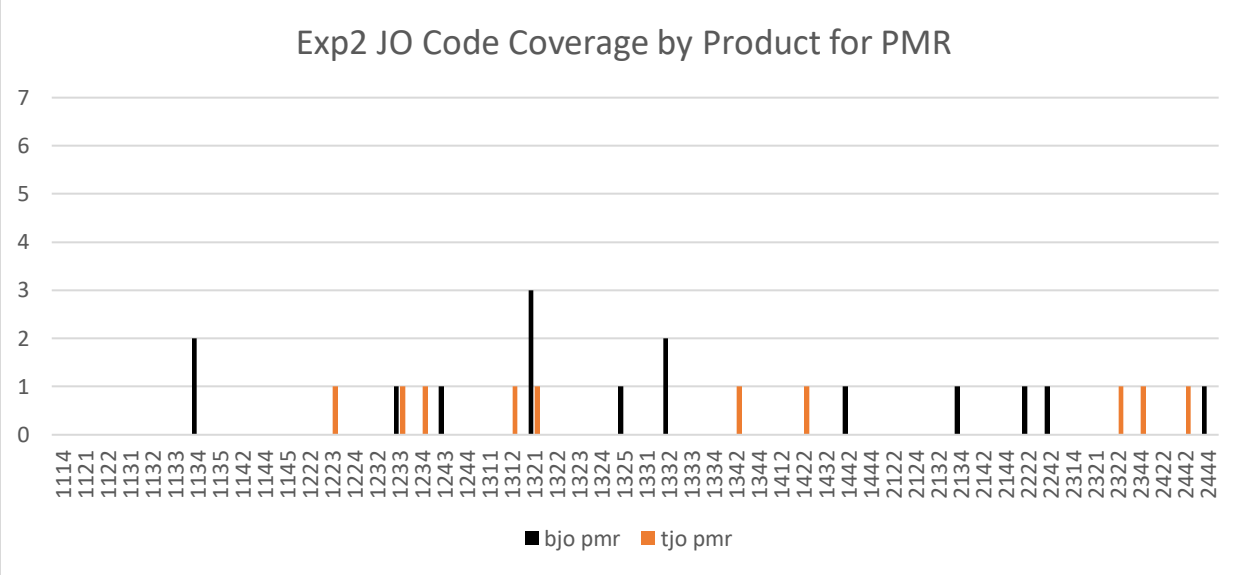


Figure 51: J Code Coverage by Product for PMR

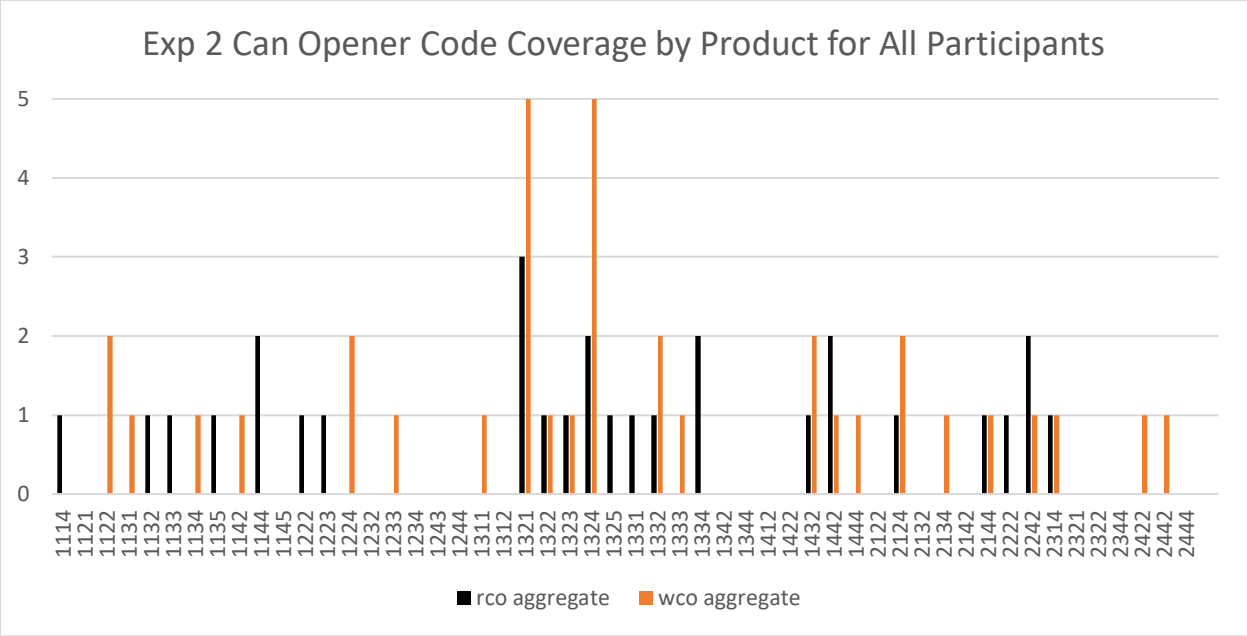


Figure 52: C Code Coverage by Product Over All Participants

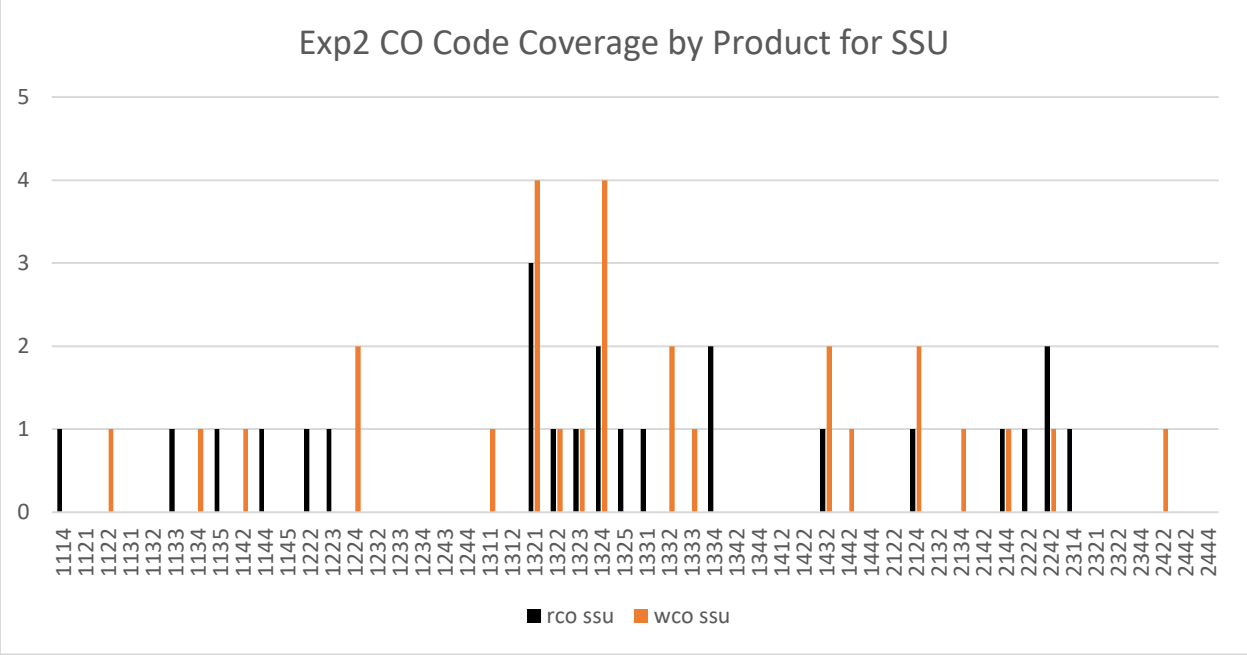


Figure 53: C Code Coverage by Product for SSU

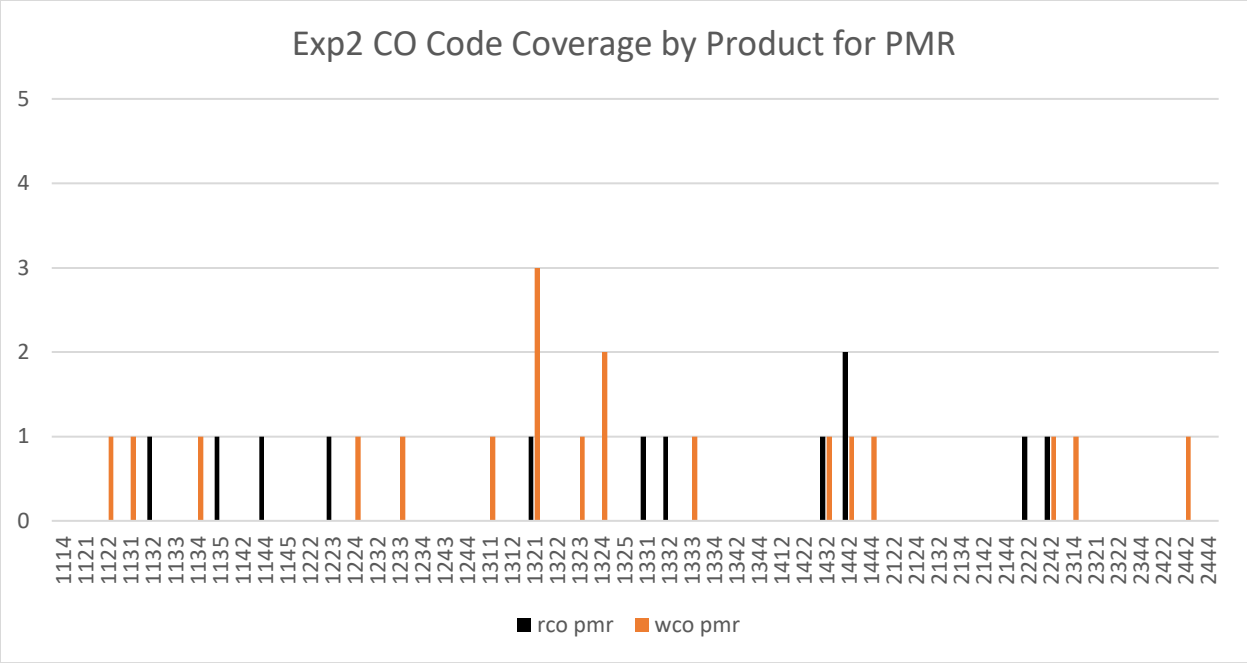


Figure 54: C Code Coverage by Product for PMR

Looking at these charts the orange bars are always the inclusive product. The observations based on these charts as to the difference between exclusive and inclusive products are as follows.

As a reminder of what the ontology code numbers mean…

Category	Value	Classification
Market	1	General
	2	Niche
Message	1	Constraint
	2	Specification
	3	Objective
	4	Solution
Performance	1	Safety
	2	Human factor
	3	Device
	4	None
What	1	Aesthetics
	2	Features
	3	Main function
	4	Supporting function
	5	Environment

Figure 55: Ontology Code Naming Reminder

The inclusive products tend to have CNs with niche codes that the exclusive does not elicit (2321-2442). This could indicate a tendency for the inclusive product to have more

inclusive features that are more obviously helpful to a niche population. Due to their nature, they are more likely to have specialized or assistive features. Therefore, this code coverage observation would be logical.

The WCO inclusive can opener has obviously more and higher inclusive peaks. This is not the case for the others, though I would offer the same suggestion as above as to its reason. The WCO product contained the most obvious assistive feature of the locking mechanism. The other inclusive products were less obvious in their differences and inclusivity. The peaks occur at 1321 and 1324, which means (general/objective/human factors/(aesthetics and supporting function)). These would indicate a higher rate of notice of the more useful/ nicer feeling/ nicer looking aspects of this particular inclusive product when compared with its exclusive counterpart. The exclusive product also peaks at these areas (though lower), which would indicate the lack of these things are also being noticed in the exclusive product upon comparison.

All the product pair graphs has somewhat of a gap between 1224 and 1311 that the Inclusive product fill and the exclusive does not. The can opener graphs is where this gap is most obvious, but the others also have a higher rate of inclusive mention through that area (though they have a bit of exclusive coverage to different extents). This would indicate to me that the ability to provide specification style CNs is improved during the use of inclusive products more so than the other message styles. Furthermore, being able to think about specification style messages rather than objectives (13##) (which there may look to be slightly more of in the exclusive data series) may be being impeded during the use of exclusive products.

Table 25: Product Type Code Coverage Analysis Numbers

List	# of Matches	Inclusive Adds	Exclusive Adds	Incl #	Excl #	more in Type	higher by #	largest in order
G all	14	8	4	22	18	i	4	m/i/e
G pmr	6	7	3	13	9	i	4	i/m/e
G ssu	11	9	5	20	16	i	4	m/i/e
J all	12	14	5	26	17	i	9	i/m/e
J pmr	2	8	9	10	11	e	1	e/i/m
J ssu	10	12	4	22	14	i	8	i/m/e
C all	10	12	10	22	20	i	2	i/m/e
C pmr	4	12	7	16	11	i	5	i/e/m
C ssu	8	10	11	18	19	e	1	e/i/m

Since there were so few obvious visual distinctions in the graphs, a numerical type analysis was also performed. This is in Table 25 above. From this it can be seen that across the board the inclusive product is adding more unmatched codes to the list than the exclusive product, and therefore has the greater coverage of the code space. The inclusive product is higher by 2-9 codes, with an average of 5 codes, except for Jpmr and Cssu, which have the exclusive product being higher by only 1. This result indicates that inclusive products cause people to elicit a wider range of CNs than exclusive ones.

Additionally, unlike with the subgroup code coverage breakdowns, the matched codes are not occurring most often, and are in fact strewn throughout the order, (2 most, 4 middle, 2 least). There is not enough information (of the right sort) present to reliably be able to speculate as to the reason for this. It is simply an interesting notice.

Additional analysis of the product type trends over each separate taxonomy might shed some light on further relationships, that would speak less to overall code coverage (one aspect of ontology use) and more to specific areas CN categories which would inform design effort and emphasis decisions (more supporting functions on I than E, more HF needs in E than I, more safety needs with E than I, more performance needs with I than E, etc.) The relationship of this sort that can be most easily shown visually by the overall coverage charts is niche vs general, which was the first identified trend.

For these, there is only a slight difference in the size of the count graphs vs the percent graphs and only two turn overs in the shapes. We show the percent graphs in Figure 56-58, which is the percent of the CNs on that list coded with that taxonomy.

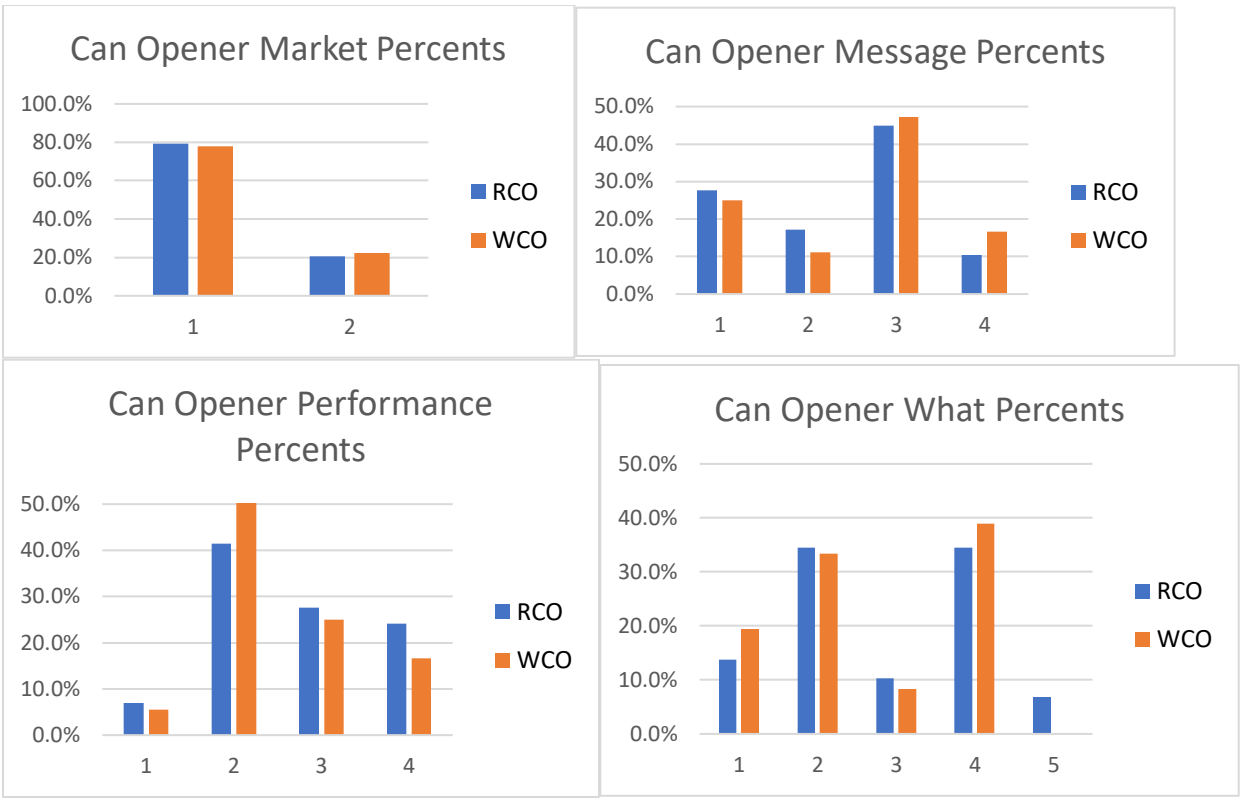


Figure 56: Can Opener Taxonomy Breakdowns by Product Type

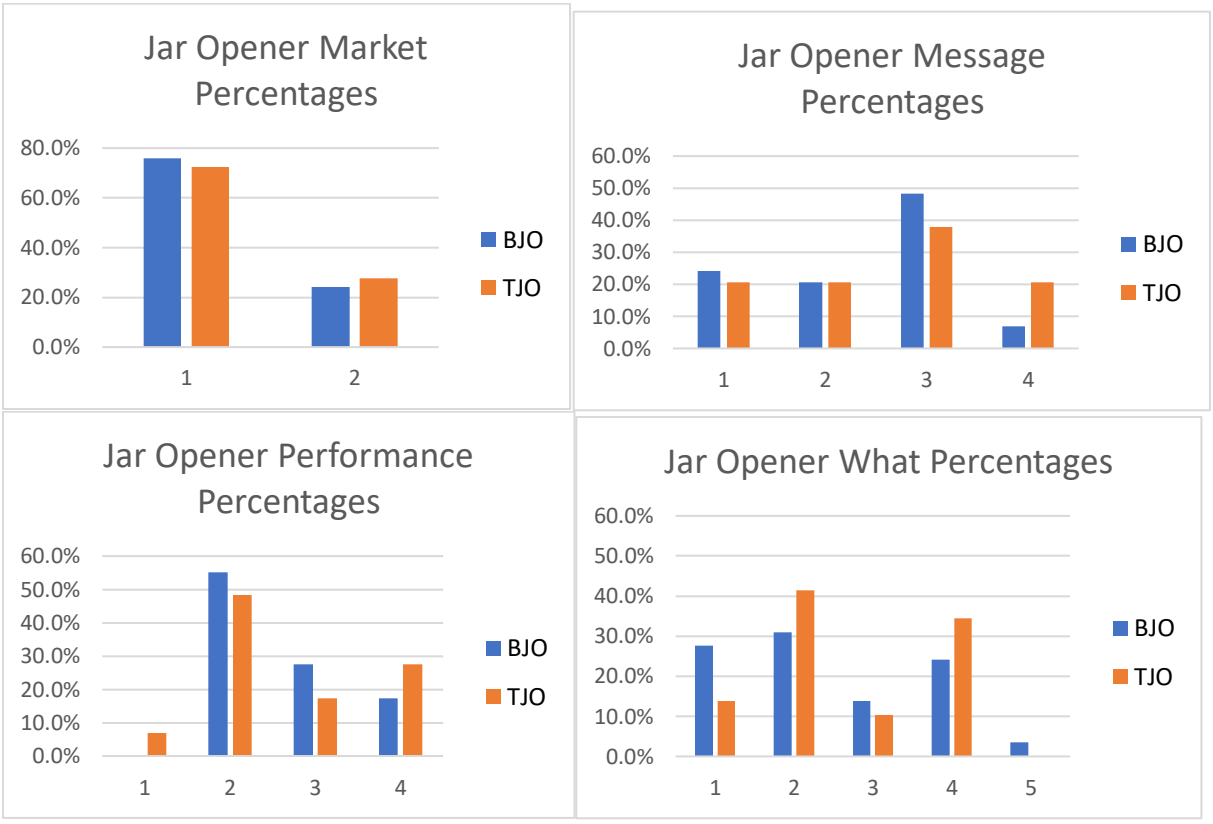


Figure 57: Jar Opener Taxonomy Breakdowns by Product Type

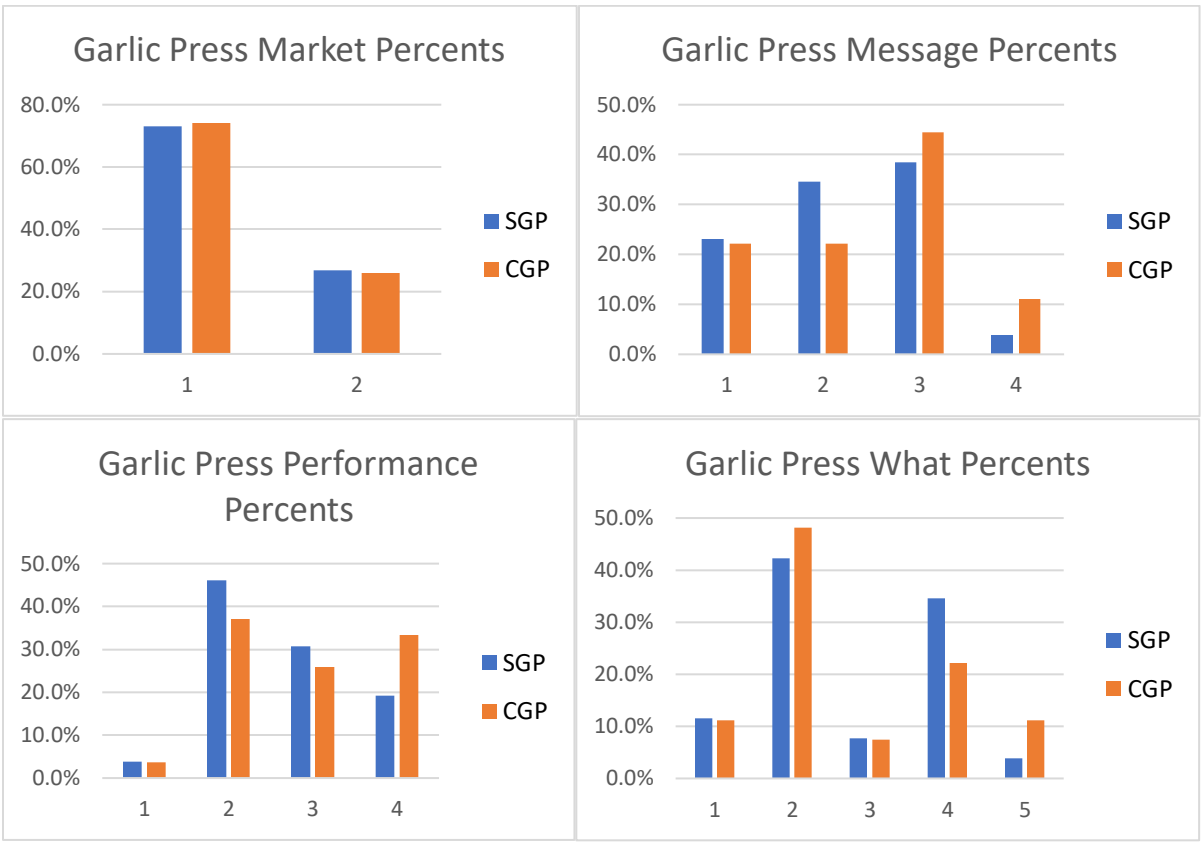


Figure 58: Taxonomy Breakdown Graphs by Product Type

These graphs indicate that the product types (inclusive vs exclusive) are equal or almost equal across most aspects of the coding. Remember SGP/BJO/RCO are the exclusive product types and CGP/TJO/WCO are the inclusive product types. They also indicate that most of the noticeable differences between product types do not hold for all three product pairs. This makes general conclusions difficult and tenuous.

When broken down by taxonomy it shows that specification style needs are slightly more common for the exclusive products than the inclusive. This is in direct contradiction to one of the conclusions from above, showcasing the need for both analysis styles.

For a more direct comparison of the product's coverage we present Figures 59-61, where the codes' counts for each product pair list is placed onto the axis of all the possible codes present in the ontology, not just the ones from Exp2.

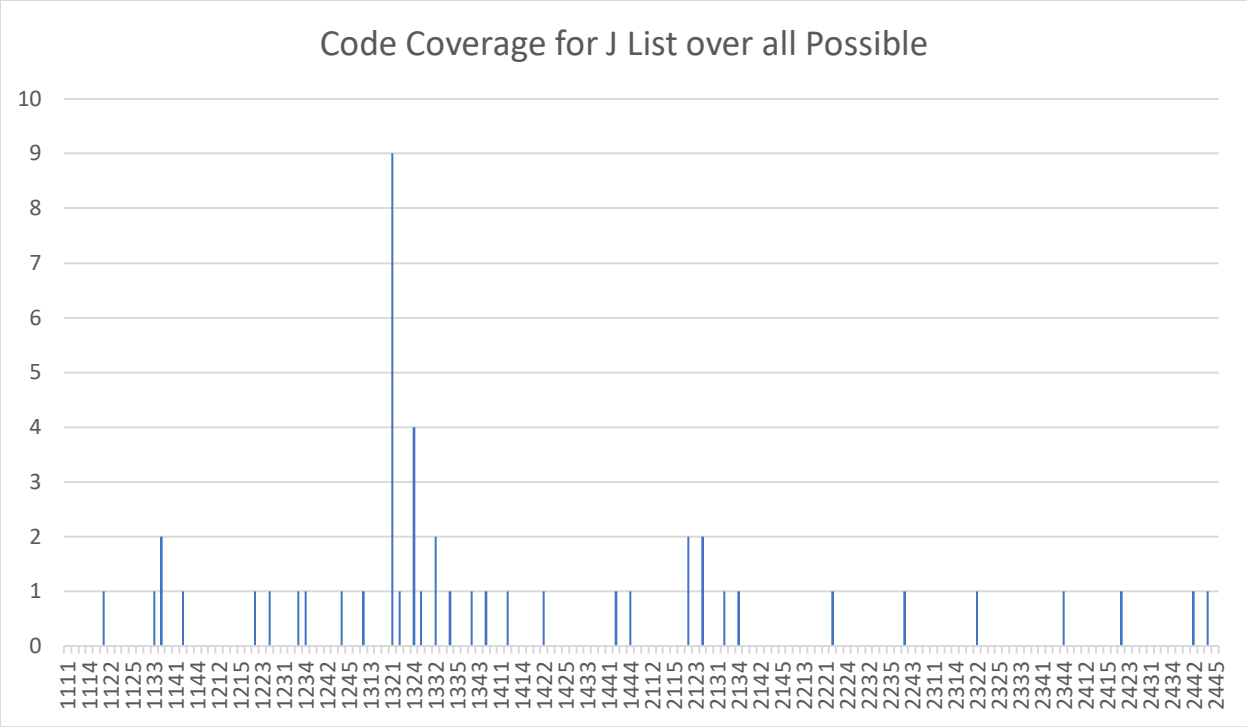


Figure 59: Exp2 Jar Opener Product Pair List Overall Code Coverage

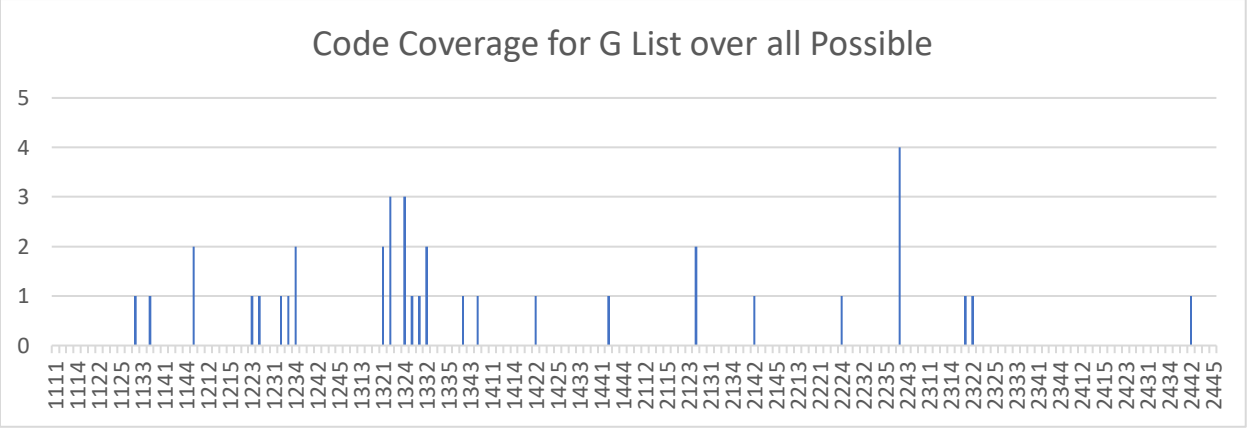


Figure 60: Exp2 Garlic Press Product Pair List Overall Code Coverage

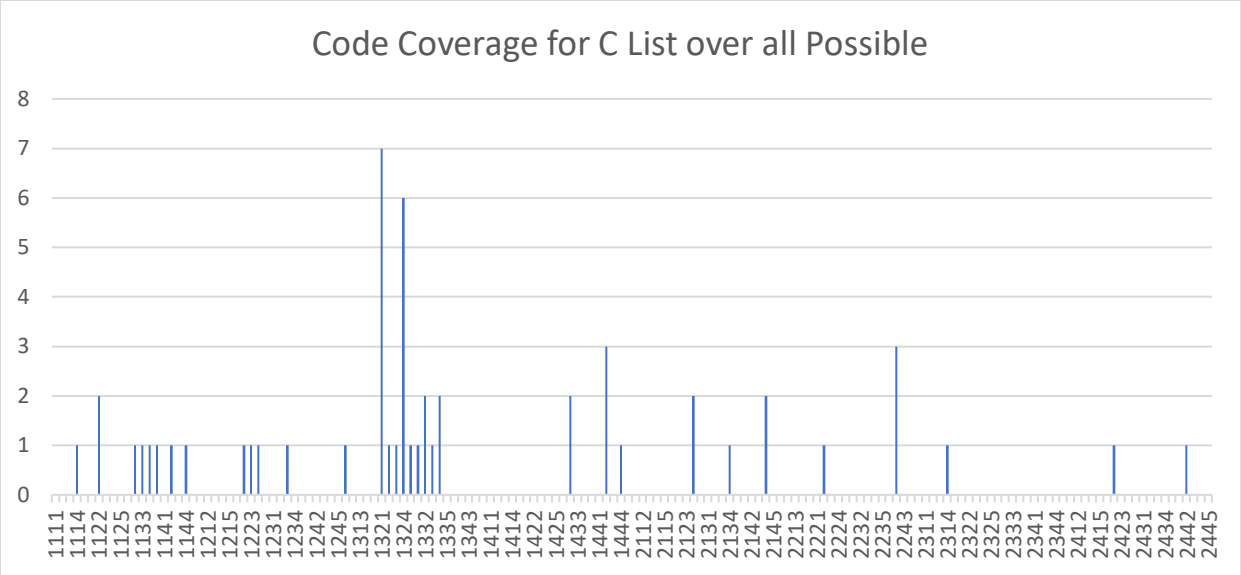


Figure 61: Exp2 Can Opener Product Pair List Overall Code Coverage

Observing Figures 59-61, two trends can be seen. One is that the size of the code peaks changes a bit between product pairs. There is no noticeable correlation between this increase and the number of CNs in the list, or % of PMR needs coverage of the list, or other examined factors. Another is that placement of the codes and the peaks does not change tremendously for product function (they all have roughly the same shape). This indicates that manual products are similar in terms of elicitation potential of categories. If we had a much different type of product, with different interaction methods and mental models we would likely see a larger (more noticeable) difference.

Chapter 6: Occupational Therapy Related Results and Discussion

This chapter focuses on research question 3 and presents results on the integration, performance and information provided by the Occupational Therapy Metrics. Much of this information was present in Chapter 4 because validation of the suit involved extensive use of the OT metrics. However, a more detailed account of the selected OT tests and the break downs of the resulting data is now presented.

6.1 Functional Capability Metrics:

This section will discuss the selected tests and how they function and fit within the study.

6.1.1 Selected Tests:

Range of motion: Range of motion (ROM) metrics are achieved simply with goniometer measurements. The suit was designed with the intent of not creating ROM restrictions. It was meant to allow people wearing it to be able to achieve normal range of motion, with some extra effort. Therefore, part of the ROM tests involves checking that persons in the suit have no hard limits imposed. It is not necessarily a negative result to have ROM restrictions. As part of the exploratory nature of the study, it is important to know the type and extent of suit restrictions, to analyze the suit functionality. It is also important to have a thorough measure of the limitations of participant with actual motion restrictions. This could be done by measuring each ROM of the upper extremities, but that would take quite a long time. A middle ground was settled on for the study procedures. All the participants mimic the full range of motion sequence performed by the research assistant. Then any motion that is not able to be achieved at the unrestricted, and therefore "normal", ROM of the research assistant, was carefully measured with goniometers to determine the exact range possible. This means that any measurement taken is an indication of failure of ROM functioning and any unmeasured ROM dimension indicates normal functioning.

Measurements include: Shoulder flexion, shoulder extension, shoulder abduction, shoulder horizontal abduction, shoulder horizontal adduction, and shoulder rotation, elbow flexion, elbow extension, wrist flexion, wrist extension, wrist deviation, and forearm rotation, also the flexion and extension of each the three joints in the fingers and the finger movement away from midline. Measurements are performed with goniometers as shown in Figure 62.

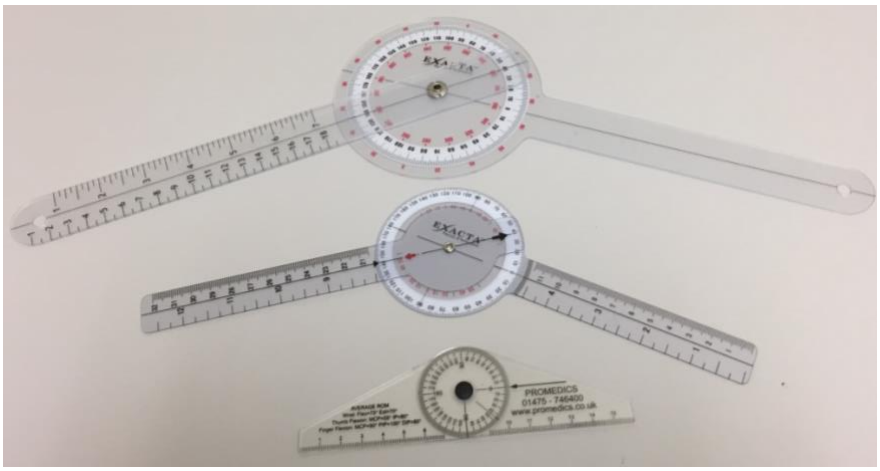


Figure 62: Goniometers.

Strength: Strength testing is also fairly straightforward via a hand evaluation kit from North Coast Medical. This included an Exacta Hydraulic Pinch gauge grip and an Exacta Hydraulic Hand dynamometer, finger goniometer, as well as usage instructions for each. This is one of the more expensive pieces of equipment required for this research. However, it is durable, reliable and precisely calibrated equipment, used widely by professional, so there will be confidence in our measurements. Multiple measurements of each strength aspect are done and the average is used as the metric for the participant.

Figure 63: Hand Evaluation Kit.

Measuring the strength of the major arm muscles was a more complex issue. For this a Desik Instruments Push Pull Gauge is used. This is held against the participant as they perform

strength actions with their arms. These include shoulder abduction upwards, shoulder extension backwards, shoulder flexion forwards, elbow flexion and extension, and wrist flexion and extension. These actions were based on a consultation with a biomechanics subject matter expert. One important component of these tests is to maintain a consistent lever arm so that the dynamometer force data can be transformed into joint torque information down the line if needed. Therefore, lever arms were chosen and maintained throughout the testing. The lever arm for the wrist movements was the participants' palm width so the gauge was places at their knuckles. The other lever arms were 5 inches from the elbow for the forearm movements, and 8 inches from the shoulder center for the shoulder. These were ensured by putting one end of a guide at the joint center and putting the gauge at the other end. Attachment straps for the pulling actions were used.

Figure 64: Push-Pull Dynamometer.

It is also important to make sure that each participant is performing the same exact motion. Different angles would provide different inherent mechanical advantages based on biology. I tried creating rigs to maintain standard positioning, but this proved too difficult given the variety of sizes of persons and the different measurements desired. Therefore, I simply developed a set of neutral positions and made it the responsibility of the research assistant administering the tests to make sure the participant was performing the movement as prescribed. The tests involved holding the dynamometer at the appropriate distance from the joint center and the participant simply pushes against it in the ways demonstrated. With this method, it is essential that the researcher is not pushing and adding to the measurement, but only resisting the motions and remaining stationary. It is also necessary to watch that they are only pushing with

the one joint and not with a set of muscles. This is done partially by resting the adjacent body part on a chair for the elbow and wrist pushes and partially by watching them carefully to make sure they are not leaning.

Dexterity: The 9 hole peg test (9HPT) [179, 176] was used in the original suit validation activities, and its use was continued throughout the project. It is a widely used test, which provides opportunities for data comparisons with other studies. The equipment required for this test is inexpensive, it is easy to administer, and a large amount of normative data is available. However, it was felt that this was not a sufficient measure of dexterity by itself, so more tests were investigated that cover different dexterity movements/aspects.

Figure 65: 9 Hole Peg Test (9HPT).

There are many tests available to evaluate dexterity. Each test has its own procedures and equipment. Due to the wide variety of options available, several tests were considered and articles such as [180] were consulted. The major determining factors for these tests were complexity and cost, and whether it replicates an aspect to be examined in this study. As an example, the Jebson-Taylor test [181] was considered early on, as it encompasses much of the movement data required, but the test is incredibly bulky and expensive, so it was disregarded in favor of others.

The Minnesota Dexterity Test [182, 183] was also purchased with the intent of use for data collection. However, this was abandoned for several reasons. The instructions are complicated, and if they are not followed correctly the data is useless for comparisons with other studies and the normative data. The test itself takes upwards of twenty minutes with a practiced

administrator. Based on time constraints, a choice would be required between a participant doing this test, or all of the others, which would have introduced unnecessary confounding into the research. Also, the normative values available were not as applicable to this specific research. The Purdue Pegboard test [184] was also obtained, tried and discarded. The test requires a level of fine motor control that is exceedingly difficult while wearing the original research suit. The normative data available for this test is also too specific to be of immediate use for our purposes. The new finger mechanisms might make it more feasible, but it would still be exceptionally difficult. I felt than since there was not any improvement in this test of fine motor skills over the 9 hole peg test that the Purdue Pegboard was unnecessary.

The additional dexterity measure that was finally selected was the "Box and Blocks" test. The Box and Block test (BBT) [185] is used to evaluate gross motor skills. In our testing, it demonstrates and measures the interference of the shoulder restraints nicely. Observing participants during the original testing with the 9 hole peg test, I saw that they were changing how they moved to avoid using their shoulders and their full range of motion. They would encounter the shoulder resistance and adapt rather than fight it, developing arm movement reminiscent of a T-Rex. Therefore, I wanted to pick at least one functional capability metric test that forced them into doing large arm sweeps, to analyze this motion. A commercial test kit was purchased, since having all of the pieces be exactly identical is a necessity for getting proper data. In this test, participants move as many blocks from one side of the test kit to the other as they can in thirty seconds. Most participants found this test to be fun and engaging.

Figure 66: Box and Blocks Test (BBT)

6.1.2 Application:

Training is a critical component of this part of the study. It must be ensured that the various test administrators are consistently recording measurements in the same way. It must be ensured that all the measurements have the same neutral positions and that there is attention to detail in the data collection and entry. Apart from training on the proper handling of participant information, it takes over 10 hours of training and practice for the research assistants to master the procedures involved in the study so that consistent useful data collection can be assured. There is also a degree of sensitivity and professionalism in working this closely with human subjects and subject matter experts.

Deciding on a good order for the tests is also important, to address the issue of fatigue. It is known that persons get tired wearing this suit. It was their main comment in a prior study. By performing the product tests before the functional capability metric tests for all participants, it ensures that fatigue does not confound the product experience. Doing it after would have meant that different base strengths and endurance levels would result in a different starting point. The functional metrics are then randomized in their order so that the fatigue factor is spread out across participants.

6.1.3 Analysis of Test/Research Interaction:

Following the research on functional capability metrics, three main areas were identified for obtaining measurements: range of motion, strength and dexterity. The selection criterion guided the type of tests to be administered to participants in the motion restriction simulation suit. Afterword, an analysis was performed to determine how well the selected tests relate to the activities in the research, and also how they related to the verbs used in the International Classification of Functioning (ICF).

This section specifically addresses the research question Q 3.1 Is the selection and incorporation of the Occupational Therapy metrics and tests appropriate for the study and its goals?

The type of upper body restrictions that the simulation suit mimics, cast in the language of the ICF verbs [95] describing the impacted body functioning, are shown in Table 26. For each of the ICF verbs, an interpretation for user activity from [21], the list of products from our study that require this user activity, the selected functional capability test(s) and the resulting metrics from each functional capability test are listed.

Additionally, Table 27 shows the correlation of how much the metric mimics the actions taken in the usage of each product type. This is rated either low, medium or high. Our study has six products in three pairs, two can openers, two jar openers, and two garlic presses. If the two products in the pair have different ratings, they are listed separately, with the inclusively designed product on the right.

Taken together these tables show that the choices made during the OT metric selection are well founded, and should produce results allowing a clear picture of participant limitations to be obtained and utilized.

Table 26: OT Metric and ICF Activity Correlation

Verb	**Interpretation for activity (task) modeling**	**Product**	**Functional Capability Metrics**
Reaching	Reach out to specific location	All	ROM, Flat Reach
Reaching	Reach out or extend outwards to position an object using hands	All	BBT, Arm Strength
Picking up	Picking up hand held products	All	9HPT, BBT, ROM, Grip, Pinch
Release	Release hand held objects	All	ROM, BBT
Grasping	Hold an object firmly in hand for required operation	All	9HPT, BBT, ROM, Grip
Manipulating	Complex hand activities that requires manipulation with fingers	All, GP most	9HPT, Pinch, ROM
Pushing	Pushing with finger, arm, hand	All, JO most	Strengths
Pulling	Pulling with finger, arm, hand	All	Strengths
Turning	Rotate something with hand	All, CO most	ROM
Carry (moving)	For importing and positioning an object	All	BBT, ROM, Strengths

Table 27: Product and OT Test Correlation

Correlation	**Can Openers (E/I)**	**Jar Openers (E/I)**	**Garlic Presses (E/I)**
9HPT	Med/High	Med	High/Med
BBT	Med	Med	Med
Grip Strength	High	Med/High	High
Pinch Strength	Low/Med	Low/Med	Med/High
Arm Strength	Med	High	High
ROM	High	High	Med

6.1.4 Discussion regarding Use of Occupational Therapy Metrics:

OSU's motion restriction simulation suit restricts all the desired aspects of the upper extremities (shoulders, elbows, wrists, fingers). Metrics for all of the movement aspects of concern to the research have been chosen and vetted, including tests for i) the strength of the involved muscles; ii) both gross and fine motor dexterity measures; and iii) a range of motion measurement technique that balances data retrieval and timeliness.

The results thus far indicate that recording this level of functional capability metrics is relatively easy to achieve, both from an administrator and participant standpoint. Suitable procedures to ensure consistency and accuracy have been established as well.

Overall, I have a defined set of functional capability metrics that allows correlation to physical limitations and is mapped to the user functioning that is required for product operation. Later work will use the data collected to determine correlations between physical limitation and customer needs in a way that can inform inclusive design. Having such rigorous and complete metrics on the limitations of the participants will assist in future analyses of the data sets obtained from this study.

Part of the original intention of adding OT metrics to the study was to be able to investigate how the CN lists and CN spaces change given different participant limitations. The framework is setup to make this possible, however that does require a wide range and large sample size of different participant limitations. Since this was not obtained during the research, the use of OT metrics for analyses had to be rethought. It is a strength of the framework that this was easily completed and other connections are possible. Research Questions such as "Q 3.5.1 Can ICF code/descriptions of participant limitations be developed using only the occupational therapy metrics?" were added to use the OT metrics to form connections with aspects that are more informing of inclusive design. The question of whether, without interviewing someone, if presented with their metrics after the fact, it can be accurately determined what their restrictions are using the ICF, informs both the usefulness of the metrics and the ICF.

6.1.5 Discussion regarding additional information collection:

This section in part addresses the research question Q 3.4 What additional comparisons and analyses are available by having so much functional capability information available?

The additional participant information collected during the study has also proved useful. Most of these aspects will be discussed in detail elsewhere, but a summary is provided here. We

have been able to analyze the user responses in relation to experience, identify the suit fit issues which speak to the surrogate experience, identify additional factors contributing to the Range of Motion measurements, and begin to examine the difference in objective measures and subjective experience.

In looking at the WHODAS (World Health Organization's Disability Access Survey) it becomes clear that there is a distinct difference in the objective measures of functioning and subjective measures. The persons with more OT metric limitations do not rate their everyday life as being more impeded. It makes sense to an extent that not being able to do a certain motion might not have a large ongoing effect on their life after an initial adjustment period. At the same time, we are seeing a larger than expected difference between subjective and objective measures of functioning. This shows how important it is to have both in design. This helps to justify our research approach of providing both kinds of data and multiple connections options. Parts of our observations during the study, which cannot be shared due to identity protections for the participants, suggested additional effects in play. Therefore, I suggest further study of the factors that cause differences in subjective and objective measures of disability. As an example, we considered the idea of length of time with a disability being highly corelated with a lowered subjective response. However, within in our limited sample set this appears to be false.

6.1.6 Visual breakdowns of participant functional capability results:

This section also partially addresses the research question Q 3.4 What additional comparisons and analyses are available by having so much functional capability information available?

It also partially speaks to Q 3.2 Is the tracking and connection between OT metrics and CNs manageable? In that this is where all the metric data is presented, tracked by participant number. Pair this with all the CN data also being tracked by contributing participant number and connecting the data sets becomes fairly straightforward.

The metric results that are easy to visualize are now presented. The 9HPT information is presented first, as that is of the highest importance to our study and its comparisons. Then the data for the results of participant functioning are presented in Tables 28-35 and Figure 67. The remaining metric tables are presented in the Appendix N as they are quite large. Most interesting

of those is the ROM table with the actual degree data replaced with what % of normal range of motion that number represents in relation to [186]

Table 28: Peg Test Data for all participants from Exp2

Peg Test (seconds for task completion)					
Participant #	**Age/Gender**	**Dominant Hand**	**Non-Dominant Hand**	**Dominant**	**Type**
1	19/m	unable	unable	L	NA
2	61-70/m	21	25	R	PMR
3	51-60/f	22	24	R	PMR
4	20/m	24.18	25.01	R	SSU
5	21-30/m	17.69	106.39	R	PMR
6	19/m	22.25	25.19	R	SSU
7	19/f	25.83	24.51	R	SSU
8	41-50/f	37	40	L	SSU
9	51-60/m	21.77	25.57	R	SSU
10	19/m	35	34	R	SSU
11	18/m	26.88	21.18	R	SSU
12	19/f	23.59	26.62	R	SSU
13	24/f	20.2	28.3	R	SSU
14	34m	22.86	27.13	R	SSU
15	20-29/m	23.89	25.85	R	SSU
16	20-29/m	23.07	22.96	R	SSU

Table 29: BBT Results

Box and Blocks Test (number achieved in 30 secs)				
Participant #	**Dominant Hand**	**Dominant Hand**	**Non-Dominant Hand**	**ROM Notes**
1	left	unable	unable	unable
2	right	23	25	finger
3	right	33	28	finger
4	right	24	29	all rom normal
5	right	31	19	finger
6	right	23	25	all rom normal
7	right	27	24	all rom normal
8	left	26	25	all rom normal
9	right	26	28	shoulder
10	right	23	29	all rom normal
11	right	24	23	only wrist
12	right	27	22	only wrist
13	right	28	29	all rom normal
14	right	28	29	only wrist
15	right	30	29	only wrist
16	right	36	28	all rom normal

Table 30: Grip Strength Data

Grip Strength (KG)		
Participant #	**Dominant Hand**	**Non-Dominant**
1	10.0	12.0
2	27.7	29.6
3	19.1	16.9
4	38.6	39.5
5	57.0	3.3
6	35.5	33.9
7	22.2	22.2
8	48.3	22.2
9	56.7	NA
10	23.7	26.0
11	30.5	21.9
12	21.2	14.2
13	18.9	15.6
14	51.3	51.7
15	44.2	39.3
16	47.0	42.3

Table 31: Pinch Strength Test Data

Pinch Tests (Measured data converted into KG)							
Participant #	**test order**	**Tip Pinch (Dom)**	**Tip Pinch (Non_Dom)**	**Key Pinch (Dom)**	**Key Pinch (Non-Dom)**	**Palmer Pinch (Dom)**	**Palmer Pinch (Non-Dom)**
1.00	na	0	0	0	0	3.1	2.0
2.00	p/t/k	6.5	8.0	7.9	8.5	6.8	6.7
3.00	t/k/p	1.4	6.6	8.5	10.4	2.8	2.9
4.00	t/k/p	6.4	6.5	11.2	9.8	10.6	11.1
5.00	t/k/p	6.2	3.3	12.5	3.6	10.6	1.7
6.00	t/k/p	5.3	6.0	9.4	9.1	8.2	7.6
7.00	t/k/p	7.9	7.1	7.9	8.0	7.9	6.7
8.00	t/k/p	5.1	5.1	5.7	7.6	5.3	7.3
9.00	k/t/p	10.6	6.8	4.7	5.1	9.4	8.6
10.00	t/k/p	6.5	18.7	22.3	22.3	17.7	21.0
11.00	p/t/k	6.2	5.7	7.1	6.7	6.7	5.7
12.00	t/k/p	6.0	4.9	5.8	5.5	7.3	6.8
13.00	t/k/p	5.3	6.0	7.6	7.0	1.8	2.6
14.00	t/p/k	7.9	8.9	13.1	13.1	9.4	10.3
15.00	k/p/t	6.5	7.8	11.4	10.7	10.1	9.5
16.00	p/t/k	5.1	4.5	9.8	10.2	9.9	8.2

Table 32: Main Strength Test Results (lbs)

Test Name \ Participant #	1	2	4	5	6	7	8	9	11	12	13	14	15	16
Forearm Push Down(left)	13	22.75	35	18.75	32	19.75	17.875	18	11.25	16	16.625	25.25	25	29
Forearm Push Down(right)	23	34.75	34.75	17	32.75	18	15	17.5	13.625	16.75	16	15.875	20.75	26.5
Forearm Push Up(left)	24.5	27.25	39	34.75	42.5	18	17.875	21	12	20.75	10.375	18	23.875	36.75
Forearm Push Up(right)	17.5	34.8	46.5	34	38.5	19.75	17.625	25	16.125	17.875	10.5	14.25	29.875	33.125
upper arm push out(left)	15	25.25	18.625	22.5	25.75	16.125	25.75	18.5	14.25	14.25	11.375	12.75	17.375	22
upper arm push out(right)	14	22.375	15.125	30.25	31.25	19.875	24.125	19	11.375	21.25	11.875	12	16.75	35
upper arm push front(left)	10	27.75	17.125	25	24.25	18.375	21.875	20.375	16.875	16.25	15	16.5	14	22.125
upper arm push front(right)	9	31.5	16.5	25.5	29.75	18.625	20.625	20.5	16.875	16.25	15.375	17.5	17.75	42.75
upper arm push back(left)	0	23.375	15	27	23.5	19.875	22.75	21.25	13.125	15.75	12.375	17	16	24
upper arm push back(right)	0	22.7	15.25	24.75	26.25	15.375	19.5	21.5	12.625	17	13.875	17.5	16.75	24.25
wrist push down(left)	0	21.75	21.25	13	31.5	14.75	16.375	20	9.75	13.125	10.625	19	19.75	31.75
wrist push down(right)	0	18.45	19	26	34	15.625	13.875	23.75	10.75	13.75	8.125	23.375	19.5	34.5
wrist push up(left)	0	19.75	14.375	6.5	29	13.375	14.5	25	5.75	8.75	8.125	20.25	15.25	25
wrist push up(right)	0	15.75	13.875	18.75	29.75	13.375	14.625	18.5	6	12.625	5.125	19.1	19.5	28

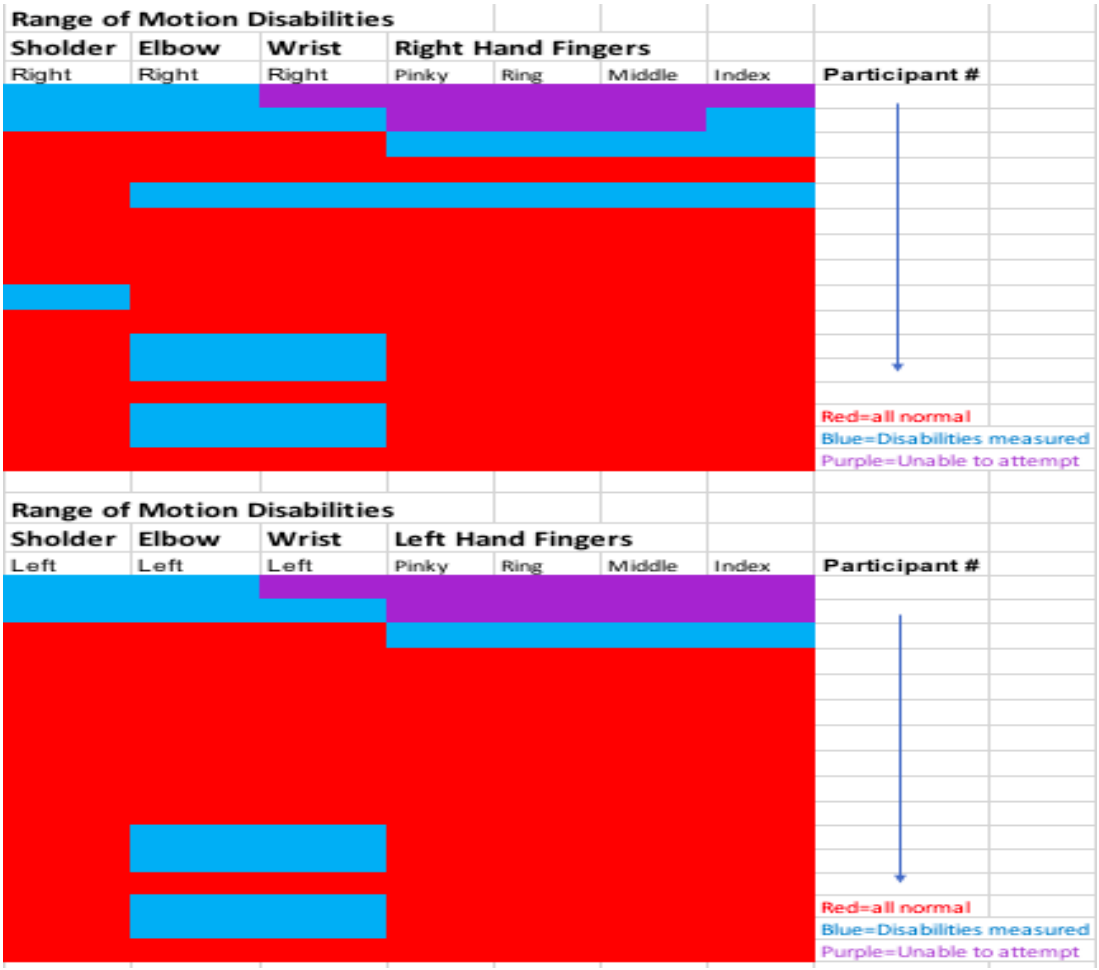


Figure 67: Range of Motion Visual Breakdown for Participants

Table 33: Shoulder ROM Results

Shoulder Range of Motion Right Side (degrees)						
Participant #	**Flexion**	**Extension**	**Abduction**	**Horizontal Abduction**	**Horizontal Adduction**	**Rotation**
1	0	0	30	0	0	0
2	128	34	103	35	98	267
3						
4	norm	norm	norm	norm	norm	norm
5						
6	norm	norm	norm	norm	norm	norm
7	norm	norm	norm	norm	norm	norm
8	norm	norm	norm	norm	norm	norm
9				110		
10	norm	norm	norm	norm	norm	norm
11						
12						
13	norm	norm	norm	norm	norm	norm
14						
15						
16	norm	norm	norm	norm	norm	norm
Shoulder Range of Motion Left Side (degrees)						
Participant #	**Flexion**	**Extension**	**Abduction**	**Horizontal Abduction**	**Horizontal Adduction**	**Rotation**
1	0	0	30	0	0	0
2	128	34	103	35	98	267
3						
4	norm	norm	norm	norm	norm	norm
5	norm	norm	norm	norm	norm	norm
6	norm	norm	norm	norm	norm	norm
7	norm	norm	norm	norm	norm	norm
8	norm	norm	norm	norm	norm	norm
9	norm	norm	norm	norm	norm	norm
10	norm	norm	norm	norm	norm	norm
11						
12						
13	norm	norm	norm	norm	norm	norm
14						
15						
16	norm	norm	norm	norm	norm	norm

Table 34: Arm ROM results

Right Elbow Flexion-Extension	Left Elbow Flexion-Extension	Right Wrist Flexion-Extension	Right Wrist Deviation	Left Wrist Flexion-Extension	Left Wrist Deviation	Participant #
norm	norm	0	0	0	0	1
140	105	125	61	125	63	2
norm	norm	norm	norm	norm	norm	3
norm	norm	norm	norm	norm	norm	4
107	norm	110	21	norm	norm	5
norm	norm	norm	norm	norm	norm	6
norm	norm	norm	norm	norm	norm	7
norm	norm	norm	norm	norm	norm	8
norm	norm	norm	norm	norm	norm	9
norm	norm	norm	norm	norm	norm	10
80	80	norm	47	norm	81	11
norm	norm	100	52	113	42	12
norm	norm	norm	norm	norm	norm	13
108	108	norm	83	norm	89	14
norm	norm	106	54	106	54	15
norm	norm	norm	norm	norm	norm	16

Table 35: 9HPT Aggregate Results (seconds)

group	average dom	stdev dom	average non dom	stdev nd
pmr	20.62	2.00	24.86	0.79
ssu	25.89	5.31	26.68	5.32
all	24.48	5.18	26.81	4.80

Chapter 7 : ICF-Related Results and Discussion

This chapter presents results related to research question 4 and discusses the implication of the findings. It determines if the code descriptions from the WHO ICF (World Health Organization's International Classification of Functioning) can be applied to the data sets in this framework and provide avenues for developing meaningful design information.

To begin with, the one planned ICF activity (making ICF codes from the OT metrics) is presented. Other activities were also performed that were logical follow-ons with the ICF given the information available and if they provided generalizable assistance to inclusive designers. These activities were done as a consequence of previous analyses within this research and contain many different aspects. Therefore, a self-contained section with all the ICF related activities, analyses and results was chosen as the most sensible manner to present the findings.

The answer to the question of whether the OT metrics alone can be used to create ICF codes for a participant is clear "yes." The initial analysis was completed by an undergraduate research assistant who familiarized themselves with the ICF. Only the relevant sections of the ICF (based on what the OT metrics cover) were used for this analysis. These sections include: B7 (NEUROMUSCULOSKELETAL AND MOVEMENT-RELATED FUNCTIONS), S7 (STRUCTURES RELATED TO MOVEMENT), and D4 (MOBILITY). This activity was performed for the three PMR participants and one of the ROM restricted SSU participants. The results are in Table 36 below.

Table 36: Participant ICF Codes developed from the study's OT metrics.

Part2	**Part3**	**Part5**	**Part12**
b710-2	b710-3	b710-3	b710-1
b730-1	b730-3	b730-3	b730-1
b735-1	b735-3	b735-3	d430-2
d440-2	d430-2	d430-3	d440-1
s720-1	d440-4	d440-2	s730-2
s730-2	s720-1	s720-2	
	s730-3	s730-3	

As you can see, there is a high correlation between people, even though their restrictions are different. This makes sense since the tests are primarily aimed at identifying information about the specific functioning of the test. Only one code was chosen for each category, even though multiple codes are potentially applicable to each participant. No inferences were made from the reduced OT metric to user activity. The level of information available from just the OT metrics makes for successful, though limited ICF codes.

Following this, the ICF codes were checked to see if one could be identified from the description of their disability the participants gave, and what the similarities and differences might be between those results. A different researcher assisted with this analysis. They were shown the ICF Browser and how the trees could be expanded and all the descriptions available for each. They were told to watch the video description and write down codes based on what was said, to as detailed a level as possible. The results for this are in Table 37 below. For this procedure, Participant 3 did not give a description, but we did have descriptions for participants' 2 and 5, as well as 9 (self-identified as PMR but later removed from results).

Table 37: Participant ICF Codes developed from Participant Descriptions.

Part2	**Part 5**	**Part 9**
b710-several times	b710	b710
b1300	d4401	s7201
b1400	s7300	s7202
b160 or b164	s7302	s7209
b28018/b28018/b28016	s73013	
d2100	s73003	
d4452	s73011	
s7104		
s7209		

The variability in this information was observed to more closely match the variability in the restrictions of the people in the study. There is more detail to be gained from these descriptions, since more specificity in the structure of the restrictions can be gained from this method compared to the OT metrics. This method is reliant on the people mentioning what is most important or salient to them. This can bring out some factors and obscure others. The fact that they can't do some particular motion well which would be caught by the OT measurements,

may not be most in their minds when they give the description. The description allows them the opportunity to speak in an open ended fashion so that factors like cognitive effects, fatigue, and pain issues can be captured.

Lastly, the ICF codes to Customer Needs mappings that were elicited by each participant were checked to see what kind of correlation there would be between their codes and the types of ICF related issues that they spoke about during elicitation. This analysis was completed by parsing through the data and listing the CN statements for each participant, putting all those CN with an associated ICF relation into a table, and marking where CN duplication (i.e., the same statement made for both products in the pair) happened. This yielded a final list of ICF codes that could be logically related to the statements made during participants' product interactions, shown in Table 38 below. The duplicates are shown in grey italics.

Table 38: ICF Codes elicited during participant product interactions.

Part2	**Part3**	**Part5**	**Part9**
b156/b199	b156/b199	b156/b260/b265/b1649	d166/b210
b164	b156/b260/b265/b1649	b164	d6401
b710/ s73011	b210/b156	*b164*	s730
b730/b7300	b730/b7300	b164/b1640	s7302
b730/b7300	b7301/d445(0/1)	*b164/b1640*	
b7301/d445(0/1)	d166	b210/b1649	
b7401	d4402/d440	b715/b7101	
d166/b210	d4453	b730/b7300	
d4401	d6401	b7301	
d4401	s7302	d4453	
d4402/d445(0/1)		d6401	
d6401		*d6401*	
		s7302	
		s7302	
		s7302	

The main thing to notice with this result is that the product interactions bring out a lot of cognitive style codes, based on statements like "Product should be easy to understand". Also there are more details about muscle power and endurance functions from statements like "Product should not require a lot of strength to use".

The last step is comparing the ICF codes across all three methodologies to formulate some general conclusions. For this process each batch and marked for whether the code was covered by one or multiple methods. Only two participants had information from all three methods, so this is a limited comparison. The complete table for this is in the Appendix L. An abbreviated table is below in Table 39. It is color coded and marked, C for CN, D for participant description, O for occupational therapy metrics

Table 39: Code Source Comparison

Participant 2					
ICF Codes from OT	covered by	ICF Codes from Description	covered by	ICF Codes from CNs	covered by
b7102	D&C	b710!	O&C	b156/b199	none
b7301	C	b1300	none	b164	D
b7351	none	b1400	none	b710/ s73011	O&D/none
d4402	C	b160 or b164	C	b730/b7300	O
s7201	D	b28018/b28016	none	*b730/b7300*	*O*
s7302	none	d2100	none	b7301/d445(0/1)	O/?
		d4452	none	b7401	none
		s7104	none	d166/b210	none
		s7209	O	d4401	none
				d4401	*none*
				d4402/d445(0/1)?	O/?
				d6401	none
Participant 5					
ICF Codes from OT	covered by	ICF Codes from Description	covered by	ICF Codes from CNs	covered by
b710-3	D&C	b710	O&C	b156/b260/b265/b1649	none
b730-3	C	d4401	O	b164	none
b735-3	none	s7300	O	*b164*	*none*
d430-3	none	s7302	O&C	b164/b1640	none
d440-2	D	s73013	none	*b164/b1640*	*none*
s720-2	none	s73003	none	b210/b1649	none
s730-3	D yes C sort of	s73011	none	b715/b7101	O&D
				b730/b7300	O
				b7301	O
				d4453	none
				d6401	none
				d6401	*none*
				s7302	D
				s7302	*D*
				s7302	D

The main result here is that there are many entries in each method that are not covered by the others. This indicates further that all three methods should be used, since only a partial

picture can be obtained from each, as the emphasis of each is different. The other interesting thing is how few Mobility codes there are in this in relation to the other and in relation to the whole set of ICF codes for the CNs.

The other thing to note is that for the CN statements, many were assigned multiple codes that relate to that need (104 out of 177 or 58%, with a breakdown of 42.8% for Exp2 and 26.9% for Exp1). For example "Product should be easy to grasp" would have an obvious grasping (d4401) code, but "Product should position user's hands comfortably" would be two different codes (s7302: structure of the hand, and b7102: mobility of joints generalized). Also a biomechanical or ICF application expert would have more input on these relationship, as well as how well the choices of ICF codes corresponds to the needs, given sufficient training in customer needs.

The ICF code browser and its expandable tree was the primary resource for this process. An initial pass through the tree to harvest potentially useful codes was made. Then, each customer need was read and and an applicable codes assigned. Often codes from the initial list applied, but often additional searching was required to fully explain the customer need. A running tally of the codes used was kept, as well as which codes were often used together. Whenever the list of accrued codes was insufficient, further code research was done to find the proper code or code group.

A more in depth, precise and prescriptive procedure for applying ICF codes to CN statements may be able to be created in future, but may also be unnecessary given the relative simplicity as observed in this particular approach described above.

The overall finding is "yes," the ICF can be applied to our framework data and provide support to inclusive design. It is a fairly straightforward process to connect the descriptions in the ICF to the types of issues described in CN statements in the style 'Product should Blank'. A particular participant limitation can also be easily traced to the codes. This allows designers to have a starting guess for what will be important to that type of user. Mainly, by providing a connection between the information in the CN statement and the related ICF information regarding human functioning, designers could have an idea of what effect the choices they make about how to accomplish or address a CN statement could potentially have on the types of users who could use the product, or the ways in which it would be used.

As an end cap to this section I present a summary of the comparison between the ICF Codes used in Exp1 vs Exp2. What codes are covered, and how much overlap between the experiences is presented in Table 40 on the next page. This shows that in both cases, there are various degrees of grouping and detail from both Exp2 and Exp1. There is direct overlap in 17 of the codes. Exp2 has only 5 individual ICF codes not used by Exp1 and Exp1 has only 6 not used in Exp2 (marked in yellow). A few others are not used at the same detail level but are closely covered (marked in off yellow). This tells me that, if the groupings are ignored (a level of inference only recommended under certain design circumstances) the experiences are quite similar. On an experimental level, with the code groups relating directly to the CNs, they appear notably different. Therefore, how these relationships are analyzed will make a great deal of difference to design choices.

Table 40: ICF Code Experience Comparison

Exp2	**Exp1**
b156	b156
b156/b199	b156/d199
b156/b260/b265/b1649	
	b156/d199/d440
b164	b164
b164/b1640	
b164/b1640/d166/b210-279	b164/b1640/d166/b210-279
b164/b199	
b198/b199/b156/d6401	
b210/b156	
b210/b1649	b210/b1649
b210/d110	
b210-b279	
b710	
b710/s73011	b710/s73011
	b7101/d498/s730
	b7102
b715/b7101	
b730	b730
	b730/b7401
b730/b7300	b730/b7300
b7301	
b7301/d445(0/1)	
b740	
b7401	
b760/d4402	
b7601	
	b7601/b176
	d131/d155/d159/d160/d199
d166	
d166/b210	d166/b210
d430	
	d430/d440/d445
d4301/d4400/d4402	
d440	d440
d440/d4402	
	d4400
d4401	d4401
d4402	d4402
d4402/d4305	d4402/d4403
d4402/d440	
d4402/d4403/d445(0/1)	
d4402/d445(0/1)	
d445(0/1)/b710	
d4450	
	d4451
d4453	d4453
d4453/s730	
d570	
d6401	d6401
d7601/2/b176	
s730	s730
	s730/d449
s7301	
s7302	s7302
	s7302/b7102
s7308	

Chapter 8: Results and Discussion for the Comparison of Overall Study Experiences

This chapter discusses findings related to the research question Q 5.3 in that it examines various aspects of how Exp1 and Exp2 differ. It also relates to Q 1.3 in that it begins with a discussion of how Exp2 provides a surrogate experience that causes the needs of exceptional users (EU) to be covered more thoroughly by the surrogate users than Exp1.

8.1 Comparison of Customer Needs Elicitation:

The most pressing concern for the comparison of the experiences is the coverage of Exceptional User needs (PWD and PMR) by Surrogate Users (FSU and SSU). This has already been discussed in detail during the validation results. The needs coverage table for both experiences are printed below in Table 41-42.

Table 341 compares the experiences using the original data from Exp1. This shows that there is a slight increase in the coverage of the exceptional users' needs in Exp2 compared to Exp1. This could indicate that the surrogate experience from Exp2 was slightly better at simulating the mindset of exceptional users. It could also be due to the fact that so many more needs per person were elicited during Exp2.

Table 42 compares the experiences using the reformulated data, recall from a previous section the discussion of how the Exp1 data was reexamined using the mindset of Ontology coding to perform the CN matching to determine EU coverage. This produced lower EU coverages for Exp1 data than the original work [73] had concluded. Using the reformulated coverage numbers from the Exp1 data provides a slightly more direct comparison, given that both coverages in the table were developed with the same process and mindset. If these numbers are used for the comparison, then Exp2 is *significantly* better at causing SU coverage of EU customer needs.

Table 41: Percent Coverage of EU Needs from Exp1&2

List	PWD Needs Coverage Percent Exp1	List	PMR Needs Coverage Percent Exp2
GP	62.9	G	84.21
CO	60.3	C	62.07
JO	81.8	J	60.87

Table 42: Percent Coverage of EU needs from Exp1&2, including reformulated similarity matches using new knowledge base.

List	PWD Needs Coverage Percent Reformulated	List	PMR Needs Coverage Percent Exp2
GP	51	G	84.21
CO	33	C	62.07
JO	60	J	60.87

Note the difference in where the coverage happened, as well as the similarity in overall coverage percentage. It is interesting that the larger coverage areas appear in different products for the different experiences. Jar opener coverage was lowest on Exp2 and highest for Exp1. The only speculation as to this cause is the differences inherent in the prior experience and physical restrictions of the participants in the sets of both experiences. More investigation would be required to determine other causes.

The other most pressing concern is the elicitation results on an individual level. This has also been previously discussed. The overall result is that Exp2 had a significantly higher number of CNs elicited on a per person basis across the board, as shown in Table 43. There is also a slightly lower variation in the individual elicitation as shown in Table 44. Both these factors contribute to the idea that Exp2 is a better CN gathering process than Exp1.

Table 43: Experience Comparison of Individual Elicitation

	Exp2	Exp1
EU CNs per person average number	30.7	14.2
SU CNs per person average number	22.1	16.0
Total Stated CNs per person average number	24.2	15.5
Overall List CNs per person average number	9.3	8.0

Table 44: Experience Comparison of Individual Variations

group	avg # CNs	min	max	stdev # CNs	med	variance in # CNs
pmr	4.75	2	9	3.10	4	9.58
ssu	10.55	4	16	3.91	11	15.27
exp2	9.00	2	16	4.47	9	20.00
pwd	14.27	9	22	4.86	14	23.62
fsu	16.08	10	24	3.86	16	14.91
exp1	15.52	9	24	4.46	15	19.93

8.2 Comparison of Complete Code Coverage:

An interesting comparison to perform is examining the difference between the overall coverage of the possible ontology space between from Exp2 from this study and Exp1 from my Masters work study. These two surrogate experiences have both now been proved valid and the differences and similarities between them will assist in informing surrogate experience use and development. The following section shows graphs and data tables which show what kind of code coverages differences there are between the experiences, presented at a variety of detail levels.

First is the basic coverage chart for Exp2 with no manipulation to show comparison or spread (Figure 68). This is developed by placing all 6 product CN lists with their codes together and counting how many of each codes is used. As with the development of all the code coverage graphs, this involves copying the codes to a new column and removing duplicates to create a column of 'all codes used', then using the Excel 'Countif' command between that column and the column with all the codes in it. Then a bar chart is simple to make by plotting the counts and labelling the horizontal axis with the codes used.

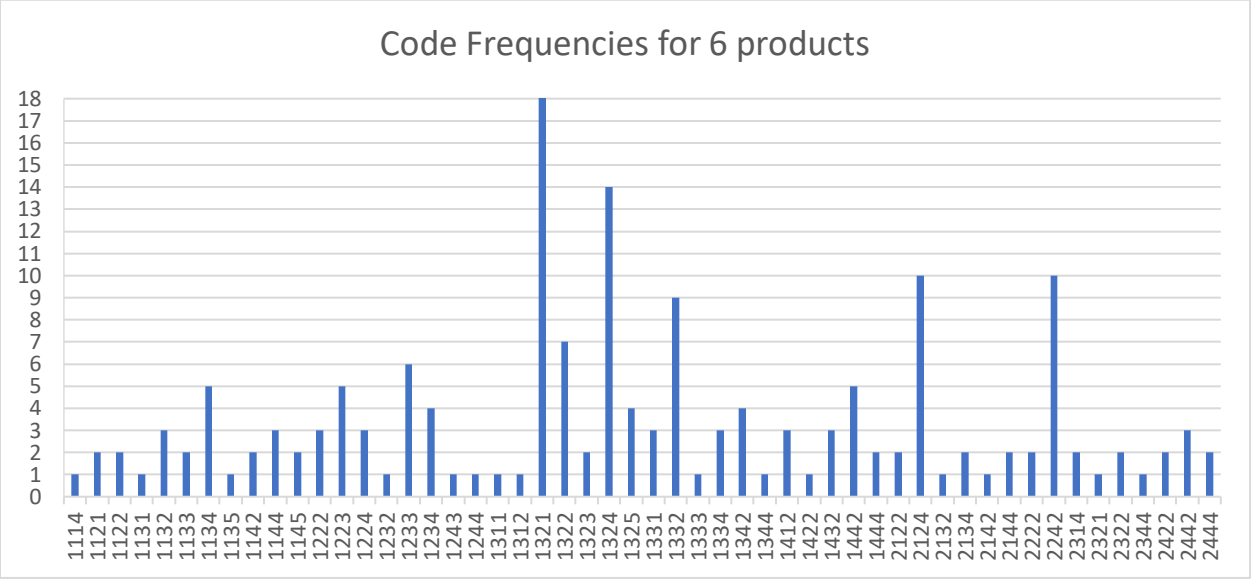


Figure 68: Aggregated Code Coverage Used to Represent Exp2

Comparison to other codes coverage charts should be done when the axes are the same. Therefore, to compare the experiences we must spread out each into the largest possible arena of the complete possible codes provided by the ontology. This is what is shown in Figures 69-70.

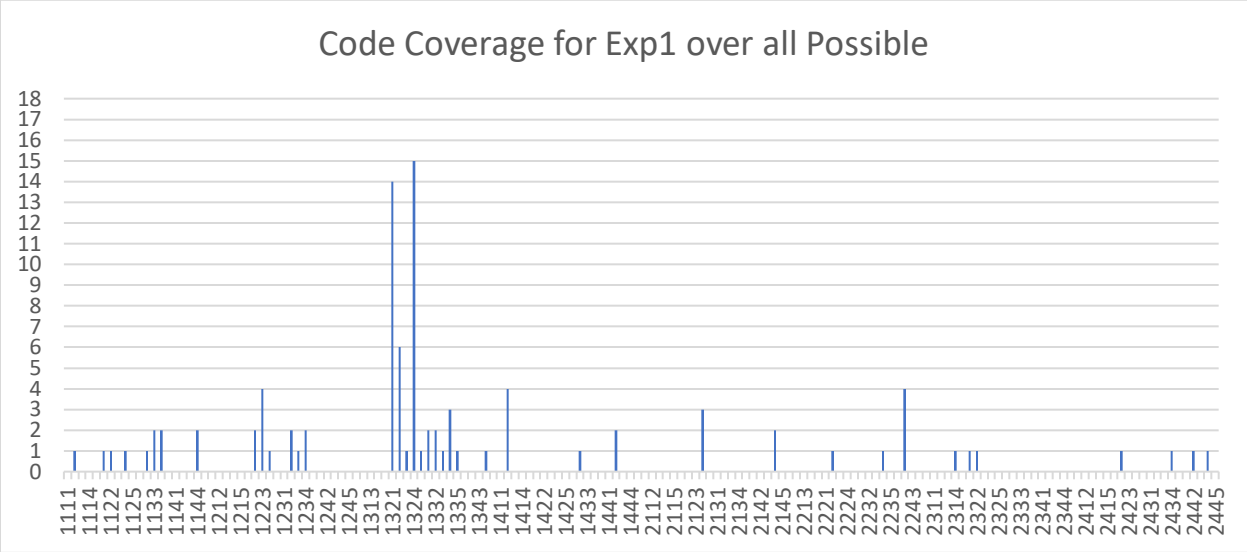


Figure 69: Code Coverage for Exp1 over all possible ontology codes

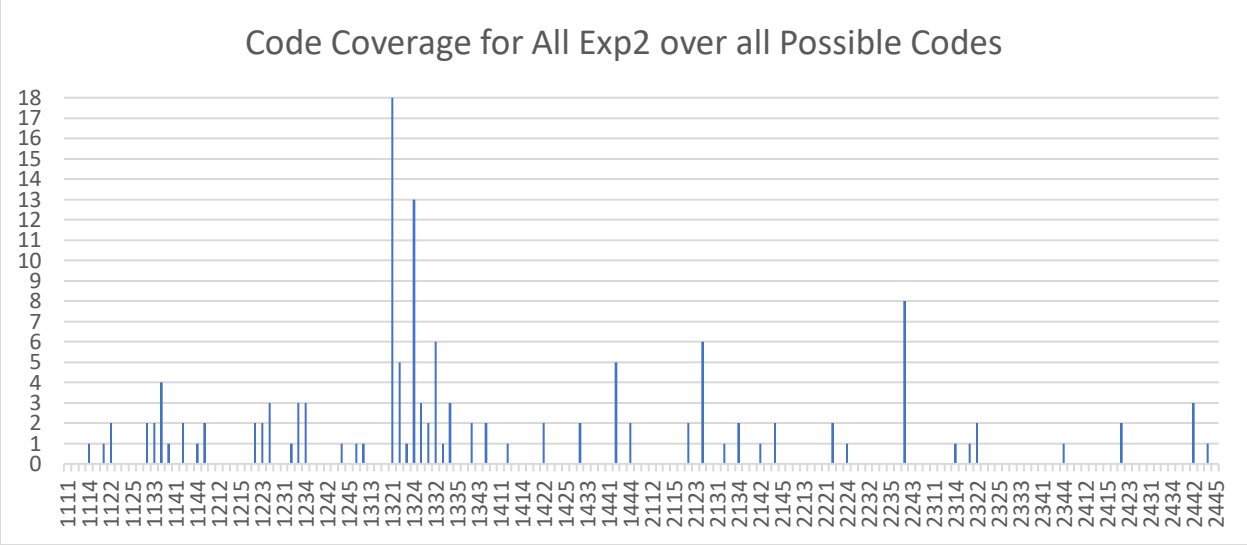


Figure 70: Code Coverage for Exp2 over all possible ontology codes.

These graphs show very little difference in the coverage of the space. But given the difficulty of viewing information at this scale, an explicit comparison the overall Codes Used by Both Experiences is presented below in Table 45. This shows that, though the frequency of codes

and so the CNs involved may be different, the overall space being seen is not very different. Exp2 is missing 1 and adding 2 codes compared to Exp1, but is basically the same view of the overall Ontology code possibilities as Exp1. This indicates a possible limit in the types of codes possible to see for manual handheld kitchen type products, or these specific 6 products.

Table 45: Codes and Names for Both Exp's to show overlap

Exp1					Exp2				
Code	Market	Message	Performance	What	Code	Market	Message	Performance	What
1114	General	Constraint	Safety	Supporting Function	1114	General	Constraint	Safety	Supporting Function
1121	General	Constraint	Human Factors	Aesthetics	1121	General	Constraint	Human Factors	Aesthetics
1122	General	Constraint	Human Factors	Features	1122	General	Constraint	Human Factors	Features
					1131	General	Constraint	Device	Aesthetics
1132	General	Constraint	Device	Features	1132	General	Constraint	Device	Features
1133	General	Constraint	Device	Main Function	1133	General	Constraint	Device	Main Function
1134	General	Constraint	Device	Supporting Function	1134	General	Constraint	Device	Supporting Function
1135	General	Constraint	Device	Environment	1135	General	Constraint	Device	Environment
1142	General	Constraint	None	Features	1142	General	Constraint	None	Features
1144	General	Constraint	None	Supporting Function	1144	General	Constraint	None	Supporting Function
1145	General	Constraint	None	Environment	1145	General	Constraint	None	Environment
1222	General	Specification	Human Factors	Features	1222	General	Specification	Human Factors	Features
1223	General	Specification	Human Factors	Main Function	1223	General	Specification	Human Factors	Main Function
1224	General	Specification	Human Factors	Supporting Function	1224	General	Specification	Human Factors	Supporting Function
1232	General	Specification	Device	Features	1232	General	Specification	Device	Features
1233	General	Specification	Device	Main Function	1233	General	Specification	Device	Main Function
1234	General	Specification	Device	Supporting Function	1234	General	Specification	Device	Supporting Function
					1243	General	Specification	None	Main Function
1244	General	Specification	None	Supporting Function	1244	General	Specification	None	Supporting Function
1311	General	Objective	Safety	Aesthetics	1311	General	Objective	Safety	Aesthetics
1312	General	Objective	Safety	Features	1312	General	Objective	Safety	Features
1321	General	Objective	Human Factors	Aesthetics	1321	General	Objective	Human Factors	Aesthetics
1322	General	Objective	Human Factors	Features	1322	General	Objective	Human Factors	Features
1323	General	Objective	Human Factors	Main Function	1323	General	Objective	Human Factors	Main Function
1324	General	Objective	Human Factors	Supporting Function	1324	General	Objective	Human Factors	Supporting Function
1325	General	Objective	Human Factors	Environment	1325	General	Objective	Human Factors	Environment
1331	General	Objective	Device	Aesthetics	1331	General	Objective	Device	Aesthetics
1332	General	Objective	Device	Features	1332	General	Objective	Device	Features
1333	General	Objective	Device	Main Function	1333	General	Objective	Device	Main Function
1334	General	Objective	Device	Supporting Function	1334	General	Objective	Device	Supporting Function

1342	General	Objective	None	Features	1342	General	Objective	None	Features
1344	General	Objective	None	Supporting Function	1344	General	Objective	None	Supporting Function
1412	General	Solution	Safety	Features	1412	General	Solution	Safety	Features
1422	General	Solution	Human Factors	Features	1422	General	Solution	Human Factors	Features
1432	General	Solution	Device	Features	1432	General	Solution	Device	Features
1442	General	Solution	None	Features	1442	General	Solution	None	Features
1444	General	Solution	None	Supporting Function	1444	General	Solution	None	Supporting Function
2122	Niche	Constraint	Human Factors	Features	2122	Niche	Constraint	Human Factors	Features
2124	Niche	Constraint	Human Factors	Supporting Function	2124	Niche	Constraint	Human Factors	Supporting Function
2132	Niche	Constraint	Device	Features	2132	Niche	Constraint	Device	Features
2134	Niche	Constraint	Device	Supporting Function	2134	Niche	Constraint	Device	Supporting Function
2142	Niche	Constraint	None	Features	2142	Niche	Constraint	None	Features
2144	Niche	Constraint	None	Supporting Function	2144	Niche	Constraint	None	Supporting Function
2222	Niche	Specification	Human Factors	Features	2222	Niche	Specification	Human Factors	Features
2224	Niche	Specification	Human Factors	Supporting Function					
2242	Niche	Specification	None	Features	2242	Niche	Specification	None	Features
2314	Niche	Objective	Safety	Supporting Function	2314	Niche	Objective	Safety	Supporting Function
2321	Niche	Objective	Human Factors	Aesthetics	2321	Niche	Objective	Human Factors	Aesthetics
2322	Niche	Objective	Human Factors	Features	2322	Niche	Objective	Human Factors	Features
2344	Niche	Objective	None	Supporting Function	2344	Niche	Objective	None	Supporting Function
2422	Niche	Solution	Human Factors	Features	2422	Niche	Solution	Human Factors	Features
2442	Niche	Solution	None	Features	2442	Niche	Solution	Human Factors	Features
2444	Niche	Solution	None	Supporting Function	2444	Niche	Solution	None	Supporting Function

8.3 Comparison of Code Taxonomies:

Next we investigate the code coverage on the individual taxonomy. Complete graphs and data tables for the taxonomy breakdowns are available in Appendix O&P. Figure 71 presents one set of charts showing how these are generally viewed. This set is for the combined result of all 6 products considered as the complete Exp2 breakdown. These pie charts show what percent of the list has what category in each taxonomy.

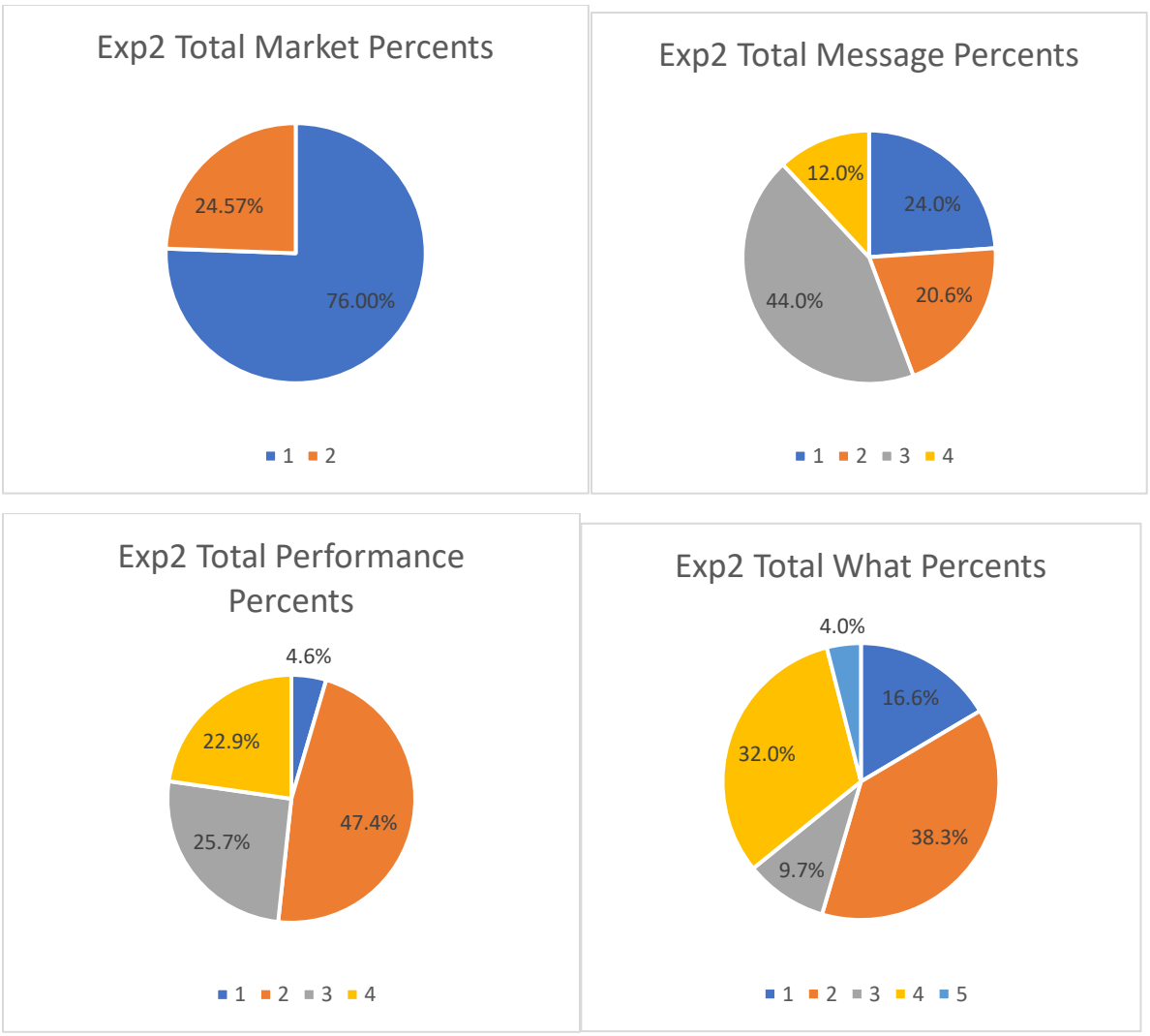


Figure 71: Exp2 Taxonomy Pie Charts

However, a more compacted view is presented by the numerical analysis presented in Table 46-47. Looking at all the Pie Charts for the Taxonomy Code Percentages for each product and pair list in Exp2 we developed Table 46. Then we developed Table 47, showing which is the most highly occurring, and which is the second highest occurring in each category.

Table 46: Complete Taxonomy Breakdown Counts for Exp2

total count	Names	Mark 1	Mark 2	Mess 1	Mess 2	Mess 3	Mess 4	Perf 1	Perf 2	Perf 3	Perf 4	What 1	What 2	What 3	What 4
7	J1	7	0	0	2	5	0	0	7	0	0	3	2	0	2
14	C1	12	2	0	8	6	0	0	9	5	0	3	4	2	5
8	G1	8	0	0	0	6	2	2	6	0	0	3	2	0	3
12	J2	12	0	0	2	10	0	0	12	0	0	4	0	3	6
19	C2	17	2	0	2	15	2	0	13	2	4	5	7	0	7
17	G2	15	2	0	4	11	2	2	11	2	2	5	6	0	6
47	All 1	43	4	0	8	35	4	4	39	0	4	14	14	4	15
32	All 2	28	4	0	12	20	0	0	27	5	0	9	4	4	15
78	All Exp1	72	6	0	21	57	0	0	70	8	0	23	20	9	26
77	All Exp2	57	20	10	16	42	0	0	52	15	10	21	26	6	24

Table 47: Exp2 Taxonomy Numerical Breakdown

	Highest Occurrence				Second Highest Occurrence			
List	Market	Message	Performance	What	Market	Message	Performance	What
Can	1	3	2	2 & 4	2	1	3	2 & 4
Garlic	1	3	2	2	2	2	4	4
Jar	1	3	2	2	2	1	3 & 4	4
SGP	1	3	2	2	2	2	3	4
CGP	1	3	2	2	2	1 & 2	4	4
RCO	1	3	2	2 & 4	2	1	3	2 & 4
WCO	1	3	2	4	2	1	3	2
TJO	1	3	2	2	2	1 & 2 & 4	4	4
BJO	1	3	2	2	2	1	3	1
Exp2	1	3	2	2	2	1	3	4

This shows that there is always more General needs than Niche needs, which is how it should be by definition. This shows that Objective is the most common, with Constraint being second (which makes some sense given that the CNs are worded as Product Should/Should Not Blank and this lends itself to does it or does it not style interpretations). The 'Performance' taxonomy has HF being highest, and Device being second highest. This is no surprise, given that most statements based on human product interaction are going to involve either the human or the product, with human being first in elicitation priority. Of the What codes, Features is the highest, Supporting Function is second, though they switch places somewhat often. This makes sense because from a cognitive standpoint, a products' features will be more salient to participants than

the more abstract product functions. It also makes sense that the one product that was the most difficult to understand (BJO) elicited aesthetic related CNs second most often.

Then the same table of highest occurring taxonomies was developed for Exp1 to provide a comparison. This is presented in Table 48. This showed overall similarity between experiences, except for a large difference in 'Message' occurrence.

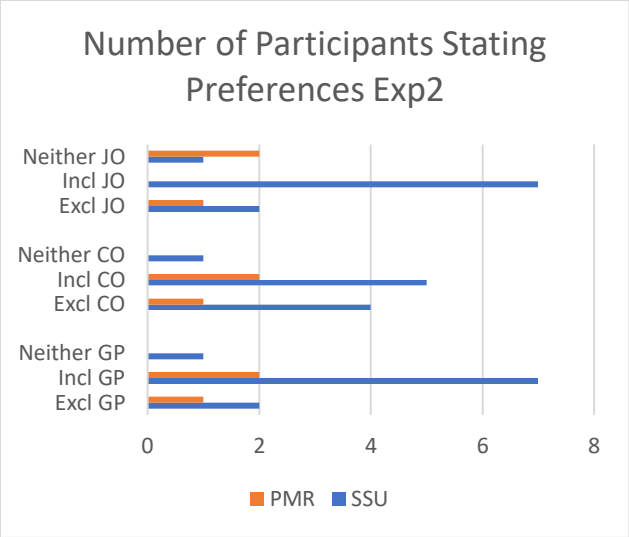
Table 48: Exp1 Taxonomy Numerical Breakdown

	Highest Occurring				Second Highest Occurring			
Group	Market	Message	Performance	What	Market	Message	Performance	What
All FSU	1	2	2	4	2	1	3	2
CO-FSU	1	2	2	2	2	1	4	4
GP-FSU	1	2	2	2	2	1	3	4
JO-FSU	1	2	2	4	2	1	3	1 & 2
CO-PWD	1	1 & 2	2	2 & 4	2	1 & 2	3	2 & 4
GP-PWD	1	2	2	2	2	1 & 3	3	4
JO-PWD	1	2	2	4	2	4	1 & 3	1 & 2
All PWD	1	2	2	2 & 4	2	1	3	2 & 4

An oddity observed was that Exp1 has such a different breakdown of the Message taxonomy. Having specification style CNs happening most often is not as expected. HF is still the most prevalent performance issue, and the rest of the breakdowns are very similar to Exp2. There is a slightly higher tendency to have two codes share the placements, but this table is organized by subgroup rather than product type, so comparisons are more difficult. Apart from the very obvious fact that Exp1 is better at specification style needs and worse at objective style needs than Exp2, the experiences are similar across the taxonomy breakdown aspect. Depending on the individual design situation, desiring objective style versus specification style needs, will be one factor influencing the choice of surrogate experience.

8.4 Comparison of Participant Preferences:

An additional comparison performed between experience one from the Masters study (Exp1) and experience two from the PhD study (Exp2) is the preference distribution of the participants for the products. The participant preference graphs from Exp1 and Exp2 were created for direct comparison. Both the graphs for the preference counts and the percent of the groups that represents are presented in Figures 72-73.



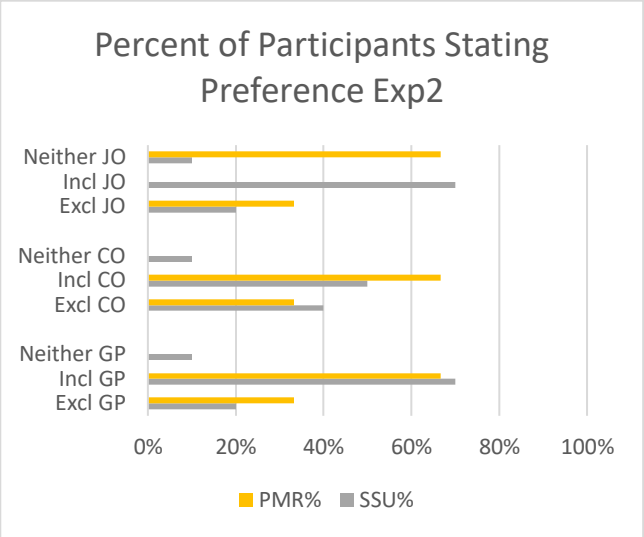
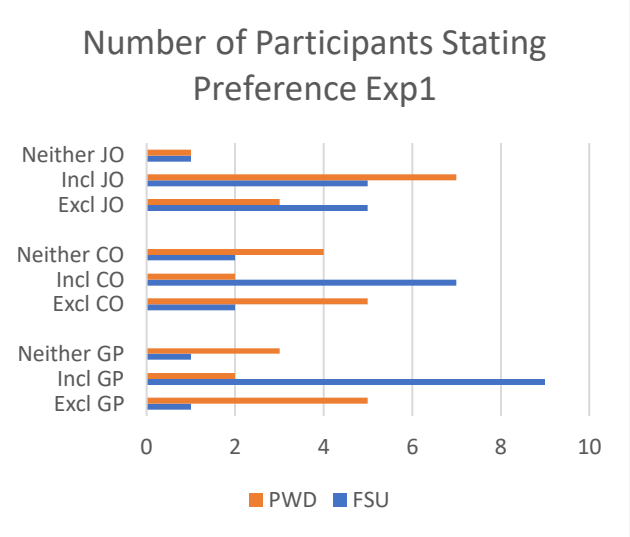


Figure 72: Exp2 Preference Count and Percentage Chart



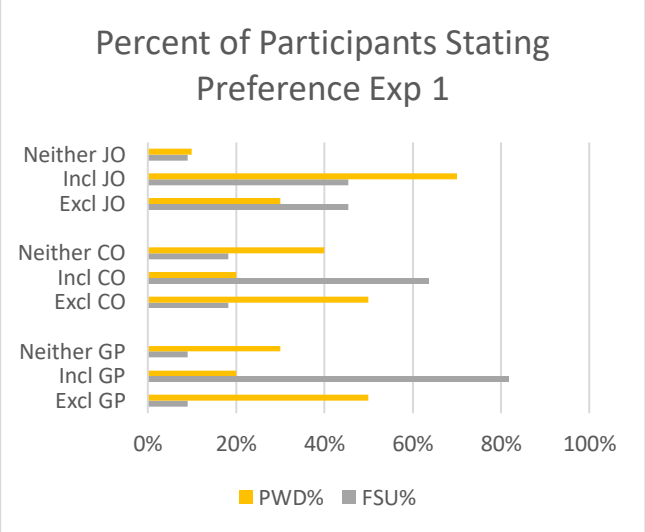


Figure 73: Exp1 Preference Count and Percent Charts

As shown, Exp2 did not show the same preference trends as Exp1. Exp1 indicated that people with disabilities did not prefer the inclusively designed products. This was an interesting result from Exp1 that did not necessarily have an explanation. In Exp2 this trend did not appear with people with motion restrictions. In fact all participant categories preferred the inclusive product over the exclusive ones except the jar opener with PMR where no preference is largest. This result is more like what was expected originally. This indicates that there are additional factors which go into preference and are present in the experiences that are not being specifically addressed. There is a wide variety of research in existence on user preferences [195-198] which might be useful in applying to later studies to shed some light on the reasons for this. Examining

the difference in preference of different types of users for inclusive product feature would be a useful contribution.

8.5 Comparison of Weighting Aspect:

Weight information for the CNs is an important component in the investigation of modular product design, and an important part of the Exp1 study. Weights were also gathered for this study following the same methodology. All CN statements were placed into an Excel file with pictures of the products as a reminder. This file included an explanation of the 1-5 weighting scale they were to use, with instructions on how to fill in and return the file. This file was sent to the study participants so they could provide weights for all the CNs collected during the study. The survey was approved by the IRB. A screen shot of the survey is presented in Figure 74.

Straight Garlic Press Need Statements 	**Weight 1-5 NA=not applicable, 1=not important 5=very important**	**Curved Garlic Press Need Statements** 	**Weight 1-5 NA=not applicable, 1=not important 5=very important**	**Twisting Jar Opener Need Statements** 	**Weight 1-5 NA=not applicable, 1=not important 5=very important**	**Black Jar Opener Need Statements** 
Product should Not have to open very far to access		Product should be lightweight		Product should have a simple design		Product should be durable
Product should be easy to clean		Product should look cool		Product should have a clear center of rotation		Product should be easy to clean
Product should Not need two hands to use		Product should have an adequate sized container		Product should hold onto the jar as well		Product should Not be too unfamiliar
Product should be durable		Product should open Easily		Product should Not allow contents to spill upon opening		Product should Not look scary
Product should Not have a lot of moving parts		Product should have an easy to access container to load garlic		Product should be made of stainless steel		Product should Not have parts that can be lost

Figure 74: Survey

It was returned by only two participants, one from SSU and one from PMR. Since we desired weight information to be available for use, we also reached out for two alternative sources.

First, access to a class of mechanical engineering students, who as part of their class had received some introduction to inclusive design and design for disabilities was available. Students

in the class were offered the opportunity to fill out a survey to weight the CNs on the product *pair* lists. Since they had no particular experience with the individual products, the more generic product *types* were presented in order to provide context. As part of this survey they were asked to rate their level of experience with inclusive design. Other demographics included only for age, class standing and major.

Second, an additional participant with real motion restrictions rated the product list. This gave one additional input option, someone who could act as a confirmation step to the gathered needs. Internal to the study, using the PMR participants as confirmation is good and necessary. But the option always remains to get external confirmation, depending on the needs of the individual design situation. When people with motion restriction, both internal and external to the study, are used as consultants, an interesting analysis regarding any results of the difference in perspective could be performed. There is bound to be a difference there, since each participant sees different aspects. Using both would also likely result in a better acceptance of the product and would always be recommended for any similar study or use of the framework for future design work.

Unlike the data produced with Exp1, there is a discernible weight difference between types of users in Exp2. This is very likely due to the fact that there is only one sample for each type of user. It would be recommended to get more people to provide weights for the customer needs that were elicited from Exp2. From the attempt that was made to do this, given that the response rate to the survey was very low, we observe a large difference in the overall weight with reported user experience. The weights provided by the class showed that those who rated themselves at a higher experience level with inclusive design, provided almost entirely higher weights for all CNs than those with a lower experience level. Meta-analysis was begun on the weight difference between types of groups and the types of experience levels, but more can be achieved later. These analyses are shown in Appendix ZZ. Part of the low response rate for Exp2 compared to Exp1 is likely due to the time between when the participants performed the study and when the survey was sent. For Exp1 this time was between 1-4 months, whereas in Exp2 this time was 3-12 months. This will also have an effect on the participants' ability to accurately recall the experience and provide accurate weights. This interval could also be studied for effect.

8.6 Comparison of the Common Module:

Since we have weight and frequency information for all customer needs, I decided to create customer needs space graphs for all data sets in order to examine the common module. For the creation of the CN space graphs, the weight used was the average of the weights from the three actual participants. This allows a further validation opportunity of the hypotheses in [71] shown in Figure 75.

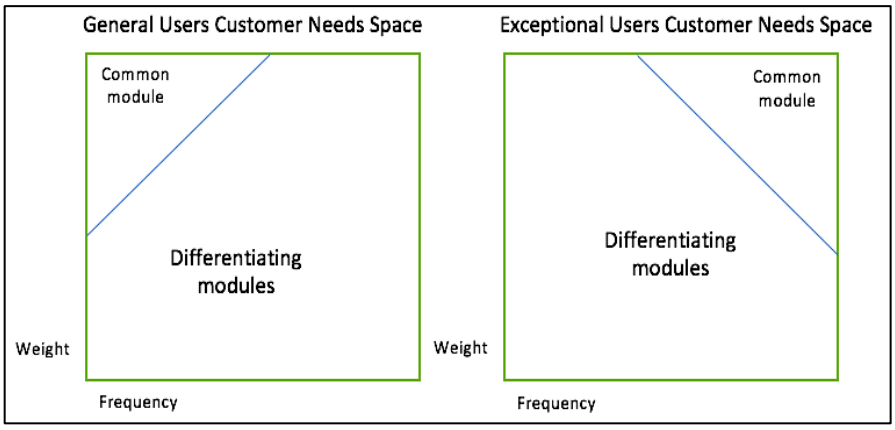


Figure 75: Common Module Spaces

The customer needs space plot was created for each product list, and the Product Tag places as a data label on each dot on the graphs. These are presented in the Appendix T only. I also plotted all Exp2 statements on one CN space graph too see what the common module suggestions for general handheld kitchen gadgets might be. This is presented in Figure 76, without data labels, since the overlap made them unreadable.

Then, a cut off line for was added to separate out what was considered to be the high-weight/high-frequency space. This line was moved downward, until it began to encounter customer needs statements that were illogical to be included in the common module space. The cutoff was chosen to be the green line on the Figure 76 graph and the resulting needs list is presented in Table 49.

The definition of the high-weight/high-frequency space can be dependent on the design situation, as the boundary line has no predetermined or exact placement other than to indicate a triangular space in one of the graph's quadrants.

The resulting common module needs are mainly about ease of use and main product functions. Durability and a few identified problems with the devices were also present. These are logical, and similar to Exp1.

Since all the product lists were included on this graph, it is possible to have the same need in different places on the space. Out of 21 statements present in the common modules, only 10 did not indicate some level of overlap with other statements, which is a positive reinforcement of those needs being common.

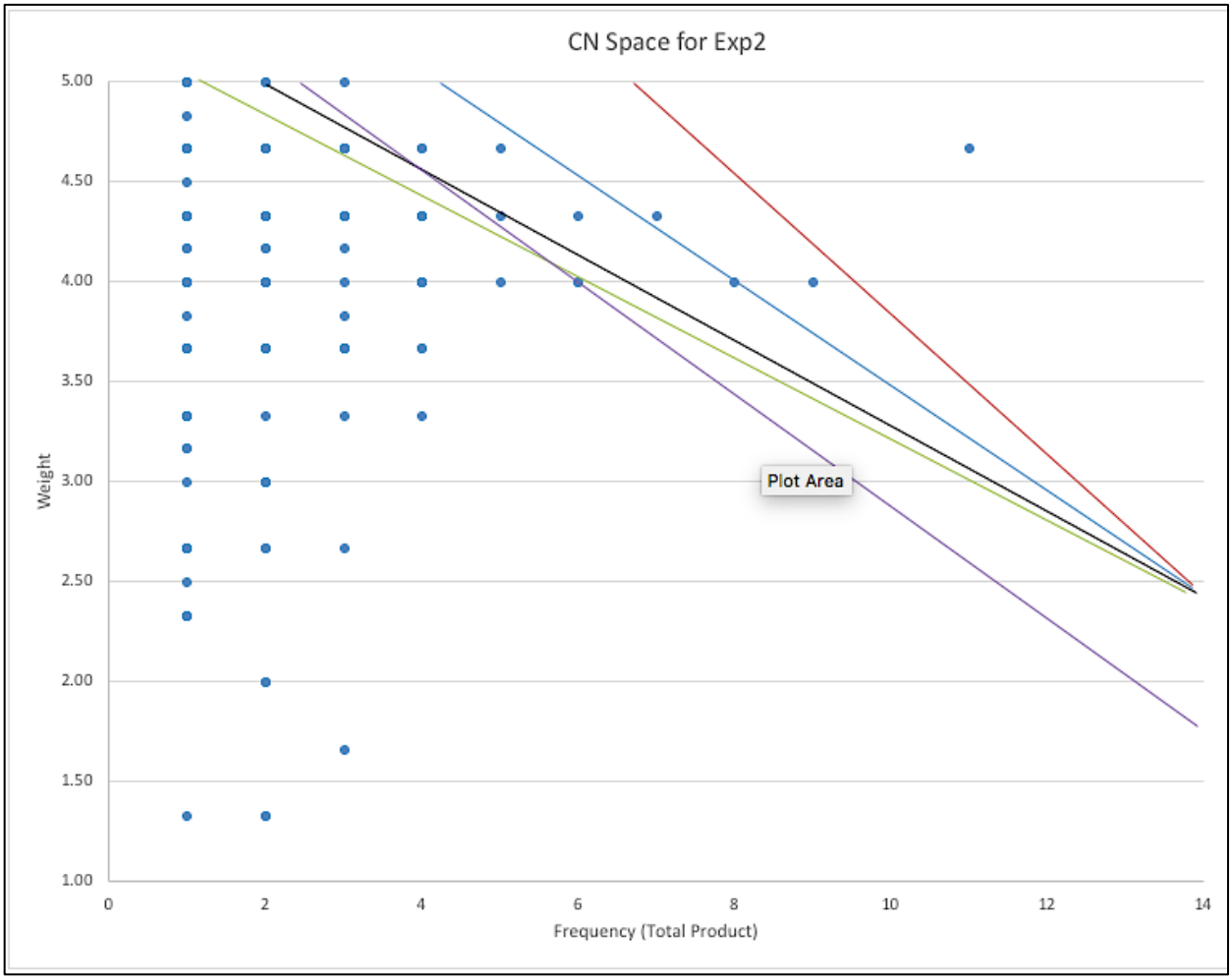


Figure 76: CN Space Graph for all Exp2

Table 49: Common Module Needs at different Lines and their info.

Com?	Match	CN Statement	Ptag	Ctag	Product type	Total Prod Freq	Weight (Partic Avg)
yes	1	Product should be easy to clean	cgp-18	G19	Inclusive	9	4.00
yes	2	Product should be easy (require little effort to) squeeze closed	cgp-26	G33	Inclusive	11	4.67
yes	4	Product should be easy to turn	rco-20	C42	Exclusive	7	4.33
yes	1	Product should be easy to clean	sgp-02	G19	Exclusive	8	4.00
		blue line					
yes		Product should Not open too far / Not need full extension of hands to use	cgp-15	G16	Inclusive	3	5.00
?		Product should help release the garlic	cgp-23	G24	Inclusive	5	4.33
yes		Product should not allow contents to spill	rco-01	C01	Exclusive	1	4.67
yes	2?	Product should not need a lot of grip force to puncture can	rco-22	C18	Exclusive	5	4.67
yes		Product should work quickly	wco-14	C02	Inclusive	2	5.00
yes		Product should have comfy rubber grips on handles	wco-20	C44	Inclusive	6	4.33
?		Product should not feel flimsy	wco-23	C08	Inclusive	2	5.00
yes	2?	Product should take little pressure to press closed	wco-25	C18	Inclusive	4	4.67
		black line					
yes	2	Product should require little pressure to squeeze closed	sgp-16	G33	Exclusive	6	4.00
yes		Product should stay locked in place on can	wco-27	C52	Inclusive	6	4.00
		close to black line					
yes	5	Product should have instructions that are easy to read	bjo-19	J17	Exclusive	3	4.67
yes		Products' parts should all align automatically	cgp-12	G13	Inclusive	3	4.67
yes	3	Product should be easy/comfy to grasp/grip	cgp-22	G23	Inclusive	3	4.67
yes		Product should be simple	rco-09	C03	Exclusive	3	4.67
yes	3?	Product should be easy to grasp/grip	rco-18	C39	Exclusive	3	4.67
yes		Product should be durable	sgp-04	G26	Exclusive	3	4.67
yes	4?	Product should have knobs that are easy to turn	tjo-29	J43	Inclusive	3	4.67
		green line					
yes	5?	Product should have clear directions	bjo-18	J16	Exclusive	4	4.33
?		Product should have an easy to access container to load garlic	cgp-05	G04	Inclusive	4	4.33
no		Product should have big enough handles for two hands	wco-21	C48	Inclusive	4	4.33
		close to green line					

Comparing the groupings in the customer need space of the different product types, there is a distinct difference in the shape of the clustering with the jar openers as compared to the other

two. While the CO and GP spaces look similar, with clusters that appear to grow from the upper left corner and grow evenly outward, with more obviously separated outliers along the edges, the jar openers do not grow evenly, they are missing the tail on the high-weight/high-frequency end and instead have more and more further spread outliers in the low-weight/low-frequency direction. However, there is not a difference in the shape of the clustering between the two different products in a pair, indicating no CN space difference between inclusive and exclusive product elicitation.

Comparing the customer needs spaces from Exp1 to Exp2, one can see that Exp2 is clustered in a more organic way – spreading from the top left corner outward in a triangular fashion with smaller jumps and less obvious outliers. As a sample of this I present Figure 77 with a sample of Exp1 CN spaces and Figure 78 with a sample of Exp2 CN spaces.

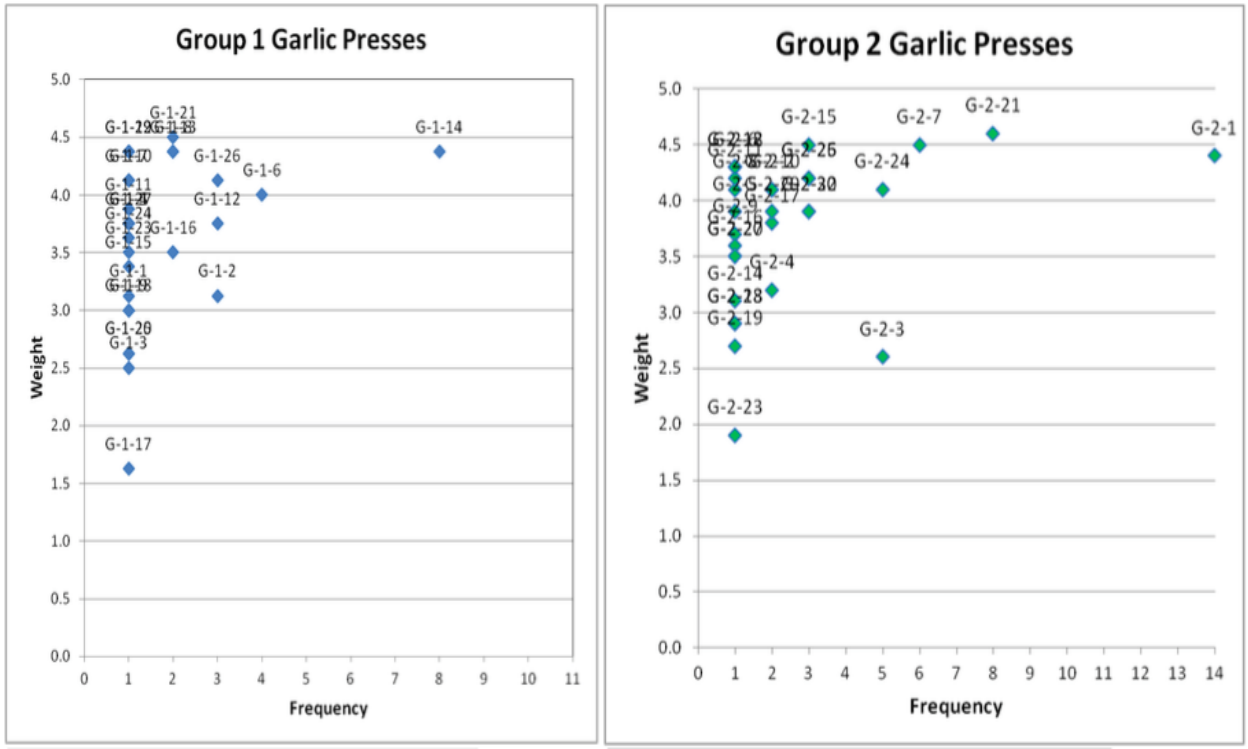


Figure 77: Exp1 CN Space Examples

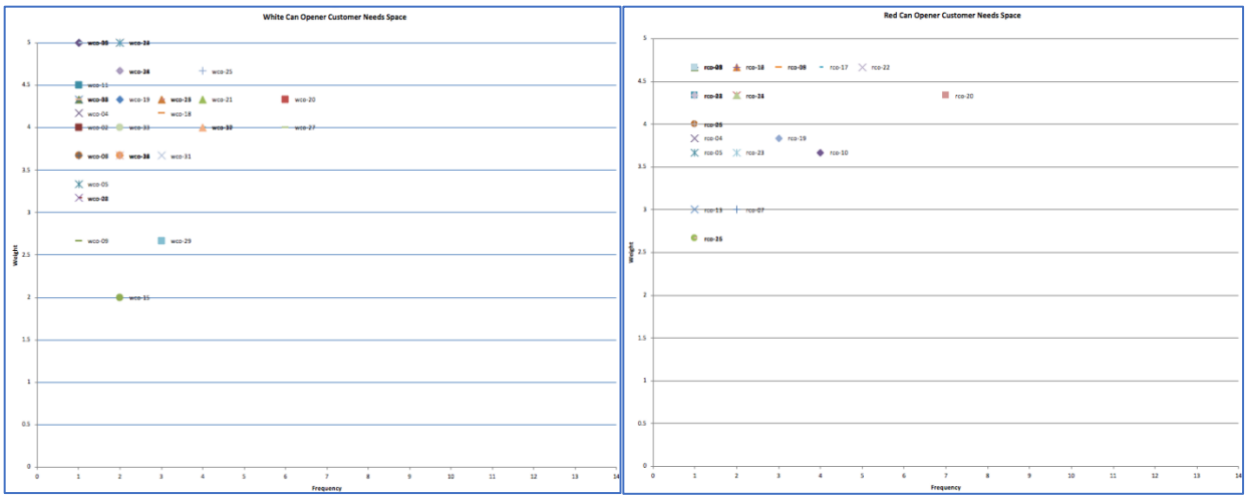


Figure 78: Exp2 CN Space Examples

The common module needs in the Exp1 WvsF CN Spaces were obvious outliers from the main cluster, whereas in experience 2 they are not as disconnected. The customer needs space graphs for the product pairs are not made which would be a more direct comparison with Exp1, but the general ideas are still shown. These spaces are not greatly explored, so any further information about the shape and placement of CNs within the WvsF space can inform modular product design techniques.

8.7 Baseline Motion Restriction Customer Needs List:

As a last effort to show how the PhD and Masters Studies were different, I now present the Baseline Exceptional User Customer Needs List, created by putting the PWD and PMR CN lists together. This is presented completely in Table 50. This shows that the two experiences are causing quite different needs to be elicited. This process was performed in a similar manner to the combining efforts of product lists into product pair lists from Exp2. They were all placed together the statements carefully read and codes compared to see what CNs from Exp1 appeared to match with what CNs from Exp2. Any matches were tracked and tagged with the tags from both experiences.

The main result is the lack in overlap and the fairly even addition from both Exp's. Jar Opener Evaluation = 5 same, 17 PWD, 17 PMR. Garlic Press Evaluation = 9 same, 19 PWD, 10 PMR. Can Opener Evaluation = 8 same, 21 PWD, 21 PMR. Leading to a 12.5% overlap on J and a 24.3% overlap in G and a 16% overlap in C.

This supports the idea that adding more people with motion restrictions gives you a wider variety of customer information, which is the basis of inclusive design. Since people with motion restrictions are so varied, their needs will also be varied, and input from a lot more people than a less varied subgroup would be required. It also supports the idea of using a wide variety of CN collection methods when performing actual design work. These are two similar protocol analysis results and they show a large difference in what is produced for exceptional users. This data represents only 14 participants total, which is still a small group, even given the knowledge tracking trends. It is not expected to be indicative of the complete possible situation of restricted product interaction, and a larger EU participant pool would be recommended for real empathic design style customer needs gathering activities. If the FSU and SSU participants can be added to the lists (as we have shown to be a valid option repeatedly now), then the information widens, and lowers in variation, into a better CN set for design use.

Since this data represents only 3 PMR Exp2 Participants, there is likely to be a higher overlap if more PMR were added, as they could say some of the PWD needs. However, the amount of needs not in PWD given only those three, showcases once more the improved elicitation potential of the Exp2 experience compared to Exp1.

Table 50: Baseline EU (exceptional user) CN (customer need) List

Baseline J Tag	Tags from the Product Pair List	Exp Source	Baseline Frequency	Code	Customer Need Statement	Part #	weight
1	J-1-11	1	1	1111	not have exposed sharp edges		4.00
2	J-1-13	1	1	1114	unscrew without knocking over the jar		4.38
3	J-1-15	1	8	1121	have clear directions/indicate direction of turn		3.50
4	J-1-9	1	1	1132	have a feature to assist with breaking the seal		4.00
5	J29	2	1	1134	Product should Not strip the lid	3	x
6	J48	2	1	1134	Product should Not slide on lid	3	
7	J-1-19	1	1	1222	operate with as few steps as possible		3.63
8	J37/ J-1-8	1/2	4	1223	Product should need only low strength/forces to use	5	3.88
9	J-1-14	1	3	1223	require low torque to twist off lid		4.38
10	J28	2	1	1233	Product should provide good leverage	3	
11	J31	2	1	1234	Product should adjust to remove to all lid sizes	5	
12	J-1-16	1	1	1311	look safe		2.50
13	J35	2	1	1312	Product should have a low chance of mechanical failure	5	
14	J-1-10	1	2	1314	provide stability		3.63
15	J15/J-1-4	1/2	7	1321	Product should be easy to understand	2,5	4.13
16	J18	2	1	1321	Product should grip lid easily	5	
17	J20	2	1	1321	Product should have a simple design	5	
18	J-1-1	1	1	1321	look simple		2.50
19	J-1-18	1	2	1321	have a nice grip		3.88
20	J17	2	1	1321	Product should have instructions that are easy to read	2	

21	J-1-3	1	2	1324	be easy to assemble		4.17
22	J-1-22	1	2	1324	be easy to attach to lid		4.25
23	J02	2	1	1325	Product should be easy to clean	5	
24	J01	2	1	1332	Product should be durable/heavyduty	5	
25	J10	2	1	1332	Product should work quickly	2	
26	J-1-21	1	6	1333	grip lid securely		4.00
27	J-1-17	1	1	1334	work on multiple jar sizes		4.13
28	J42	2	1	1342	Product should Not have too many moving parts	5	
29	J43/ J-1-12	1/2	4	1422	Product should have knobs that are easy to turn	5	3.88
30	J14/J-1-5	1/2	2	1442	Product should have rubber nonslip grip on handle	5	2.75
31	J-1-6	1	1	2122	require only one hand to work		3.50
32	J-1-2	1	2	2124	be usable by either hand		3.88
33	J45	2	1	2134	Product should only work in one direction (the intended direction)	2	
34	J47	2	1	2222	Product should have small enough handles to hold	5	
35	J-1-20	1	2	2222	have large gripping surface		3.13
36	J11	2	1	2242	Product should have big handles	5	
37	J12	2	1	2322	Product should work with small hands	3	
38	J33	2	1	2344	Product should also assist with putting the lid back on	2	
39	J24	2	1	2442	Product should be made of stainless steel	5	
40	J22/J-1-7	1/2	3	2444	provide a way to grip/hold onto the jar as well	2	3.88
Baseline J Tag	**Tags from the Product Pair List**	**Exp Source**	**Baseline Frequency**	**Code**	**Customer Need Statement**	**Part #**	**weight**
1	G-1-10	1	1	1114	prevent user fingers from being caught or squished		4.13
2	G35	2	2	1132	Product should have an adequate sized container	2,5	
3	G33/G-1-14	1/2	11	1223	Product should be easy (require little effort/grip force /pressure) to squeeze closed	2,3, 5	4.38
4	G-1-2	1	3	1224	require only modest hand spans		3.13
5	G02/G-1-16	1/2	3	1232	Product should be lightweight	2	3.50
6	G25	2	1	1233	Product should provide good leverage	2	
7	G-1-22	1	1	1234	allow application of uniform pressure		4.38
8	G32	2	1	1234	Product should Not waste much garlic	2	
9	G-1-20	1	1	1321	have a familiar shape		2.63
10	G-1-1	1	1	1321	have an obvious holder		3.13
11	G-1-12	1	3	1321	have obvious operation		3.75
12	G37	2	1	1322	Product should have easy to grip handles	2	
13	G23/G-1-19	1/2	2	1322	Product should be easy/comfy to grasp/grip	2	4.38
14	G-1-24	1	1	1324	be conducive to apply pressure		3.63
15	G-1-26	1	3	1324	be easy to manipulate / maneuver		4.13
16	G-1-13	1	2	1324	have simple garlic insertion method		4.38
17	G05	2	1	1324	Product should open Easily	2	
18	G19/G-1-21	1/2	5	1325	Product should be easy to clean	2,3, 5	4.50
19	G-1-8	1	2	1332	accommodate multiple sizes of garlic		4.38
20	G26	2	2	1332	Product should be heavyduty	2,5	
21	G08/G-1-7	1/2	3	1334	Product should be efficient (lots separated, none wasted)	3,5	4.13
22	G-1-4	1	1	1334	provide stability		3.75
23	G09	2	1	1342	Product should have few moving parts	5	
24	G24	2	1	1344	Product should help release the garlic	5	
25	G06/G-1-11	1/2	2	1412	Product should have rounded edges so as not to cut into the hand	5	3.88
26	G-1-5	1	1	1412	have a non-slip grip surface		3.75
27	G-1-15	1	1	1422	have cushy grip surfaces		3.38

28	G-1-27	1	1	1434	employ pressing rather than squeezing mechanism		3.75
29	G-1-23	1	1	2122	only involve one hand		3.50
30	G-1-3	1	1	2142	not be sloped		2.50
31	G11/G-1-17	1/2	2	2242	Product should Not have thick handles	5	1.63
32	G-1-25	1	1	2242	have large handles		2.63
33	G30	2	1	2242	Product should have small handles	5	
34	G15	2	1	2322	Product should fit small hands easily	5	
35	G-1-18	1	1	2422	be large enough to accommodate both hands		3.00
36	G13/G-1-6	1/2	5	1134/1444	Products' parts should all align automatically without manual adjustment	2	4.00
37	G07/G-1-9	1/2	2	2442/2322	Product should have curved handles	5	3.00
Baseline J Tag	**Tags from the Product Pair List**	**Exp Source**	**Baseline Frequency**	**Code**	**Customer Need Statement**	**Part #**	**weight**
1	C11	2	1	1122	Product should have instructions	3	
2	C-1-26	1	1	1122	have a non-slip grip surface		3.50
3	C-1-5	1	2	1124	not require hand to stay closed		3.75
4	C31	2	1	1131	Product should Not squeak	5	
5	C28	2	1	1132	Product should not catch the teeth in the blade	5	
6	C52	2	2	1134	Product should stay locked in place on can	2,5	
7	C-1-18	1	1	1134	remain in cutting position		4.25
8	C32	2	1	1135	Product should Not rust	5	
9	C29	2	1	1144	Product should not have any wiggle in it	5	
10	C18/C-1-25	1/2	5	1223	Product should require only minimal squeeze force to press closed to puncture can	2,3	4.25
11	C-1-20	1	2	1224	require only low force to hold closed		4.00
12	C-1-29	1	1	1224	put user at the right height		3.75
13	C-1-24	1	2	1232	be lightweight		3.50
14	C-1-27	1	1	1232	remain sharp as long as possible		3.63
15	C25/C-1-17	1/2	2	1233	Product should provide good leverage	2	4.25
16	C-1-16	1	1	1233	turn smoothly		4.25
17	C07	2	1	1311	Product should look safe	5	
18	C05/C-1-22	1/2	4	1321	Product should be familiar	2,3	2.63
19	C08	2	2	1321	Product should not feel flimsy	3,5	
20	C12/C-1-28	1/2	3	1321	Product should be easy to understand	5	4.00
21	C27	2	1	1321	Product's extra features should be visible/obvious	3	
22	C-1-19	1	3	1321	have a nice gripping surface		4.00
23	C-1-10	1	1	1322	position user's hands comfortably		3.50
24	C17	2	1	1323	Product should be easy to attach to can	3	
25	C40	2	1	1324	Product should Not need large movements	5	
26	C24	2	1	1333	Product should cut through the can consistently	2	
27	C-1-8	1	1	1334	be efficient		4.38
28	C-1-14	1	1	1334	function with pressure from multiple angles		3.13
29	C-1-23	1	2	1334	remain in position easily		3.88
30	C09/C-1-1	1/2	2	1335	Product should be durable	5	4.00
31	C03/C-1-11	1/2	2	1341	Product operation should be simple	5	3.88
32	C-1-6	1	2	1412	have blunt/padded edges so as not to dig into user		4.25
33	C33	2	2	1432	Product should have mechanisms that turn smoothly/fluidly	3,5	
34	C-1-9	1	1	1432	have longer knob for more leverage		3.25
35	C21	2	1	1442	Product should have a sharp blade	3	
36	C45	2	1	1442	Product should have nonslip handles	5	
37	C20	2	1	1444	Product should keep the blades touching	5	
38	C-1-2	1	2	2124	be usable with either hand		3.88
39	C-1-21	1	6	2132	not have a separate release		2.38

40	C-1-12	1	1	2134	operate with a push action instead of a squeeze		3.13
41	C36	2	1	2222	Product should not require large wrist motions to operate	2	
42	C-1-4	1	1	2222	allow sufficient grip with one hand		3.38
43	C-1-7	1	1	2222	have large handles		3.38
44	C47	2	1	2242	Product should not have thin/narrow handles	2	
45	C49	2	1	2242	Product should have large turning handle	5	
46	C14	2	2	2314	Product should assist with removal of the lid after cutting	2,5	
47	C-1-13	1	1	2342	shape should not be straight		3.00
48	C53	2	1	2442	Product should have curved handles	5	
49	C44/C-1-3	1/2	3	2442/1442	Product should have comfy rubber coating on handles	2,5	3.00
50	C42/C-1-15	1/2	6	1324/1223	Product should be easy to turn	3	4.25

Chapter 9: Serendipitous Analysis

This chapter describes all the results that were found that were unplanned in the original research approach and were not part of the original set of comparisons. Results shown here typically arose from observations of graphical representations of the data and appropriate analyses were formulated to explore if a relationship did exist.

9.1 Suit Variability Conclusions:

A useful and fortuitous result has emerged from the review of the participant videos. When the forearm is not restricted in its ability to rotate, the experience provided by the suit is greatly diminished. Users are able to adapt their motions to get around the restrictions that the suit provides. This effect is even explained specifically by one of the Participants. The most common misapplication of the suit is the wrists being allowed to rotate, followed by the fingers not being in the right place to restrict all joints well. These issues and a few others are documented in the table of misapplication in Table 51 below.

Table 51: Suit Fit Issues

Part #	People wearing suit correctly	Suit mis-fitting in wrist	suit mis-fitting in fingers	suit mis-fitting other
4		wrists not secured from rotating	fingers a bit loose?	
6		wrists not secured from rotating	fingers a bit loose?	hand brace too small?
7		wrists not secured from rotating	fingers not down far enough	
8		wrists not secured from rotating		
10		wrists not secured from rotating and wrist came undone	fingers not done right	brace not on hand in right places/too big
11	mostly correct	mostly secured wrists		elbows off a little
12	correct			
13		wrists not very secured from rotating	fingers too bunched	hand brace too big, arm brace too loose
14	correct	bigger arms		
15	correct			
16	correct			

Being able to provide this guidance to future users of the suit is a particularly useful result. Knowing that the wrist rotation restriction is very important to the experience is an excellent starting point. However, more exacting analysis, from the perspective of biomechanical

and normal human capability expertise could reveal more. A physical interaction analysis of the suit using the participant videos may be advisable. Additionally, further investigation into how/which OT metrics show the sources of the greatest impact to movement, would also be informative.

A researcher trained specifically in human biomechanical functioning would likely be able to watch participant actions and determine exactly which part of the suit is changing normal motion patterns, and to what extent. The transcripts of the participants talking about what the suit did to them will be helpful in identifying which parts of the suit are mentioned, both positively and negatively. That data is available upon request.

It can also be seen from watching the videos that the people who the suit is applied properly to, are the surrogates that had the ROM difficulties during OT measurement. The ROM restrictions in SSU occurred with participants 11, 12, 14, and 15, which were incidentally where some of the best suit applications occurred.

Knowing this allows a correlation analysis between suit application correctness and the participants' experience of the suit. This obvious but incomplete correlation is easy to observe, since it is a small data set. This is shown in Table 52 where the suit application rating (developed based on how many and how severe the suit application errors were), and the perceived difficulty (developed based on listening to the participants' comments regarding the functioning of the suit) are both shown. This corresponds well to a moderate positive correlation shown by the Excel result of a Correl of -.565. The more correctly the suit is applied, the more likely the participant is to have a high perceived difficulty in their product interaction.

Table 52: Suit Experience

Perceived Difficulty	Participant	Suit Application Rating
5	4	1.5
no data	6	2
4	7	2
4	8	1
3	10	4
4	11	0.5
5	12	0
2	13	3.5
3.5	14	0
5	15	0
3	16	0

This knowledge is very helpful for future use of the suit as a surrogate experience tool. It also speaks to the future possibility of tuning the suit to mimic a specific type or level of experience in participants. We can confidently conclude that correct and consistent application is important to the surrogate experience of the participant.

9.2 Participant Experience Spectrum:

An interesting possibility inherent in the data available for this study is the ranking of participants by experience. There are two types of experience. Their experience with disabilities prior to the study, and their perceptions of the surrogate experience.

For our actual participants, we have several pieces of information about experience. We have their background survey to determine prior experience, with a question where they rate their own experience, and questions that ask how many people with disabilities they know. From this information I could develop an aggregated experience score. This was done by assigning points to the various answers, as shown in Table 53.

The aggregation of the different types of prior experience allows the plotting of participants on a spectrum, as in Figure 79. This visually shows that in our participant group there is a nice spread of experience levels. It also shows that the PMR participants are generally higher, which is to be expected.

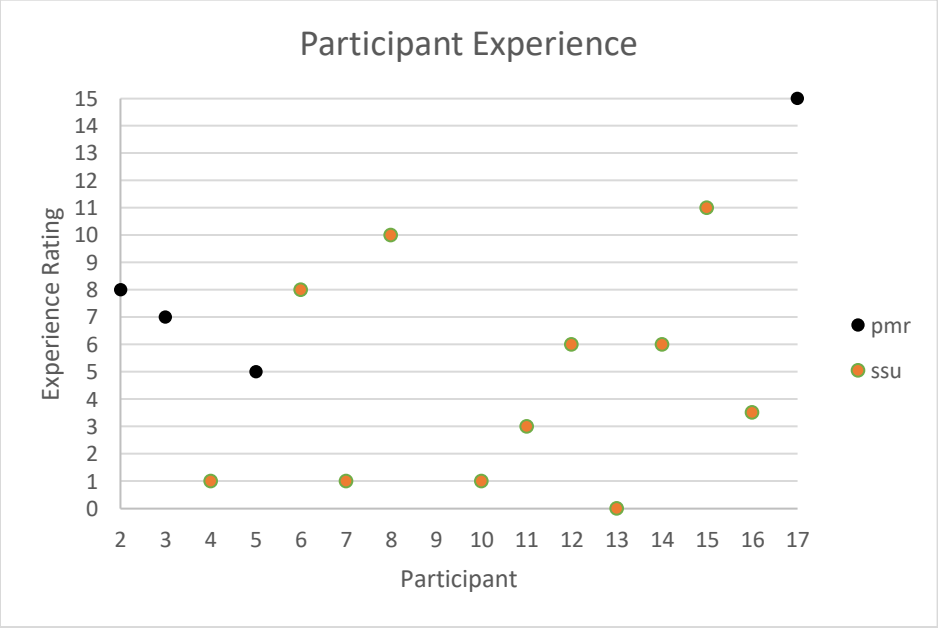


Figure 79: Participant Prior Experience Plot

Table 53: Development of the Prior Experience Rating

Participant #	***Prior Experience Points from # and closeness of PWD known***	***Self-assessment of experience with PWD***	***Inclusive Design Knowledge***	***Aggregated***	***Type***
4	1	Not well at all	no	1	ssu
6	5	Well	no	8	ssu
7	0	A little bit	no	1	ssu
8	5	Well	Yes	10	ssu
10	0	A little bit	no	1	ssu
11	2	A little bit	no	3	ssu
12	5	A little bit	no	6	ssu
13	0	Not well at all	no	0	ssu
14	4	A little bit	Some	6	ssu
15	9	A little bit	Some	11	ssu
16	0.5	A little bit	Yes	3.5	ssu
9	3	a little bit	no	4	x
17	10	very well	some	15	pmr
2	5	well	no	8	pmr
3	6	a little bit	no	7	pmr
5	1	very well	no	5	pmr
	Scale	**Scale**	**Scale**	**Scale of 1-15**	
	2pts per first order knowledge	not at all = 0 pt	yes=2pt		
	1 pt per second order	a little = 1 pt	some = 1pt		
	.5 pts per third order	some = 2 pt	no = 0		
		well = 3 pt			
		very well = 4 pt			

Turning to the surrogate experience, we have statement information that measures how the study was perceived. The surrogate participants are asked the question if it makes them better understand, which they answered either explicitly, with a yes or no followed by and explanation, or implicitly, just an explanation. There is also statements about suit effects that can be interpreted into a perceived difficulty rating of 1-5. The results, across all of these aspects are presented in Table 54.

Table 54: Surrogate Experience Perception Table

Participant	***explicit answer***	***implicit answer***	***perceived difficulty***
4	yes	yes	5
6	no data	no data	no data
7		yes	4
8	yes		4
10		no	3
11		yes	4
12	yes		5
13		no	2
14	yes		3.5
15	yes		5
16	maybe		3
			scale of 1-5
			1=no perceived impediment
			2=requires adjustment, but still easy to perform tasks
			3=suit provides noticeable impediment, but allows activity
			4=suit contradicts some normal muscle memory motions
			5=use of suit noticeably strains user

The development of these experience ratings were straightforward, given the available information. These scales apply only to the data in this study. If experience is to be used in other studies as a factor under investigation, either these scales, or some other applicable scale could be used for experience. These two experience spectrums lead directly to the interesting question of what the effect of these experience factors was. The option this research explored is in the next section. There are others within the data set that could also be explored, as discussed in future work. There are also other validated methods of determining experience that could be incorporated in future investigations.

9.3 Factors Influencing Customer Needs Elicitation:

The best, in fact the only numerical option for correlation analysis, was the number of Customer Need Statements made by the participant. This was done since it looked like the lower experience people and the people who the suit did not restrict as much had less to say overall.

I ran several correlation tests in Excel. The correlation between prior experience and #CNs was .659. The correlation between perceived difficulty of the surrogate experience and

#CNs was .542. The correlation between prior experience and perceived difficult is .480. Then I tried combining the prior experience and perceived difficulty effects (by both addition and multiplication, after normalizing). The correlation between the combined effects and the #CNs was .795 and .814.

As a result, we can say that there is a correlation between suit experience and previous experience and number of needs stated. Both individually and in combinations. Knowing that both their prior experience and their surrogate experience contribute to how many CNs they generate is useful information for future designers. Below, in Figures 80-82, I provide the charts for the correlations so that visually the linearity and relations of the different aspects can be viewed. This is a trend well observed in this data set, but future studies would have to repeat and expand this finding before it can be considered a general fact, but it is good to keep it in mind during the design and development of surrogate experiences.

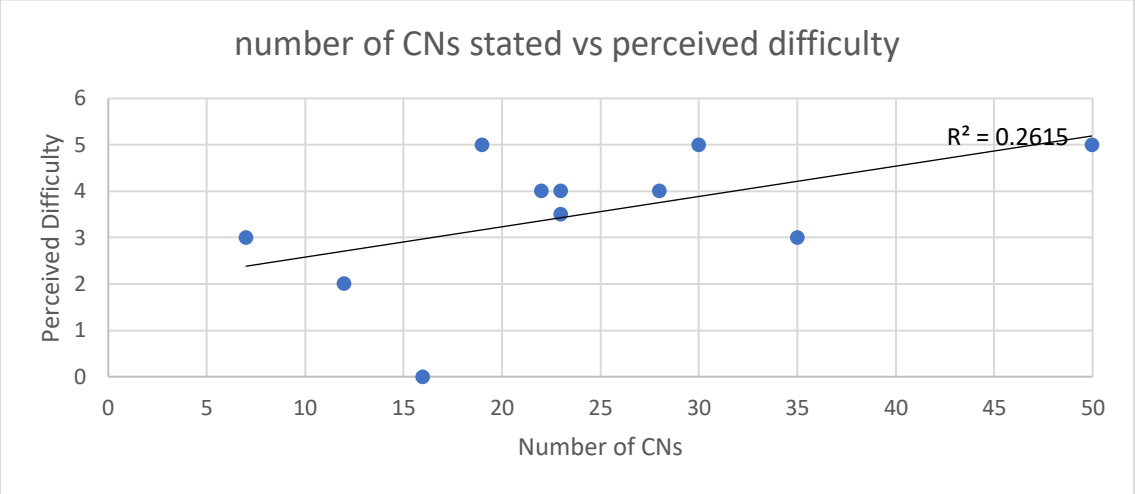


Figure 80: Difficulty vs Elicitation

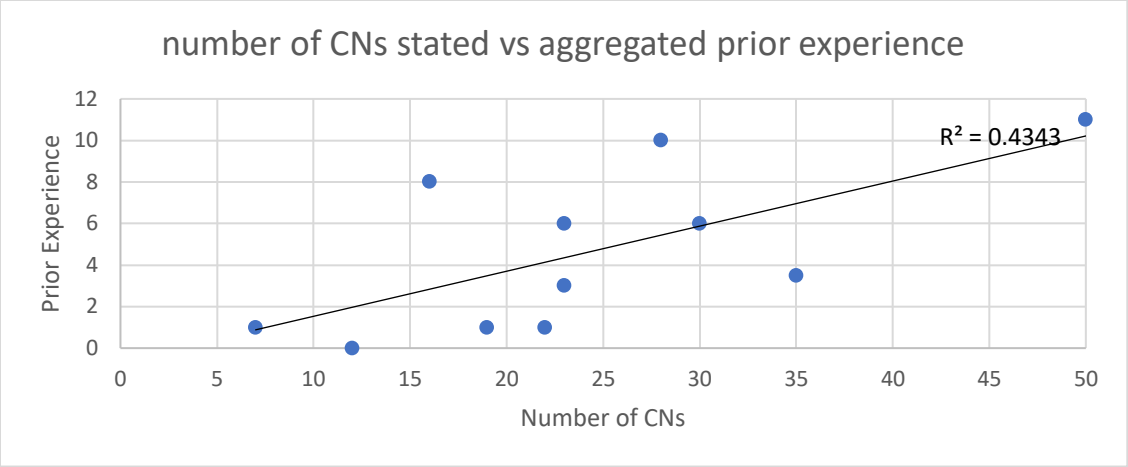


Figure 81: Prior Experience vs Elicitation

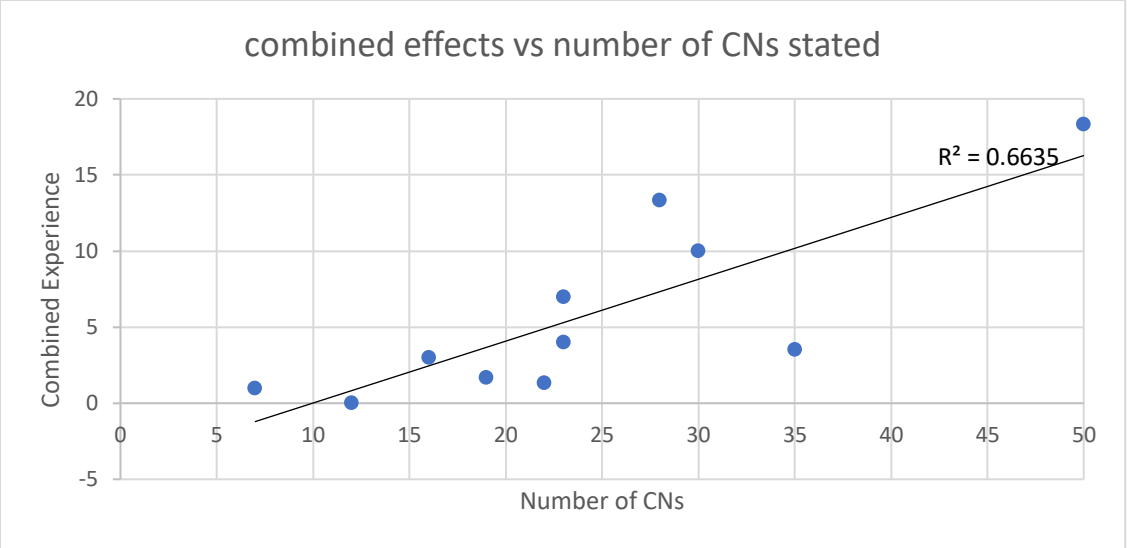


Figure 82: Relationship between Experience and Elicitation

9.4 Top Codes and Guidelines:

In examining the code coverage, it was quite clear that there were a limited set of codes occurring with significant frequency. Most codes were stated one or two times and only some seemed to rise above the noise. Those that did had their codes and counts pulled out and put onto what I called the Top Code lists for each set. Then the CNs associated with those codes were also pulled out onto a list as well, so we could identify any trend in these special CNs. This was done for both Exp1 and Exp2 so that they could also be compared across the top code dimension.

It should be noted that the different levels of aggregation of the CN lists produced different top code cutoffs, as the noise level changed with smaller lists. For example, for the

aggregated jar opener product pair list (J) we get a lower cutoff for top codes than for the individual product lists of TJO or BJO. Looking at Table 55-56, one will notice the lowest frequency for the product lists is 2 while the lowest on the pair lists is 3 and the lowest on the subgroup aggregate lists is 4 and the lowest on the whole experience lists is 6.

Various options for the presentation code coverage information exists, and many have been shown previously. Which is best depends, on the goal of the visual search and analysis. The graphs made out of the top code information are presented in the Appendix Z, and only a few pieces are presented here to serve with the explanations.

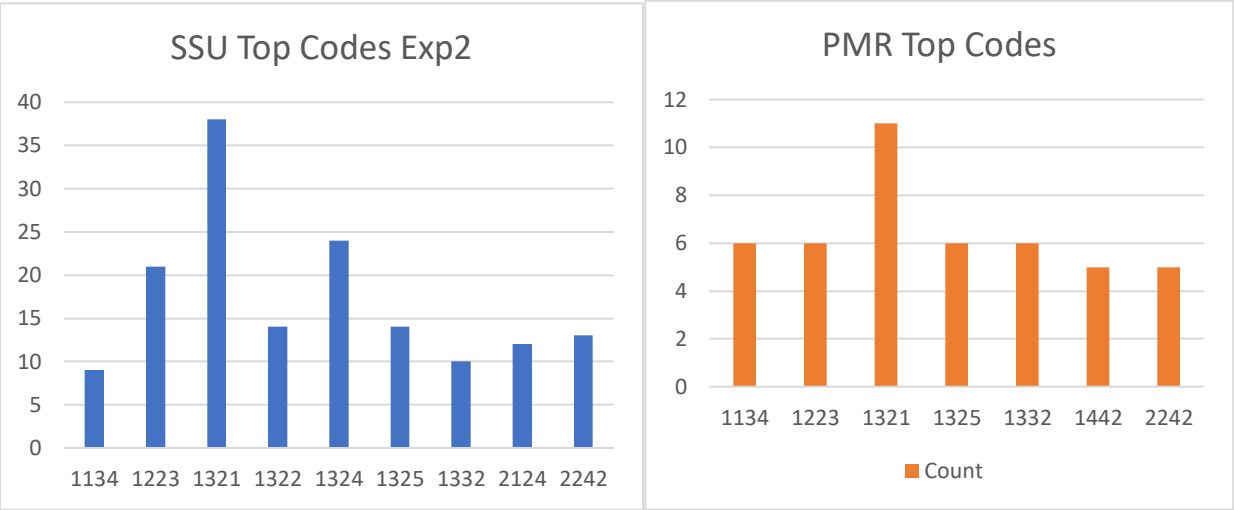


Figure 83: Top Codes for Subgroup Lists of Exp2

Looking at the graphs in Figure 83 above, it is easy to see that the top code sets for SSU is larger in terms of both magnitude and spread. Looking closer between the two, only one PMR top codes is not a top codes for SSU, that is 1442 (meaning General/Solution/None/Features). SSU adds 3 top codes, which are 1322 (meaning General/Objective/HumanFactors/Features), 1324 (meaning General/Objective/HumanFactors/SupportingFunction), and 2124 (meaning Niche/Constraint/HumanFactors/SupportingFunction). A different type of comparison is provided by placing both on the 'all codes used by Exp2' axis, illustrating not only where they match and don't but the similarity in the shape, and the lack of noise. This is provided below by Figures 84-85.

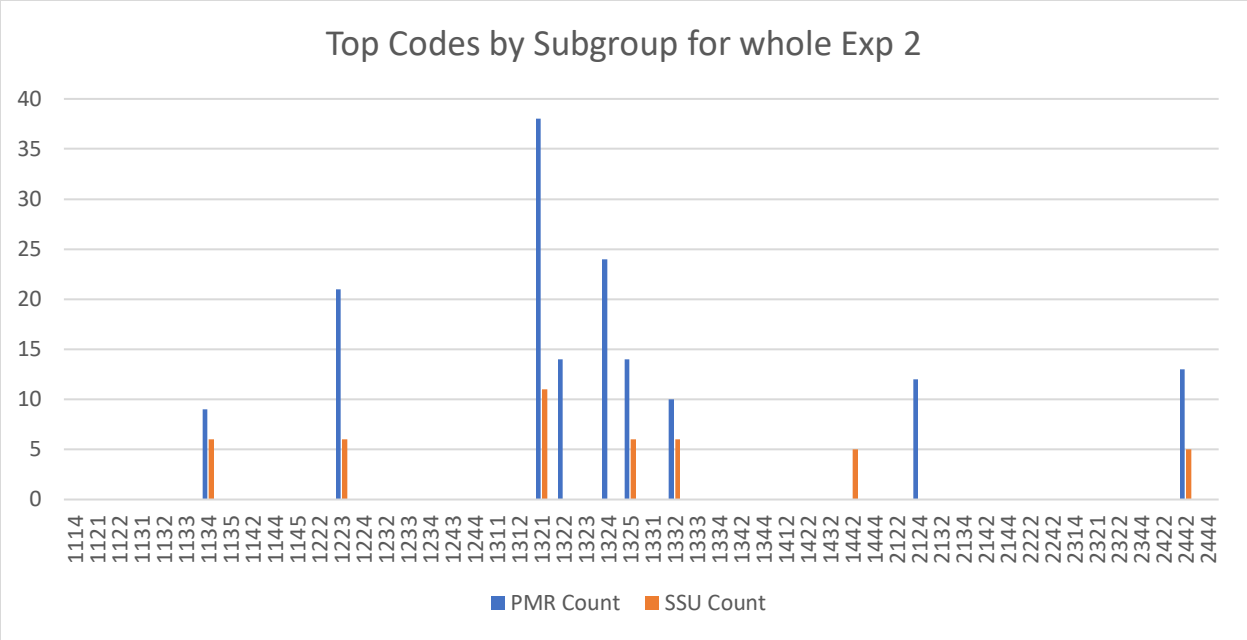


Figure 84: Top Codes by Subgroup over Exp2

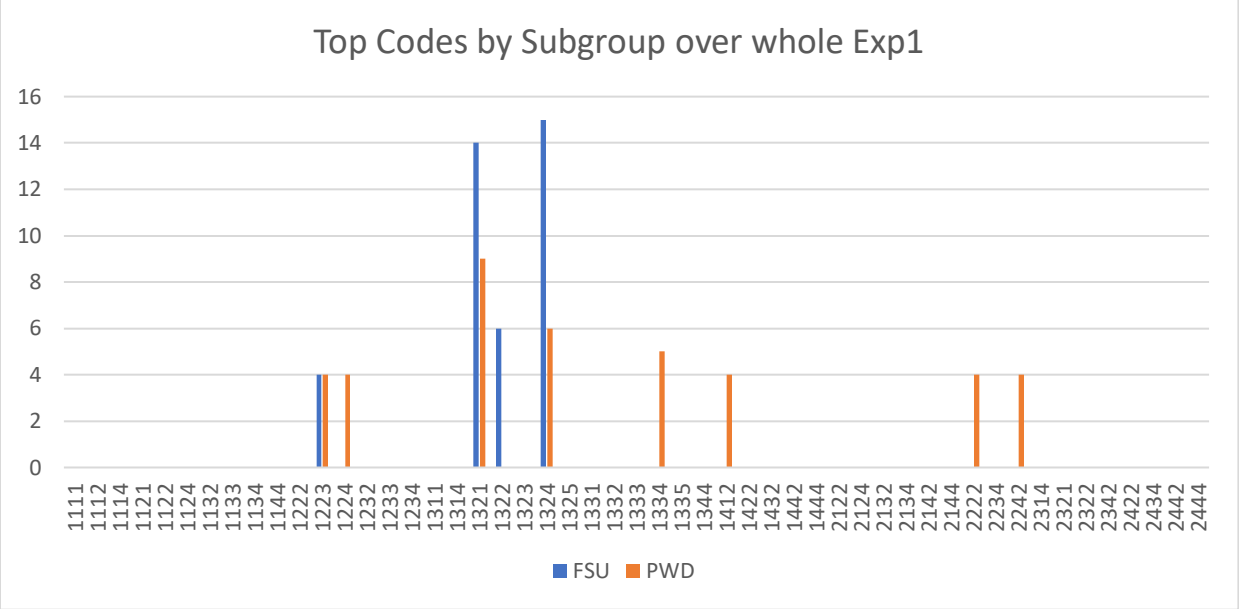


Figure 85: Top Codes by Subgroup over Exp1

These figures also provide a good comparison between Exp1&2. There is less spread of the Exp1 codes, fewer overall top codes for Exp1, and fewer matching between participant types' top codes for Exp1. The FSU group is significantly more constrained in their top codes than the PMR group. This cannot be turned into too strong a conclusions, since much information has been removed with the noise codes. However, it is interesting that there are such obvious

differences in the top codes when viewed in this manner, since viewing the entire code coverages by subgroup in this manner reveal much more subtle/suggested differences.

Remember, the blank spaces on these are not actually blank, they do contain CNs that have codes which were not stated at a high enough volume to be picked out as important for the top codes analysis. This can be seen in Figure 86, where the same group of codes as above was placed together, and the empty spaces filled in with the actual frequency of mention of those codes.

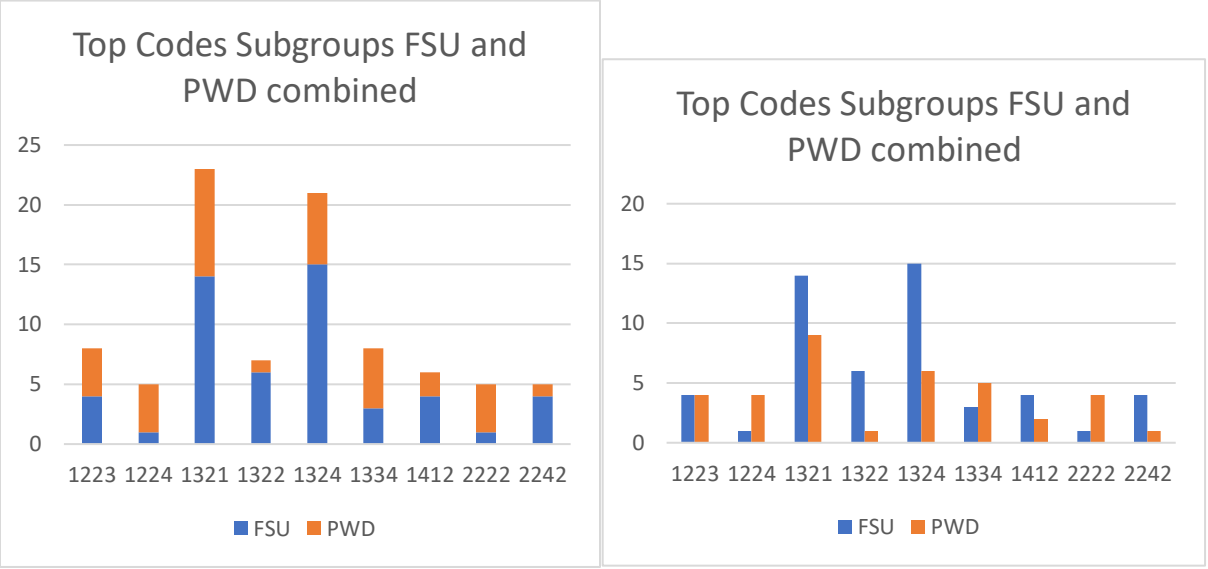


Figure 86: Top Codes (Filled in) by Subgroup

A more thorough explanation of the top codes and their relationships is provided by the data tables in Table 55-56. These combine all the code placements and magnitudes across the various lists. Looking at these can show which top codes occurred on which lists and where they match between which lists. This shows the difference between list detail level as to what are top codes and the fact that some codes are almost always a top code no matter the breakdown.

Table 55: Exp1 Top Codes by Product Type and Participant Type with HF analysis

Code	Exp1	All PWD	GP-PWD	CO-PWD	JO-PWD	All FSU	GP-FSU	CO-FSU	JO-FSU
1222	6				2				
1223	9	4		2		4			2
1224		4		2					
1232				2					
1234							2		
1321	23	9	3	3	3	14	5	5	4
1322	8					6	2	3	
1324	18	6	3		2	15	4	5	6
1334	8	5		3				2	
1412			3			4	2		
1442								2	
2222	6	4		2					
2242						4	2	2	

Table 56: Exp2 Top Codes by List: Counts and HF analysis

Code	Exp2	TJO	BJO	SGP	CGP	RCO	WCO	C	G	J
1122							2			
1134			2							
1144						2				
1145					2					
1224							2			
1233	6		2							
1234				2						
1321	21	3	7	2		3	5	7		9
1322	7				2				3	
1324	14	2	2	2		2	5	6	3	4
1332	9		2	2	2		2			
1334						2				
1432							2			
1442						2		3		
2124	10			3	2		2			
2242	10			3	2	2		3	4	

As a reminder of what the codes mean…

Category	Value	Classification
Market	1	General
	2	Niche
Message	1	Constraint
	2	Specification
	3	Objective
	4	Solution
Performance	1	Safety
	2	Human factor
	3	Device
	4	None
What	1	Aesthetics
	2	Features
	3	Main function
	4	Supporting function
	5	Environment

Figure 87: Ontology Code Naming Reminder

The top codes for Exp1 represents 38.6% of the total needs elicited during Exp1. The PWD top codes represents 35.2% of the total PWD needs, the FSU top codes represent 42.34% of the total FSU needs. The Top Codes for Exp2 represent 44.0% of the total needs elicited for Exp2. This shows that a subset (16 out of the 52 stated (30.7%)) of CN Ontology Codes can accurately represent a portion of the Customer Needs.

Additionally, comparing top codes from Exp1 and Exp2 across the aspects of interests of validation coverage and addition as done in a previous section in Table 41-42, we arrive at the information in Table 57, presented below. This information was able to be developed for both experiences given the information breakdown provided by the framework. Of note is the higher percentage of the PMR participant stated needs that the surrogate needs covered as compared to the PWD participant stated needs of Exp1. This further lends credence to Exp2 methodology being better suited to elicit valid surrogate needs – whether by improvement to the specific interview steps or improvements to suit 2.0 or a combination of both.

Table 57: Top Code Coverages and Additions of Interest for Both Experiences

Exp2		**Exp1**	
% of PMR codes covered by SSU	% of the SSU list only SSU said	% of PWD covered by FSU	% of FSU list only by FSU
94.87	26	71.05	28.95
Counts of PMR covered by SSU	Counts of the SSU list only SSU said	Counts of PWD covered by FSU	Counts of FSU list only by FSU
20	13	11	13

One obvious thing that was noticed what how much of the top codes were HF (human factors) based needs/codes. The HF code counts and the percent of the list it represents is presented in Table 58. All but 2 of the lists have over half of the top codes being HF. Most are quite a high percent, and three are 100% HF. Looking at the taxonomy data charts for the whole CN lists in the Appendices will show that this is higher than the HF spread across the whole of the lists. The HF codes represent 30-44% of the codes on the various whole lists, making it the top performance code on every list, but still lower than the HF portion of the top codes. This strengthens the argument that HF style customer needs are an excellent starting point for design and especially inclusive design.

Table 58: Complete Top Codes HF Analysis.

Customer Needs from the Top Codes			
Subset List Name	**Total Needs**	**HF style needs**	**HF%**
All FSU	47	39	83
CO-FSU	19	13	68.4
GP-FSU	17	13	76.5
JO-FSU	12	12	100
All PWD	32	27	84.4
CO-PWD	14	9	64.3
GP-PWD	8	6	75
JO-PWD	7	7	100
Exp1	78	70	89.7
Exp2	77	52	67.5
BJO	15	9	60
TJO	5	5	100
SGP	14	7	50
CGP	10	4	40
RCO	13	5	38.5
WCO	20	16	80
C (can pair list)	19	13	68.4
G (garlic pair list)	10	6	60
J (jar pair list)	13	13	100

In addition to looking at just what the codes were, it is helpful to know what CNs those codes encompass. All the CNs for the top codes were extracted from the lists, in order to be examined separately. This showed the types of needs that were represented by the most frequently assigned codes and allowed the creation of design guidelines. These design guidelines would, theoretically, be more *immediately* helpful, since they would rise above the noise of the infrequently stated types and get to the heart of the issues.

The complete table of the CNs associated with the top codes is in Appendix Y. A table of the guidelines derived from examination of these CNs is below in Table 59. This is showing how the data from the framework can be set-up so that a connection analysis and development of guidelines based on the CNs can be performed. This type of work, for whatever aspects are of most pressing interest, should be easily performed on data from this, and other studies, in the future.

Table 59: Top Code Based Design Guidelines

Ontology Categorization	Code	Guideline
General, Constraint, Human Factors, Feature	1122	Clear instructions are either on or provided with the product.
General, Constraint, Device, Supporting Function	1134	Provide non-slip surfaces for interactions with other objects.
General, Constraint, None, Supporting Function	1144	Rotary user input should be accepted in either direction.
General, Constraint, None, Environment	1145	Use food-safe materials for food related products and ensure food contacting parts are easy to clean/sanitize (e.g., can be placed in dishwasher).
General, Specification, Human Factors, Features	1222	Minimize effort required to turn rotary interfaces.
General, Specification, Human Factors, Main Function	1223	Minimize force required by user.
General, Specification, Human Factors, Supporting Function	1224	Minimize effort or discomfort required by user.
General, Specification, Device, Features	1232	Minimize weight of product if manipulation of entire product is required.
General, Specification, Device, Main Function	1233	Utilize lever arms to magnify user input effort.

General, Specification, Device, Supporting Function	1234	Use mechanical advantage to transfer user effort.
General, Objective, Human Factors, Aesthetics	1321	User operation of the device should be clear or intuitive.
General, Objective, Human Factors, Aesthetics	1321	User interaction should feel familiar and substantial.
General, Objective, Human Factors, Features	1322	Include handling surfaces that are easy to grip and guide positioning of hand.
General, Objective, Human Factors, Supporting Function	1324	Ensure ease of operation with few steps required.
General, Objective, Device, Features	1332	Maximize durability of product.
General, Objective, Device, Features	1332	Minimize the time it takes to complete a task.
General, Objective, Device, Supporting functions	1334	Maximize reliability of key product functions.
General, Solution, Safety, Features	1412	Provide non-slip surfaces for interactions with user.
General, Solution, Device, Features	1432	Minimize looseness (or slop) in rotary input parts.
General, Solution, None, Features	1442	Precise job output is supported by enabling sure input and durable internal parts (e.g., blades that remain sharp or self-sharpen, gearing that is low wear, etc.)
Niche, Constraint, Human Factors, Supporting function	2124	Operation of product only requires one hand and provide status signal to user.
Niche, Specification, Human Factors, Features	2222	Gripping surfaces must be large enough for one-handed use.
Niche, Specification, None, Features	2242	Enlarge parts that allow handling of the product to accommodate reduced dexterity but not to an extent that the parts are cumbersome for remaining product operation.

One thing to keep in mind is that this analysis is ‘coding frequency’ rather than ‘statement frequency.’ This means some of the top code needs are only said by one person, which sets them at a lower importance when considered in the alternative weight versus frequency (WvF) domain. The coding frequency shows what types of needs are most common, and while they are likely to have similar considerations, the needs themselves are not necessarily solved the same way. A methodology may exists which would be able to effectively combine the

'total combined frequency' information with the 'frequency of code assignment'. However, this is out of the scope of investigation of this study. In contemplating this idea, and looking at the distribution of frequencies, I did notice that the trends in 'frequency of statement' were basically the same throughout the different data sets. Low frequency is the most common, with 30-70% of the CN lists being mentioned by only one participant. This percentage descends as frequency (of both statement and code) ascends. This can be seen in the two sample Tables 60-61 below. This shows that high frequency would also be a good way to break out a subset of important CNs.

Table 60: Frequency counts across can opener lists

frequency counts RCO							
1	2	3	4	5	6	7	8
9	1	1	1	0	0	1	0
normalized							
69%	8%	8%	8%	0%	0%	8%	0%
frequency counts WCO							
1	2	3	4	5	6	7	8
8	6	3	3	0	0	0	0
normalized							
40%	30%	15%	15%	0%	0%	0%	0%

Table 61: Percent of the different List types of interest vs frequency of (statement/code)

Frequency	C	C top	P	P top I	P top E
1	40.7%	36.8%	50.9%	40.0%	69.2%
2	32.1%	36.8%	24.0%	30.0%	7.7%
3	20.0%	0.0%	12.6%	15.0%	7.7%
4	15.7%	15.8%	7.4%	15.0%	7.7%
5	6.4%	0.0%	1.7%	0.0%	0.0%
6	2.9%	5.3%	1.7%	0.0%	0.0%
7	1.4%	0.0%	0.6%	0.0%	7.7%
8	2.9%	5.3%	0.6%	0.0%	0.0%

The activity of pulling out and examining the top codes has demonstrated a beneficial performance of this framework. It allows examination of subsets of the data. As a starting point for developing design information a subset of just the most important needs could easily be considered first. Then as resources allow, the rest of the information the framework provides can

be added to consideration as design progresses and decision points require more input. This is a less inclusive methodology, but a valid one if dealing with limitations. The inclusion of PMR information throughout the framework should ensure that even subsets of examination should lead to more inclusive product designs. For this research we chose top codes (those CN statements associated with the most commonly mentioned type of need) as the most 'important' subset to examine for developing design guidelines. Looking at top codes allows looking at multiple products, takes out the dependency on frequency and avoids the normalization issues inherent in Frequency analyses. However, depending on the individual design situation and the priorities of the users of the framework, they might be interested in a different subset. Examining top code CNs gives you most common sentiment type, where examining high frequency CNs would give you most common identified need. Discussion and decisions regarding possible consideration of 'importance' for the CNs for a specific design situation will be required before creating and analyzing data subsets.

9.5 Alternate Subgroup:

Given that participant 9 identified themselves as a PMR, but after performing the tests, expressed the fact that their disability did not in any way impair their use of these particular products on that day, they cannot be included in the PMR group and were removed from the data sets. This participant is included in some of the non-CN based analyses, and their data was maintained separately when it was removed from the main data sets.

Additionally, upon review of the empathy questions and videos, two other participants in the SSU group expressed that the suit did not really feel like it restricted them. This was likely due to the observed misapplication of the suit discussed previously. This leads to the idea that we could create a third group of participants with just these three less restricted people to see if there is any observable difference. This was done for the Pair Lists.

Compared to the PMR and SSU groups, the alternate subgroup produced fewer overall needs, fewer unique needs, and almost no internal overlap. With this small of a group, participants are hitting on different issues. The knowledge tracking represented by the last two columns of Table 62 indicates that as with the three person PMR group, this group does not have a complete picture of the experience. Three people is 20% of the total participant pool, but these three are not adding anywhere near 20% of the needs.

Table 62: Group 3 Needs Analysis

List	total needs from this group	unique needs from only this group	internal overlap	percent of unique needs in just this group's list	% of unique needs from whole list contributed by this group
C	6	2	0	33.3%	3.7%
G	13	4	1	30.8%	10.8%
J	7	1	1	14.3%	2.1%

This group in essence gives us a group of people further down the surrogate experience spectrum to examine. Pulling together this group provides one data point to be used as an example of an alternate surrogate experience. The idea is that PMR group is at the top of the spectrum as the actual exceptional users, followed closely (as we have shown) by the surrogate suit users, followed by the less effective surrogates, followed by general users with some knowledge of inclusive design(the class who gave weight survey responses), followed by general users.

Meta-analyses on the important differences between the different groups could be performed to better understand the progression down the spectrum of surrogate and exceptional users shown at the very front of this paper in Figures 2-3. Especially if the framework is expanded to intentionally include those groups, and gather similar information from all of them.

Additionally, the addition of General Users to the framework would provide a direct comparison option and showcase the benefits of inclusive information collection methods. Being able to see what additional information is gained by the inclusion of both surrogate and real exceptional users (as compared to performing the CN gathering just with general users) will inform inclusive design even further. We have validated that surrogate users are representative of exceptional users in this framework. However, there is nothing preventing this framework from being expanded to include gathering and comparing CNs from General Users as well.

Chapter 10: Conclusions

In this chapter, both the general and limited conclusions of this research are presented. The answers to the overarching questions will be discussed. Conclusions regarding how the results of this work could be used to connect to the larger design context are also made. One of the most straightforward ways to present conclusions is to specifically answer and discuss the research sub-questions. That will be the main format of this chapter. The implications of the study results are explained, with some of these implications being internal to the study and some being external with broader impacts.

10.1 Overall Data Set Usability and Benefits Conclusions:

The most salient conclusion to the author, is that the current manual data manipulation strategies of the framework are awkward. Even with the small sample size, the data set is quite large and unwieldy. Performing all the analyses required repeated reprocessing and reorganization of the data, which took time and increased the possibility of errors. The large amount of raw information, added to its interconnected nature, means that the framework has a high potential to inform inclusive design decisions. On the other hand, it also means that careful data manipulation techniques are required. The standard research process of keeping track of everything in Excel worksheets will be inadequate for future framework usage under realistic design and product investigation conditions. Therefore, an upfront investment in data management techniques is recommended.

10.2 The Overall Implications of the Planned Comparisons:

These conclusions were discussed in previous chapters and are only briefly summarized here. The overall conclusion is that it is possible to find useful design information by examining different aspects of the contents of the framework's data.

Covered in Section 5.2…

Q 5.1: What useful differences exist in the information content of the customer needs between a general purpose and a niche product?

- Inclusive Products may cause people to notice more niche type needs.
- Inclusive products have a higher rate of notice of the more useful/ nicer feeling/ nicer looking aspects of the product.

- Inclusive product use creates a wider range of CNs.
- Inclusive products prompt more specification style statements.

Covered in Section 5.3…

Q 5.2: What useful differences exist in the information content of the customer needs between an exceptional and surrogate user?

- The SSU (surrogate suit user) group states over 50% of the CNs (customer needs) that the PMR (people with motion restriction) group states.
- Across the board, the SSU group has stated most of the Ontology codes that the PMR group stated, reinforcing the fact that the Exp2 methodology is prompting the surrogate users to find the majority of the needs that the actual exceptional users identify.
- SSU group identified codes that the PMR group did not.
- There are no obvious differences between subgroups in terms of where they do and do not cover codes on the overall ontology spaces.

Covered in Chapter 8…

Q 5.3: What useful differences exist in the information content of the customer needs between surrogate experiences (Exp1 and Exp2)?

- Exp2 caused a noticeably higher rate of CN elicitation among participants.
- Exp2 produced a similar number of CN statements.
- Exp2 had a similar coverage of EU (exceptional user) CNs to the original Exp1 data.
- Exp2 had a significantly better coverage of EU CNs than the reformulated Exp1 data.
- Exp2 had a similar ontology code coverage.
- Exp2 had similar taxonomy breakdowns, apart from it being much better at ‘Objective’ style CNs where Exp1 was better at “Specification” style CNs.
- Exp2 also showed that the top-right corner of the weight versus frequency CN space contained the common module needs.
- Exp2 had a different preference outcome for the inclusive vs. exclusive products. These matched the researchers’ expected preference outcomes, whereas Exp1 did not.

The conclusion is that Exp2 was similar, but overall considered to be a better than Exp1 in terms of elicitation of surrogate customer needs and overall data collection capability. Further

determination of quality will be largely based on future work involving design decision resulting from framework use.

10.3 Validation aspects:

Covered in Chapter 4…

Q 1.1 Are the surrogate users wearing the suit for the experience eliciting needs that cover more than 50% of the CNs stated by people with actual motion restrictions?

Yes, all aspects are above 50%, with most above 60% and some as high as 84% coverage. Therefore, the suit is a valid simulation and the needs collected through its use can be considered as PMR needs and used for inclusive design.

Q 1.2 Are the people wearing the suit exhibiting physical restrictions comparable to motion restricted individuals?

Yes, in a variety of ways.

Q 1.2.1 Where does the suit function fall on the three disability scales regarding dexterity from our previous research and how does that compare to the previous version of the suit?

The motion restriction simulation suit is placing participants at the low to medium level in both the EDSS and H&Y scales. The previous suit placed them on the medium to severe levels of those scales. The suit is not placing participants on the RA scale (with two notable SSU participant exceptions who did particularly poorly on the 9HPT). The previous version of the suit had a partial slight match to the RA scale.

Q 1.2.2 Does the additional OT information allow us to determine the placement and range of restrictions of participants in regards to normal functioning as established by other associated external data sets?

Yes, it does. We can examine aspects of suit functionality variety of physical conditions of the upper extremities and compare against normative data to confirm suit effects across differing dimensions.

Covered in Section 9.2…

Q 1.2.3 Can the perception of the suit's restriction be determined and a rating assigned based on participant comments?

Yes it can. The process is actually fairly straightforward, as criteria were obvious from the statements. An initial consecutive series of difficulty steps was immediately apparent (no impact, some impact, great impact). Listening to more speakers easily created a finer series of steps on the scale. The scale is one to five where 1 equals no perceived impediment; 2 equals requires adjustment but still easy to perform tasks; 3 equals suit provides noticeable impediment but allows activity; 4 equals suit contradicts some normal muscle memory motions; and 5 equals use of suit noticeably strains user. This process works as a relative scale on the study population as a whole, but would be significantly less reliable if performed as an absolute rating on a single participant data point.

Summary:

The suit is providing an adequate surrogate experience based on the various aspects of the coverage of the needs of PMR and the placement of functional capabilities away from normal across various attributes. Additionally, the suit has been shown to provide an empathic experience in that it was clear that at least 80% of the participants were having an empathic experience. These items all validate the motion restriction simulation suit as a tool for empathic and surrogate design.

10.4 Limitations Conclusions:

The number of recruited study participants was not large enough to make robust conclusions or to compute statistical significance. From the knowledge tracking, it was shown that more participants are needed to assure that the majority of information for the situation is obtained. Comparing the knowledge tracking from the two surrogate experiences indicated that more than 25 participants would be needed for ample design information for the Exp2 surrogate experience.

If further research wanted to investigate statistical comparisons of OT metric subgroups (specific physical limitations), many more participants would be required, specifically enough participants for each subgroup. This would require officially establishing categories and boundaries, as well as a completely different recruitment strategy. It should be cautioned, though, that changing the strategy and motivation for participation, may have an effect on the overall experience for users.

Due to the low sample size and collection methodology, we lack the data for statistical inference. Therefore, conclusions are limited to specific participants and situations in the study, and cannot be generalized. We can form hypotheses based on observations of the data, but they will have to be studied and confirmed through other means before becoming strong general conclusions.

10.5 Occupational Therapy Conclusions:

Covered in Chapter 6…

Conclusion List:

Q 3.1 Is the selection and incorporation of the Occupational Therapy metrics and tests appropriate for the study and its goals?

Yes. The tests are covering the activities of interest in a manner that is easy to administer consistently.

Q 3.2 Is the tracking and connection between OT metrics and CNs manageable?

Yes, it is. Although metric information needed to remain somewhat separate from the CN lists, the common factor for connecting was the participant number tag. A more integrated approach to data management might assist in connecting these more thoroughly.

Q 3.3 Do the OT metrics provide additional options for evaluation or organization of CNs based on functional limitations?

Yes, though we did not do this, because we lacked sufficient participants. I have shown, and personally experienced, how easy it was to sort the data based on who stated the CN and extract separate lists. The format of the data table helped with that process, but this method likely would not be as feasible for larger data sets.

Q 3.4 What additional comparisons and analyses are available by having so much functional capability information available?

Many. Using this framework, if participants display a wide range of limitations, one can compare a wide range of limitations across many aspects. This specific research did not acquire such a range of participants. With caution on sampling and sample size, limitation subset

investigations becomes more a matter of prescribed study design, rather than exploratory work in future.

Q 3.5 Do the OT metrics provide a clear and encompassing picture of the restrictions of the participants?

Yes. They provide a clear picture of the functions of the upper extremities.

Q 3.5.1 Can ICF code/descriptions of participant limitations be developed using only the occupational therapy metrics?

Yes. The ICF codes created from the OT metrics only cover the specific subset related to the motions involved in the tests. They leave out issues of cognition and pain, since the OT metrics do not capture this.

Q 3.5.2 Does the additional OT information allow us to determine the placement and range of restrictions of participants in regards to what is considered 'normal functioning' as established by other associated external data sets?

Yes. It does allow us a closer look at individual levels of functioning in relation to normative data. This allowed us to determine that the effects of the suit vary on an individual basis. Our usage shows the connection potential, but there are probably other studies, with other factors of functioning built in, that this framework could connect with to provide a broader impact.

Occupational Therapy Conclusion Summary:

Overall, we have chosen and vetted a set of functional capability metrics that allows correlation to physical limitations and mapping of user functioning required for product operation. We have tests for: i) the strength of the involved muscles; ii) both gross and fine motor dexterity measures; and iii) a range of motion measurement technique that balances data retrieval and timeliness. The motion restriction simulation suit restricts all the desired aspects of the upper extremities (shoulders, elbows, wrists, fingers).

The results thus far indicate that recording this level of functional capability metrics is relatively easy to achieve, both from an administrator and participant standpoint. We have found a way to ensure accuracy and have established suitable procedures to ensure consistency. Later work will use the data collected to determine correlations between physical limitations and customer needs in a way that can inform inclusive design.

10.6 Ontology Conclusions:

Covered in Chapter 5…

Conclusion List:

Q 2.1 Is it possible to code this type of customer need data with the ontology?

Yes. It is in fact quite easy to interpret the statement style "Product should Blank," into CN Ontology Codes. Some factors are clearer than others, as would be expected when interpreting human desires.

Q 2.2 How should the ontology be adapted to apply easily in this research?

It was adapted to pull out the 'Performance' taxonomy from the 'What' taxonomy and a priority order established. The priority order definitely helped the process go more smoothly. There may be some non-independence between 'Performance' and 'What' but none sufficient to cause noticeable problems thus far. This may also be inherent in the CN style rather than the ontology organization.

Q 2.3 Have we achieved enough accuracy in coding to be confident in the results?

Yes. However, this was only after several additional checking and reconciliation steps for internal inconsistencies. This confidence is further bolstered by the third party confirmation step.

Q 2.4 What does the code coverage look like across various dimensions of the data?

Using the CN Ontology to code the information gained from participant interaction with this set of manual handheld products cause a coverage of the ontology space of 52 out of a possible 160 codes, 32.5%. This is similar across the different experiences and the different product pairs. There is some noticeable differences in the coverage and taxonomy breakdowns for product type and some possible differences in the coverage and taxonomy breakdowns for participant type. The examination of all these differences at the different levels of detail (coverages across all, coverage across Exp, coverage across subset, coverage by taxonomy) showed that going to a lower level generally increases the ability to notice differences and make design recommendations.

Ontology Conclusion Summary:

In the process of applying the ontology we determined that a slight reorganization was necessary to make the ontology easily applied to the needs set. Over the course of the research, the benefits of reorganizing the ontology were made apparent. Less conflict was present while

coding, inter-rate reliability was acceptable, and while some uncertainty remained, the impression of the ease of the process was higher than with the original organization. Conclusions from this study can be related to the application of the ontology to other handheld manual products and their needs.

It will be up to future work to determine if this new scheme is more generalizable than the original, or if its matching potential was heavily based on the style of customer needs statements in this study. Either way, good information will be gained. If it is better overall, then we have achieved the next step in the overall evolution of the ontology. If it is not, then we have still informed the ontology coverage of another customer needs gathering technique. This can be added to the application knowledge for the ontology along with the few techniques from the original development work [103].

The most helpful part of the ontology evolution in this research was the new ordering/prioritization scheme. Assigning weight and priority to need categories greatly eases the decision process when classifying needs. The priority order also helps foster agreement between raters on needs stated with more complexity.

The ontology organization determined in this study has shown good coding agreement. The fact that only 12% of the 271 needs showed disagreement is encouraging. The new 'Performance' taxonomy and the new 'What' taxonomy had good agreement, and a nice consistent spread.

Of all the categories, the 'Message' taxonomy is the most likely to require further definition, with provided examples, or a reordering of the priority. It was the least consistent taxonomy throughout the different aspects of the coding. This might be due in part to the fact that the coding is colored heavily by the raters' experience with customer needs, with design specification and requirements development, and with design in general. This inherent bias based on experience makes this category significantly less universally applicable, which is unfortunate, since the ontology is meant to be a universal tool. The preference order of the 'Message' categories was the least certain when the ontology was given to the raters, and the discussions demonstrated the lack of an obvious logical hierarchy, such as that in the 'Performance' and the 'What' taxonomies. A suggested reorder would be to go by the order of specificity. Solution is the most specific, telling the designer how to solve the need. 'Constraint' would be the next most specific with the current definition since you must meet the boundary condition. 'Specification'

would be the next specific as it puts bounds on a target. Then ‘Objective’ would be least specific with either definition (trying to move the design in one direction, or simply identifying attributes with no performance aspect).

Now, returning to the discussion of the ways the ontology can help designers, I determined different outcomes for each aspect, as well as a new possible benefit. The first pertains to the code being an accurate reflection of the exact type of information and intent contained in the CN statement. An acceptable result for the new ontology organization was found. However, the remaining uncertainty suggests some level of automation would be beneficial. The second pertains to the examination of the CN lists’ coverage of the possible ontology space. This aspect remains a useful addition of the ontology, and an additional benefit for the separated ‘Performance’ and ‘What’ taxonomy organization. More information about the way the needs are covering the types of information can be provided by examining the needs lists and the different elicitation techniques which use these codes.

An additional benefit of ontology usage was also discovered. The raters identified an increase in their personal understanding of the CNs and the customer’s views of the product interactions developed during the process of coding. This translates to a benefit for any current product development cycle for which the ontology is used as a tool, as well as any designers’ product development and customer needs gathering skills in general. Therefore, even if automation is produced for the coding of CNs for practical application, the process of using the ontology to classify needs will remain a useful teaching and learning tool.

Finally, it has been shown that the most frequently occurring Ontology Codes and their associated CNs can be used to formulate a set of design guidelines.

10.7 International Classification of Functioning Conclusions:

Covered in Chapter 7…

Conclusion List:

Q 4.1 Can ICF code descriptions be assigned based on the content and interpretation of the CN statements?

Yes. This resulted in mainly a pair or group of codes assigned to a CN, rather than a single ICF code, which happened less often. This is due to the multifaceted nature of CNs, and the interconnected nature of human functioning.

Q 4.2.1 Can ICF code descriptions of participant limitations be developed using only the occupational therapy metrics?

Yes.

Q 4.2.2 Can ICF code descriptions of participant limitations be developed using only the descriptions given by participants of their physical disability?

Yes. In fact, it was shown that the description offered the opportunity to assign a code at a greater detail level than the OT metrics.

Q 4.3 Does the availability of ICF information inform inclusive design?

I believe strongly that it can and will, as soon as connection between this study and other studies that used the ICF can be arranged/performed. This will be helped by actually creating guidelines for inclusive design from this framework. Once we have made generalizable conclusions, the ICF can identify specific avenues of action. Also, the ICF has the potential to show us where and to what extent our data can inform design. There is the potential to identify varying correlation levels between ICF aspects and framework aspects. This would further drive design guidelines.

Q 4.4 Can the ICF codes/descriptions be used to match the general type of loss of function the suit simulates and note overlap with the loss of function that the persons with disabilities have?

Probably. This test would need to be performed, but it would also need a bigger data set, with more limitations.

Summary:

Comparing the ICF results across the different connections, the main conclusion is that all three connection types are useful in different ways and that all three avenues are required for a more complete picture of the way the product design relates to human functioning. Providing ICF connection is fairly straightforward and should allow useful design information in future.

10.8 Other Conclusions:

Covered in Chapter 9…

This study observed and confirmed the same common module hypothesis regarding the weight vs. frequency spaces as Exp1. The common module for EUs is further confirmed to be in the high-weight/high-frequency region of the customer needs space. The CNs in that region are logical common module needs and a small portion of the overall needs. Furthermore, the Exp2 process shows that less common module type needs start entering the space as the line is moved, so the placement of this line remains an active design decision.

There are effects of both prior experience of participants and their perception of the simulation suit experience on the elicitation of customer needs. Both of these experience levels can be interpreted into a quantitative rating scale relatively easily. The information provided by the framework of Exp2 made it possible to investigate and identify these correlations.

10.9 Main Research Question Conclusions:

In answering the two main research questions, the results point to initial success.

For "Can we bridge the gap in designers' experience with exceptional users and environments through surrogate experiences?" the conclusion is that this can be done in many different ways. The surrogate experience we have developed and presented provides an effective tool to gather information about EUs that can be incorporated into design.

For "How do we gather information rich customer needs that will be useful for future inclusive design decisions?" the study concludes that the analysis of the interconnected, information rich customer needs has developed tentative design information. The process of incorporation and understanding will be proved through realistic usage of the framework, but the potential has been thoroughly demonstrated in this work. By following the process laid out by this framework information rich customer needs can be developed and used fairly easily. Add in a better data management strategy and the framework will be more universally useful and adaptable to the needs of various designers.

Chapter 11: Future Work

Beginning note: Future publication of these results can be done to distribute the various aspects of the knowledge this work has created to appropriate communities. The plan is for the Ontology work (including the top codes and the design guidelines) to go to Design Studies. For the OT work, along with the ICF analyses, submission will target a more suitable biomechanical design venue.

This chapter will collect and reiterate all the previous mentions of future work from the prior chapters and string them together logically with the intent of providing guidance for the various avenues of future work and how they would relate to the impacts of the work.

The main part of the future work will be using this framework in actual product design work and making sure that it is usable by industry on real design situations. The idea behind the work is that this framework is useful for making inclusive design decisions. This can only really be proved by doing real designs and seeing how well this happens. Different parts are bound to be differently useful for inclusivity. With repeated use of this framework, examinations of the inclusivity of the resulting products and the ease of incorporating the information into design decisions can be performed, and conclusions drawn about how helpful the framework is in developing or increasing inclusivity. This would answer the question "How are our information rich customer needs useful for future inclusive design decisions?"

A likely first step of future work should be mainly, to repeat this research (or recommence data collection and add new data to these sets) in order to procure a much wider and larger participant pool. A larger study should be performed, with more robust participant recruitment, so that we can collect CNs from enough people to actually get enough information from all the desired comparison groups, and show sufficient knowledge tracking in all of them.

11.1 General Investigation Recommendations:

Investigate and develop a database style information management system to streamline and simplify the tracking of the various pieces of interconnected data for analysis. In the meantime, I have written out an Excel file with columns such that all the information for every

need could be tracked. Once all the current data has been carefully placed into this format, data collection could recommence and be incorporated smoothly. However, this still uses the current method of manual connection between user information and CN information using the participant number. This causes problems with utilizing most statistics and visualization software because all the ones that we investigated could not parse this data arrangement. They required duplication of the information for each participant, rather than being able to automatically relate the CN info to the info of *all* the participants who stated that CN. It would be better to have the data in a data base system, with each piece of information as an entry instead of a column, so that they could all be properly linked. That way when designers want to organize or analyze based on (CN or Tag or list or type or participant or limitation), it could be done more easily, without as much effort and without a potential loss of data. The level of ease of use and maintenance must be considered for this system, both for input and analysis aspects.

Given that this research has been largely exploratory, many trends have been observed. Tests should then be designed and undertaken to formulate conclusions and generalizations about these trends, to see if they are real sources of variation in the wider world, rather than just this study. Source of variation investigations can also be performed. Are the discovered differences coming from the people, the circumstance, or the product type itself? These kinds of questions will require more specific investigation and testing with non-exploratory, controlled data collection.

11.2 Customer Needs Ontology:

It would be a good direction for future work to automate the coding process, to remove the inconsistencies inherent in human rating activities. The issues involved in using this ontology manually became obvious when coding 271 related needs.

The strategy difference and experience levels of the raters should be more specifically examined, and connections made to the inter-rater reliability effects. It is suggested that a more formalized process be given to raters to walk them through the coding activities, both to streamline the process and make the resulting codes more consistent. This would be the first step in automation of the coding. Further examination of the reasons for internal inconsistencies in the rating of the same needs across the data sets could also be performed to find ways to combat this. There could also be an investigation on a middle ground between the current freeform human rater approach and complete coding automation.

Since the customer needs in this study are derived in a specific way, at a specific point in the design process, it would be a good idea to compare the ontology coding of the needs at this stage to the ontology coding of the needs at a different stage. The non-interpreted customer statements are available for analysis from before they were aggregated and turned into CN statements of the style Product Should Blank. Looking at the similarities and differences in the ontology codes for the same set of data at both stages will inform whether the ontology information is dictated by the stage of the process in which it is used. Investigation as to exact information loss or change with designers CN manipulation should be done, and the ontology is a good tool for this.

Given the separation of the performance categories into their own taxonomy, there is likely to be a relationship between the 'What' and 'Performance' taxonomies that should be explored. Since both taxonomies have human centered categories and device centered categories, it is a good idea to check whether the codes maintain the logical relationships inherent in that. Since the goal of the ontology is to be independent and complete, explicit testing of these relationships should be performed to ensure no unintended overlap. It will help inform customer needs gathering activities even further to understand whether a technique can yield needs with multi-aspect needs versus more singular needs.

As stated during the conclusions, direct benefit for the ontology would be gained by further definition of the 'Message' taxonomy to help coders make decisions about detail level, including a redefinition of 'Constraint'. Additionally, the development of hint tree for raters, suggesting that certain words in the CN tends to indicate certain code categories, may also be helpful.

Finally, the learning effect observed of ontology coding increasing the understanding of the similarity of customer need statements, should also be replicated and studied.

11.3 Functional Capability Metrics:

While we have achieved a good result, as this research progresses, the ability to quantify the inaccuracy in our measurements would be helpful. Additionally, further eliminating any inaccuracy between testers would be beneficial.

Through continued testing we expect to get an appropriate variety of data to run correlation studies using the functional capability metrics as a bridge to see if there is customer

needs clustering by restriction type. This would further inform product modularity aspects and help to develop differentiating module information.

11.4 Motion Restriction Simulation Suit:

To begin, minor changes to improve the simulation suit have been mentioned. These include changing the elbow shaft material for improved reliability, adding thumb restriction mechanisms (of the same kind as the other fingers), and specific wrist rotation restriction mechanisms (Velcro or Bands).

Ultimately, offering a simulation suit that can be calibrated to mimic pre-defined levels of upper extremity restrictions will be more helpful in investigating specific aspects of inclusivity, and would support inclusive design for exceptional users. A study in which the suit is tuned to get every person to the exact same set/placement of limitations could be performed. This could be either in terms of relative percent decrease in personal functioning, or to a specific target set of capabilities on the OT or other metrics, whichever is of most interest in furthering knowledge about possible relationships between customer needs and functioning.

This adaptation of the suit is left to future work, but the suit usage process has now been validated. Additional commercialization efforts for the OSU motion restriction simulation suit is also recommended, so that it can be easily distributed and used as a design tool.

Further evaluation of specific aspects of the empathic experience of the suit should be performed. This may be able to be done with the data already collected, but would benefit from additional data, of both this research type, and others. This could begin with a physical interaction analysis of the suit restrictions by biomechanics experts. I propose a targeted empathy study. In this, the suit is applied to engineering and non-engineering students, for a period of several hours, performing a similar daily routine, and then the experience evaluated with a questionnaire designed to investigate variables of interest. This could show the variation in the experience based on a number of factors, including the individual frame of reference and starting capabilities. It could also show potential differences between engineers and non-engineers, which would further inform surrogate experience as a design tool. This would require/assist with further development of empathy metrics. Further correlating the experience of the suit with various elicitation activities and aspects of CN type and weightings, would also be of use.

11.5 ICF Connections:

Additional evaluation of the ICF connection process would be useful. The design insights gained from these connections should also be further investigated. This could be done with this data, or with a fabricated set, which would give more control and statistical capability to the conclusions. There might also be a relationship between participant weighting and ICF description that could be investigated. Correlation trials between ICF aspects and other informational aspects within this framework, would be recommended. This can be followed by a broader study of the connection between this framework, and other design studies using the ICF descriptors as a bridge.

Possible research questions for further ICF investigations include:

- What other ICF codes can be extrapolated that relate to the non-human factors related CNs? There were a few HF CNs that I could not come up with adequate ICF representations for, and I spotted a few non-HF CNs that I could think of ICF relations for, so an attempt should be made to perform ICF connection across the whole data set (possibly with more expert assistance). This will better inform how much of the data set has ICF relationships, then those relationships can be analyzed.
- Can a more prescriptive process be developed and applied for performing this ICF to CN connection? The possibility of adapting ICF guidelines to CN style statements, or providing word relation advice or setting up automation all come to mind.
- ICF codes vs the group type (PMR, SSU, Both) that stated the related CN (Are different subgroups more likely to state needs relating to a certain set of or detail level of ICF limitation codes?)
- ICF codes vs various weighting options of CN statements (Are different ICF codes related CNs more likely to be rated as higher or lower in importance?) This can inform what the most important ICF information(s) to design might be.
- ICF code vs frequency of CN statement (Are the higher frequency CNs more likely to be related to an ICF code, or a certain type of ICF code?)

11.6 Direct Next Step Analyses:

Several options arise that can be accomplished from information already available in the data set.

Perform the same activity of listening to the participant comments about the suit and the experience and interpreting them onto both the perceived restriction scale and empathic experience scales developed by this research for the videos for the participants from Exp1. This will allow for firmer conclusions to be made regarding the differences, and maybe quality, of the experiences provided.

Perform more specific ontology and taxonomy code breakdowns, with possible statistics, to determine if any of the trends noticed in this study can be hypothesized and proved/disproved. This could be done in a targeted way, based on what investigations would yield useful design knowledge.

In the interim before real-world use proves the design outcomes of this work, there are some activities that could serve as initial validations. The needs and design guidelines discovered by this research could be evaluated by general and expert designers and questions asked regarding their perceived usefulness in terms of both the general and inclusive design. The needs and design guidelines discovered by this research could be used as the basis of educational design activity. This could provide initial evidence as to what portions are most/least helpful in terms of the various dimensions of quality of design. The needs and design guidelines discovered by this research could be compared to other existing sets of both inclusive and general guidelines to examine where they do and do not match and how the differences would inform/change designs, both positively and negatively.

11.7 Other Relationships:

Other relationships and activities to be investigated and performed have been identified during this research. This tendency to elicit other ideas in the researcher/designer is a major strength of the framework and its information content. These ideas are now listed briefly.

- Investigate the effects of fatigue on suit users and the resulting elicitations.
- Investigate the information provided by the validation of the needs by external EUs.
- Investigate the differences between SSU validations using actual exceptional users who are internal vs external to the study.

- Verify/study the hypothesis for the different postulated reasons for the higher elicitation in Exp2.
- Develop a more precise relation between participant experience and CN weighting. The study has information which inferred that there will be a difference in weighting. This was shown by looking at both the weights given by the class and its trend towards higher weights at higher previous inclusive experience, as well as the observed differences between the weights provided by the PMR/SSU/EU survey responses. Both should be investigated.
- Further correlating specific aspects of a priori experience to elicitation activities. Once information from enough participants to form sufficient background subgroups has been collected.
- Further study of the factors that cause differences in subjective vs objective measures of functionality. Investigate whether there is a tendency for PMR to ignore difficulties because of expectations of not be served by products. A more specific investigation into the thought processes of participants would be recommended to discover expectations held by and adaptation made by people with actual motion restrictions during product use. Additionally, investigations into the salience of the aspects of the provided surrogate experience to users would be useful. Issues of 'newness' and 'contrast to normal' may be emphasizing certain interaction portions, and knowing this would help designers perform inclusive design.
- Investigate the amount of positive vs negative statements made during product interactions, and where they were placed among the both subgroup and product type. As previously stated, this data was obscured by the methodology of this framework, but it may be helpful to examine in other customer needs elicitation studies.
- Specifically study user preference effects. User limitation and elicitation experience is likely influencing preference, but this work was not setup to study this specifically. Examining the difference in preference of different types of users for inclusive product features would be a useful contribution.

11.8 Expansion of the design areas:

Finally, we return all the way back to the issues in the introduction chapter of this work, to the broader picture of surrogate experience and edge-case design.

Expansion of the use of the OSU motion restriction suit and this framework for surrogate experience beyond manual handheld products will widen their applicability to product design. These products are an excellent starting point, given the lack of inclusive information in that region. However, expanding to other products that engaging persons with motion restriction in other real-world activities will broaden the knowledge needed to design more inclusive workspaces and living spaces.

It is recommended to evaluate the differences in the CN results of different levels of surrogate or empathic experiences. This was begun, serendipitously, by this study, but a concerted effort, with a specific study design, would be useful. This would involve specifically developing and performing other experiences on the spectrum of Figure 6, with common metrics for evaluation of effects. Knowing more about more of the options on the surrogate spectrum will inform the designers when they make their choice of surrogate experience as one of the first steps in inclusive design research.

There is also the whole extreme environment axis of the EE vs EU spectrum from Figure 7 to be explored. There should be some knowledge transfer possibilities between the EU investigations performed by this, and other inclusive design work, and the extreme environment /general user quadrant. Those there will also be other issues and investigations still unknown. EE/GU studies could be on the effects of the use of personal protective equipment (PPE) or space suits. They could be done in real environments or simulations, and would also have various levels of surrogate experience options, as speculated in Figure 7.

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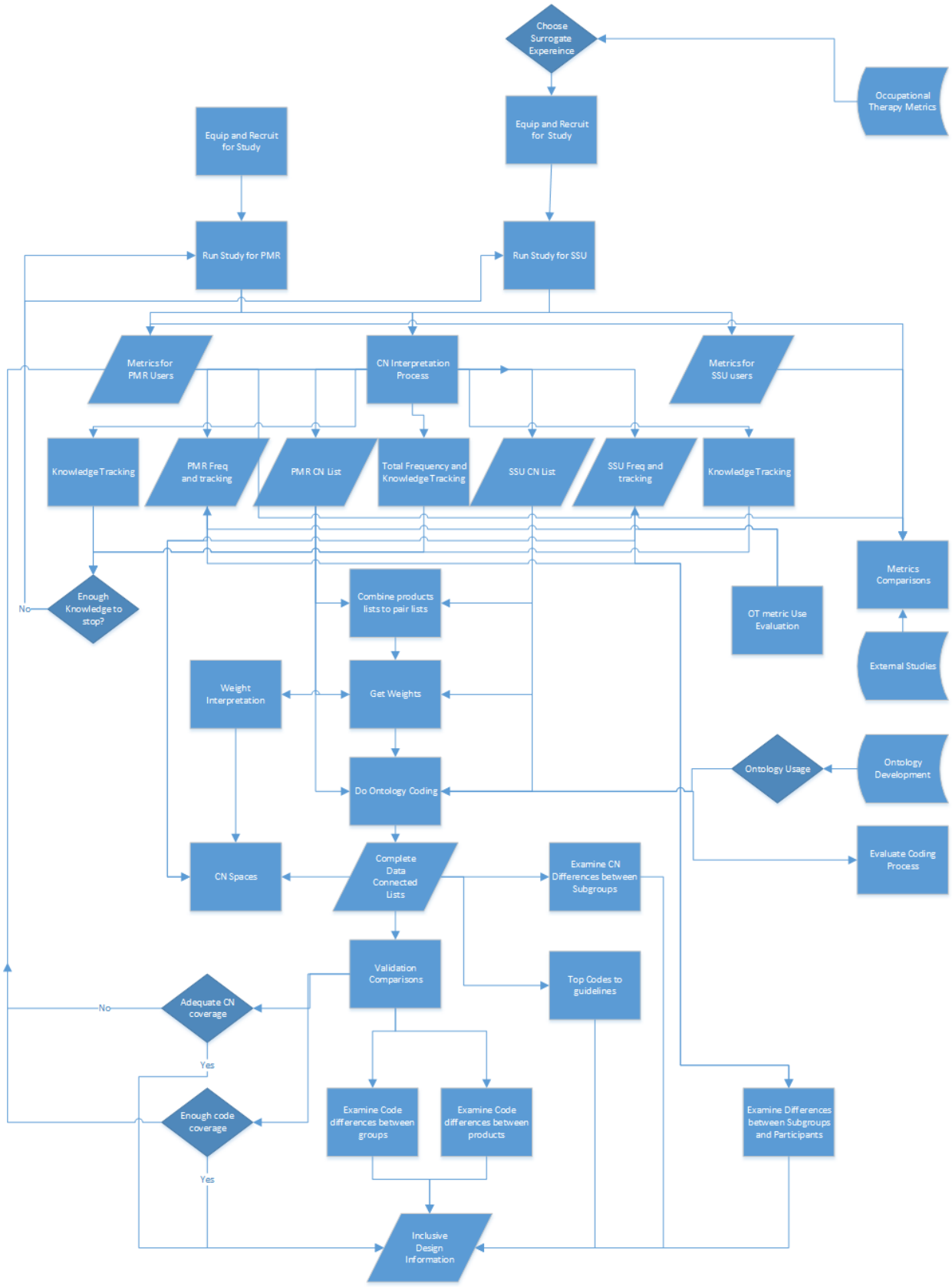
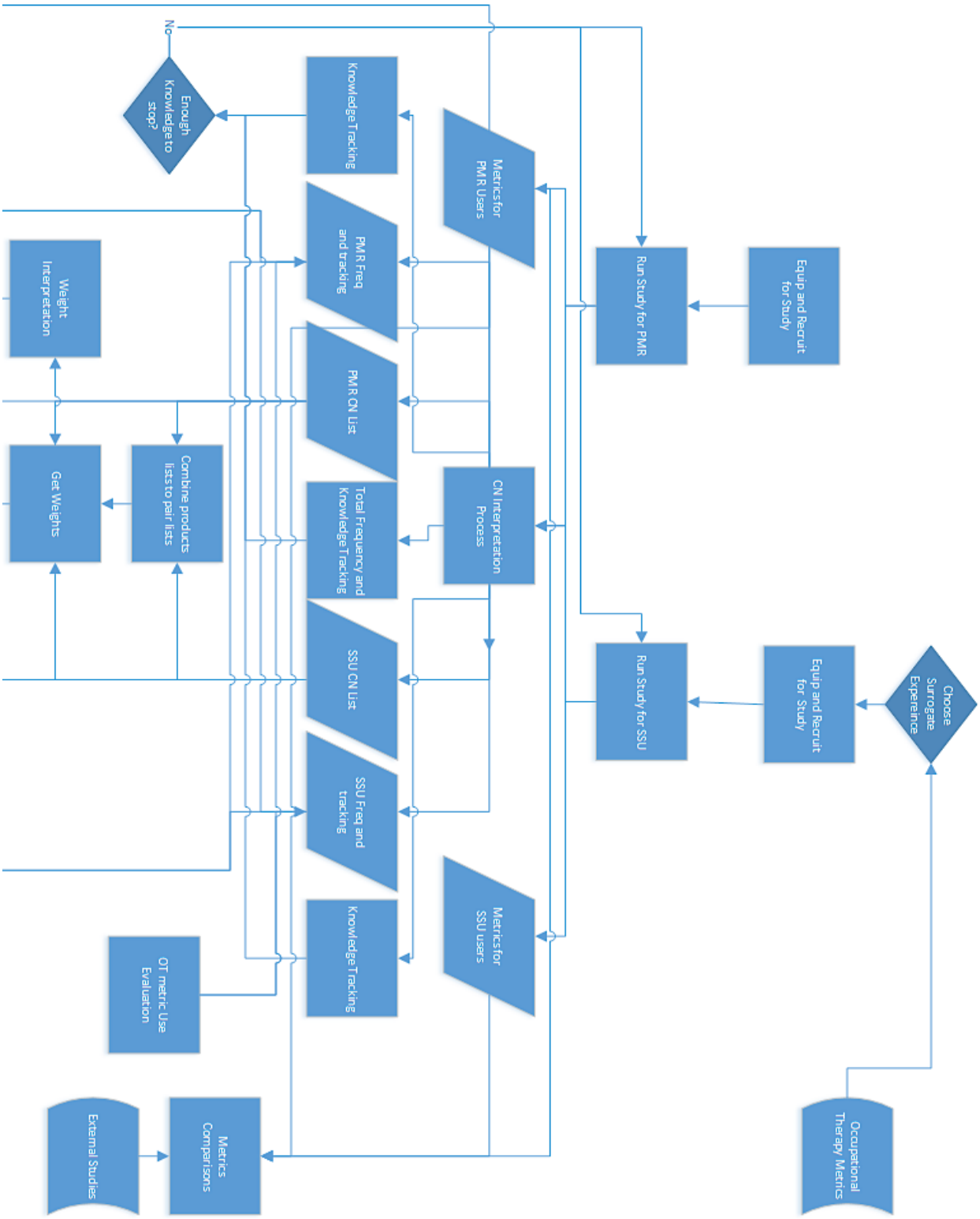
Appendices

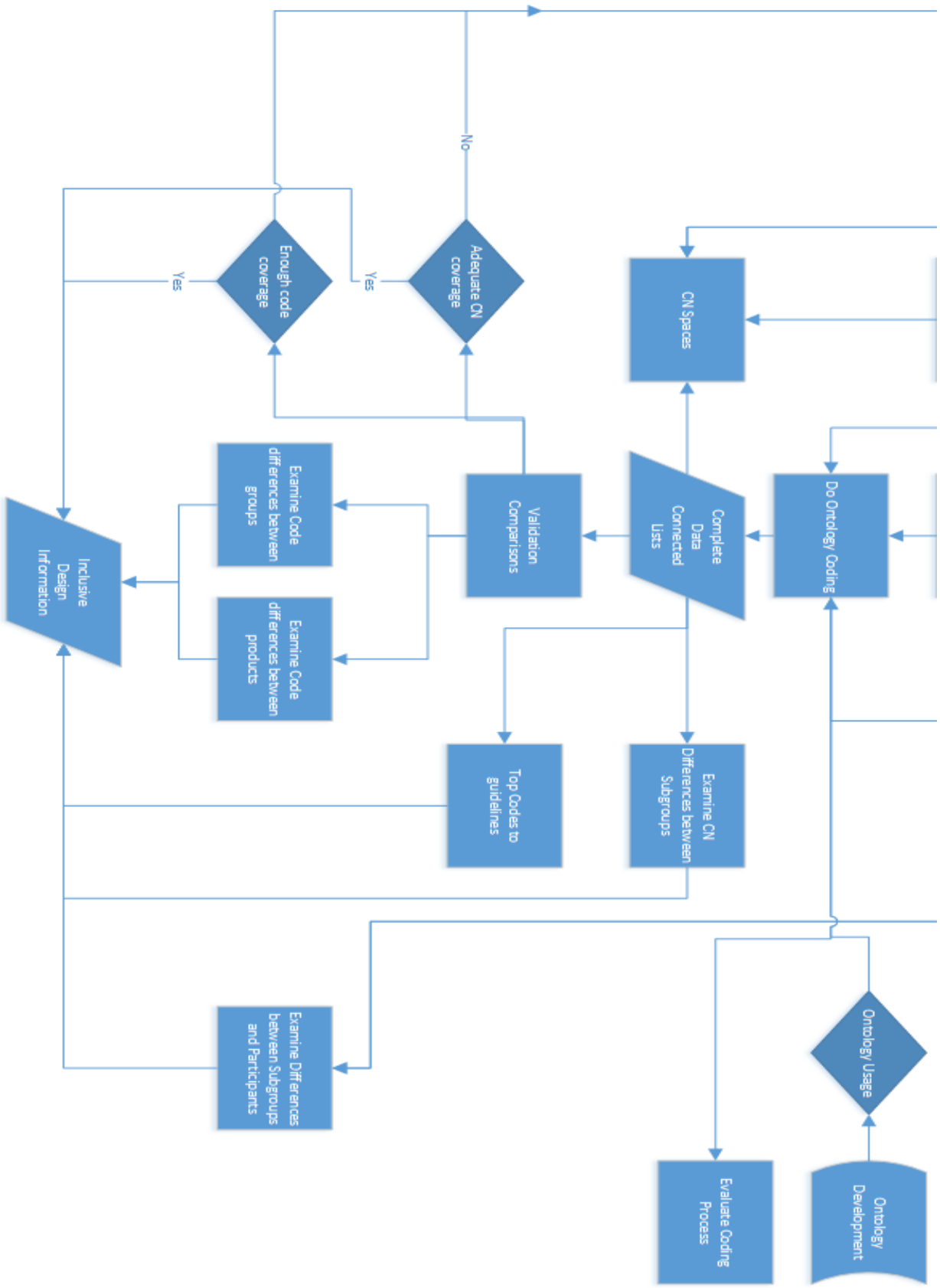
The appendices begin on the next page. The page numbering starts over at 1. The appendix section contains 27 subsections with 168 pages of graphs, charts and tables.

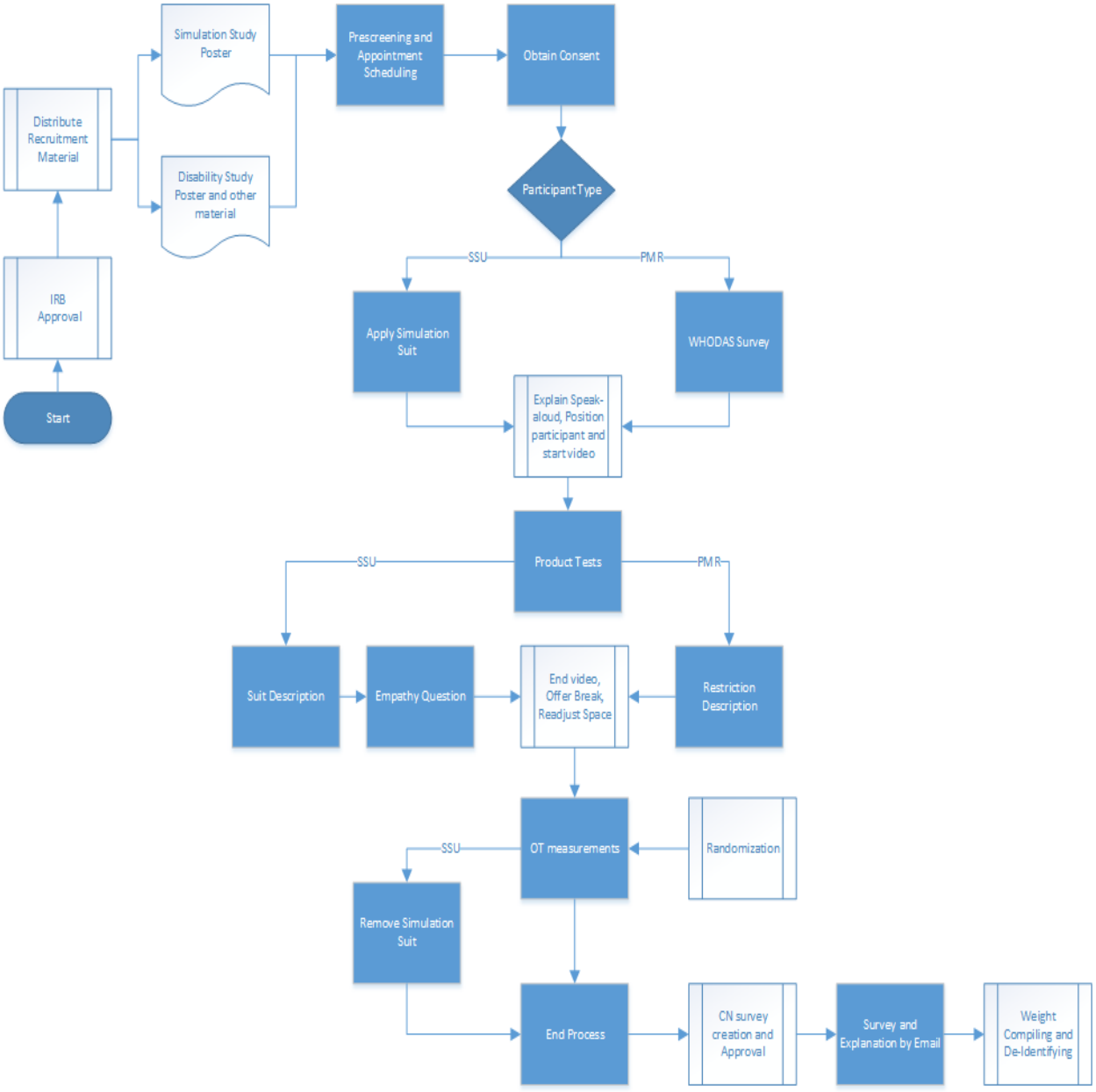
APPENDIX

Appendix A: Process Flow Charts




Occupational Therapy Metrics
Choose Surrogate Experience
Equip and Recruit for Study
Run Study for SSU
Equip and Recruit for Study
Run Study for PMR
Metrics for PMR Users
Metrics for SSU users
CN Interpretation Process
Knowledge Tracking
PMR Freq and tracking
PMR CN List
Total Frequency and Knowledge Tracking
SSU CN List
SSU Freq and tracking
Knowledge Tracking
Enough Knowledge to stop?
No
Weight Interpretation
Get Weights
Combine products lists to pair lists
OT metric Use Evaluation
Metrics Comparisons
External Studies


Ontology Development
Ontology Usage
Evaluate Coding Process
Examine Differences between Subgroups and Participants
Examine CN Differences between Subgroups
Top Codes to guidelines
Inclusive Design Information
Examine Code differences between products
Examine Code differences between groups
Validation Comparisons
Complete Data Connected Lists
Do Ontology Coding
CN Spaces
Adequate CN coverage
Enough code coverage
No
Yes
Yes


Simulation Study Poster
Prescreening and Appointment Scheduling
Obtain Consent
Distribute Recruitment Material
Disability Study Poster and other material
Participant Type
SSU
PMR
IRB Approval
Apply Simulation Suit
WHODAS Survey
Start
Explain Speak-aloud, Position participant and start video
Product Tests
SSU
PMR
Suit Description
Empathy Question
End video, Offer Break, Readjust Space
Restriction Description
OT measurements
Randomization
SSU
Remove Simulation Suit
End Process
CN survey creation and Approval
Survey and Explanation by Email
Weight Compiling and De-Identifying

Appendix B: Nix Customer Needs Ontology

Who Category: Who is this need intended for?		
A1	User	The person (people) using the product
A2	Purchaser	The person (people) buying the product
A3	Manufacturer	The person (people) making the product
A4	Seller	The person (people) selling the product
A5	Investor	The person (people) who are monetary stakeholders in the products success

What: What is the need about?		
B1	Main Function	The main function the product will complete. The function that would be found in a black box model of the device. These needs are directly about the function and NOT how it will be accomplished.
B2	Supporting Function	The supporting functions that the device completes. These needs directly describe the function and NOT how it will be accomplished.
B3	Environment	The environment(s) the product will be used in. The boundary must contain entire product. This would be the boundary around black box model flows.
B4	Human Factors	The user interaction with the product. These needs may also contain judgement on user experience or needs for the human experience or performance variables or aesthetic information that explains HOW it will enhance the user experience.
B5	Aesthetic	The visual appearance of the product, including but not limited to color, shape, texture. These needs may relate with the study of the mind and emotions in relation to the sense of beauty with the product.
B6	Performance	The performance objectives of the product (speed, lightness, quickness). These needs typically include adjectives describing product performance and are measurable (possibly after more defining). These are not to be confused with human factors needs where a performance metric directly enhances the user experience. These needs may or may not contain a target or number.
B7	Safety	How the product may injure/protect the users or other people near it during operation. These needs may sound similar to human factors but when coding safety supersedes human factors. Safety needs may contain performance variables that explain HOW it will enhance the safety of the product.
B8	Features	A way to accomplish a function. These needs will not always contain the function being accomplished but will provide information on how it will be accomplished. Solutions (from the Message taxonomy are typically features).

Message: What message is the need conveying?		
C1	Solution	A specific way to accomplish the "what". They are typically ways a customer envisions a need being solved.
C2	Specification	A measurable target value for the product. There are acceptable bounds on both sides of a specification. The target may or may not be numerical at this phase in the process.
C3	Objective	An expression of the attributes and behaviors that the client or potential users would like to see in the product.
C4	Constraint	A restriction or limitation that will result in a boundary. These differ from objectives in that exceeding or not meeting this boundary is not an option. The boundary may or may not be numerical at this phase in the process.

Innovation: How innovative is the need		
D1	Basic	Needs expected by the customer and assumed to be available. One would be unable to buy a current product that does not already meet this need.
D2	Direct	Needs that the customer will have no trouble declaring because it is something they are concerned about and the better the need is met, the more satisfied the customer is. Products that meet this need are currently available on the market and products that do not meet this need are still currently available on the market.
D3	Exciting	Needs the customer will typically have difficulty expressing because they may not have had the necessary insight, however these needs are very beneficial. Products that currently meet this need are typically not on the market or are extremely rare.
D4	Un-beneficial	Needs that are Un-beneficial to the product even if the product meets them. Products on the market currently do not meet these needs for good reason.

Target Market: How much of the customer population does this need affect?		
E1	General	A desirable expectation to most of the users (>25%) in the customer population for this product.
E2	Niche	A desirable expectation to a smaller segment (<25%) of the customer population. They may restrict the customer population or only affect power users of the product. May drive a customer to purchase a different similar product because they do not want this capability.

Appendix C: Revised CN Ontology

Market		
1	General	A desirable expectation to most of the users (>75%) in the customer population for this product.
2	Niche	A desirable expectation to a smaller segment (<75%) of the customer population. They may restrict the customer population or only affect power users of the product. May drive a customer to purchase a different similar product because they do not want this capability.
Message		
1	Constraint	A restriction or limitation that will result in a boundary. These different from objectives in that exceeding or not meeting this boundary is not an option. The boundary may or may not be numerical at this phase in the process.
2	Specification	A measurable target value for the product. There are acceptable bounds on both sides of a specification. The target may or may not be numerical at this phase in the process.
3	Objective	An expression of the attributes and behaviors that the client or potential users would like to see in the product.
4	Solution	A specific way to accomplish the "what". They are typically ways a customer envisions a need being solved.
Performance		
1	Safety	How the product may injure/protect the users or other people near it during operation. These needs may sound similar to human factors but when coding safety supersedes human factors. Safety needs may contain performance variables that explain HOW it will enhance the safety of the product.
2	Human Factors	The user interaction with the product. These needs may also contain judgement on user experience or needs for the human experience or performance variables or aesthetic information that explains HOW it will enhance the user experience.
3	Device	The performance objectives of the product (speed, lightness, quickness). These needs typically include adjectives describing product performance and are measurable (possibly after more defining). These are not to be confused with human factors needs where a performance metric directly enhances the user experience. These needs may or may not contain a target or number.
4	None	A need that does not relate to performance. More what the device does, rather than how well.
What		
1	Aesthetics	The visual appearance of the product, including but not limited to color, shape, and texture. These needs may relate with the study of the mind and emotions in relation to the sense of beauty with the product.
2	Features	A way to accomplish a function. These needs will not always contain the function being accomplished but will provide information on how it will be accomplished. Solutions (from the Message taxonomy are typically features).
3	Main Function	The main function the product will complete. The function that would be found in a black box model of the device. These needs are directly about the function and NOT how it will be accomplished.
4	Supporting Function	The supporting functions that the device completes. These needs directly describe the function and NOT how it will be accomplished.
5	Environment	The environment(s) the product will be used in. The boundary must contain entire product. This would be the boundary around black box model flows.

Appendix D: Remaining Participant Functional Capability Metric Results

Available Upon Request – Protected Information

Appendix E: Weights and Frequencies Product Customer Needs List

Ptag	Total Product Frequency	ProdFreqPMR	ProdFreqSSU	Total Combined Frequency	CombFreqPMR	Comb Freq SSU	Weight by PMR	Weight by SSU	Weight by Add	Weight Avg of Participants	Weight by Class Exp of 5	Weight by Class Exp of 4	Weight by Class Exp of 3	Weight by Class Exp of 2	Weight by Whole Class
bjo-01	1	1	0	1	1	0	5	4	5	4.67	4.00	4.57	4.07	3.45	**4.07**
bjo-02	1	1	0	1	1	0	5	1	4	3.33	4.56	4.71	4.29	3.45	**4.26**
bjo-03	1	0	1	1	0	1	3	3	2	2.67	3.67	3.43	3.21	3.45	**3.52**
bjo-04	1	0	1	1	0	1	1	1	2	1.33	4.00	3.43	2.93	3.00	**3.38**
bjo-05	1	0	1	1	0	1	3	5	5	4.33	4.78	4.29	4.14	3.73	**4.33**
bjo-06	1	0	1	1	0	1	3	3	5	3.67	3.56	3.86	3.93	3.18	**3.64**
bjo-07	2	0	2	2	0	2	4	2	3	3.00	3.67	3.43	3.14	3.45	**3.40**
bjo-08	1	0	1	1	0	1	5	5	5	5.00	4.56	3.71	4.21	4.00	**4.21**
bjo-09	2	1	1	2	1	1	4	5	5	4.67	4.22	3.43	3.73	3.09	**3.65**
bjo-10	2	0	2	2	0	2	3	4	4	3.67	4.78	4.14	4.33	3.64	**4.28**
bjo-11	2	1	1	2	1	1	4	5	3	4.00	3.44	3.57	3.20	3.09	**3.35**
bjo-12	1	0	1	2	1	1	5	2	4	3.67	4.33	3.71	3.93	3.73	**4.02**
bjo-13	4	1	3	5	1	4	4	1	5	3.33	3.22	3.14	3.33	2.36	**3.07**
bjo-14	1	1	0	1	1	0	4	3	1	2.67	3.44	3.29	2.87	2.91	**3.16**
bjo-15	2	0	2	3	0	3	4	4	4	4.00	4.56	4.43	4.53	3.27	**4.33**
bjo-16	3	1	2	3	1	2	3	4	4	3.67	4.33	3.71	4.13	2.82	**3.88**
bjo-17	5	2	3	8	2	6	3	4	5	4.00	4.67	4.00	4.00	3.64	**4.14**
bjo-18	4	0	4	4	0	4	4	5	4	4.33	4.44	4.14	4.27	3.64	**4.21**
bjo-19	3	1	2	3	1	2	4	5	5	4.67	4.78	4.14	4.00	3.64	**4.19**
bjo-20	1	1	0	1	1	0	5	4	3	4.00	4.67	4.43	4.80	3.91	**4.56**
bjo-21	1	1	0	1	1	0	5	4	5	4.67	4.67	4.14	4.60	3.73	**4.44**
bjo-22	2	1	1	3	1	2	5	3	5	4.33	4.44	3.71	4.13	3.36	**4.00**
bjo-23	1	1	0	2	1	1	4	4	4	4.00	4.44	4.71	4.40	3.73	**4.35**
bjo-24	1	0	1	4	0	4	2	5	3	3.33	4.00	3.57	3.47	2.73	**3.49**
bjo-25	4	1	3	5	1	4	2	5	5	4.00	4.33	3.29	4.07	3.00	**3.86**
bjo-26	3	0	3	5	1	4	5	3	5	4.33	4.78	4.71	4.33	3.73	**4.40**
bjo-27	1	0	1	1	0	1	5	4	2	3.67					
bjo-28	1	1	0	1	1	0	0	4	4	2.67					
bjo-29	1	0	1	1	0	1	1	4	2	2.33					

cgp-01	2	1	1	2	1	1	3	1	4	2.67	4.33	3.71	3.53	3.18	3.80
cgp-02	2	0	2	2	0	2	0	1	3	1.33	1.78	2.00	1.79	1.70	1.88
cgp-03	1	0	1	4	2	2	4	3	5	4.00	4.00	4.00	3.67	3.18	3.80
cgp-04	2	1	1	2	1	1	4	4	5	4.33	4.67	4.00	4.29	3.82	4.28
cgp-05	4	0	4	4	0	4	3	5	5	4.33					
cgp-06	2	1	1	2	1	1	3	3	2	2.67	3.44	3.43	3.00	3.00	3.18
cgp-07	2	0	2	3	0	3	3	4	5	4.00	4.56	3.71	3.80	3.64	3.98
cgp-08	1	1	0	1	1	0	3	4	5	4.00	3.89	3.57	3.47	2.82	3.52
cgp-09	1	0	1	1	0	1	4	5	2	3.67	4.00	4.00	3.86	3.00	3.79
cgp-10	1	1	0	1	1	0	2	3	2.5	2.50	2.89	2.71	2.47	2.55	2.66
cgp-11	2	0	2	2	0	2	4	4	4	4.00	3.11	3.00	2.93	2.36	2.91
cgp-12	3	0	3	5	1	4	4	5	5	4.67	4.89	4.14	4.07	3.18	4.14
cgp-13	3	0	3	4	0	4	2	4	5	3.67	4.00	3.71	3.53	3.09	3.61
cgp-14	3	1	2	3	1	2	4	3	4	3.67	4.00	4.14	3.80	3.27	3.82
cgp-15	3	0	3	4	0	4	5	5	5	5.00	4.22	4.29	3.80	3.45	4.00
cgp-16	4	0	4	4	0	4	4	5	3	4.00	4.67	3.86	4.27	3.45	4.26
cgp-17	1	0	1	1	0	1	5	5	4.5	4.83	4.78	4.71	4.87	3.91	4.68
cgp-18	9	3	6	11	3	8	4	5	3	4.00	4.78	4.71	4.60	3.82	4.52
cgp-19	2	0	2	2	0	2	4	5	3.5	4.17	4.44	4.14	4.40	3.18	4.14
cgp-20	1	0	1	3	0	3	4	3	3	3.33	4.44	4.29	4.20	3.00	4.05
cgp-21	2	1	1	3	2	1	4	3	4	3.67	4.67	4.43	4.47	3.82	4.43
cgp-22	3	1	2	3	1	2	5	4	5	4.67	4.13	3.86	4.20	3.55	4.00
cgp-23	5	1	4	5	1	4	4	5	4	4.33	4.33	4.00	3.93	3.09	3.84
cgp-24	1	1	0	2	1	1	5	5	4	4.67	4.56	4.29	4.07	3.82	4.18
cgp-25	2	2	0	4	2	2	2	5	5	4.00	3.89	4.43	3.87	2.82	3.75
cgp-26	11	2	9	13	3	10	5	4	5	4.67	4.67	4.29	4.40	3.91	4.43
cgp-27	1	0	1	3	1	2	2	5	5	4.00	4.56	4.43	3.60	3.27	3.93
rco-01	1	0	1	1	0	1	4	5	5	4.67	4.38	4.14	4.33	3.18	4.09
rco-02	1	0	1	1	0	1	4	4	5	4.33	3.63	3.71	3.33	2.64	3.33
rco-03	1	0	1	1	0	1	5	4	5	4.67					
rco-04	1	1	0	1	1	0	5	4	2.5	3.83	4.22	3.86	3.60	2.91	3.59
rco-05	1	0	1	2	0	2	3	3	5	3.67	3.22	3.00	3.33	2.45	3.07
rco-06	1	0	2	2	0	2	4	3	5	4.00	4.78	4.71	4.40	3.45	4.41
rco-07	2	1	1	2	1	1	1	4	4	3.00	3.56	3.29	3.53	2.64	3.22
rco-08	1	0	1	3	1	2	5	5	4	4.67	4.00	4.00	3.80	3.27	3.86
rco-09	3	1	2	3	1	2	5	4	5	4.67	4.50	4.67	3.93	4.18	4.26
rco-10	4	2	2	4	2	2	3	4	4	3.67	3.25	3.71	3.27	3.45	3.44
rco-11	1	0	1	1	0	1	5	5	3	4.33	4.78	4.29	3.93	3.55	4.16
rco-12	2	1	1	2	1	1	5	4	5	4.67	4.56	4.00	4.33	3.91	4.30

rco-13	1	0	1	2	0	2	4	2	3	3.00	4.11	4.00	3.73	2.82	3.61
rco-14	2	0	2	4	2	2	4	4	5	4.33	3.89	4.00	3.53	3.27	3.70
rco-15	1	0	1	1	0	1	2	1	5	2.67	2.88	3.57	3.47	2.64	3.16
rco-16	2	0	2	3	0	3	5	4	5	4.67	4.78	4.43	4.33	3.55	4.32
rco-17	4	0	4	6	1	5	5	4	5	4.67	4.56	3.86	4.33	4.09	4.34
rco-18	3	0	3	3	0	3	5	5	4	4.67	4.89	4.29	4.40	3.18	4.27
rco-19	3	0	3	3	0	3	4	5	2.5	3.83					
rco-20	7	0	7	8	1	7	5	5	3	4.33	4.78	4.00	4.27	3.64	4.23
rco-21	2	1	1	4	2	2	5	3	5	4.33	4.56	4.14	3.93	3.30	4.02
rco-22	5	2	3	7	2	5	5	4	5	4.67	4.67	4.71	4.27	3.91	4.36
rco-23	2	1	1	2	1	1	2	5	4	3.67	4.11	3.57	3.53	3.00	3.68
rco-24	1	1	0	2	1	1	5	5	4	4.67	4.00	4.57	4.20	3.45	4.09
rco-25	1	1	0	1	1	0	5	4	3	4.00	3.67	3.43	3.57	2.91	3.49
rco-26	1	1	0	1	1	0	3	3	2	2.67	4.00	4.00	4.27	3.00	3.86
rco-27	1	0	2	2	0	2	5	4	5	4.67					
rco-28	1	1	0	1	1	0	4	4	5	4.33	3.89	3.43	3.47	2.73	3.43
rco-29	1	0	1	4	0	4	4	5	5	4.67	4.11	3.86	3.53	2.55	3.48
sgp-01	2	0	2	4	0	4	2	3	4	3.00	4.22	4.29	3.80	3.45	4.00
sgp-02	8	1	7	11	3	8	4	4	4	4.00	4.78	4.71	4.60	3.82	4.52
sgp-03	1	0	1	3	0	3	3	2	5	3.33	4.44	4.29	4.20	3.00	4.05
sgp-04	3	1	2	4	2	2	5	4	5	4.67	3.89	4.43	3.87	2.82	3.75
sgp-05	1	1	0	1	1	0	3	3	5	3.67	3.89	3.57	3.47	2.82	3.52
sgp-07	2	1	1	2	1	1	5	4	4	4.33	4.13	3.86	4.20	3.55	4.00
sgp-08	2	1	1	3	1	2	4	5	5	4.67	4.56	4.43	3.60	3.27	3.93
sgp-09	1	1	0	3	2	1	4	5	5	4.67	4.67	4.43	4.47	3.82	4.43
sgp-10	1	1	1	2	0	2	4	4	4	4.00	3.11	3.00	2.93	2.36	2.91
sgp-11	1	0	1	1	0	1	4	4	4.5	4.17	3.56	2.86	3.20	2.55	3.07
sgp-12	2	1	1	2	1	1	1	2	1	1.33	2.89	2.43	2.67	2.36	2.59
sgp-13	1	0	1	4	0	4	2	3	2	2.33	4.00	3.71	3.53	3.09	3.61
sgp-14	2	0	2	2	0	2	4	5	1	3.33	4.78	4.29	4.33	3.73	4.39
sgp-15	1	1	0	1	1	0	4	2	2	2.67	4.22	4.43	4.07	3.18	4.00
sgp-16	6	1	5	13	3	10	4	4	4	4.00	4.67	4.29	4.40	3.91	4.43
sgp-17	1	0	1	4	0	4	4	3	4	3.67	4.67	3.86	4.27	3.45	4.16
sgp-18	1	0	1	3	0	3	4	2	5	3.67	4.56	3.71	3.80	3.64	3.98
sgp-19	3	2	1	4	2	2	2	3	5	3.33	4.00	4.00	3.67	3.18	3.80
sgp-20	1	0	1	1	0	1	3	4	5	4.00	4.33	4.43	4.20	3.55	4.20
sgp-21	1	0	1	1	0	1	3	1	4	2.67	3.56	2.86	2.67	2.27	2.77
sgp-22	1	0	1	2	1	1	5	4	4	4.33	4.56	4.29	4.07	3.82	4.18
sgp-23	2	0	2	2	0	2	5	4	3.5	4.17	4.44	4.14	3.93	3.45	3.98

sgp-24	4	1	3	5	1	4	4	3	5	4.00	4.89	4.14	4.07	3.18	4.14
sgp-25	2	0	2	2	0	2	5	3	5	4.33	4.44	3.57	4.09	3.09	3.93
sgp-26	1	0	1	1	0	1	5	4	5	4.67	3.33	3.00	3.67	2.82	3.36
tjo-01	1	1	0	2	1	1	3	2	5	3.33	4.22	3.43	3.73	3.09	**3.65**
tjo-02	1	0	1	1	0	1	3	2	5	3.33	3.89	4.00	3.33	3.00	**3.49**
tjo-03	1	0	1	5	1	4	3	4	3	3.33	4.33	3.29	4.07	3.00	**3.86**
tjo-04	1	0	1	1	0	1	4	5	5	4.67	4.33	4.29	4.47	3.55	**4.30**
tjo-05	1	1	0	1	1	0	2	3	2	2.33	2.56	2.71	2.40	2.30	**2.52**
tjo-06	1	0	1	1	0	1	3	4	5	4.00	3.78	3.00	3.07	2.64	**3.21**
tjo-07	1	0	1	1	0	1	2	2	4	2.67	3.67	2.57	3.33	2.55	**3.14**
tjo-08	1	0	1	1	0	1	4	4	5	4.33	4.56	4.14	4.27	3.27	**4.14**
tjo-09	1	1	0	2	1	1	5	4	5	4.67	4.33	3.71	3.93	3.73	**4.02**
tjo-10	1	0	1	3	1	2	5	5	5	5.00	4.44	3.71	4.13	3.36	**4.00**
tjo-11	1	0	1	1	0	1	5	4	4	4.33					
tjo-12	3	0	3	3	0	3	5	4	4	4.33	4.56	4.14	4.33	3.64	**4.30**
tjo-13	2	1	1	2	1	1	4	5	5	4.67	4.44	4.71	4.40	3.73	**4.35**
tjo-14	2	0	2	2	0	2	4	4	4	4.00	4.67	4.14	4.20	3.55	**4.16**
tjo-15	2	1	1	2	1	1	2	2	2	2.00	3.89	3.29	3.20	2.45	**3.21**
tjo-16	1	0	1	1	0	1	5	4	5	4.67	4.78	4.29	4.07	3.45	**4.19**
tjo-17	3	1	2	3	1	2	4	5	3	4.00	4.11	4.71	4.47	3.82	**4.33**
tjo-18	3	0	3	4	0	4	1	3	1	1.67	4.00	3.57	3.47	2.73	**3.49**
tjo-19	2	1	1	5	1	4	4	5	4	4.33	4.78	4.71	4.33	3.73	**4.40**
tjo-20	1	0	1	1	0	1	4	3	4	3.67	3.67	4.14	3.87	3.36	**3.81**
tjo-21	1	0	1	3	0	3	5	4	4	4.33	4.56	4.43	4.53	3.27	**4.33**
tjo-22	1	0	1	1	0	1	5	5	5	5.00					
tjo-23	1	0	1	1	0	1	3	4	3	3.33					
tjo-24	1	1	0	1	1	0	5	3	5	4.33					
tjo-25	1	0	1	5	1	4	5	2	5	4.00	3.22	3.14	3.33	2.36	**3.07**
tjo-26	1	0	1	1	0	1	4	4	4	4.00					
tjo-27	1	1	0	1	1	0	3	4	1	2.67					
tjo-28	4	0	4	8	2	6	3	5	3	3.67	4.67	4.00	4.00	3.64	**4.14**
tjo-29	3	1	2	3	1	2	5	4	5	4.67					
wco-01	1	0	1	1	0	1	5	5	5	5.00	4.33	3.71	4.27	3.09	3.98
wco-02	1	0	1	2	1	1	4	5	3	4.00	4.00	4.57	4.20	3.45	4.09
wco-03	1	0	1	1	0	1	4	5	4	4.33	4.00	4.00	3.13	2.64	3.36
wco-04	1	0	1	1	0	1	5	3	4.5	4.17	4.56	3.86	4.20	3.82	4.23
wco-05	1	0	1	1	0	1	5	3	2	3.33	3.56	3.43	3.67	3.09	3.50
wco-06	1	0	1	1	0	1	4	4	3	3.67	4.56	4.14	4.27	3.73	4.25
wco-07	1	0	1	2	0	2	3	3	5	3.67	4.11	4.00	3.73	2.82	3.61

wco-08	1	1	0	1	1	0	3	2	4.5	3.17	2.67	3.00	2.33	2.55	2.66
wco-09	1	0	1	2	0	2	1	2	5	2.67	3.22	3.00	3.33	2.45	3.07
wco-10	1	1	0	1	1	0	5	5	5	5.00	3.89	3.86	3.93	2.64	3.64
wco-11	1	1	0	1	1	0	na	4	5	4.50					
wco-12	1	1	0	1	1	0	3	5	5	4.33	4.22	4.29	3.67	3.64	3.95
wco-13	3	0	3	4	0	4	4	4	5	4.33	4.11	2.86	3.53	2.55	3.48
wco-14	2	0	2	2	0	2	5	5	5	5.00	3.38	3.43	3.27	3.18	3.35
wco-15	2	0	2	2	0	2	1	1	4	2.00	2.50	2.00	2.40	1.91	2.33
wco-16	2	1	1	2	1	1	4	2	5	3.67	3.50	3.86	4.00	3.27	3.79
wco-17	4	1	3	4	1	3	4	3	5	4.00	4.78	3.86	4.27	4.09	4.30
wco-18	3	0	2	2	0	2	4	4	4.5	4.17	3.22	3.43	3.07	2.36	3.09
wco-19	2	1	1	2	1	1	4	4	5	4.33	3.89	3.14	3.36	3.18	3.47
wco-20	6	2	4	6	2	4	3	5	5	4.33	3.78	3.29	3.67	2.55	3.48
wco-21	4	0	3	3	0	3	4	4	5	4.33	3.22	2.86	2.80	2.82	2.98
wco-22	1	1	0	1	1	0	5	3	1.5	3.17					
wco-23	2	2	0	2	2	0	5	5	5	5.00	3.88	4.00	4.00	3.45	3.98
wco-24	2	0	2	2	0	2	4	2	5	3.67	3.89	3.57	3.27	3.36	3.43
wco-25	4	1	3	7	2	5	5	4	5	4.67	4.67	4.71	4.27	3.91	4.36
wco-26	3	1	2	6	1	5	5	4	4	4.33	4.56	3.86	4.33	4.09	4.34
wco-27	6	2	4	6	2	4	5	3	4	4.00	4.22	4.29	4.20	3.27	4.02
wco-28	2	0	2	2	0	2	5	4	5	4.67	3.78	4.00	4.27	3.73	4.25
wco-29	3	0	3	3	0	3	2	1	5	2.67	2.50	2.57	2.40	2.20	2.38
wco-30	4	1	3	8	1	7	5	3	4	4.00	4.78	4.00	4.27	3.64	4.23
wco-31	3	2	1	4	2	2	5	4	2	3.67	4.56	4.14	3.93	3.30	4.02
wco-32	2	1	1	2	1	1	3	3	5	3.67	3.33	3.29	3.27	2.91	3.30
wco-33	2	1	0	4	2	2	4	3	5	4.00	3.89	4.00	3.53	3.27	3.70
wco-34	2	1	1	3	1	2	5	4	5	4.67	4.00	4.00	3.80	3.27	3.86
wco-35	1	0	1	3	0	3	5	5	5	5.00	4.78	4.43	4.33	3.55	4.32
wco-36	1	1	0	1	1	0	4	5	4	4.33	4.56	4.00	4.20	3.18	4.09

Appendix F: Surrogate Suit User Customer Needs Lists

TJO SSU LIST

SSU PTag	SSU Frequency	SSU Track	User Type	CN Statement
tjo-02	1	16	s	Product should have a clear center of rotation
tjo-03	1	15	s	Product should hold onto the jar as well
tjo-04	1	12	s	Product should Not allow contents to spill upon opening
tjo-06	1	12	s	Product should tell user when it is attached
tjo-07	1	12	s	Product should Not require a turning motion
tjo-08	1	7	s	Product should give the user good control
tjo-10	1	14	s	Product should Not deform the lid
tjo-11	1	8	s	Product should grip the lid easily and not slip
tjo-12	3	4,12,14	s	Product should lock onto the lid
tjo-13	1	11	b	Product should adjust to all lid sizes
tjo-14	2	11,15	s	Product should maintain control of the lid
tjo-15	1	15	b	Product should also assist with putting the lid back on
tjo-16	1	8	s	Product should be easy to detach from lid
tjo-17	2	15,16	b	Product should have a low chance of mechanical failure (durable/heavyduty)
tjo-18	3	11,13,15	s	Product should indicate direction of turn
tjo-19	1	13	b	Product should make it so that very little effort will remove the lid
tjo-20	1	6	s	Product should have a good turning angle
tjo-21	1	6	s	Product should Not be hard to grip
tjo-22	1	8	s	Product should Not have sharp edges on turning knobs
tjo-23	1	15	s	Product should have a place to hold on both sides
tjo-25	1	4	s	Product should have large handles
tjo-26	1	8	s	Product should Not be clunky
tjo-28	4	7,11,13,16	s	Product should be easy to understand/intuitive/obvious
tjo-29	2	4,12	b	Product should have knobs that are easy to turn

BJO SSU LIST

SSU PTag	SSU Frequency	SSU Track	User Type	CN Statement
bjo-03	1	7	s	Product should not allow contents to spill
bjo-04	1	12	s	Product should Not be free swinging
bjo-05	1	15	s	Product should be easy to align the blade
bjo-06	1	16	s	Product should work being turned in both directions
bjo-07	2	11,16	s	Product should be easy to maneuver
bjo-08	1	16	s	Product should not have thin/narrow handles
bjo-09	1	16	b	Product should cut consistently
bjo-10	2	6,12	s	Product should be simple
bjo-11	1	6	b	Product should be familiar
bjo-12	1	15	s	Product should be easy to clean
bjo-13	3	11,15,16	s	Product should not require large wrist motions to operate
bjo-15	2	14,16	s	Product should be usable with only one hand
bjo-16	2	11,15	b	Product should assist with removal of the lid after cutting
bjo-17	3	6,12,13	b	Product should look simple
bjo-18	4	7,13,14,15	s	Product should work at comfortable arm/wrist angles
bjo-19	2	7,13	b	Product should be easy to attach to can
bjo-22	1	12	b	Product should be easy to grasp/grip
bjo-24	1	14	s	Product should not need to be held closed
bjo-25	3	4,14,15	b	Product should be easy to turn
bjo-26	3	8,12,15	s	Product should have mechanisms that turn smoothly/fluidly
bjo-27	1	12	s	Product should not need a lot of grip force to puncture can
bjo-29	1	11	s	Product should not rust

CGP SSU LIST

SSU PTag	SSU Frequency	SSU Tracking	User Type	CN Statement
cgp-01	1	10	b	Product should be lightweight
cgp-02	2	8,11	s	Product should look cool
cgp-03	1	8	s	Product should have an adequate sized container
cgp-04	1	4	b	Product should open Easily
cgp-05	4	4,6,12,15	s	Product should have an easy to access container to load garlic
cgp-06	1	15	s	Product should have curved handles
cgp-07	2	11,15	s	Product should Not be too complicated
cgp-09	1	15	s	Product should have rubber nonslip grip on handles
cgp-11	2	15,16	s	Product should have big handles
cgp-12	3	4,15,16	s	Products' parts should all align automatically
cgp-13	3	8,10,12	s	Product should be compact
cgp-14	2	7,15	b	Product should fit small hands easily
cgp-15	3	7,10,11	s	Product should Not open too far / Not need full extension of hands to use
cgp-16	4	8,11,12,14	s	Product should be easy to understand
cgp-17	1	15	s	Product should be food sanitary
cgp-18	6	6,7,8,12,14,15	b	Product should be easy to clean
cgp-19	2	14,15	s	Product should be dishwasherable
cgp-20	1	15	s	Product should be usable with only one hand
cgp-21	1	12	b	Product should be efficient (lots separated, none wasted)
cgp-22	2	8,16	b	Product should be easy/comfy to grasp/grip
cgp-23	4	6,7,11,15	b	Product should help release the garlic
cgp-26	9	4,6,8,10,11,12,14,15,16	b	Product should be easy (require little effort to) squeeze closed
cgp-27	1	8	s	Product should have rounded edges

SPG SSU LIST

SSU PTag	SSU Frequency	User Tracking	User type	Need Statement
sgp-01	2	8,11	s	Product should Not have to open very far to access
sgp-02	7	4,6,7,8,10,14,15	b	Product should be easy to clean
sgp-03	1	16	s	Product should Not need two hands to use
sgp-04	2	15,16	b	Product should be durable
sgp-07	1	15	b	Product should have easy to grip handles
sgp-08	1	16	b	Product should have tapered edges so that it can't catch on the hand
sgp-10	1	15	s	Product should Not have small handles
sgp-11	1	15	s	Product should Not have short handles
sgp-12	1	7	b	Product should have small handles
sgp-13	1	13	s	Product should be compact
sgp-14	2	6,15	s	Product should be easy to apply pressure (angle)
sgp-16	5	10,11,12,13,14	b	Product should require little pressure to squeeze closed
sgp-17	1	8	s	Product should be intuitive
sgp-18	1	16	s	Product should be simple
sgp-19	1	6	b	Product should have a chamber big enough for all garlic
sgp-20	1	12	s	Product should be easy to insert garlic
sgp-21	1	12	s	Product should signal that the crunch is complete
sgp-22	1	6	s	Product should provide good leverage
sgp-23	2	4,10	s	Product should be comfortable to hold
sgp-24	3	4,8,15	b	Product's parts should not misalign
sgp-25	2	4,8	s	Product should be easy to manipulate
sgp-26	1	4	s	Product should Not be too small

WCO SSU LIST

SSU Ptag	SSU Frequency	SSU Tracking	User Type	CN Statement
wco-01	1	8	s	Product should require only low dexterity to operate
wco-02	1	16	s	Product should be durable
wco-03	1	4	s	Product should provide enough clearance from the can
wco-04	1	7	s	Product should be easy to detach from can
wco-05	1	11	s	Product should have efficient twisting mechanism with no play
wco-06	1	12	s	Product should Not require a lot of actions
wco-07	1	16	s	Product should work with only one hand
wco-09	1	14	s	Product should turn and cut in both directions
wco-13	3	7,15,16	s	Product should have an ergonomic shape
wco-14	2	8,16	s	Product should work quickly
wco-15	2	7,15	s	Product should look good
wco-16	1	12	b	Product should look safe
wco-17	3	8,12,14	b	Product should be easy to understand
wco-18	2	6,12	s	Product should Not have unfamiliar extra features
wco-19	1	7	b	Product's extra features should be visible/obvious
wco-20	4	7,8,15,16	b	Product should have comfy rubber grips on handles
wco-21	3	11,15,16	s	Product should have big enough handles for two hands
wco-24	2	8,14	s	Product should indicate when it is engaged/closed
wco-25	3	6,7,13	b	Product should take little pressure to press closed
wco-26	2	14,16	b	Product should be easy to attach to can
wco-27	4	8,11,15,16	b	Product should stay locked in place on can
wco-28	2	14,15	s	Product should take little or no pressure to stay closed
wco-29	3	4,7,8	s	Product should Not require user to push a button
wco-30	3	11,14,16	b	Product should be easy to turn
wco-31	1	8	b	Product should have smooth turning mechanism
wco-32	1	15	b	Product should have large turning handle
wco-34	1	14	b	Product should cut through the can well
wco-35	1	13	s	Product should Not need awkward angles to use

RCO SSU LIST

SSU PTag	SSU Frequency	SSU Tracking	User Type	CN Statement
rco-01	1	12	s	Product should not allow contents to spill
rco-02	1	13	s	Product should Not be free swinging
rco-03	1	16	s	Product should be easy to align the blade
rco-05	1	15	s	Product should work being turned in both directions
rco-06	2	4,12	s	Product should be easy to maneuver
rco-07	1	16	b	Product should not have thin/narrow handles
rco-08	1	15	s	Product should cut consistently
rco-09	2	12,16	b	Product should be simple
rco-10	2	4,16	b	Product should be familiar
rco-11	1	16	s	Product should be easy to clean
rco-12	1	4	b	Product should not require large wrist motions to operate
rco-13	1	15	s	Product should be usable with only one hand
rco-14	2	7,15	s	Product should assist with removal of the lid after cutting
rco-15	1	12	s	Product should look simple
rco-16	2	11,15	s	Product should work at comfortable arm/wrist angles
rco-17	4	4,7,12,16	s	Product should be easy to attach to can
rco-18	3	14,15,16	s	Product should be easy to grasp/grip
rco-19	3	12,14,15	s	Product should not need to be held closed
rco-20	7	7,8,11,13,14,15,16	s	Product should be easy to turn
rco-21	1	7	b	Product should have mechanisms that turn smoothly/fluidly
rco-22	3	6,11,15	b	Product should not need a lot of grip force to puncture can
rco-23	1	16	b	Product should not rust
rco-27	2	14,15	s	Product should have large handles
rco-29	1	8	s	Product should have comfortably curved handles

EXP2 SSU List with Codes

SSU PTag	SSU Freq	SSU Track	Code	CN Statement
tjo-02	1	16	1142	Product should have a clear center of rotation
tjo-03	1	15	2444	Product should hold onto the jar as well
tjo-04	1	12	1244	Product should Not allow contents to spill upon opening
tjo-06	1	12	2124	Product should tell user when it is attached
tjo-07	1	12	2122	Product should Not require a turning motion
tjo-08	1	7	1324	Product should give the user good control
tjo-10	1	14	1134	Product should Not deform the lid
tjo-11	1	8	1133	Product should grip the lid easily and not slip
tjo-12	3	4,12,14	1444	Product should lock onto the lid
tjo-13	1	11	1234	Product should adjust to all lid sizes
tjo-14	2	11,15	1334	Product should maintain control of the lid
tjo-15	1	15	2344	Product should also assist with putting the lid back on
tjo-16	1	8	1324	Product should be easy to detach from lid
tjo-17	2	15,16	1312	Product should have a low chance of mechanical failure (durable/heavyduty)
tjo-18	3	11,13,15	1121	Product should indicate direction of turn
tjo-19	1	13	1223	Product should make it so that very little effort will remove the lid
tjo-20	1	6	1222	Product should have a good turning angle
tjo-21	1	6	1322	Product should Not be hard to grip
tjo-22	1	8	1412	Product should Not have sharp edges on turning knobs
tjo-23	1	15	2422	Product should have a place to hold on both sides
tjo-25	1	4	2242	Product should have large handles
tjo-26	1	8	1321	Product should Not be clunky
tjo-28	4	7,11,13,16	1321	Product should be easy to understand/intuitive/obvious
tjo-29	2	4,12	1422	Product should have knobs that are easy to turn
bjo-03	1	7	1321	Product should Not be too unfamiliar
bjo-04	1	12	1321	Product should Not look scary
bjo-05	1	15	1342	Product should Not have parts that can be lost
bjo-06	1	16	1321	Product operation should be visible
bjo-07	2	11,16	2132	Product operation should be one step
bjo-08	1	16	1324	Product should be easy/simple to attach
bjo-09	1	16	1321	Product should have a simple design
bjo-10	2	6,12	1324	Product should Not need precision/complex movements

bjo-11	1	6	1332	Product should work quickly
bjo-12	1	15	1233	Product should provide good leverage
bjo-13	3	11,15,16	2242	Product should have big handles
bjo-15	2	14,16	1322	Product should be easy to grip/grasp
bjo-16	2	11,15	1442	Product should have rubber nonslip grip on handle
bjo-17	3	6,12,13	1321	Product should be easy to understand
bjo-18	4	7,13,14,15	1321	Product should have clear directions
bjo-19	2	7,13	1321	Product should have instructions that are easy to read
bjo-22	1	12	1134	Product should Not strip the lid
bjo-24	1	14	1121	Product should indicate direction of turn
bjo-25	3	4,14,15	2444	Product should hold onto the jar as well
bjo-26	3	8,12,15	1223	Product should need only low strength to use
bjo-27	1	12	2122	Product should Not need constant application of force
bjo-29	1	11	2124	Product should work towards user instead of away
cgp-01	1	10	1232	Product should be lightweight
cgp-02	2	8,11	2321	Product should look cool
cgp-03	1	8	1132	Product should have an adequate sized container
cgp-04	1	4	1324	Product should open Easily
cgp-05	4	4,6,12,15	1322	Product should have an easy to access container to load garlic
cgp-06	1	15	2442	Product should have curved handles
cgp-07	2	11,15	1331	Product should Not be too complicated
cgp-09	1	15	1442	Product should have rubber nonslip grip on handles
cgp-11	2	15,16	2242	Product should have big handles
cgp-12	3	4,15,16	1144	Products' parts should all align automatically
cgp-13	3	8,10,12	1332	Product should be compact
cgp-14	2	7,15	2322	Product should fit small hands easily
cgp-15	3	7,10,11	2124	Product should Not open too far / Not need full extension of hands to use
cgp-16	4	8,11,12,14	1321	Product should be easy to understand
cgp-17	1	15	1145	Product should be food sanitary
cgp-18	6	6,7,8,12,14,15	1325	Product should be easy to clean
cgp-19	2	14,15	1145	Product should be dishwasherable
cgp-20	1	15	2124	Product should be usable with only one hand
cgp-21	1	12	1234	Product should be efficient (lots separated, none wasted)
cgp-22	2	8,16	1322	Product should be easy/comfy to grasp/grip
cgp-23	4	6,7,11,15	1344	Product should help release the garlic

cgp-26	9	4,6,8,10,11,12,14,15,16	1223	Product should be easy (require little effort to) squeeze closed
cgp-27	1	8	1412	Product should have rounded edges
sgp-01	2	8,11	1222	Product should Not have to open very far to access
sgp-02	7	4,6,7,8,10,14,15	1325	Product should be easy to clean
sgp-03	1	16	2124	Product should Not need two hands to use
sgp-04	2	15,16	1332	Product should be durable
sgp-07	1	15	1322	Product should have easy to grip handles
sgp-08	1	16	1412	Product should have tapered edges so it can't catch on the hand
sgp-10	1	15	2242	Product should Not have small handles
sgp-11	1	15	2242	Product should Not have short handles
sgp-12	1	7	2242	Product should have small handles
sgp-13	1	13	1332	Product should be compact
sgp-14	2	6,15	1224	Product should be easy to apply pressure (angle)
sgp-16	5	10,11,12,13,14	1223	Product should require little pressure to squeeze closed
sgp-17	1	8	1321	Product should be intuitive
sgp-18	1	16	1331	Product should be simple
sgp-19	1	6	1132	Product should have a chamber big enough for all garlic
sgp-20	1	12	1324	Product should be easy to insert garlic
sgp-21	1	12	2124	Product should signal that the crunch is complete
sgp-22	1	6	1233	Product should provide good leverage
sgp-23	2	4,10	1321	Product should be comfortable to hold
sgp-24	3	4,8,15	1134	Product's parts should not misalign
sgp-25	2	4,8	1324	Product should be easy to manipulate
sgp-26	1	4	2142	Product should Not be too small
wco-01	1	8	1324	Product should require only low dexterity to operate
wco-02	1	16	1332	Product should be durable
wco-03	1	4	1142	Product should provide enough clearance from the can
wco-04	1	7	1324	Product should be easy to detach from can
wco-05	1	11	1432	Product should have efficient twisting mechanism with no play
wco-06	1	12	1324	Product should Not require a lot of actions
wco-07	1	16	2124	Product should work with only one hand
wco-09	1	14	2144	Product should turn and cut in both directions
wco-13	3	7,15,16	1321	Product should have an ergonomic shape
wco-14	2	8,16	1332	Product should work quickly
wco-15	2	7,15	1321	Product should look good

wco-16	1	12	1311	Product should look safe
wco-17	3	8,12,14	1321	Product should be easy to understand
wco-18	2	6,12	1122	Product should Not have unfamiliar extra features
wco-19	1	7	1321	Product's extra features should be visible/obvious
wco-20	4	7,8,15,16	1442	Product should have comfy rubber grips on handles
wco-21	3	11,15,16	2422	Product should have big enough handles for two hands
wco-24	2	8,14	2124	Product should indicate when it is engaged/closed
wco-25	3	6,7,13	1224	Product should take little pressure to press closed
wco-26	2	14,16	1323	Product should be easy to attach to can
wco-27	4	8,11,15,16	1134	Product should stay locked in place on can
wco-28	2	14,15	1224	Product should take little or no pressure to stay closed
wco-29	3	4,7,8	2134	Product should Not require user to push a button
wco-30	3	11,14,16	1324	Product should be easy to turn
wco-31	1	8	1432	Product should have smooth turning mechanism
wco-32	1	15	2242	Product should have large turning handle
wco-34	1	14	1333	Product should cut through the can well
wco-35	1	13	1322	Product should Not need awkward angles to use
rco-01	1	12	1114	Product should not allow contents to spill
rco-02	1	13	2144	Product should Not be free swinging
rco-03	1	16	1334	Product should be easy to align the blade
rco-05	1	15	1144	Product should work being turned in both directions
rco-06	2	4,12	1324	Product should be easy to maneuver
rco-07	1	16	2242	Product should not have thin/narrow handles
rco-08	1	15	1133	Product should cut consistently
rco-09	2	12,16	1331	Product should be simple
rco-10	2	4,16	1321	Product should be familiar
rco-11	1	16	1325	Product should be easy to clean
rco-12	1	4	2222	Product should not require large wrist motions to operate
rco-13	1	15	2124	Product should be usable with only one hand
rco-14	2	7,15	2314	Product should assist with removal of the lid after cutting
rco-15	1	12	1321	Product should look simple
rco-16	2	11,15	1222	Product should work at comfortable arm/wrist angles
rco-17	4	4,7,12,16	1323	Product should be easy to attach to can

rco-18	3	14,15,16	1322	Product should be easy to grasp/grip
rco-19	3	12,14,15	1334	Product should not need to be held closed
rco-20	7	7,8,11,13,14,15,16	1324	Product should be easy to turn
rco-21	1	7	1432	Product should have mechanisms that turn smoothly/fluidly
rco-22	3	6,11,15	1223	Product should not need a lot of grip force to puncture can
rco-23	1	16	1135	Product should not rust
rco-27	2	14,15	2242	Product should have large handles
rco-29	1	8	1321	Product should have comfortably curved handles

Appendix G: Persons with Motion Restrictions Customer Needs Lists

TJO PMR LIST

PMR PTag	PMR Freq	PMR Track	Covered	User Type	CN Statement
tjo-01	1	5	0	r	Product should have a simple design
tjo-05	1	5	0	r	Product should be made of stainless steel
tjo-09	1	3	0	r	Product should provide good leverage
tjo-13	1	5	1	b	Product should adjust to all lid sizes
tjo-15	1	2	1	b	Product should also assist with putting the lid back on
tjo-17	1	5	1	b	Product should have a low chance of mechanical failure (durable/heavyduty)
tjo-19	1	5	1	b	Product should make it so that very little effort will remove the lid
tjo-24	1	3	0	r	Product should work with small hands
tjo-27	1	5	0	r	Product should Not have too many moving parts
tjo-29	1	5	1	b	Product should have knobs that are easy to turn

BJO PMR LIST

PMR PTag	PMR Freq	PMR Track	Covered	User Type	CN Statement
bjo-01	1	5	0	r	Product should be durable
bjo-02	1	5	0	r	Product should be easy to clean
bjo-09	1	5	1	b	Product should have a simple design
bjo-11	1	2	1	b	Product should work quickly
bjo-13	1	5	1	b	Product should have big handles
bjo-14	1	5	0	r	Product should have small enough handles to hold
bjo-16	1	5	1	b	Product should have rubber nonslip grip on handle
bjo-17	2	2,5	1	b	Product should be easy to understand
bjo-19	1	2	1	b	Product should have instructions that are easy to read
bjo-20	1	5	0	r	Product should grip lid easily
bjo-21	1	3	0	r	Product should Not slide on lid
bjo-22	1	3	1	b	Product should Not strip the lid
bjo-23	1	5	0	r	Product should remove all sizes of lids
bjo-25	1	2	1	b	Product should hold onto the jar as well
bjo-28	1	2	1	b	Product should only work in one direction (the intended direction)

CGP PMR LIST

PMR PTag	PMR Freq	PMR Track	Covered	User Type	CN Statement
cgp-01	1	2	1	b	Product should be lightweight
cgp-04	1	2	1	b	Product should open Easily
cgp-06	1	5	1	b	Product should have curved handles
cgp-08	1	5	1	b	Product should have few moving parts
cgp-10	1	5	0	r	Product should Not have thick handles
cgp-14	1	5	1	b	Product should fit small hands easily
cgp-18	3	2,3,5	1	b	Product should be easy to clean
cgp-21	1	3	1	b	Product should be efficient (lots separated, none wasted)
cgp-22	1	2	1	b	Product should be easy/comfy to grasp/grip
cgp-23	1	5	1	b	Product should help release the garlic
cgp-24	1	2	0	r	Product should provide good leverage
cgp-25	2	2,5	0	r	Product should be heavyduty
cgp-26	2	2,5	1	b	Product should be easy (require little effort to) squeeze closed

SGP PMR LIST

PMR PTag	PMR Freq	PMR Track	Covered	User Type	CN Statement
sgp-02	1	5	1	b	Product should Not have to open very far to access
sgp-04	1	5	1	b	Product should be durable
sgp-05	1	5	0	r	Product should Not have a lot of moving parts
sgp-07	1	2	1	b	Product should have easy to grip handles
sgp-08	1	5	1	b	Product should have tapered edges so it can't catch on the hand
sgp-09	1	5	0	r	Product should get a lot of garlic per effort (efficient)
sgp-12	1	5	1	b	Product should have small handles
sgp-15	1	2	0	r	Product should Not waste much garlic
sgp-16	1	3	1	b	Product should require little pressure to squeeze closed
sgp-19	2	2,5	1	b	Product should have a chamber big enough for all garlic
sgp-24	1	2	1	b	Product's parts should not misalign

WCO PMR LIST

PMR PTag	PMR Freq	PMR Track	Covered	User Type	CN Statement
wco-8	1	5	0	r	Product should Not squeak
wco-10	1	2	0	r	Product should provide good leverage
wco-11	1	5	0	r	Product should keep the blades touching
wco-12	1	3	0	r	Product should have instructions
wco-16	1	5	1	b	Product should look safe
wco-17	1	5	1	b	Product should be easy to understand
wco-19	1	3	1	b	Product's extra features should be visible/obvious
wco-20	2	2,5	1	b	Product should have comfy rubber grips on handles
wco-22	1	5	0	r	Product should have curved handles
wco-23	2	3,5	0	r	Product should not feel flimsy
wco-25	1	2	1	b	Product should take little pressure to press closed
wco-26	1	3	1	b	Product should be easy to attach to can
wco-27	2	2,5	1	b	Product should stay locked in place on can
wco-30	1	3	1	b	Product should be easy to turn
wco-31	2	5,3	1	b	Product should have smooth turning mechanism
wco-32	1	5	1	b	Product should have large turning handle
wco-33	1	2,5	0	r	Product should help remove the lid after cutting
wco-34	1	2	1	b	Product should cut through the can well
wco-36	1	5	0	r	Product should Not need large movements

RCO PMR LIST

PMR PTag	PMR Freq	PMR Track	Covered	User Type	CN Statement
rco-04	1	3	0	r	Product should have a sharp blade
rco-07	1	2	1	b	Product should not have thin/narrow handles
rco-09	1	5	1	b	Product should be simple
rco-10	2	2,3	1	b	Product should be familiar
rco-12	1	2	1	b	Product should not require large wrist motions to operate
rco-21	1	5	1	b	Product should have mechanisms that turn smoothly/fluidly
rco-22	2	2,3	1	b	Product should not need a lot of grip force to puncture can
rco-23	1	5	1	b	Product should not rust
rco-24	1	5	0	r	Product should not be flimsy
rco-25	1	5	0	r	Product should not catch the teeth in the blade
rco-26	1	5	0	r	Product should have nonslip handles
rco-28	1	5	0	r	Product should not have any wiggle in it

EXP2 PMR List with Codes

PMR PTag	PMR Freq	PMR Track	Code	Covered	CN Statement
tjo-01	1	5	1321	0	Product should have a simple design
tjo-05	1	5	2442	0	Product should be made of stainless steel
tjo-09	1	3	1233	0	Product should provide good leverage
tjo-13	1	5	1234	1	Product should adjust to all lid sizes
tjo-15	1	2	2344	1	Product should also assist with putting the lid back on
tjo-17	1	5	1312	1	Product should have a low chance of mechanical failure (durable/heavyduty)
tjo-19	1	5	1223	1	Product should make it so that very little effort will remove the lid
tjo-24	1	3	2322	0	Product should work with small hands
tjo-27	1	5	1342	0	Product should Not have too many moving parts
tjo-29	1	5	1422	1	Product should have knobs that are easy to turn
bjo-01	1	5	1332	0	Product should be durable
bjo-02	1	5	1325	0	Product should be easy to clean
bjo-09	1	5	1321	1	Product should have a simple design
bjo-11	1	2	1332	1	Product should work quickly
bjo-13	1	5	2242	1	Product should have big handles
bjo-14	1	5	2222	0	Product should have small enough handles to hold
bjo-16	1	5	1442	1	Product should have rubber nonslip grip on handle
bjo-17	2	2,5	1321	1	Product should be easy to understand
bjo-19	1	2	1321	1	Product should have instructions that are easy to read
bjo-20	1	5	1233	0	Product should grip lid easily
bjo-21	1	3	1134	0	Product should Not slide on lid
bjo-22	1	3	1134	1	Product should Not strip the lid
bjo-23	1	5	1243	0	Product should remove all sizes of lids
bjo-25	1	2	2444	1	Product should hold onto the jar as well
bjo-28	1	2	2134	1	Product should only work in one direction (the intended direction)
cgp-01	1	2	1232	1	Product should be lightweight
cgp-04	1	2	1324	1	Product should open Easily
cgp-06	1	5	2442	1	Product should have curved handles
cgp-08	1	5	1342	1	Product should have few moving parts
cgp-10	1	5	2242	0	Product should Not have thick handles
cgp-14	1	5	2322	1	Product should fit small hands easily
cgp-18	3	2,3,5	1325	1	Product should be easy to clean
cgp-21	1	3	1234	1	Product should be efficient (lots separated, none wasted)
cgp-22	1	2	1322	1	Product should be easy/comfy to grasp/grip

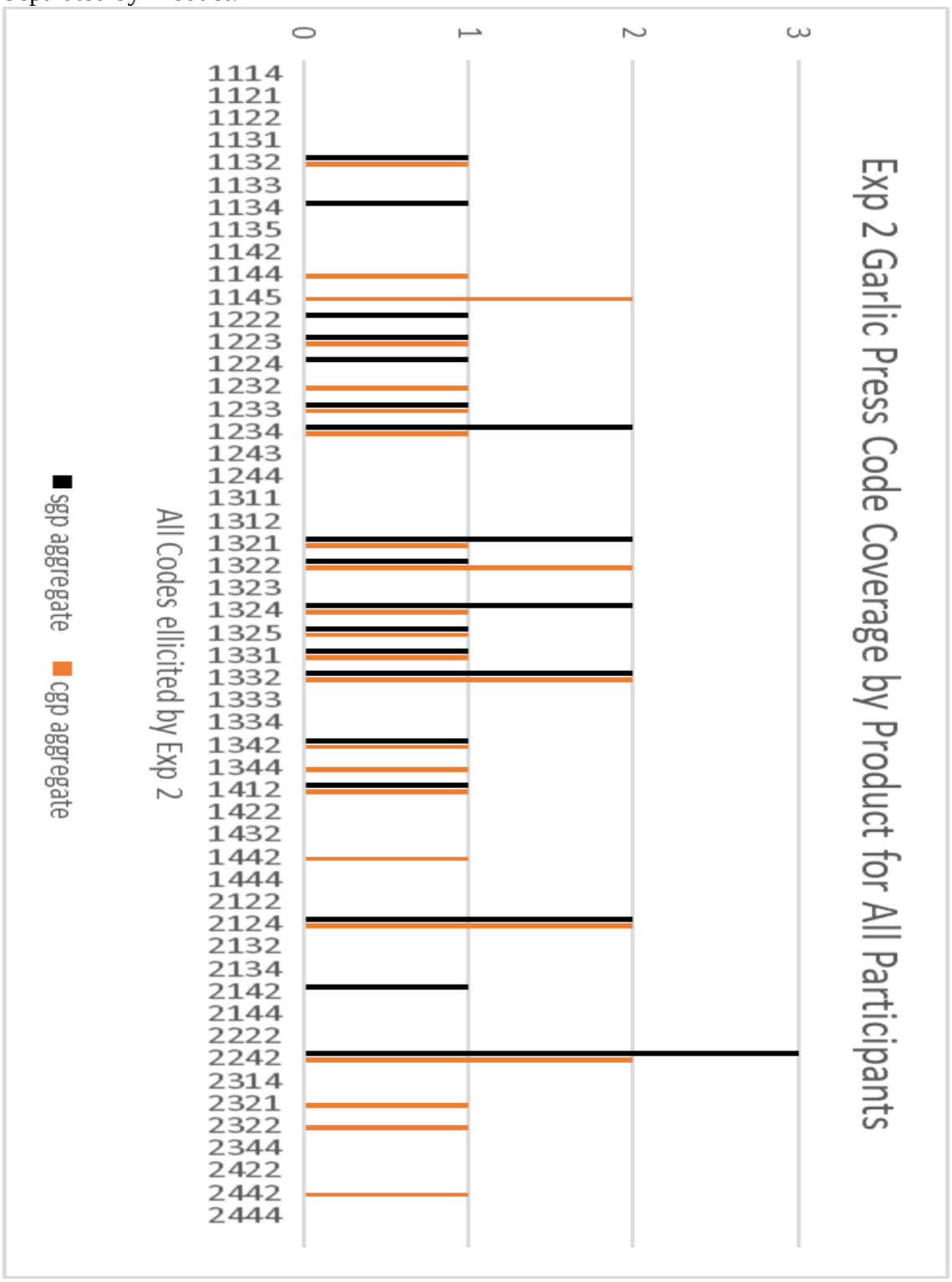
cgp-23	1	5	1344	1	Product should help release the garlic
cgp-24	1	2	1233	0	Product should provide good leverage
cgp-25	2	2,5	1332	0	Product should be heavyduty
cgp-26	2	2,5	1223	1	Product should be easy (require little effort to) squeeze closed
sgp-02	1	5	1325	1	Product should Not have to open very far to access
sgp-04	1	5	1332	1	Product should be durable
sgp-05	1	5	1342	0	Product should Not have a lot of moving parts
sgp-07	1	2	1322	1	Product should have easy to grip handles
sgp-08	1	5	1412	1	Product should have tapered edges so it can't catch on the hand
sgp-09	1	5	1234	0	Product should get a lot of garlic per effort (efficient)
sgp-12	1	5	2242	1	Product should have small handles
sgp-15	1	2	1234	0	Product should Not waste much garlic
sgp-16	1	3	1223	1	Product should require little pressure to squeeze closed
sgp-19	2	2,5	1132	1	Product should have a chamber big enough for all garlic
sgp-24	1	2	1134	1	Product's parts should not misalign
wco-8	1	5	1131	0	Product should Not squeak
wco-10	1	2	1233	0	Product should provide good leverage
wco-11	1	5	1444	0	Product should keep the blades touching
wco-12	1	3	1122	0	Product should have instructions
wco-16	1	5	1311	1	Product should look safe
wco-17	1	5	1321	1	Product should be easy to understand
wco-19	1	3	1321	1	Product's extra features should be visible/obvious
wco-20	2	2,5	1442	1	Product should have comfy rubber grips on handles
wco-22	1	5	2442	0	Product should have curved handles
wco-23	2	3,5	1321	0	Product should not feel flimsy
wco-25	1	2	1224	1	Product should take little pressure to press closed
wco-26	1	3	1323	1	Product should be easy to attach to can
wco-27	2	2,5	1134	1	Product should stay locked in place on can
wco-30	1	3	1324	1	Product should be easy to turn
wco-31	2	5,3	1432	1	Product should have smooth turning mechanism
wco-32	1	5	2242	1	Product should have large turning handle
wco-33	1	2,5	2314	0	Product should help remove the lid after cutting
wco-34	1	2	1333	1	Product should cut through the can well
wco-36	1	5	1324	0	Product should Not need large movements
rco-04	1	3	1442	0	Product should have a sharp blade
rco-07	1	2	2242	1	Product should not have thin/narrow handles
rco-09	1	5	1331	1	Product should be simple

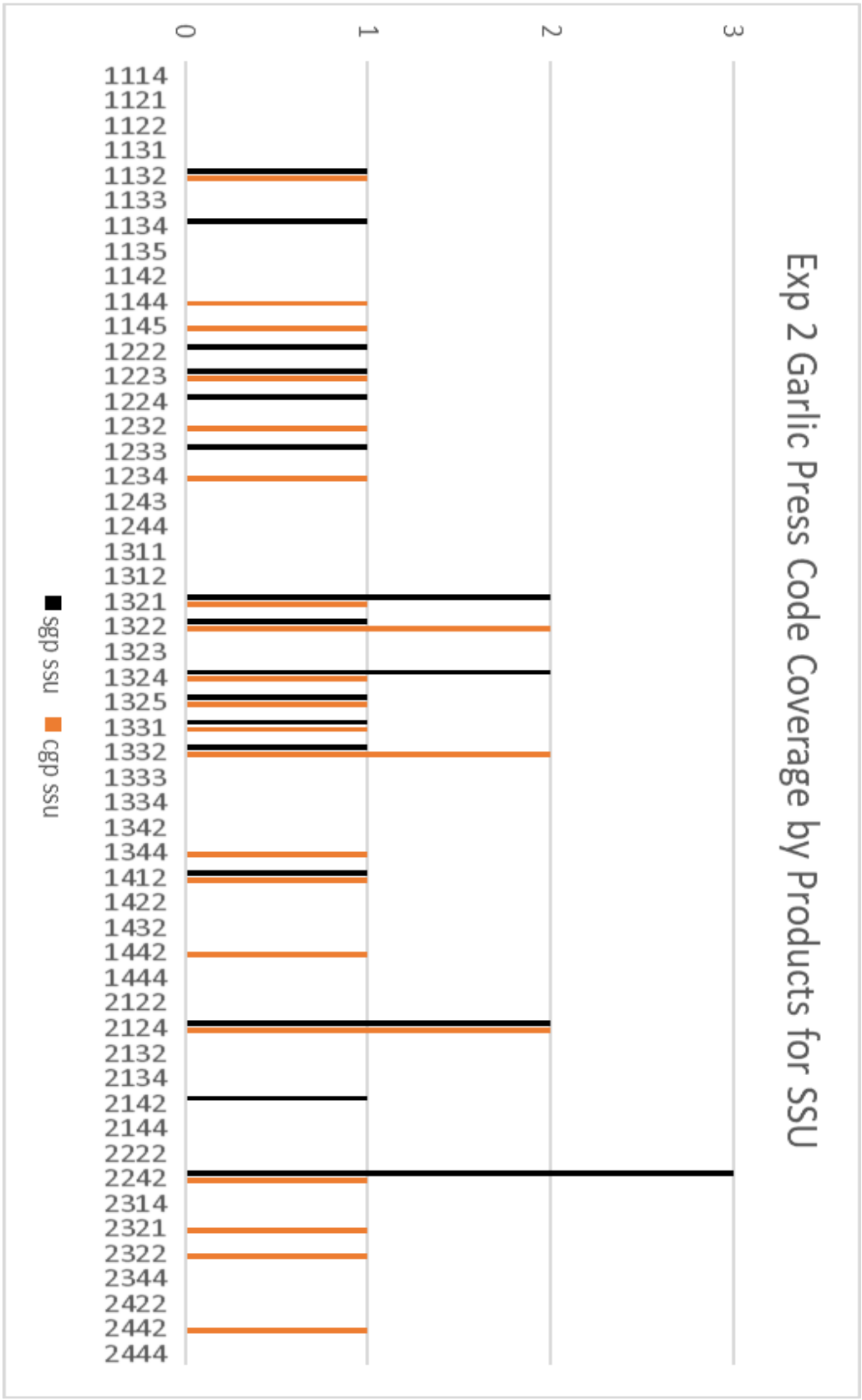
rco-10	2	2,3	1321	1	Product should be familiar
rco-12	1	2	2222	1	Product should not require large wrist motions to operate
rco-21	1	5	1432	1	Product should have mechanisms that turn smoothly/fluidly
rco-22	2	2,3	1223	1	Product should not need a lot of grip force to puncture can
rco-23	1	5	1135	1	Product should not rust
rco-24	1	5	1332	0	Product should not be flimsy
rco-25	1	5	1132	0	Product should not catch the teeth in the blade
rco-26	1	5	1442	0	Product should have nonslip handles
rco-28	1	5	1144	0	Product should not have any wiggle in it

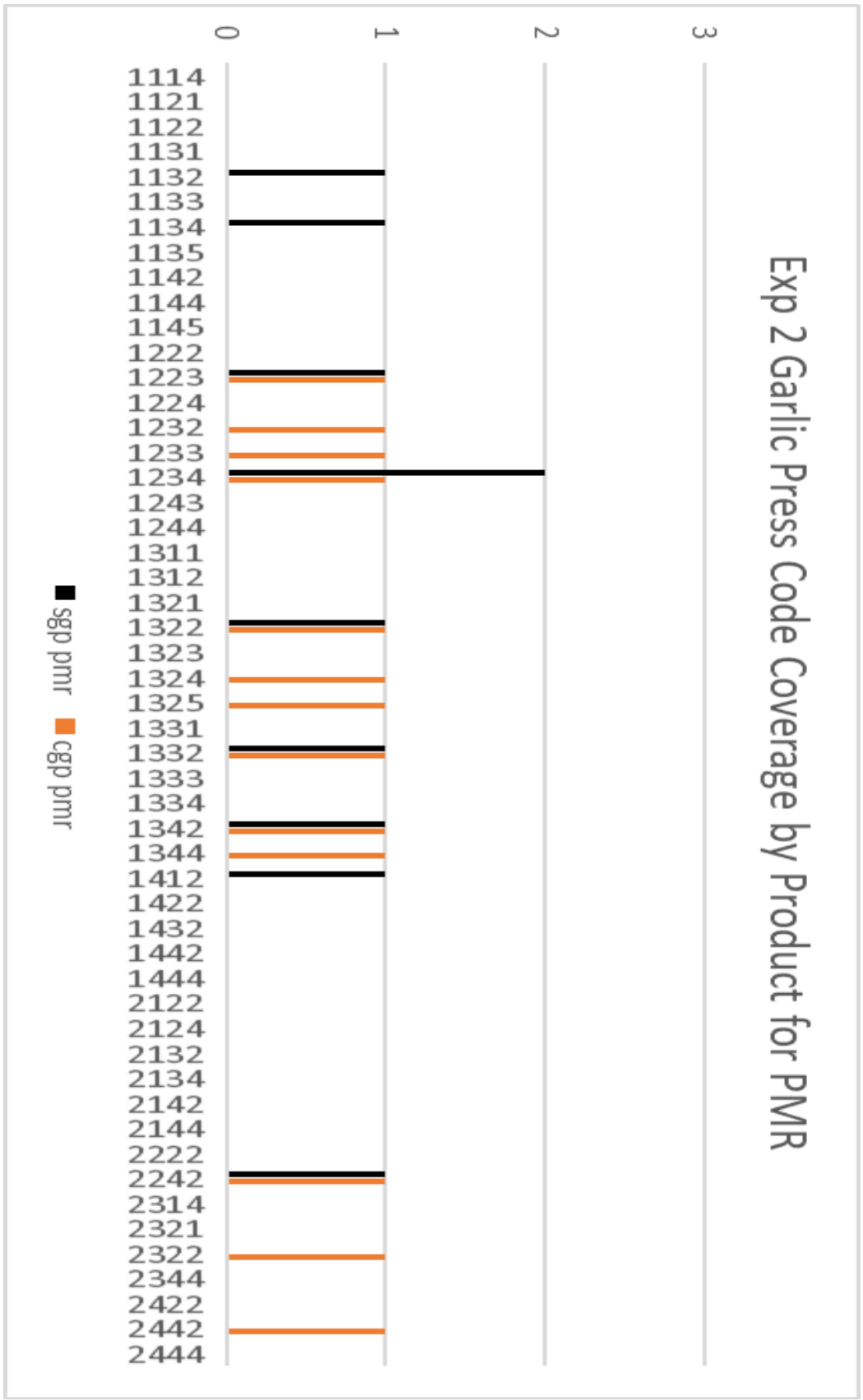
Appendix H: Code Coverage Comparison Charts

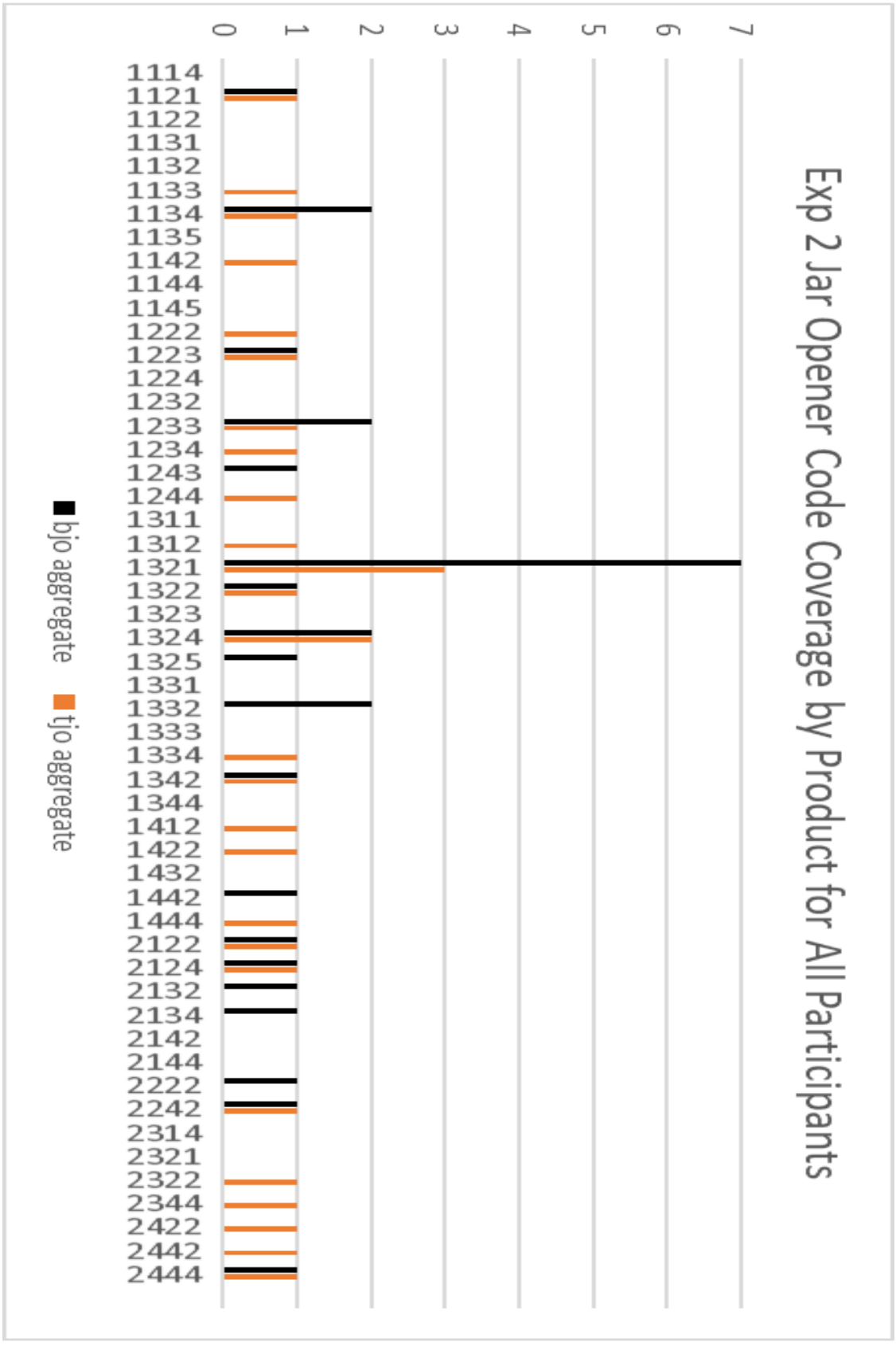
Product Type Comparisons

Histograms for Pairs Lists for each Subgroup, Code Counts across all Codes from Exp2, Separated by Product:




Exp 2 Garlic Press Code Coverage by Products for SSU
0
1
2
3
1114
1121
1122
1131
1132
1133
1134
1135
1142
1144
1145
1222
1223
1224
1232
1233
1234
1243
1244
1311
1312
1321
1322
1323
1324
1325
1331
1332
1333
1334
1342
1344
1412
1422
1432
1442
1444
2122
2124
2132
2134
2142
2144
2222
2242
2314
2321
2322
2344
2422
2442
2444
sgp ssu
cgp ssu


Exp 2 Garlic Press Code Coverage by Product for PMR
0
1
2
3
1114
1121
1122
1131
1132
1133
1134
1135
1142
1144
1145
1222
1223
1224
1232
1233
1234
1243
1244
1311
1312
1321
1322
1323
1324
1325
1331
1332
1333
1334
1342
1344
1412
1422
1432
1442
1444
2122
2124
2132
2134
2142
2144
2222
2242
2314
2321
2322
2344
2422
2442
2444
sgp pmr
cgp pmr


Exp 2 Jar Opener Code Coverage by Product for All Participants
0
1
2
3
4
5
6
7
1114
1121
1122
1131
1132
1133
1134
1135
1142
1144
1145
1222
1223
1224
1232
1233
1234
1243
1244
1311
1312
1321
1322
1323
1324
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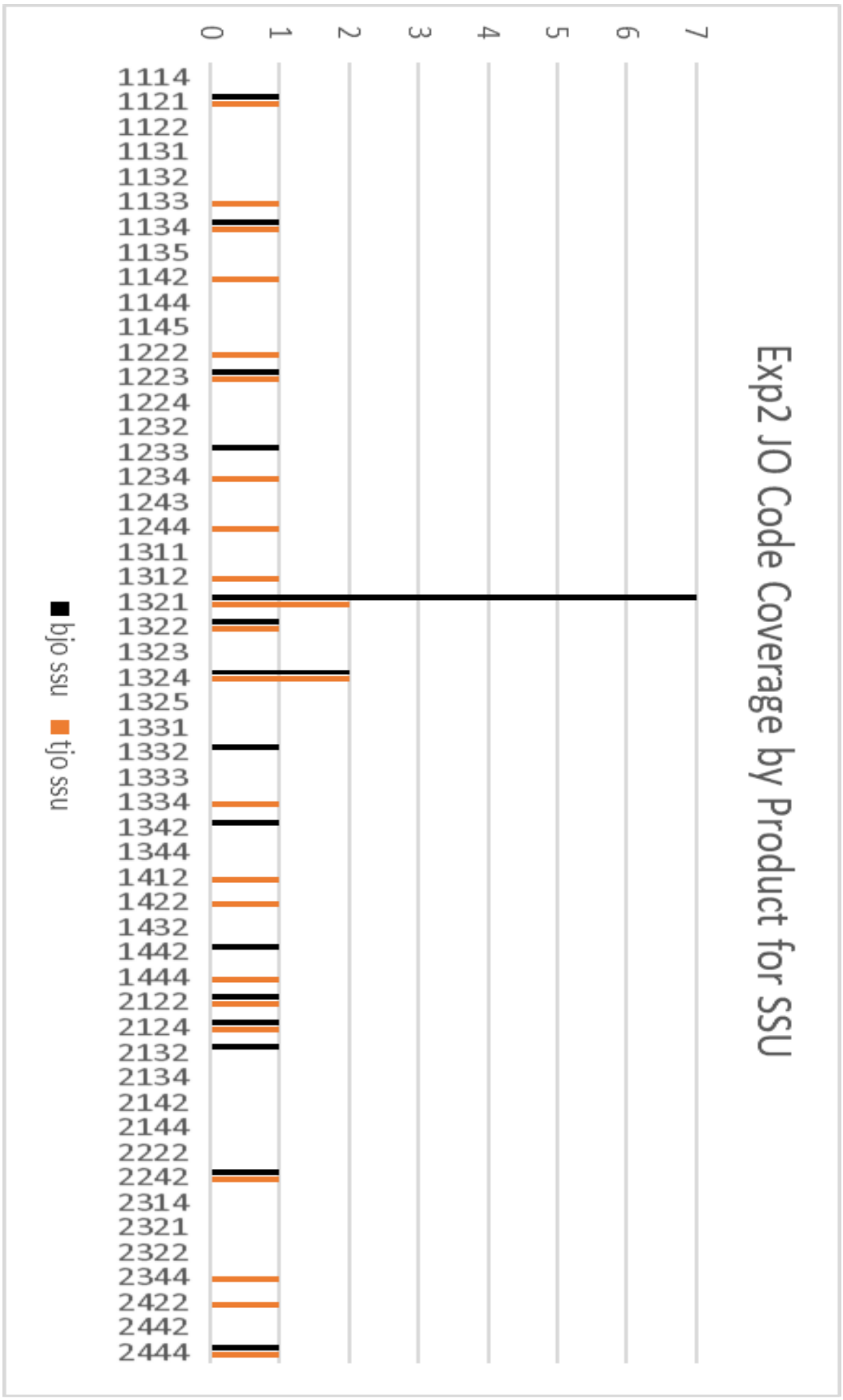
1331
1332
1333
1334
1342
1344
1412
1422
1432
1442
1444
2122
2124
2132
2134
2142
2144
2222
2242
2314
2321
2322
2344
2422
2442
2444
bjo aggregate
tjo aggregate


Exp2 JO Code Coverage by Product for SSU
bjo ssu
tjo ssu
0
1
2
3
4
5
6
7
1114
1121
1122
1131
1132
1133
1134
1135
1142
1144
1145
1222
1223
1224
1232
1233
1234
1243
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1332
1333
1334
1342
1344
1412
1422
1432
1442
1444
2122
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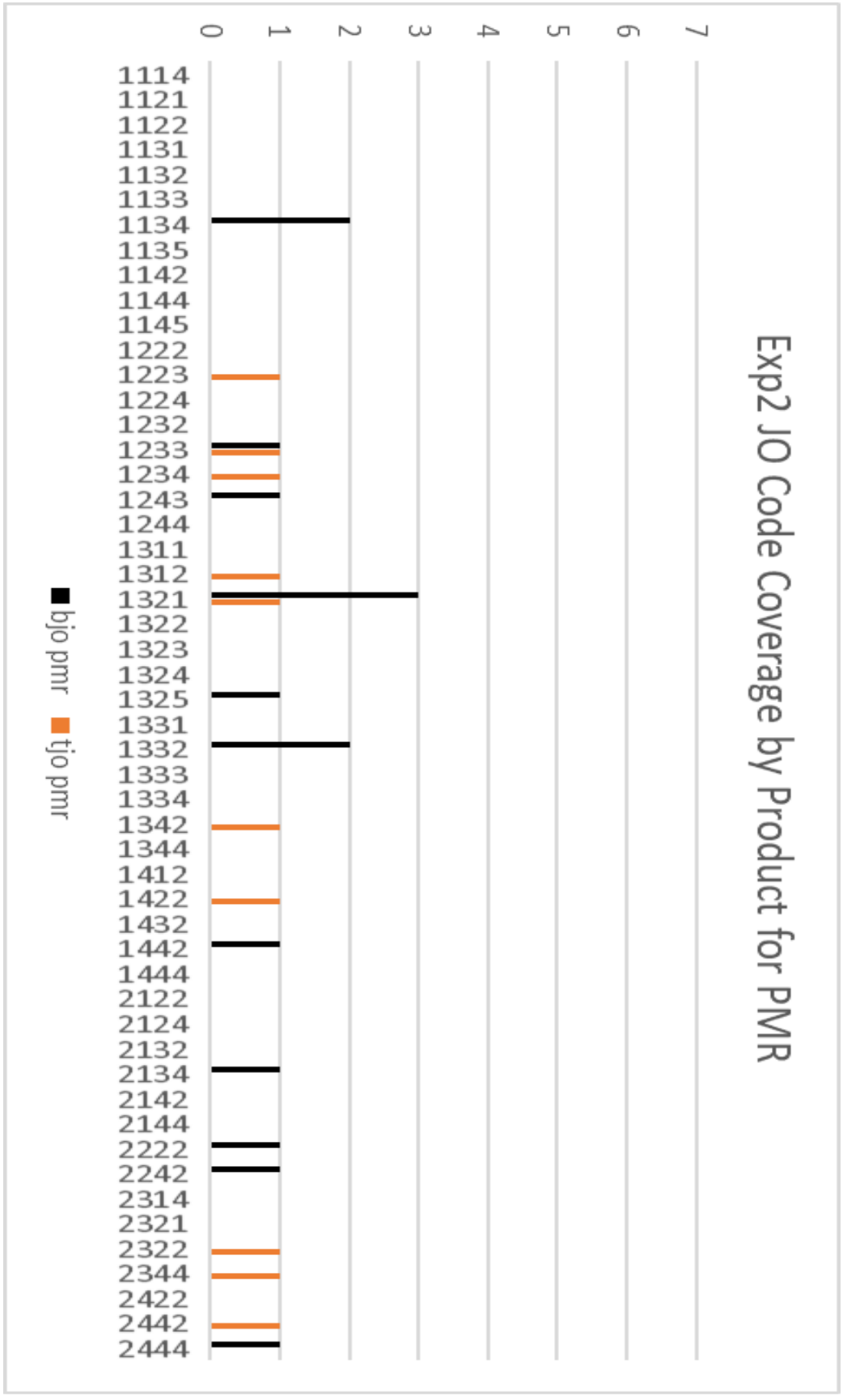
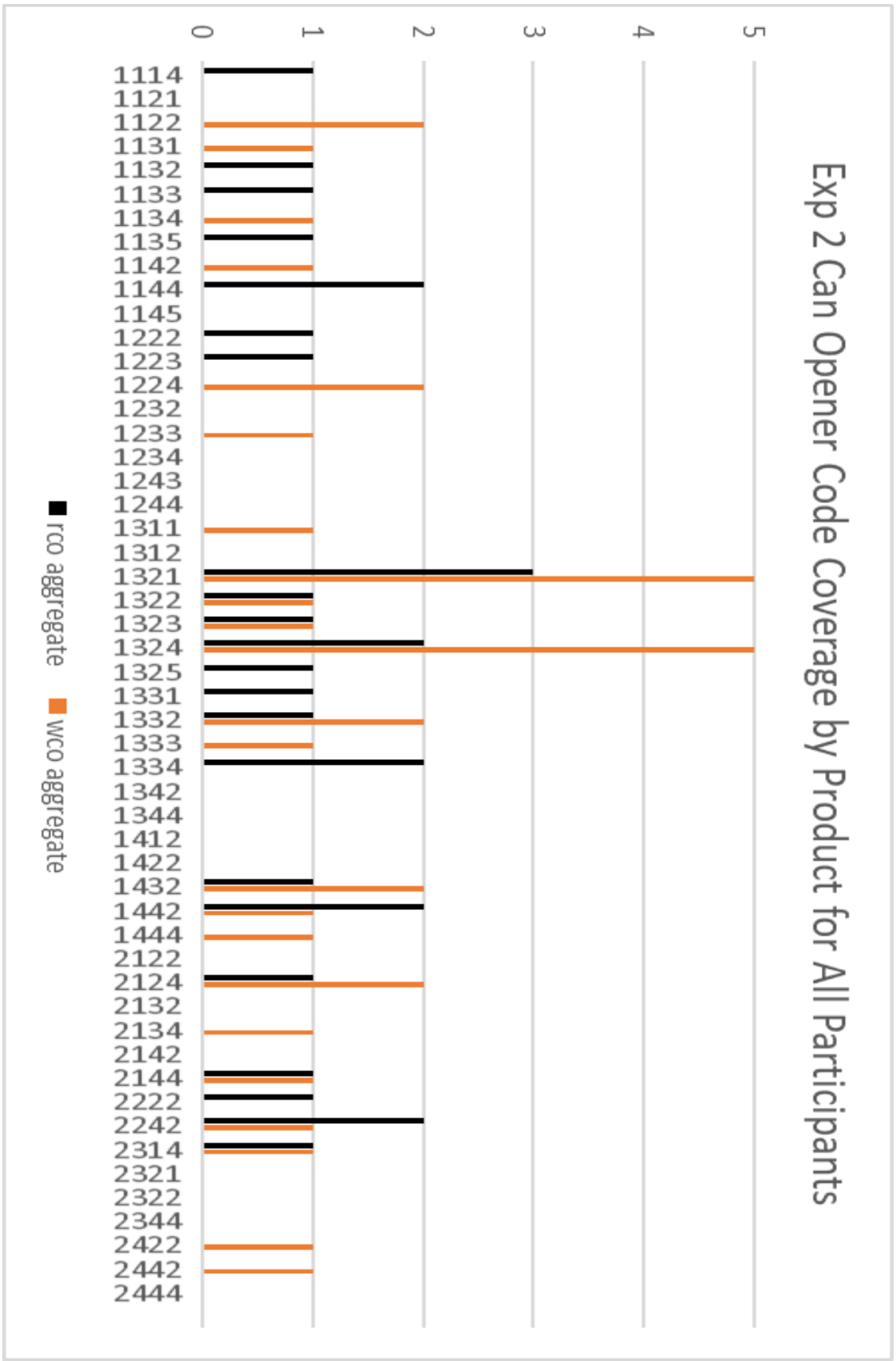
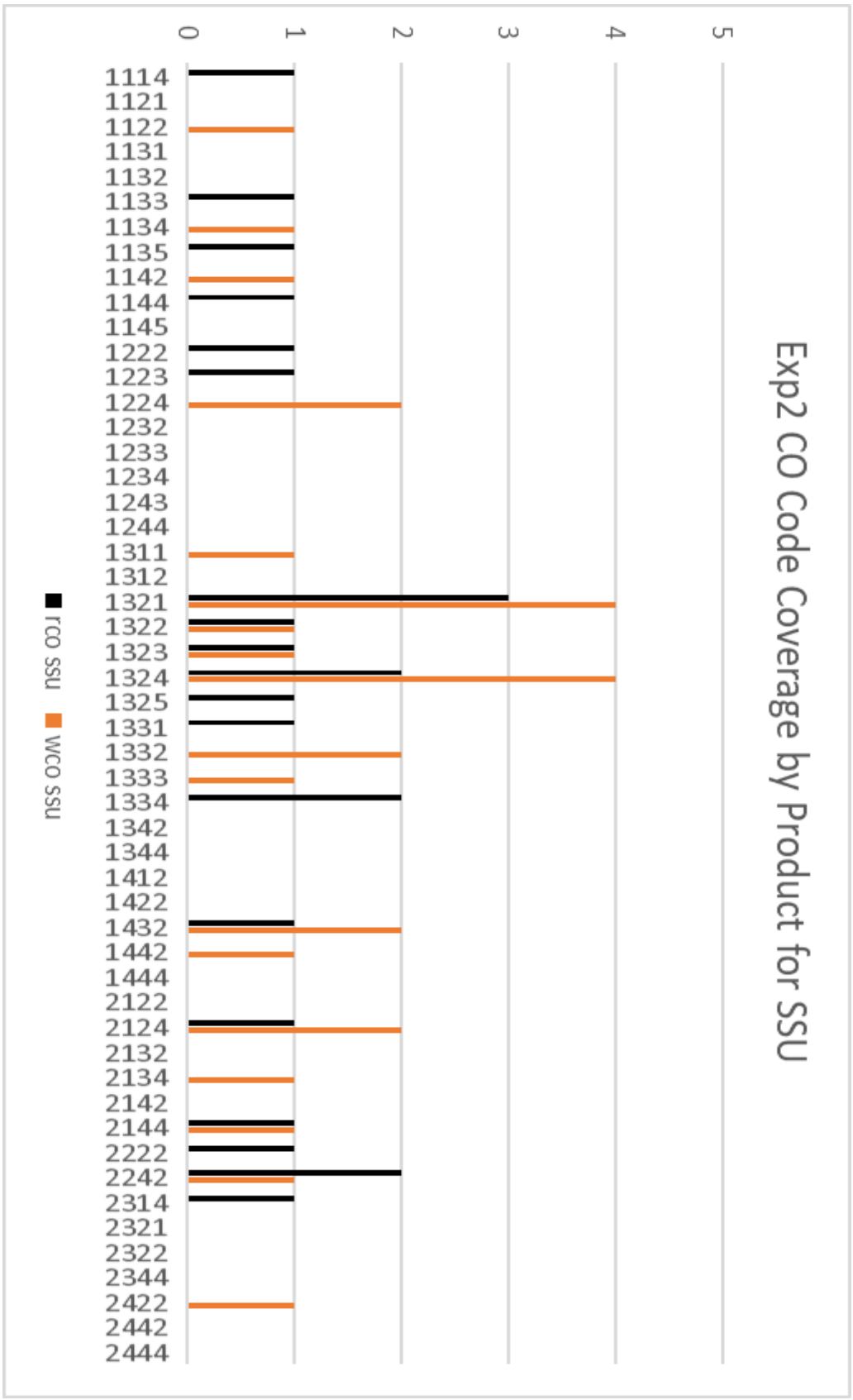
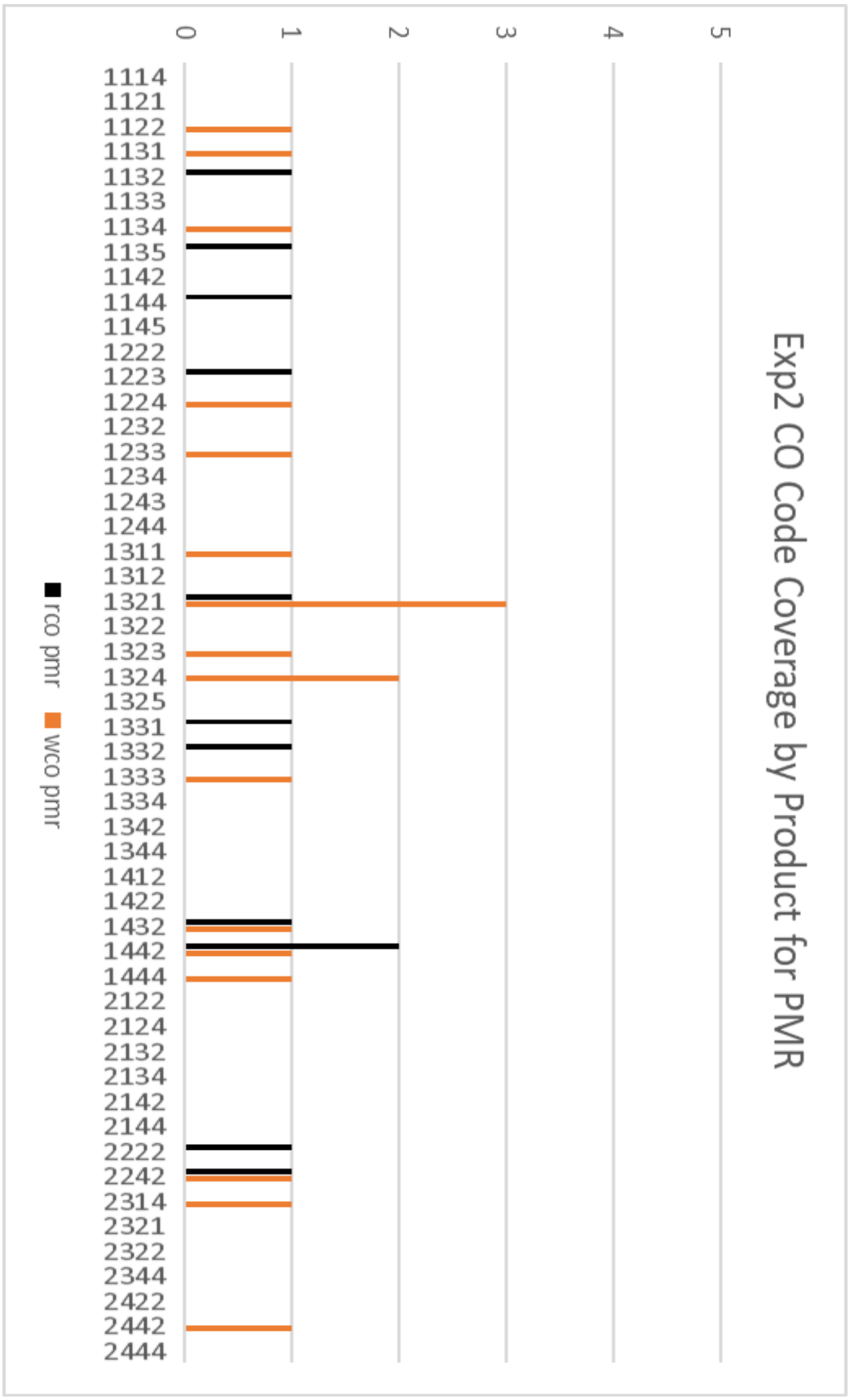
2134
2142
2144
2222
2242
2314
2321
2322
2344
2422
2442
2444


Exp2 JO Code Coverage by Product for PMR
0
1
2
3
4
5
6
7
1114
1121
1122
1131
1132
1133
1134
1135
1142
1144
1145
1222
1223
1224
1232
1233
1234
1243
1244
1311
1312
1321
1322
1323
1324
1325
1331
1332
1333
1334
1342
1344
1412
1422
1432
1442
1444
2122
2124
2132
2134
2142
2144
2222
2242
2314
2321
2322
2344
2422
2442
2444
bjo pmr
tjo pmr

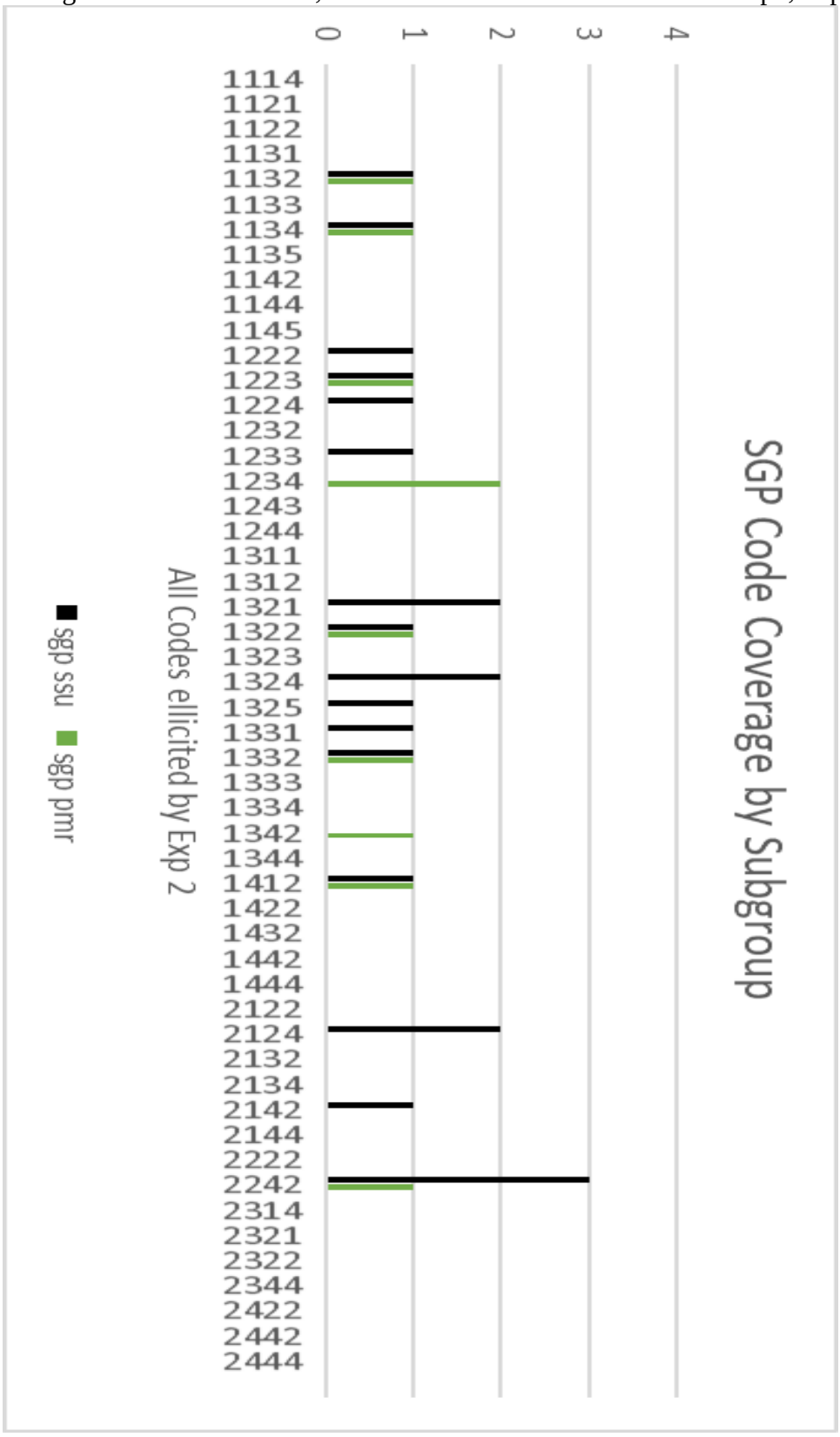

Exp 2 Can Opener Code Coverage by Product for All Participants
0
1
2
3
4
5
1114
1121
1122
1131
1132
1133
1134
1135
1142
1144
1145
1222
1223
1224
1232
1233
1234
1243
1244
1311
1312
1321
1322
1323
1324
1325
1331
1332
1333
1334
1342
1344
1412
1422
1432
1442
1444
2122
2124
2132
2134
2142
2144
2222
2242
2314
2321
2322
2344
2422
2442
2444
rco aggregate
wco aggregate

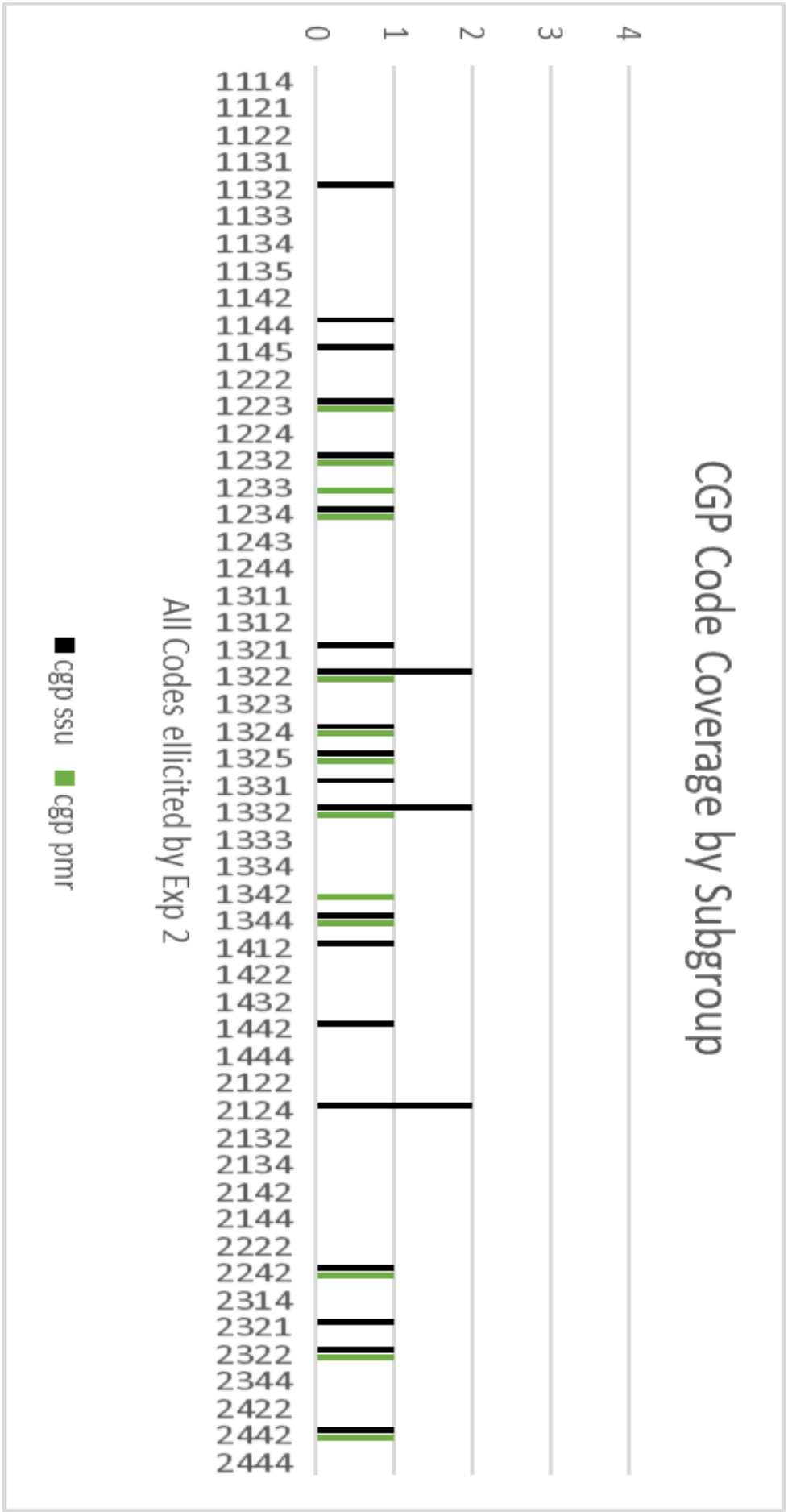

Exp2 CO Code Coverage by Product for SSU
0
1
2
3
4
5
1114
1121
1122
1131
1132
1133
1134
1135
1142
1144
1145
1222
1223
1224
1232
1233
1234
1243
1244
1311
1312
1321
1322
1323
1324
1325
1331
1332
1333
1334
1342
1344
1412
1422
1432
1442
1444
2122
2124
2132
2134
2142
2144
2222
2242
2314
2321
2322
2344
2422
2442
2444
rCO ssu
WCO ssu

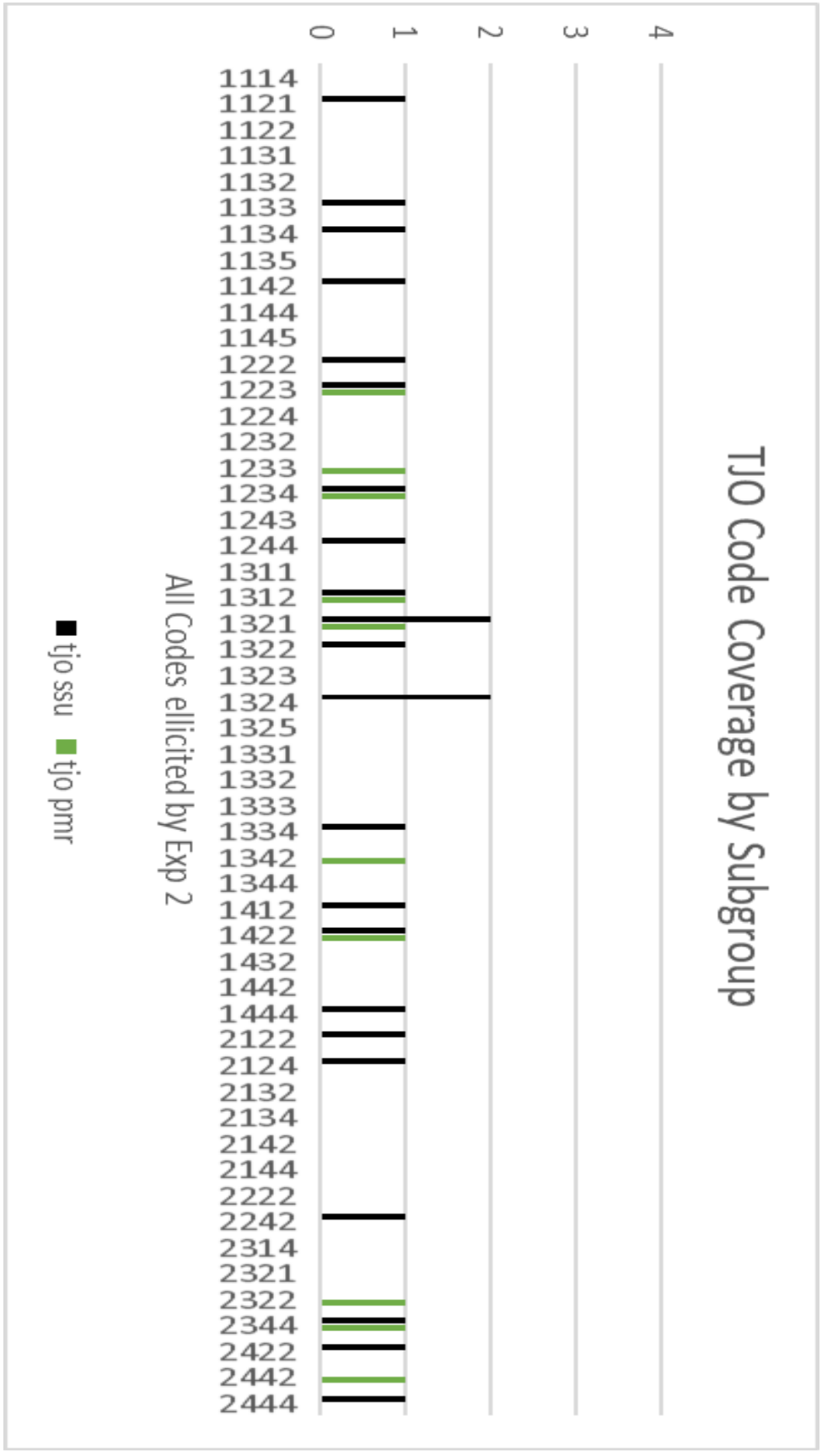

Exp2 CO Code Coverage by Product for PMR
0
1
2
3
4
5
1114
1121
1122
1131
1132
1133
1134
1135
1142
1144
1145
1222
1223
1224
1232
1233
1234
1243
1244
1311
1312
1321
1322
1323
1324
1325
1331
1332
1333
1334
1342
1344
1412
1422
1432
1442
1444
2122
2124
2132
2134
2142
2144
2222
2242
2314
2321
2322
2344
2422
2442
2444
rco pmr
wco pmr

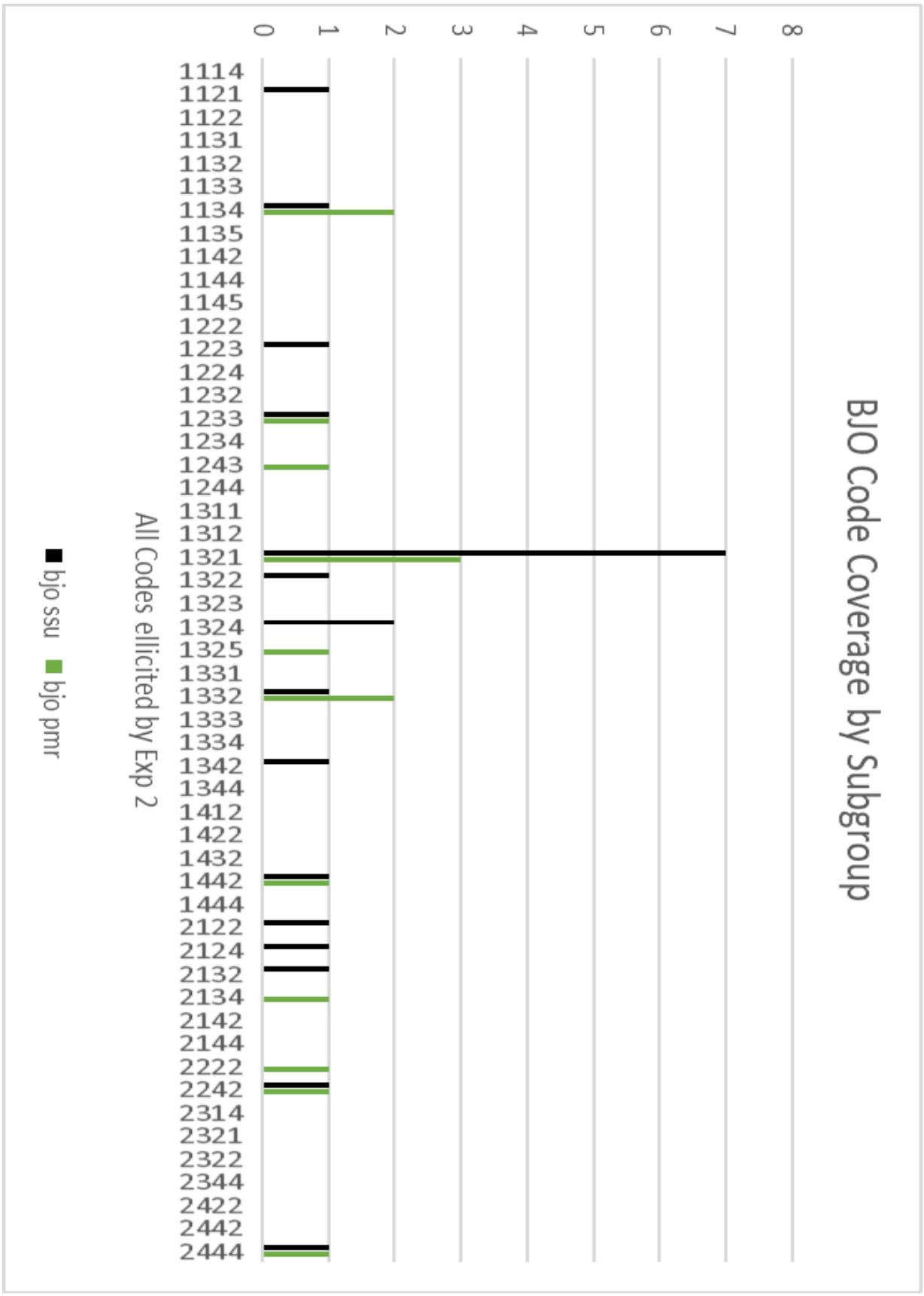
Subgroup Comparisons

Histograms of Product Lists, Code Counts across all Codes from Exp2, Separated by Subgroup:




CGP Code Coverage by Subgroup
0
1
2
3
4
1114
1121
1122
1131
1132
1133
1134
1135
1142
1144
1145
1222
1223
1224
1232
1233
1234
1243
1244
1311
1312
1321
1322
1323
1324
1325
1331
1332
1333
1334
1342
1344
1412
1422
1432
1442
1444
2122
2124
2132
2134
2142
2144
2222
2242
2314
2321
2322
2344
2422
2442
2444
All Codes ellicited by Exp 2
cgp ssu
cgp pmr


TJO Code Coverage by Subgroup
0
1
2
3
4
All Codes ellicited by Exp 2
1114
1121
1122
1131
1132
1133
1134
1135
1142
1144
1145
1222
1223
1224
1232
1233
1234
1243
1244
1311
1312
1321
1322
1323
1324
1325
1331
1332
1333
1334
1342
1344
1412
1422
1432
1442
1444
2122
2124
2132
2134
2142
2144
2222
2242
2314
2321
2322
2344
2422
2442
2444
tjo ssu
tjo pmr


BJO Code Coverage by Subgroup
0
1
2
3
4
5
6
7
8
All Codes ellicited by Exp 2
1114
1121
1122
1131
1132
1133
1134
1135
1142
1144
1145
1222
1223
1224
1232
1233
1234
1243
1244
1311
1312
1321
1322
1323
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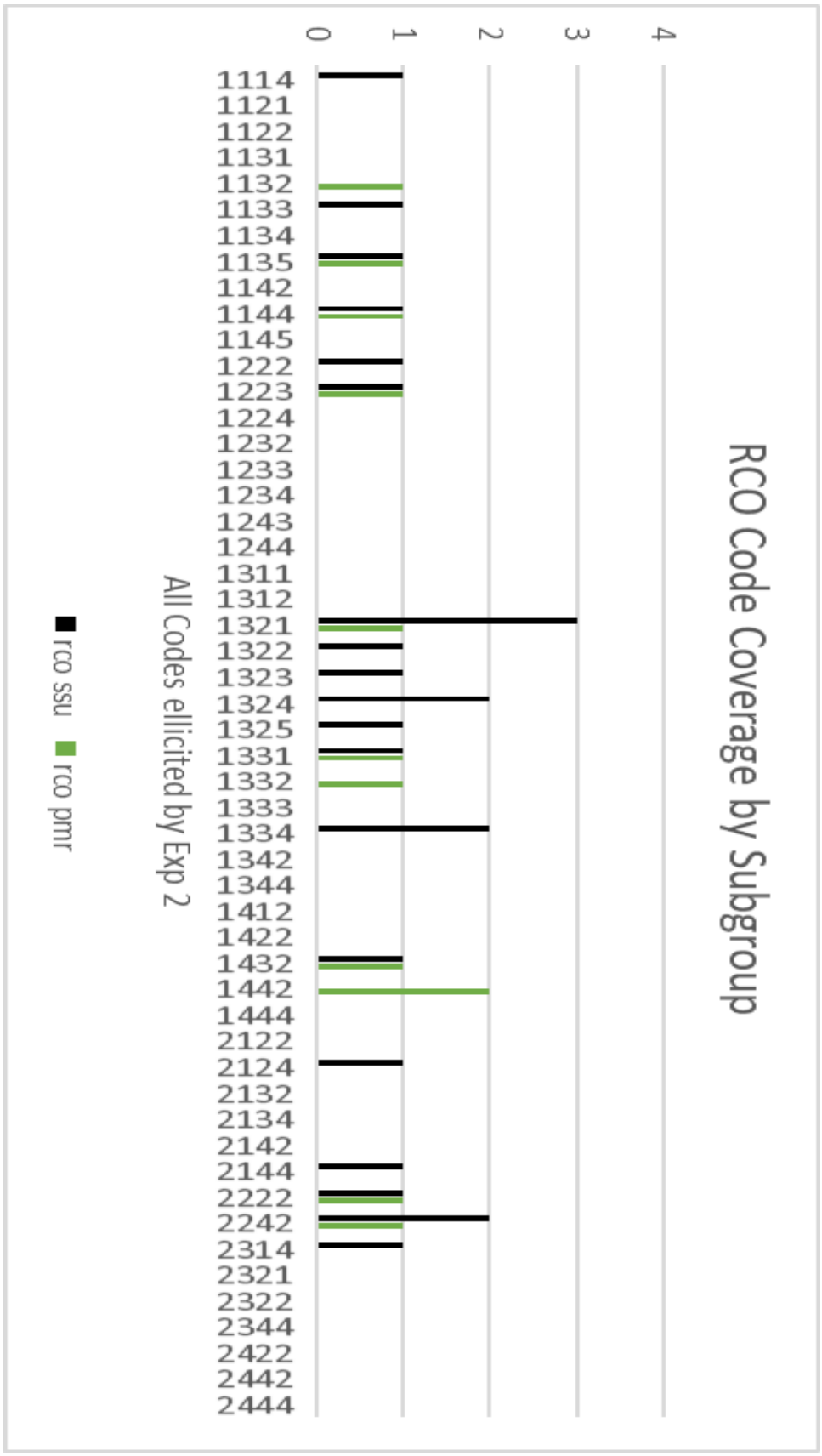
2444
bjo ssu
bjo pmr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3
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1122
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2321
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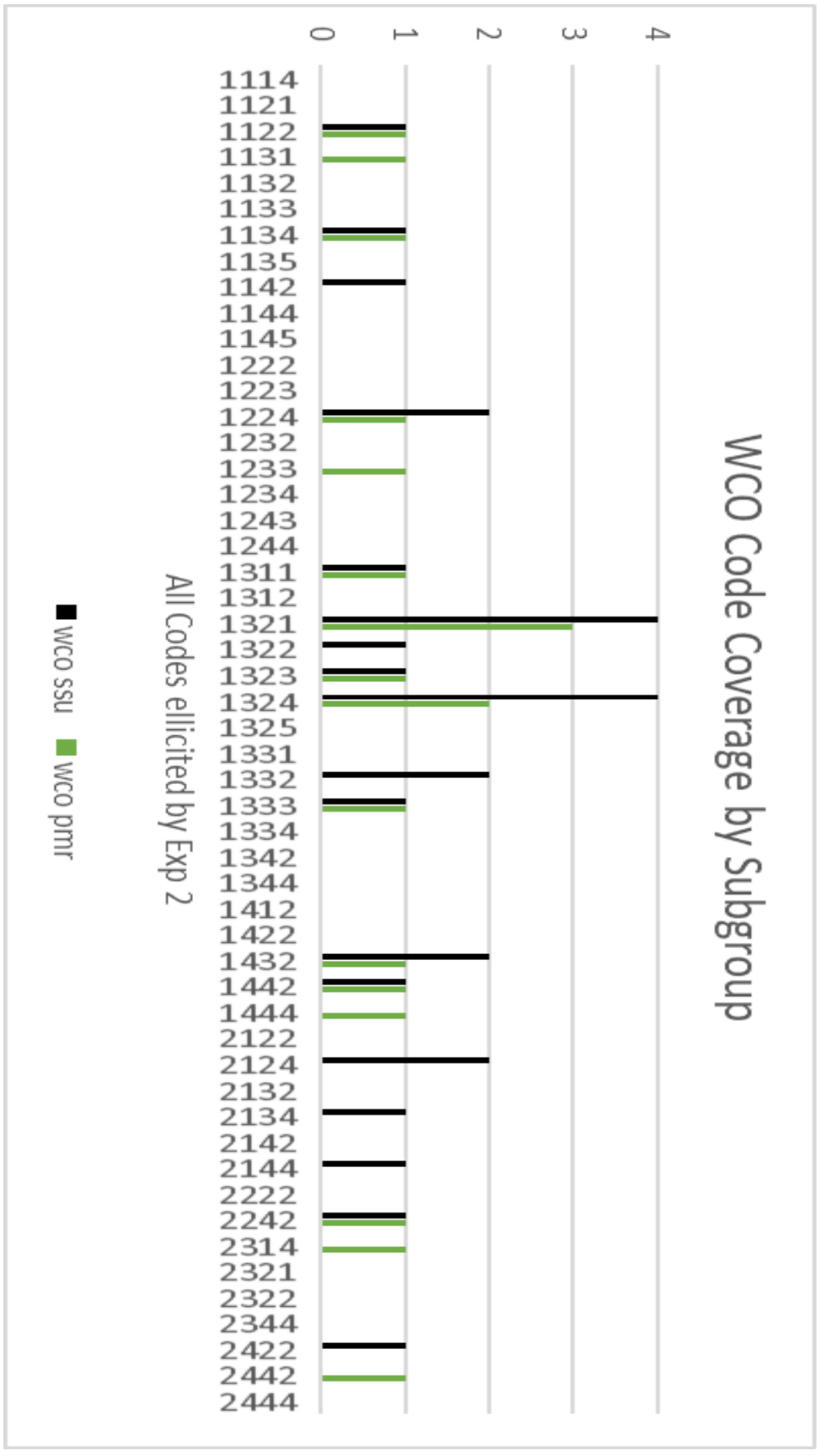
2442
2444
rco ssu
rco pmr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2
3
4
All Codes ellicited by Exp 2
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1121
1122
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1132
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1444
2122
2124
2132
2134
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2222
2242
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2322
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2442
2444
wco ssu
wco pmr

Appendix I: Combined Product Pair CN Lists

Jar Opener Lists for Exp2 (Jlist)

Jar Ctags	Jar Ptags	Combined Jar Need Statements	Combined Frequency	User Tracking	Full Codes	User Type
J01	bjo-1	Product should be durable	1	5	1332	r
J02	bjo-2	Product should be easy to clean	1	5	1325	r
J03	bjo-3	Product should Not be too unfamiliar	1	7	1321	s
J04	bjo-4	Product should Not look scary	1	12	1321	s
J05	bjo-5	Product should Not have parts that can be lost	1	15	1342	s
J06	bjo-6	Product operation should be visible	1	16	1321	s
J07	bjo-7	Product operation should be one step	2	11,16	2132	s
J08	bjo-8	Product should be easy/simple to attach	1	16	1324	s
J09	bjo-10	Product should Not need precision/complex movements	2	6,12	1324	s
J10	bjo-11	Product should work quickly	2	2,6	1332	b
J11	bjo-13/ tjo-25	Product should have big handles	5	5,4,11,15,16	2242	b
J12	tjo-24	Product should work with small hands	1	3	2322	r
J13	bjo-15/ tjo-21	Product should be easy to grip/grasp	3	6,14,16	1322	s
J14	bjo-16	Product should have rubber nonslip grip on handle	3	5,11,15	1442	b
J15	bjo-17/ tjo-28	Product should be easy to understand	8	2,5,6,7,11,12, 13,16	1321	b
J16	bjo-18	Product should have clear directions	4	7,13,14,15	1321	s
J17	bjo-19	Product should have instructions that are easy to read	3	2,7,13	1321	b
J18	bjo-20	Product should grip lid easily	1	5	1321	r
J19	tjo-11	Product should grip the lid without slipping	1	8	1133	s
J20	bjo-9/ tjo-1	Product should have a simple design	2	5,16	1321	b
J21	tjo-2	Product should have a clear center of rotation	1	16	1142	s
J22	bjo-25/ tjo-3	Product should hold onto the jar as well	5	2,4,12,14,15	2444	b
J23	tjo-4	Product should Not allow contents to spill upon opening	1	12	1244	s
J24	tjo-5	Product should be made of stainless steel	1	5	2442	r
J25	tjo-6	Product should tell user when it is attached	1	12	2124	s
J26	tjo-7	Product should Not require a turning motion	1	12	2122	s
J27	tjo-8	Product should give the user good control	1	7	1324	s
J28	bjo-12/ tjo-9	Product should provide good leverage	2	3,15	1233	b
J29	bjo-22/ tjo-10	Product should Not strip the lid	3	3,12,14	1134	b
J30	tjo-12	Product should lock onto the lid	3	4,12,14	1444	s

J31	bjo-23/ tjo-13	Product should adjust to remove to all lid sizes	2	5,11	1234	b
J32	tjo-14	Product should maintain control of the lid	2	11,15	1334	s
J33	tjo-15	Product should also assist with putting the lid back on	2	2,15	2344	b
J34	tjo-16	Product should be easy to detach from lid	1	8	1324	s
J35	tjo-17	Product should have a low chance of mechanical failure (durable/heavyduty)	3	5,15,16	1312	b
J36	bjo-24/ tjo-18	Product should indicate direction of turn	4	11,13,14,15	1121	s
J37	bjo-26/ tjo-19	Product should need only low strength to use	5	5,8,12,13,15	1224	b
J38	tjo-20	Product should have a good turning angle	1	6	1222	s
J39	tjo-22	Product should Not have sharp edges on turning knobs	1	8	1412	s
J40	tjo-23	Product should have a place to hold on both sides	1	15	2422	s
J41	tjo-26	Product should Not be clunky	1	8	1321	s
J42	tjo-27	Product should Not have too many moving parts	1	5	1344	r
J43	tjo-29	Product should have knobs that are easy to turn	3	5,4,12	1422	b
J44	bjo-27	Product should Not need constant application of force	1	12	2122	s
J45	bjo-28	Product should only work in one direction (the intended direction)	1	2	2134	r
J46	bjo-29	Product should work towards user instead of away	1	11	2124	s
J47	bjo-14	Product should have small enough handles to hold	1	5	2222	r
J48	bjo-21	Product should Not slide on lid	1	3	1134	r

Garlic Press List for Exp2 (Glist)

Gar Ctags	**Gar Ptags**	**Combined Garlic Press Need Statements**	**Combined Frequency**	**User Tracking**	**Full Codes**	User Type
G02	cgp-1	Product should be lightweight	2	2,10	1232	b
G03	cgp-2	Product should look cool	2	8,11	2321	s
G04	cgp-5	Product should have an easy to access container to load garlic	4	4,6,12,15	1322	s
G05	cgp-4	Product should open Easily	2	2,4	1324	b
G06	cgp-27/ sgp-8	Product should have rounded edges	3	5,8,16	1422	b
G07	cgp-6	Product should have curved handles	2	5,15	2342	b
G08	cgp-21/ sgp-9	Product should be efficient (lots separated, none wasted)	3	3,5,12	1234	b
G09	sgp-5/ cgp-8	Product should have few moving parts	1	5	1342	r
G10	cgp-9	Product should have rubber nonslip grip on handles	1	15	1442	s
G11	cgp-10	Product should Not have thick handles	1	5	2242	r
G12	sgp-10/ cgp-11	Product should have big handles	2	15,16	2242	s

G13	sgp-24/ cgp-12	Products' parts should all align automatically	5	2,4,8,15,16	1134	b
G14	cgp-13/ sgp-13	Product should be compact	4	8,10,12,13	1332	s
G15	cgp-14	Product should fit small hands easily	3	5,7,15	2322	b
G16	sgp-1/ cgp-15	Product should not open so far as to need full extension of hands to use	4	7,8,10,11	2224	s
G17	cgp-16/ sgp-17	Product should be easy to understand	4	8,11,12,14	1321	s
G18	cgp-17	Product should be food sanitary	1	15	1145	s
G19	sgp-2/ cgp-18	Product should be easy to clean	11	2,3,5, 4,6,7,8,10,12, 14,15	1325	b
G20	cgp-19	Product should be dishwasherable	2	14,15	1145	s
G21	sgp-3/ cgp-20	Product should be usable with only one hand	3	8,15,16	2124	s
G22	sgp-26	Product should Not be too small	1	4	2142	s
G23	cgp-22	Product should be easy/comfy to grasp/grip	3	2,8,16	1322	b
G24	cgp-23	Product should help release the garlic	5	5,6,7,11,15	1344	b
G25	cgp-24/ sgp-22	Product should provide good leverage	2	2,6	1233	b
G26	sgp-4/ cgp-25	Product should be heavyduty	4	2,5,15,16	1332	b
G27	sgp-25	Product should be easy to manipulate	2	4,8	1324	s
G28	sgp-23	Product should be comfortable to hold	2	4,10	1321	s
G29	sgp-11	Product should Not have short handles	1	15	2242	s
G30	sgp-12	Product should have small handles	2	5,7	2242	b
G31	sgp-14	Product should be easy to apply pressure (angle)	2	6,15	1224	s
G32	sgp-15	Product should Not waste much garlic	1	2	1234	r
G33	cgp-26/ sgp-16	Product should be easy (require little effort to) squeeze closed	13	2,3,5,4,6,8,10 ,11,12,13,14, 15,16	1223	b
G34	sgp-18/ cgp-7	Product should Not be too complicated	3	11,15,16	1331	s
G35	sgp-19/ cgp-3	Product should have an adequate sized container	4	2,5,6,8	1132	b
G36	sgp-21	Product should signal that the crunch is complete	1	12	2124	s
G37	sgp-7	Product should have easy to grip handles	2	2,15	1322	b
G38	sgp-20	Product should be easy to insert garlic	1	12	1324	s

Can Opener List for Exp2 (Clist)

Can CTag	Can PTags	Combined Can Opener Need Statements	Combined Frequency	User Tracking	Full Codes	User Type
C01	rco-1	Product should not allow contents to spill	1	12	1114	s
C02	wco-14	Product should work quickly	2	8,16	1332	s
C03	rco-9	Product should be simple	3	5,12,15	1341	b
C04	rco-15	Product should look simple	1	12	1321	s
C05	rco-10	Product should be familiar	4	2,3,4,16	1321	b
C06	wco-15	Product should look good	2	7,15	1321	s
C07	wco-16	Product should look safe	2	5,12	1311	b
C08	wco-23	Product should not feel flimsy	2	3,5	1321	r
C09	wco-2/ rco-24	Product should be durable	2	5,16	1335	b
C10	rco-11	Product should be easy to clean	1	16	1325	s
C11	wco-12	Product should have instructions	1	3	1122	r
C12	wco-17	Product should be easy to understand	4	5,8,12,14	1321	b
C13	wco-24	Product should indicate when it is engaged/closed	2	8,14	2124	s
C14	wco-33/ rco-14	Product should assist with removal of the lid after cutting	4	2,5,7,15	2314	b
C15	wco-3	Product should provide enough clearance from the can	1	4	1142	s
C16	wco-4	Product should be easy to detach from can	1	7	1324	s
C17	wco-26/ rco-17	Product should be easy to attach to can	6	3,4,7,12, 14,16	1323	b
C18	wco-25/ rco-22	Product should need only a little grip force to press closed to puncture can	7	2,3,6,7,11, 13,15	1223	b
C19	wco-28	Product should take little or no pressure to stay closed	2	14,15	1224	s
C20	wco-11	Product should keep the blades touching	1	5	1444	r
C21	rco-4	Product should have a sharp blade	1	3	1442	r
C22	wco-9/ rco-5	Product should work(cut) being turned in both directions	2	14,15	2144	s
C23	wco-5	Product should have efficient twisting mechanism with no play	1	11	1432	s
C24	wco-34/ rco-8	Product should cut through the can consistently	3	2,14,15	1333	b
C25	wco-10	Product should provide good leverage	1	2	1233	r
C26	wco-18	Product should Not have unfamiliar extra features	2	6,12	1122	s
C27	wco-19	Product's extra features should be visible/obvious	2	3,7	1321	b
C28	rco-25	Product should not catch the teeth in the blade	1	5	1132	r
C29	rco-28	Product should not have any wiggle in it	1	5	1144	r
C30	rco-2	Product should Not be free swinging	1	13	2144	s

C31	wco-8	Product should Not squeak	1	5	1133	r
C32	rco-23	Product should Not rust	2	5,16	1135	b
C33	wco-31/ rco-21	Product should have mechanisms that turn smoothly/fluidly	4	3,5,7,8	1432	b
C34	rco-6	Product should be easy to maneuver	2	4,12	1324	s
C35	wco-6	Product should Not require a lot of actions	1	12	1324	s
C36	rco-12	Product should not require large wrist motions to operate	2	2,4	2222	b
C37	wco-7/ rco-13	Product should be usable with only one hand	2	15,16	2124	s
C38	wco-35/ rco-16	Product should Not need awkward arm/wrist angles to use	3	11,13,15	1222	s
C39	rco-18	Product should be easy to grasp/grip	3	14,15,16	1322	s
C40	wco-36	Product should Not need large movements	1	5	1324	r
C41	wco-1	Product should require only low dexterity to operate	1	8	1324	s
C42	wco-30/ rco-20	Product should be easy to turn	8	3,7,8,11,13 , 14,15,16	1324	b
C43	wco-29	Product should Not require user to push a button	3	4,7,8	2134	s
C44	wco-20	Product should have comfy rubber grips on handles	6	2,5,7,8,15, 16	1442	b
C45	rco-26	Product should have nonslip handles	1	5	1442	r
C46	wco-13/ rco-29	Product should have comfortably curved / ergonomic handles	4	7,8,15,16	1321	s
C47	rco-7	Product should not have thin/narrow handles	2	2,16	2242	b
C48	wco-21	Product should have big enough handles for two hands	3	11,15,16	2422	s
C49	wco-32	Product should have large turning handle	2	5,15	2242	b
C50	rco-3	Product should be easy to align the blade	1	16	1334	s
C51	rco-19	Product should not need to be held closed	3	12,14,15	1334	s
C52	wco-27	Product should stay locked in place on can	6	2,5,8,11,15 ,16	1134	b
C53	wco-22	Product should have curved handles	1	5	2442	r
C54	rco-27	Product should have large handles	1	14,15	2242	s

Appendix J: Table of All Three Product Pairs connected to Tags, Types, Codes

Pair Combined Tag	Ptag(s)	User Type	Code	Pair Combined Tag	Ptag(s)	User Type	Code	Pair Combined Tag	Ptag(s)	User Type	Code
J01	bjo-1	r	1332	C01	rco-1	s	1114	G02	cgp-1	b	1232
J02	bjo-2	r	1335	C02	wco-14	s	1332	G03	cgp-2	s	2321
J03	bjo-3	s	1321	C03	rco-9	b	1331	G04	cgp-5/ sgp-20	s	1322
J04	bjo-4	s	1321	C04	rco-15	s	1321	G05	cgp-4	b	1324
J05	bjo-5	s	1342	C05	rco-10	b	1321	G06	cgp-27/ sgp-8	b	1412
J06	bjo-6	s	1321	C06	wco-15	s	1321	G07	cgp-6	b	2442
J07	bjo-7	s	2132	C07	wco-16	b	1311	G08	cgp-21/ sgp-9	b	1234
J08	bjo-8	s	1324	C08	wco-23	r	1321	G09	sgp-5/ cgp-8	r	1342
J09	bjo-10	s	1324	C09	wco-2/ rco-24	b	1332	G10	cgp-9	s	1442
J10	bjo-11	b	1332	C10	rco-11	s	1325	G11	cgp-10	r	2242
J11	bjo-13/ tjo-25	b	2242	C11	wco-12	r	1122	G12	sgp-10/ cgp-11	s	2242
J12	tjo-24	r	2322	C12	wco-17	b	1321	G13	sgp-24/ cgp-12	b	1134
J13	bjo-15/ tjo-21	s	1322	C13	wco-24	s	2124	G14	cgp-13/ sgp-13	s	1332
J14	bjo-16	b	1442	C14	wco-33/ rco-14	b	2314	G15	cgp-14	b	2322
J15	bjo-17/ tjo-28	b	1321	C15	wco-3	s	1142	G16	sgp-1/ cgp-15	s	2224
J16	bjo-18	s	1321	C16	wco-4	s	1324	G17	cgp-16/ sgp-17	s	1321
J17	bjo-19	b	1321	C17	wco-26/ rco-17	b	1323	G18	cgp-17	s	1145
J18	bjo-20	r	1321	C18	wco-25/rco-22	b	1223	G19	sgp-2/ cgp-18	b	1325
J19	tjo-11	s	1133	C19	wco-28	s	1224	G20	cgp-19	s	1145
J20	bjo-9/ tjo-1	b	1321	C20	wco-11	r	1444	G21	sgp-3/ cgp-20	s	2124
J21	tjo-2	s	1142	C21	rco-4	r	1442	G22	sgp-26	s	2142
J22	bjo-25/ tjo-3	b	2444	C22	wco-9/ rco-5	s	2144	G23	cgp-22	b	1322
J23	tjo-4	s	1244	C23	wco-5	s	1432	G24	cgp-23	b	1344
J24	tjo-5	r	2442	C24	wco-34/ rco-8	b	1333	G25	cgp-24/ sgp-22	b	1233
J25	tjo-6	s	2124	C25	wco-10	r	1233	G26	sgp-4/ cgp-25	b	1332
J26	tjo-7	s	2122	C26	wco-18	s	1122	G27	sgp-25	s	1324
J27	tjo-8	s	1324	C27	wco-19	b	1321	G28	sgp-23	s	1321
J28	bjo-12/ tjo-9	b	1233	C28	rco-25	r	1132	G29	sgp-11	s	2242
J29	bjo-22/ tjo-10	b	1134	C29	rco-28	r	1144	G30	sgp-12	b	2242
J30	tjo-12	s	1444	C30	rco-2	s	2144	G31	sgp-14	s	1224

J31	bjo-23/ tjo-13	b	1234	C31	wco-8	r	1131	G32	sgp-15	r	1234
J32	tjo-14	s	1334	C32	rco-23	b	1135	G33	cgp-26/ sgp-16	b	1223
J33	tjo-15	b	2344	C33	wco-31/ rco-21	b	1432	G34	sgp-18/ cgp-7	s	1331
J34	tjo-16	s	1324	C34	rco-6	s	1324	G35	sgp-19/ cgp-3	b	1132
J35	tjo-17	b	1312	C35	wco-6	s	1324	G36	sgp-21	s	2124
J36	bjo-24/ tjo-18	s	1121	C36	rco-12	b	2222	G37	sgp-7	b	1322
J37	bjo-26/ tjo-19	b	1224	C37	wco-7/ rco-13	s	2124	G38	sgp-20	s	1324
J38	tjo-20	s	1222	C38	wco-35/ rco-16	s	1222				
J39	tjo-22	s	1412	C39	rco-18	s	1322				
J40	tjo-23	s	2422	C40	wco-36	r	1324				
J41	tjo-26	s	1321	C41	wco-1	s	1324				
J42	tjo-27	r	1342	C42	wco-30/ rco-20	b	1324				
J43	tjo-29	b	1422	C43	wco-29	s	2134				
J44	bjo-27	s	2122	C44	wco-20	b	1442				
J45	bjo-28	r	2134	C45	rco-26	r	1442				
J46	bjo-29	s	2124	C46	wco-13/ rco-29	s	1321				
J47	bjo-14	r	2222	C47	rco-7	b	2242				
J48	bjo-21	r	1134	C48	wco-21	s	2422				
				C49	wco-32	b	2242				
				C50	rco-3	s	1334				
				C51	rco-19	s	1334				
				C52	wco-27	b	1134				
				C53	wco-22	r	2442				
				C54	rco-27	s	2242				

Appendix K: CN Lists with User Type and Ontology Codes

TJO CN List with Codes

Tags	Statement	User Type	Code
tjo-01	Product should have a simple design	pmr	1321
tjo-02	Product should have a clear center of rotation	ssu	1142
tjo-03	Product should hold onto the jar as well	ssu	2444
tjo-04	Product should Not allow contents to spill upon opening	ssu	1244
tjo-05	Product should be made of stainless steel	pmr	2442
tjo-06	Product should tell user when it is attached	ssu	2124
tjo-07	Product should Not require a turning motion	ssu	2122
tjo-08	Product should give the user good control	ssu	1324
tjo-09	Product should provide good leverage	pmr	1233
tjo-10	Product should Not deform the lid	ssu	1134
tjo-11	Product should grip the lid easily and not slip	ssu	1133
tjo-12	Product should lock onto the lid	ssu	1444
tjo-13	Product should adjust to all lid sizes	both	1234
tjo-14	Product should maintain control of the lid	ssu	1334
tjo-15	Product should also assist with putting the lid back on	both	2344
tjo-16	Product should be easy to detach from lid	ssu	1324
tjo-17	Product should have a low chance of mechanical failure (durable/heavyduty)	both	1312
tjo-18	Product should indicate direction of turn	ssu	1121
tjo-19	Product should make it so that very little effort will remove the lid	both	1223
tjo-20	Product should have a good turning angle	ssu	1222
tjo-21	Product should Not be hard to grip	ssu	1322
tjo-22	Product should Not have sharp edges on turning knobs	ssu	1412
tjo-23	Product should have a place to hold on both sides	ssu	2422
tjo-24	Product should work with small hands	pmr	*2322*
tjo-25	Product should have large handles	ssu	2242
tjo-26	Product should Not be clunky	ssu	1321
tjo-27	Product should Not have too many moving parts	pmr	1342
tjo-28	Product should be easy to understand/intuitive/obvious	ssu	1321
tjo-29	Product should have knobs that are easy to turn	both	1422

BJO CN List with Codes

Tags	Statement	User Type	**Code**
bjo-01	Product should be durable	pmr	1332
bjo-02	Product should be easy to clean	pmr	1325
bjo-03	Product should Not be too unfamiliar	ssu	1321
bjo-04	Product should Not look scary	ssu	1321
bjo-05	Product should Not have parts that can be lost	ssu	1342
bjo-06	Product operation should be visible	ssu	1321
bjo-07	Product operation should be one step	ssu	2132
bjo-08	Product should be easy/simple to attach	ssu	1324
bjo-09	Product should have a simple design	both	1321
bjo-10	Product should Not need precision/complex movements	ssu	1324
bjo-11	Product should work quickly	both	1332
bjo-12	Product should provide good leverage	ssu	1233
bjo-13	Product should have big handles	ssu	2242
bjo-14	Product should have small enough handles to hold	pmr	2222
bjo-15	Product should be easy to grip/grasp	ssu	1322
bjo-16	Product should have rubber nonslip grip on handle	both	1442
bjo-17	Product should be easy to understand	both	1321
bjo-18	Product should have clear directions	ssu	1321
bjo-19	Product should have instructions that are easy to read	both	1321
bjo-20	Product should grip lid easily	pmr	1233
bjo-21	Product should Not slide on lid	pmr	1134
bjo-22	Product should Not strip the lid	both	1134
bjo-23	Product should remove all sizes of lids	pmr	1243
bjo-24	Product should indicate direction of turn	ssu	1121
bjo-25	Product should hold onto the jar as well	both	2444
bjo-26	Product should need only low strength to use	ssu	1223
bjo-27	Product should Not need constant application of force	ssu	2122
bjo-28	Product should only work in one direction (the intended direction)	pmr	2134
bjo-29	Product should work towards user instead of away	ssu	2124

CGP CN List with Codes

Tags	Statement	User Type	**Code**
cgp-01	Product should be lightweight	both	1232
cgp-02	Product should look cool	ssu	2321
cgp-03	Product should have an adequate sized container	ssu	1132
cgp-04	Product should open Easily	both	1324
cgp-05	Product should have an easy to access container to load garlic	ssu	1322
cgp-06	Product should have curved handles	ssu	2442
cgp-07	Product should Not be too complicated	ssu	1331
cgp-08	Product should have few moving parts	pmr	1342
cgp-09	Product should have rubber nonslip grip on handles	ssu	1442
cgp-10	Product should Not have thick handles	pmr	2242
cgp-11	Product should have big handles	ssu	2242
cgp-12	Products' parts should all align automatically	ssu	1144
cgp-13	Product should be compact	ssu	1332
cgp-14	Product should fit small hands easily	both	2322
cgp-15	Product should Not open too far / Not need full extension of hands to use	ssu	2124
cgp-16	Product should be easy to understand	ssu	1321
cgp-17	Product should be food sanitary	ssu	1145
cgp-18	Product should be easy to clean	both	1325
cgp-19	Product should be dishwasherable	ssu	1145
cgp-20	Product should be usable with only one hand	ssu	2124
cgp-21	Product should be efficient (lots separated, none wasted)	both	1234
cgp-22	Product should be easy/comfy to grasp/grip	both	1322
cgp-23	Product should help release the garlic	both	1344
cgp-24	Product should provide good leverage	pmr	1233
cgp-25	Product should be heavyduty	pmr	1332
cgp-26	Product should be easy (require little effort to) squeeze closed	both	1223
cgp-27	Product should have rounded edges	ssu	1412

SGP CN List with Codes

Tags	Statement	User Type	**Code**
sgp-01	Product should Not have to open very far to access	ssu	1222
sgp-02	Product should be easy to clean	both	1325
sgp-03	Product should Not need two hands to use	ssu	2124
sgp-04	Product should be durable	both	1332
sgp-05	Product should Not have a lot of moving parts	pmr	1342
sgp-07	Product should have easy to grip handles	both	1322
sgp-08	Product should have tapered edges so it can't catch on the hand	both	1412
sgp-09	Product should get a lot of garlic per effort (efficient)	pmr	1234
sgp-10	Product should Not have small handles	ssu	2242
sgp-11	Product should Not have short handles	ssu	2242
sgp-12	Product should have small handles	both	2242
sgp-13	Product should be compact	ssu	1332
sgp-14	Product should be easy to apply pressure (angle)	ssu	1224
sgp-15	Product should Not waste much garlic	pmr	1234
sgp-16	Product should require little pressure to squeeze closed	both	1223
sgp-17	Product should be intuitive	ssu	1321
sgp-18	Product should be simple	ssu	1331
sgp-19	Product should have a chamber big enough for all garlic	both	1132
sgp-20	Product should be easy to insert garlic	ssu	1324
sgp-21	Product should signal that the crunch is complete	ssu	2124
sgp-22	Product should provide good leverage	ssu	1233
sgp-23	Product should be comfortable to hold	ssu	1321
sgp-24	Product's parts should not misalign	both	1134
sgp-25	Product should be easy to manipulate	ssu	1324
sgp-26	Product should Not be too small	ssu	2142

WCO CN List with Codes

Tags	Statement	User Type	**Code**
wco-01	Product should require only low dexterity to operate	ssu	1324
wco-02	Product should be durable	ssu	1332
wco-03	Product should provide enough clearance from the can	ssu	1142
wco-04	Product should be easy to detach from can	ssu	1324
wco-05	Product should have efficient twisting mechanism with no play	ssu	1432
wco-06	Product should Not require a lot of actions	ssu	1324
wco-07	Product should work with only one hand	ssu	2124
wco-08	Product should Not squeak	pmr	1131
wco-09	Product should turn and cut in both directions	ssu	2144
wco-10	Product should provide good leverage	pmr	1233
wco-11	Product should keep the blades touching	pmr	1444
wco-12	Product should have instructions	pmr	1122
wco-13	Product should have an ergonomic shape	ssu	1321
wco-14	Product should work quickly	ssu	1332
wco-15	Product should look good	ssu	1321
wco-16	Product should look safe	both	1311
wco-17	Product should be easy to understand	both	1321
wco-18	Product should Not have unfamiliar extra features	ssu	1122
wco-19	Product's extra features should be visible/obvious	both	1321
wco-20	Product should have comfy rubber grips on handles	both	1442
wco-21	Product should have big enough handles for two hands	ssu	2422
wco-22	Product should have curved handles	pmr	2442
wco-23	Product should not feel flimsy	pmr	1321
wco-24	Product should indicate when it is engaged/closed	ssu	2124
wco-25	Product should take little pressure to press closed	both	1224
wco-26	Product should be easy to attach to can	both	1323
wco-27	Product should stay locked in place on can	both	1134
wco-28	Product should take little or no pressure to stay closed	ssu	1224
wco-29	Product should Not require user to push a button	ssu	2134
wco-30	Product should be easy to turn	both	1324
wco-31	Product should have smooth turning mechanism	both	1432
wco-32	Product should have large turning handle	both	2242
wco-33	Product should help remove the lid after cutting	pmr	2314
wco-34	Product should cut through the can well	both	1333
wco-35	Product should Not need awkward angles to use	ssu	1322
wco-36	Product should Not need large movements	pmr	1324

RCO CN List with Codes

Tags	Statement	User Type	**Code**
rco-01	Product should not allow contents to spill	ssu	1114
rco-02	Product should Not be free swinging	ssu	2144
rco-03	Product should be easy to align the blade	ssu	1334
rco-04	Product should have a sharp blade	pmr	1442
rco-05	Product should work being turned in both directions	ssu	1144
rco-06	Product should be easy to maneuver	ssu	1324
rco-07	Product should not have thin/narrow handles	both	2242
rco-08	Product should cut consistently	ssu	1133
rco-09	Product should be simple	both	1331
rco-10	Product should be familiar	both	1321
rco-11	Product should be easy to clean	ssu	1325
rco-12	Product should not require large wrist motions to operate	both	2222
rco-13	Product should be usable with only one hand	ssu	2124
rco-14	Product should assist with removal of the lid after cutting	ssu	2314
rco-15	Product should look simple	ssu	1321
rco-16	Product should work at comfortable arm/wrist angles	ssu	1222
rco-17	Product should be easy to attach to can	ssu	1323
rco-18	Product should be easy to grasp/grip	ssu	1322
rco-19	Product should not need to be held closed	su	1334
rco-20	Product should be easy to turn	ssu	1324
rco-21	Product should have mechanisms that turn smoothly/fluidly	both	1432
rco-22	Product should not need a lot of grip force to puncture can	both	1223
rco-23	Product should not rust	both	1135
rco-24	Product should not be flimsy	pmr	1332
rco-25	Product should not catch the teeth in the blade	pmr	1132
rco-26	Product should have nonslip handles	pmr	1442
rco-27	Product should have large handles	ssu	2242
rco-28	Product should not have any wiggle in it	pmr	1144
rco-29	Product should have comfortably curved handles	ssu	1321

Appendix L: ICF Connection Information

Exp2 with Ontology and ICF Codes

ICF Code	ICF descriptor	Ptag	CN Statement	Full Code
		bjo-01	Product should be durable	1332
d6401	Cleaning cooking area and utensils	bjo-02	Product should be easy to clean	1325
b156/b199	Perceptual functions?/ mental functions unspecified	bjo-03	Product should Not be too unfamiliar	1321
b156/b199	Perceptual functions?/ mental functions unspecified	bjo-04	Product should Not look scary	1321
		bjo-05	Product should Not have parts that can be lost	1342
b210/d110	seeing functions/watching?	bjo-06	Product operation should be visible	1321
		bjo-07	Product operation should be one step	2132
d440	fine hand use	bjo-08	Product should be easy/simple to attach	1324
b164/b1640	higher level cognitive functions/abstraction	bjo-09	Product should have a simple design	1321
b7601	control of complex movements	bjo-10	Product should Not need precision/complex movements	1324
		bjo-11	Product should work quickly	1332
		bjo-12	Product should provide good leverage	1233
		bjo-13	Product should have big handles	2242
s7302	structure of the hand	bjo-14	Product should have small enough handles to hold	2222
d4401	grasping	bjo-15	Product should be easy to grip/grasp	1322
		bjo-16	Product should have rubber nonslip grip on handle	1442
b164	higher level cognitive functions?	bjo-17	Product should be easy to understand	1321
b164/b1640/ d166/b210-279	higher level cognitive functions/abstraction/reading/sensory functions	bjo-18	Product should have clear directions	1321
d166/b210	Reading/seeing functions	bjo-19	Product should have instructions that are easy to read	1321
		bjo-20	Product should grip lid easily	1233
		bjo-21	Product should Not slide on lid	1134
		bjo-22	Product should Not strip the lid	1134
		bjo-23	Product should remove all sizes of lids	1243
d166/b210?	Reading/seeing functions	bjo-24	Product should indicate direction of turn	1121
		bjo-25	Product should hold onto the jar as well	2444
b730	muscle functions	bjo-26	Product should need only low strength to use	1223
b740	muscle endurance functions	bjo-27	Product should Not need constant application of force	2122
		bjo-28	Product should only work in one direction (the intended direction)	2134

d4450	pulling	bjo-29	Product should work towards user instead of away	2124
b7401	endurance of muscle groups	cgp-01	Product should be lightweight	1232
b198/d6401/ b156/b199		cgp-02	Product should look cool	2321
		cgp-03	Product should have an adequate sized container	1132
d4402/d445(0/1)?	manipulating/pushing/pulling	cgp-04	Product should open Easily	1324
d4402	manipulating	cgp-05	Product should have an easy to access container to load garlic	1322
		cgp-06	Product should have curved handles	2442
		cgp-07	Product should Not be too complicated	1331
		cgp-08	Product should have few moving parts	1342
		cgp-09	Product should have rubber nonslip grip on handles	1442
		cgp-10	Product should Not have thick handles	2242
		cgp-11	Product should have big handles	2242
		cgp-12	Products' parts should all align automatically	1144
		cgp-13	Product should be compact	1332
s7302	structure of the hand	cgp-14	Product should fit small hands easily	2322
s7302	structure of the hand	cgp-15	Product should Not open too far / Not need full extension of hands to use	2124
b164/b199	higher level cognitive functions?/mental functions unspecified?	cgp-16	Product should be easy to understand	1321
		cgp-17	Product should be food sanitary	1145
d6401	Cleaning cooking area and utensils	cgp-18	Product should be easy to clean	1325
		cgp-19	Product should be dishwasherable	1145
s730?	?structure of the hand?	cgp-20	Product should be usable with only one hand	2124
		cgp-21	Product should be efficient (lots separated, none wasted)	1234
d4401	Grasping	cgp-22	Product should be easy/comfy to grasp/grip	1322
		cgp-23	Product should help release the garlic	1344
		cgp-24	Product should provide good leverage	1233
		cgp-25	Product should be heavyduty	1332
b730/b7300	muscle power functions/power of isolated muscle groups	cgp-26	Product should be easy (require little effort to) squeeze closed	1223
		cgp-27	Product should have rounded edges	1412
		rco-01	Product should not allow contents to spill	1114
		rco-02	Product should Not be free swinging	2144
		rco-03	Product should be easy to align the blade	1334
		rco-04	Product should have a sharp blade	1442

		rco-05	Product should work being turned in both directions	1144
d4402	manipulating	rco-06	Product should be easy to maneuver	1324
		rco-07	Product should not have thin/narrow handles	2242
		rco-08	Product should cut consistently	1133
		rco-09	Product should be simple	1331
b156/b199	Perceptual functions?/ mental functions unspecified	rco-10	Product should be familiar	1321
d6401	Cleaning cooking area and utensils	rco-11	Product should be easy to clean	1325
b710/s73011	mobility of joint functions/wrist joint	rco-12	Product should not require large wrist motions to operate	2222
		rco-13	Product should be usable with only one hand	2124
		rco-14	Product should assist with removal of the lid after cutting	2314
b156/b199	Perceptual functions?/ mental functions unspecified	rco-15	Product should look simple	1321
b710/s73011	mobility of joint functions/wrist joint	rco-16	Product should work at comfortable arm/wrist angles	1222
d4301/d4400 /d4402?	carrying in the hands/picking up/manipulating	rco-17	Product should be easy to attach to can	1323
d4401	grasping	rco-18	Product should be easy to grasp/grip	1322
b7401	endurance of muscle groups	rco-19	Product should not need to be held closed	1334
d4453	turning or twisting the hands or arms	rco-20	Product should be easy to turn	1324
		rco-21	Product should have mechanisms that turn smoothly/fluidly	1432
b7301/d445(0/1)	power of muscles of one limb/Pushing?/Pulling?	rco-22	Product should not need a lot of grip force to puncture can	1223
		rco-23	Product should not rust	1135
		rco-24	Product should not be flimsy	1332
		rco-25	Product should not catch the teeth in the blade	1132
		rco-26	Product should have nonslip handles	1442
		rco-27	Product should have large handles	2242
		rco-28	Product should not have any wiggle in it	1144
s7302	Structure of the hand	rco-29	Product should have comfortably curved handles	1321
s7302	Structure of the hand	sgp-01	Product should Not have to open very far to access	1222
d6401	Cleaning cooking area and utensiles	sgp-02	Product should be easy to clean	1325
s7308	Structure of upper extremity, other specified	sgp-03	Product should Not need two hands to use	2124
		sgp-04	Product should be durable	1332
		sgp-05	Product should Not have a lot of moving parts	1342
s7302	Structure of the hand	*sgp-06*	*Product should be usable with either hand*	2124
d4401	Grasping	sgp-07	Product should have easy to grip handles	1322

s7302	Structure of the hand	sgp-08	Product should have tapered edges so it can't catch on the hand	1412
		sgp-09	Product should get a lot of garlic per effort (efficient)	1234
		sgp-10	Product should Not have small handles	2242
		sgp-11	Product should Not have short handles	2242
		sgp-12	Product should have small handles	2242
		sgp-13	Product should be compact	1332
d445(0/1)/ b710	Pushing/Pulling/mobility of joint functions	sgp-14	Product should be easy to apply pressure (angle)	1224
		sgp-15	Product should Not waste much garlic	1234
b730/b7300	muscle power functions/power of isolated muscle groups	sgp-16	Product should require little pressure to squeeze closed	1223
b164	higher level cognitive functions	sgp-17	Product should be intuitive	1321
		sgp-18	Product should be simple	1331
		sgp-19	Product should have a chamber big enough for all garlic	1132
d440/d4402	fine hand use/manipulating	sgp-20	Product should be easy to insert garlic	1324
b210-b279	sensory functions	sgp-21	Product should signal that the crunch is complete	2124
		sgp-22	Product should provide good leverage	1233
d430	lifting and carrying objects	sgp-23	Product should be comfortable to hold	1321
		sgp-24	Product's parts should not misalign	1134
d4402	manipulating	sgp-25	Product should be easy to manipulate	1324
		sgp-26	Product should Not be too small	2142
b164/b1640	higher level cognitive functions/abstraction	tjo-01	Product should have a simple design	1321
		tjo-02	Product should have a clear center of rotation	1142
		tjo-03	Product should hold onto the jar as well	2444
		tjo-04	Product should Not allow contents to spill upon opening	1244
		tjo-05	Product should be made of stainless steel	2442
b210-b279	sensory functions	tjo-06	Product should tell user when it is attached	2124
d4453/	turning or twisting the hands or arms/ wrist mobility?	tjo-07	Product should Not require a turning motion	2122
b760/d4402	control of voluntary movements/manipulating	tjo-08	Product should give the user good control	1324
		tjo-09	Product should provide good leverage	1233
		tjo-10	Product should Not deform the lid	1134
		tjo-11	Product should grip the lid easily and not slip	1133
		tjo-12	Product should lock onto the lid	1444
		tjo-13	Product should adjust to all lid sizes	1234
		tjo-14	Product should maintain control of the lid	1334
		tjo-15	Product should also assist with putting the lid back on	2344

d4402/d4305	manipulating/putting down objects	tjo-16	Product should be easy to detach from lid	1324
		tjo-17	Product should have a low chance of mechanical failure (durable/heavyduty)	1312
d166/b210?	Reading/seeing functions	tjo-18	Product should indicate direction of turn	1121
b7301	muscle power of one limb	tjo-19	Product should make it so that very little effort will remove the lid	1223
d4453/s730	turning or twisting the hands or arms/structure of the upper extremity	tjo-20	Product should have a good turning angle	1222
d4401	Grasping	tjo-21	Product should Not be hard to grip	1322
d570	Looking after one's health??	tjo-22	Product should Not have sharp edges on turning knobs	1412
s7302	structure of the hand	tjo-23	Product should have a place to hold on both sides	2422
s7302	structure of the hand	tjo-24	Product should work with small hands	*2322*
		tjo-25	Product should have large handles	2242
b210/b1649	seeing functions/higher level cognitive functions unspecified	tjo-26	Product should Not be clunky	1321
		tjo-27	Product should Not have too many moving parts	1342
b164	higher level cognitive functions?	tjo-28	Product should be easy to understand/intuitive/obvious	1321
d4453	turning or twisting the hands or arms	tjo-29	Product should have knobs that are easy to turn	1422
d4402	manipulating	wco-01	Product should require only low dexterity to operate	1324
		wco-02	Product should be durable	1332
s7301	structure of the forearm	wco-03	Product should provide enough clearance from the can	1142
d4402/d4403/d445(0/1)	manipulating/releasing/pushpull	wco-04	Product should be easy to detach from can	1324
		wco-05	Product should have efficient twisting mechanism with no play	1432
d7601/2/b176	control/coordination of complex voluntary movements / mental functions of sequencing complex movements	wco-06	Product should Not require a lot of actions	1324
x?	?	wco-07	Product should work with only one hand	2124
		wco-08	Product should Not squeak	1131
		wco-09	Product should turn and cut in both directions	2144
		wco-10	Product should provide good leverage	1233
		wco-11	Product should keep the blades touching	1444
d166	Reading?	wco-12	Product should have instructions	1122
s7302	structure of the hand	wco-13	Product should have an ergonomic shape	1321
		wco-14	Product should work quickly	1332
b210/b1649	seeing functions/higher level cognitive functions unspecified	wco-15	Product should look good	1321

b210/b1649	seeing functions/higher level cognitive functions unspecified	wco-16	Product should look safe	1311
b164	higher level cognitive functions?	wco-17	Product should be easy to understand	1321
b156/b199	Perceptual functions?/ mental functions unspecified	wco-18	Product should Not have unfamiliar extra features	1122
b210/b156	seeing functions/perceptual functions	wco-19	Product's extra features should be visible/obvious	1321
		wco-20	Product should have comfy rubber grips on handles	1442
s7302	structure of the hand	wco-21	Product should have big enough handles for two hands	2422
		wco-22	Product should have curved handles	2442
b156/b260/ b265/b1649	Perceptual functions ETC	wco-23	Product should not feel flimsy	1321
b156	Perceptual functions	wco-24	Product should indicate when it is engaged/closed	2124
b730/b7300	muscle power functions/power of isolated muscle groups	wco-25	Product should take little pressure to press closed	1224
d4402/d440	manipulating/fine hand use	wco-26	Product should be easy to attach to can	1323
		wco-27	Product should stay locked in place on can	1134
b740	muscle endurance functions	wco-28	Product should take little or no pressure to stay closed	1224
		wco-29	Product should Not require user to push a button	2134
d4453	turning or twisting the hands or arms	wco-30	Product should be easy to turn	1324
		wco-31	Product should have smooth turning mechanism	1432
		wco-32	Product should have large turning handle	2242
		wco-33	Product should help remove the lid after cutting	2314
		wco-34	Product should cut through the can well	1333
b710	mobility of joint functions	wco-35	Product should Not need awkward angles to use	1322
b715/b7101?	stability of joint functions/ mobility of several joints	wco-36	Product should Not need large movements	1324

Exp1 CNs with Ontology and ICF Codes

Tags	CN Statement	Ontology Codes	ICF Codes	ICF Description
J-1-1	look simple	1321	b156	Perceptual functions/
J-1-2	be usable by either hand	2124	s7302	structure of the hand
J-1-3	be easy to assemble	1324	d440	fine hand use
J-1-4	be easy to understand	1321	b164	higher level cognitive functions?
J-1-5	have a rubber coating on handle	1442		
J-1-6	require only one hand to work	2122	s730/d449	structure of the upper extremity/Carrying, moving and handling objects, other specified and unspecified
J-1-7	provide a way to grip jar as well	2134		
J-1-8	require only small forces to use	1224	b730	muscle power functions
J-1-9	have a feature to assist with breaking the seal	1132		
J-1-10	provide stability	1314		
J-1-11	not have exposed sharp edges	1111		
J-1-12	have an easy to turn knob	1222	d4453	turning or twisting the hands or arms
J-1-13	unscrew without knocking over the jar	1114		
J-1-14	require low torque to twist off lid	1223	b730	muscle power functions
J-1-15	have clear directions/indicate direction of turn	1121	d166/b210	Reading/seeing functions
J-1-16	look safe	1311		
J-1-17	work on multiple jar sizes	1334		
J-1-18	have a nice grip	1321	d4401	grasping
J-1-19	operate with as few steps as possible	1222	b7601/b176	control of complex voluntary motions/mental functions of sequencing complex movements
J-1-20	have large gripping surface	2222	d4401	grasping
J-1-21	grip lid securely	1333		
J-1-22	be easy to attach to lid	1324	d4402	manipulating
Tags	**CN Statement**	**Ontology Codes**	**ICF Codes**	**ICF Description**
C-1-1	be durable	1335		
C-1-2	be usable with either hand	2124	s7302	structure of the hand
C-1-3	have rubber coating	1442		
C-1-4	allow sufficient grip with one hand	2222	s7302	structure of the hand
C-1-5	not require hand to stay closed	1124	??	??
C-1-6	have blunt/padded edges so as not to dig into user	1412		
C-1-7	have large handles	2222	s7302	structure of the hand

C-1-8	be efficient	1334		
C-1-9	have longer knob for more leverage	1432		
C-1-10	position user's hands comfortably	1322	s7302/b7102	structure of the hand/Mobility of joints generalized
C-1-11	operation should be simple	1324	b7601/b176	control of complex voluntary motions/mental functions of sequencing complex movements
C-1-12	operate with a push action instead of a squeeze	2434		
C-1-13	shape should not be straight	2342		
C-1-14	function with pressure from multiple angles	1334		
C-1-15	be easy to turn	1223	d4453	turning or twisting the hands or arms
C-1-16	turn smoothly	1233		
C-1-17	provide the right leverage	1234		
C-1-18	remain in cutting position	1134		
C-1-19	have a nice gripping surface	1321	d4401	grasping
C-1-20	require only low force to hold closed	1224	b730/b7401	muscle power functions/Endurance of muscle groups
C-1-21	not have a separate release	2132		
C-1-22	be familiar	1321	b156/d199	perceptual functions/mental functions
C-1-23	remain in position easily	1334		
C-1-24	be lightweight	1232		
C-1-25	require only minimal squeeze force to puncture can	1223	b730	muscle power functions
C-1-26	have a non-slip grip surface	1122		
C-1-27	remain sharp as long as possible	1232		
C-1-28	be easy to understand	1321	b164	higher level cognitive functions
C-1-29	put user at the right height	1224	b7102?	Mobility of joints generalized?
Tags	**CN Statement**	**Ontology Codes**	**ICF Codes**	**ICF Description**
G-1-1	have an obvious holder	1321	b156/d199	perceptual functions/mental functions
G-1-2	require only modest hand spans	1224	s7302	structure of the hand
G-1-3	not be sloped	2142		
G-1-4	provide stability	1314		
G-1-5	have a non-slip grip surface	1412		
G-1-6	parts should align automatically without manual adjustment	1444		
G-1-7	be efficient	1334		
G-1-8	accommodate multiple sizes of garlic	1332		
G-1-9	have curved handles	2342		
G-1-10	prevent user fingers from being caught or squished	1114		

G-1-11	be rounded so as not to cut into the hand	1412		
G-1-12	have obvious operation	1321	b156/d199	perceptual functions/mental functions
G-1-13	have simple garlic insertion method	1324	b156/d199/ d440	perceptual functions/mental functions/fine hand use
G-1-14	require only low grip force / pressure to close	1223	b730	muscle power functions
G-1-15	have cushy grip surfaces	1422	b156	perceptual functions
G-1-16	be lightweight	1232		
G-1-17	have a thin grip	2242		
G-1-18	be large enough to accommodate both hands	2422	s7302	structure of the hand
G-1-19	provide a good grip	1322	d4401	grasping
G-1-20	have a familiar shape	1321	b156/d199	perceptual functions/mental functions
G-1-21	be easy to clean	1325	d6401	Cleaning cooking area and utensils
G-1-22	allow application of uniform pressure	1234		
G-1-23	only involve one hand	2122		
G-1-24	be conducive to apply pressure	1324	b7101/d498/ s730	mobility and structure of the upper extremity
G-1-25	have large handles	2222	s7302	structure of the hand
G-1-26	be easy to manipulate / maneuver	1324	d4402	manipulating
G-1-27	employ pressing rather than squeezing mechanism	2434		

Comparing ICF Results within Participant

Participant 2					
ICF Codes from OT	ICF Codes from Description	ICF Codes from CNs	ICF Code Descriptions from CNs	Tag	group
b7102	b710!	b156/b199	Perceptual functions/ mental functions unspecified	rco-10	both
b7301	b1300	b164	higher level cognitive functions?	bjo-17	both
b7351	b1400	b710/s73011	mobility of joint functions/wrist joint	rco-12	both
d4402	b160 or b164	b730/b7300	muscle power functions/power of isolated muscle groups	cgp-26	both
s7201	b28018/b28018/b28016	b730/b7300	muscle power functions/power of isolated muscle groups	wco-25	both
s7302	d2100	b7301/d445(0/1)	power of muscles of one limb/Pushing?/Pulling?	rco-22	both
	d4452	b7401	endurance of muscle groups	cgp-01	both
	s7104	d166/b210	Reading/seeing functions	bjo-19	both
	s7209	d4401	Grasping	cgp-22	both
		d4401	Grasping	sgp-07	both
		d4402/d445(0/1)?	manipulating/pushing/pulling	cgp-04	both
		d6401	Cleaning cooking area and utensils	cgp-18	both

Participant 3					
ICF Codes from OT	ICF Codes from Description	ICF Codes from CNs	ICF Code Descriptions from CNs	Tag	group
b710-3	NA	b156/b199	Perceptual functions?/ mental functions unspecified	rco-10	both
b730-3		b156/b260/b265/b1649	Perceptual functions ETC	wco-23	pmr
b735-3		b210/b156	seeing functions/perceptual functions	wco-19	both
d430-2		b730/b7300	muscle power functions/power of isolated muscle groups	sgp-16	both
d440-4		b7301/d445(0/1)	power of muscles of one limb/Pushing?/Pulling?	rco-22	both
s720-1		d166	Reading??	wco-12	pmr
s730-3		d4402/d440	manipulating/fine hand use	wco-26	both
		d4453	turning or twisting the hands or arms	wco-30	both
		d6401	Cleaning cooking area and utensiles	cgp-18	both
		s7302	structure of the hand	tjo-24	pmr

Participant 5					
ICF Codes from OT	ICF Codes from Description	ICF Codes and descriptions from CNs		Tag	group
b710-3	b710	b156/b260/b265/b1649	Perceptual functions ETC	wco-23	pmr
b730-3	d4401	b164	higher level cognitive functions	wco-17	both
b735-3	s7300	b164	higher level cognitive functions	bjo-17	both
d430-3	s7302	b164/b1640	higher level cognitive functions/abstraction	bjo-09	both
d440-2	s73013	b164/b1640	higher level cognitive functions/abstraction	tjo-01	pmr
s720-2	s73003	b210/b1649	seeing functions/higher level cognitive functions unspecified	wco-16	both
s730-3	s73011	b715/b7101?	stability of joint functions/mobility of several joints	wco-36	pmr
		b730/b7300	muscle power functions/power of isolated muscle groups	cgp-26	both
		b7301	muscle power of one limb	tjo-19	both
		d4453	turning or twisting the hands or arms	tjo-29	both
		d6401	Cleaning cooking area and utensils	bjo-02	pmr
		d6401	Cleaning cooking area and utensils	sgp-02	both
		s7302	structure of the hand	bjo-14	pmr
		s7302	structure of the hand	cgp-14	both
		s7302	Structure of the hand	sgp-08	both

Participant 9					
ICF Codes from OT	ICF Codes from Description	ICF Codes and Descriptions from CNs			
NA	b710	d166/b210?	Reading/seeing functions	tjo-18	ssu
	s7201	d6401	Cleaning cooking area and utensils	cgp-18	both
	s7202	s730?	?structure of the hand?	cgp-20	ssu
	s7209	s7302	Structure of the hand	**sgp-06**	9 only

Appendix M: Masters Work (Exp1) CN Info

Can Opener CN Info for statements made by FSU Participants

FSU Tags	Weight	Frequency	Frequency %	Statement	Codes
C-2-01	4.1	3	21.4%	operation should be clear / obvious	1321
C-2-02	4.3	2	14.3%	stay in place	1144
C-2-03	4.1	1	7.1%	provide assistance opening the device	1124
C-2-04	1.9	2	14.3%	be attractive	1321
C-2-05	3.5	2	14.3%	have a rubber gripping surface	1442
C-2-06	4.3	1	7.1%	be easy to remove from can	1324
C-2-07	3	1	7.1%	be made of a material that feels nice to hold	1322
C-2-08	4.4	11	78.6%	be easy to turn / twist	1223
C-2-09	4	1	7.1%	hands should fit easily around knob	1222
C-2-10	4.4	5	35.7%	be easy to squeeze	1324
C-2-11	4.1	1	7.1%	remain sharp for a long time	1334
C-2-12	3.6	1	7.1%	help remove the top after cutting	2314
C-2-13	4.4	5	35.7%	pierce the can with little effort	1223
C-2-14	4.4	1	7.1%	not dig into the hand	1412
C-2-15	4.1	2	14.3%	be easy to maneuver	1324
C-2-16	3.5	2	14.3%	provide feedback that it is secure	2144
C-2-17	3.2	1	7.1%	have consistent motion	1332
C-2-18	2.8	1	7.1%	be familiar	1321
C-2-19	2.5	2	14.3%	have easy to press buttons	1322
C-2-20	3.9	1	7.1%	be simple	1331
C-2-21	4.3	6	42.9%	operate with low force / strength	1224
C-2-22	3	1	7.1%	have thick handles	2242
C-2-23	4.3	1	7.1%	operation should be easy to learn	1321
C-2-24	4.4	2	14.3%	be usable with either hand	2124
C-2-25	3	1	7.1%	have nice feeling knob and handles	1321
C-2-26	4.2	1	7.1%	have sharp blade	1442
C-2-27	4.7	2	14.3%	be easy to attach to can	1323
C-2-28	4.7	1	7.1%	cut continuously without skipping spots	1133
C-2-29	2.1	1	7.1%	have small handles	2242
C-2-30	4.2	1	7.1%	have a way to stay steady / aligned on can	1344
C-2-31	3.7	1	7.1%	have explanatory symbols	1122
C-2-32	3.4	1	7.1%	be small enough to fit well in hand	2222
C-2-33	2.6	1	7.1%	be easy to store	1335
C-2-34	4.1	3	21.4%	be easy to grip	1322
C-2-35	4.1	4	28.6%	remain closed easily	1334
C-2-36	4	1	7.1%	requires as few steps as possible to use	1222
C-2-37	1.6	1	7.1%	be curved	2442

Garlic Press CN Info for statements made by FSU Participants

FSU Tags	Weight	Frequency	Frequency %	Statement	Final Codes
G-2-01	4.4	14	100.0%	require only small force to squeeze closed	1223
G-2-02	4.1	2	14.3%	be easy to grip/grasp	1322
G-2-03	2.6	5	35.7%	have large handles	2222
G-2-04	3.2	2	14.3%	have a large gripping surface	2242
G-2-05	3.9	1	7.1%	provide force regardless of hand span or mechanism position	1134
G-2-06	4.3	1	7.1%	sized appropriately for all hands	1222
G-2-07	4.5	6	42.9%	accommodate any size garlic clove in compartment / holder	1132
G-2-08	4.1	1	7.1%	be easy to pick up	1324
G-2-09	3.7	1	7.1%	have a non-slip surface	1412
G-2-10	4.1	2	14.3%	be simple	1331
G-2-11	4.2	1	7.1%	allow one-handed usage	2124
G-2-12	4.3	1	7.1%	transfer energy efficiently	1234
G-2-13	2.9	1	7.1%	look simple	1321
G-2-14	3.1	1	7.1%	have a nice grip	1322
G-2-15	4.5	3	21.4%	be easy to insert/load garlic into place	1324
G-2-16	3.6	1	7.1%	feel durable	1321
G-2-17	3.8	2	14.3%	accommodate small hand spans	2322
G-2-18	4.3	1	7.1%	require only low dexterity	1324
G-2-19	2.7	1	7.1%	be compact	1332
G-2-20	3.5	1	7.1%	provide a mechanical advantage	1133
G-2-21	4.6	8	57.1%	parts should align automatically without manual adjustment	1144
G-2-22	3.9	3	21.4%	operation should be obvious / intuitive	1321
G-2-23	1.9	1	7.1%	be aesthetically pleasing	1321
G-2-24	4.1	5	35.7%	be easy to maneuver / manipulate	1324
G-2-25	4.2	3	21.4%	be easy to clean	1325
G-2-26	4.2	3	21.4%	be efficient (material vs. effort)	1234
G-2-27	3.5	1	7.1%	be large enough to allow use of both hands	2422
G-2-28	2.9	1	7.1%	be lightweight	1232
G-2-29	3.9	2	14.3%	have rounded edges so as not to dig into the hand	1412
G-2-30	3.9	3	21.4%	fit in the hand comfortably / well	1321

Jar Opener CN Info for statements made by FSU Participants

FSU Tags	CN Statement	Weight	Frequency	Frequency %	Final Codes
J-2-01	be easy to understand / intuitive	4.1	9	64.3%	1321
J-2-02	have a non-slip surface	4.1	2	14.3%	1412
J-2-03	require only a little dexterity / coordination	4.2	1	7.1%	1324
J-2-04	indicate direction of turn	3.5	6	42.9%	1121
J-2-05	amplify the applied torque	3.9	1	7.1%	1233
J-2-06	work in multiple positions	3.9	1	7.1%	2234
J-2-07	require only low forces to operate	4.3	5	35.7%	1223
J-2-08	be easy to twist	4.4	3	21.4%	1324
J-2-09	be easy to grip	4.2	2	14.3%	1322
J-2-10	be easy to assemble	3.7	1	7.1%	1324
J-2-11	work easily with either hand	4.2	1	7.1%	2124
J-2-12	operate with as few steps as possible	4.3	3	21.4%	1222
J-2-13	not have moving parts that can break and fail	4.2	1	7.1%	1112
J-2-14	handle should fit nicely in the hand	3.8	1	7.1%	1321
J-2-15	be easy to attach to lid	4.5	4	28.6%	1324
J-2-16	unscrew smoothly so as not to spill	4.3	1	7.1%	1432
J-2-17	have clear directions	3.9	6	42.9%	1321
J-2-18	grip lid securely	4.4	11	78.6%	1333
J-2-19	be easy to push	3.5	2	14.3%	1324
J-2-20	provide feedback that it is secure	3.2	3	21.4%	2144
J-2-21	feel secure	3.6	3	21.4%	1321
J-2-22	work on multiple can sizes	4.6	1	7.1%	1134
J-2-23	provide a method for gripping the jar as well as the lid	3.6	3	21.4%	2444
J-2-24	stay level with little effort	3.9	1	7.1%	1334
J-2-25	take off the seal with little force	4.2	1	7.1%	1223
J-2-26	appear approachable	3.2	1	7.1%	2321
J-2-27	knob should be capable of breaking the seal	3.5	1	7.1%	2434
J-2-28	be lightweight	3.2	1	7.1%	1232

Can Opener CN Info for statements made by PWD Participants

PWD Tags	CN Statement	Weight	Frequency	Frequency %	Final Codes
C-1-1	be durable	4.00	1	9.1%	1335
C-1-2	be usable with either hand	3.88	2	18.2%	2124
C-1-3	have rubber coating	3.00	1	9.1%	1442
C-1-4	allow sufficient grip with one hand	3.38	1	9.1%	2222
C-1-5	not require hand to stay closed	3.75	2	18.2%	1124
C-1-6	have blunt/padded edges so as not to dig into user	4.25	2	18.2%	1412
C-1-7	have large handles	3.38	1	9.1%	2222
C-1-8	be efficient	4.38	1	9.1%	1334
C-1-9	have longer knob for more leverage	3.25	1	9.1%	1432
C-1-10	position user's hands comfortably	3.50	1	9.1%	1322
C-1-11	operation should be simple	3.88	1	9.1%	1324
C-1-12	operate with a push action instead of a squeeze	3.13	1	9.1%	2434
C-1-13	shape should not be straight	3.00	1	9.1%	2342
C-1-14	function with pressure from multiple angles	3.13	1	9.1%	1334
C-1-15	be easy to turn	4.25	5	45.5%	1223
C-1-16	turn smoothly	4.25	1	9.1%	1233
C-1-17	provide the right levereage	4.25	1	9.1%	1234
C-1-18	remain in cutting position	4.25	1	9.1%	1134
C-1-19	have a nice gripping surface	4.00	3	27.3%	1321
C-1-20	require only low force to hold closed	4.00	2	18.2%	1224
C-1-21	not have a separate release	2.38	6	54.5%	2132
C-1-22	be familiar	2.63	2	18.2%	1321
C-1-23	remain in position easily	3.88	2	18.2%	1334
C-1-24	be lightweight	3.50	2	18.2%	1232
C-1-25	require only minimal squeeze force to puncture can	4.25	3	27.3%	1223
C-1-26	have a non-slip grip surface	3.50	1	9.1%	1122
C-1-27	remain sharp as long as possible	3.63	1	9.1%	1232
C-1-28	be easy to understand	4.00	2	18.2%	1321
C-1-29	put user at the right height	3.75	1	9.1%	1224

Garlic Press CN Info for statements made by PWD Participants

PWD Tags	CN Statement	Weight	Frequency	Frequency %	Final Codes
G-1-1	have an obvious holder	3.13	1	9.1%	1321
G-1-2	require only modest hand spans	3.13	3	27.3%	1224
G-1-3	not be sloped	2.50	1	9.1%	2142
G-1-4	provide stability	3.75	1	9.1%	1314
G-1-5	have a non-slip grip surface	3.75	1	9.1%	1412
G-1-6	parts should align automatically without manual adjustment	4.00	4	36.4%	1444
G-1-7	be efficient	4.13	1	9.1%	1334
G-1-8	accommodate multiple sizes of garlic	4.38	2	18.2%	1332
G-1-9	have curved handles	3.00	1	9.1%	2342
G-1-10	prevent user fingers from being caught or squished	4.13	1	9.1%	1114
G-1-11	be rounded so as not to cut into the hand	3.88	1	9.1%	1412
G-1-12	have obvious operation	3.75	3	27.3%	1321
G-1-13	have simple garlic insertion method	4.38	2	18.2%	1324
G-1-14	require only low grip force / pressure to close	4.38	8	72.7%	1223
G-1-15	have cushy grip surfaces	3.38	1	9.1%	1422
G-1-16	be lightweight	3.50	2	18.2%	1232
G-1-17	have a thin grip	1.63	1	9.1%	2242
G-1-18	be large enough to accommodate both hands	3.00	1	9.1%	2422
G-1-19	provide a good grip	4.38	1	9.1%	1322
G-1-20	have a familiar shape	2.63	1	9.1%	1321
G-1-21	be easy to clean	4.50	2	18.2%	1325
G-1-22	allow application of uniform pressure	4.38	1	9.1%	1234
G-1-23	only involve one hand	3.50	1	9.1%	2122
G-1-24	be conducive to apply pressure	3.63	1	9.1%	1324
G-1-25	have large handles	2.63	1	9.1%	2222
G-1-26	be easy to manipulate / maneuver	4.13	3	27.3%	1324
G-1-27	employ pressing rather than squeezing mechanism	3.75	1	9.1%	2434

Jar Opener CN Info for statements made by PWD Participants

PWD Tags	CN Statement	Weight	Frequency	Frequency %	Final Codes
J-1-1	look simple	2.50	1	9.1%	1321
J-1-2	be usable by either hand	3.88	2	18.2%	2124
J-1-3	be easy to assemble	4.17	2	18.2%	1324
J-1-4	be easy to understand	4.13	5	45.5%	1321
J-1-5	have a rubber coating on handle	2.75	1	9.1%	1442
J-1-6	require only one hand to work	3.50	1	9.1%	2122
J-1-7	provide a way to grip jar as well	3.88	2	18.2%	2134
J-1-8	require only small forces to use	3.88	3	27.3%	1224
J-1-9	have a feature to assist with breaking the seal	4.00	1	9.1%	1132
J-1-10	provide stability	3.63	2	18.2%	1314
J-1-11	not have exposed sharp edges	4.00	1	9.1%	1111
J-1-12	have an easy to turn knob	3.88	3	27.3%	1222
J-1-13	unscrew without knocking over the jar	4.38	1	9.1%	1114
J-1-14	require low torque to twist off lid	4.38	3	27.3%	1223
J-1-15	have clear directions/indicate direction of turn	3.50	8	72.7%	1121
J-1-16	look safe	2.50	1	9.1%	1311
J-1-17	work on multiple jar sizes	4.13	1	9.1%	1334
J-1-18	have a nice grip	3.88	2	18.2%	1321
J-1-19	operate with as few steps as possible	3.63	1	9.1%	1222
J-1-20	have large gripping surface	3.13	2	18.2%	2222
J-1-21	grip lid securely	4.00	6	54.5%	1333
J-1-22	be easy to attach to lid	4.25	2	18.2%	1324

Appendix N: Participant Limitation Info Tables and Charts

Participant ROM Info Normalized to % of Normal Functioning

participant	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
dominance	R	R	R	R	R	R	L	R	R	R	R	R	R	R	R
d shoulder flexion	85.33	100	100	100	100	100	100	100	100	100	100	100	100	100	100
nd shoulder flexion	85.33	100	100	100	100	100	100	100	100	100	100	100	100	100	100
d shoulder extension	68	100	100	100	100	100	100	100	100	100	100	100	100	100	100
nd shoulder extension	68	100	100	100	100	100	100	100	100	100	100	100	100	100	100
d shoulder abduction	57.22	100	100	100	100	100	100	100	100	100	100	100	100	100	100
nd shoulder abduction	57.22	100	100	100	100	100	100	100	100	100	100	100	100	100	100
d shoulder horizontal abduction	108.88	100	100	100	100	100	100	122.22	100	100	100	100	100	100	100
nd shoulder horizontal abduction	108.88	100	100	100	100	100	100	100	100	100	100	100	100	100	100
d shoulder horizontal adduction	84.44	100	100	100	100	100	100	100	100	100	100	100	100	100	100
nd shoulder horizontal adduction	77.77	100	100	100	100	100	100	100	100	100	100	100	100	100	100
d elbow flexion-extension	93.33	100	100	100	100	100	100	100	100	53.33	100	100	72	100	100
nd elbow flexion-extension	70	100	100	100	100	100	100	100	100	53.33	100	100	72	100	100
d wrist flexion-extension	83.33	100	100	73.33	100	100	100	100	100	100	100	100	100	70.66	100
nd wrist flexion-extension	83.33	100	100	100	100	100	100	100	100	100	100	100	100	70.66	100
d wrist deviation	95.31	100	100	100	32.81	100	100	100	100	72.43	81.25	100	129.68	84.37	100
nd wrist deviation	98.43	100	100	100	100	100	100	100	100	126.56	65.63	100	139.06	84.38	100
d forearm rotation	0	100	100	70	100	100	100	100	100	75	100	100	100	53.75	100
nd forearm rotation	0	100	100	100	100	100	100	100	100	116.69	100	100	53.75	100	100
d elbow flexion-extension	93.33	100	100	71.33	100	100	100	100	100	53.33	100	100	72	100	100
nd elbow flexion-extension	100	100	100	70	100	100	100	100	100	53.33	100	100	72	100	100
d wrist flexion-extension	83.33	100	100	73.33	100	100	100	100	100	100	66.67	100	100	70.66	100
nd wrist flexion-extension	100	100	100	83.33	100	100	100	100	100	100	75.33	100	100	70.66	100
d wrist deviation	95.31	100	100	100	100	100	100	100	100	73.43	81.25	100	29.68	84.37	100
nd wrist deviation	98.43	100	100	100	100	100	100	100	100	126.56	65.63	100	39.06	84.38	100
d forearm rotation	0	100	100	100	100	100	100	100	100	75	100	100	100	53.75	100
nd forearm rotation	0	100	100	100	100	100	100	100	100	100	100	100	100	53.75	100
d pinkey top flexion-extension	0	61.11	100	38.88	100	100	100	100	100	100	100	100	100	100	100
nd pinkey top flexion-extension	0	22.22	100	100	100	100	100	100	100	100	100	100	100	100	100
d ring top flexion-extension	0	22.22	100	100	100	100	100	100	100	100	100	100	100	100	100
nd ring top flexion-extension	0	4.44	100	100	100	100	100	100	100	100	100	100	100	100	100
d middle top flexion-extension	0	17.78	100	44.44	100	100	100	100	100	100	100	100	100	100	100
nd middle top flexion-extension	0	12.22	100	100	100	100	100	100	100	100	100	100	100	100	100

d index top flexion-extension	70	24.44	100	100	100	100	100	100	100	100	100	100	100	100	100
nd index top flexion-extension	0	19.14	100	100	100	100	100	100	100	100	100	100	100	100	100
d pinkey middle flexion-extension	0	47.78	100	33.33	100	100	100	100	100	100	100	100	100	100	100
nd pinkey middle flexion-extension	0	22.22	100	100	100	100	100	100	100	100	100	100	100	100	100
d ring middle flexion-extension	0	66.67	100	100	100	100	100	100	100	100	100	100	100	100	100
nd ring middle flexion-extension	0	4.44	100	100	100	100	100	100	100	100	100	100	100	100	100
d middle middle flexion-extension	0	75.56	100	66.67	100	100	100	100	100	100	100	100	100	100	100
nd middle middle flexion-extension	0	12.22	100	100	100	100	100	100	100	100	100	100	100	100	100
d index middle flexion-extension	81.11	53.33	100	100	100	100	100	100	100	100	100	100	100	100	100
nd index middle flexion-extension	0	14.44	100	100	100	100	100	100	100	100	100	100	100	100	100
d pinkey bottom flexion-extension	0	11.03	100	27.58	100	100	100	100	100	100	100	100	100	100	100
nd bottom flexion-extension	0	45.52	100	100	100	100	100	100	100	100	100	100	100	100	100
d ring bottom flexion-extension	0	20.69	100	100	100	100	100	100	100	100	100	100	100	100	100
nd ring bottom flexion-extension	0	31.72	100	100	100	100	100	100	100	100	100	100	100	100	100
d middle bottom flexion-extension	5.51	54.48	100	31.03	100	100	100	100	100	100	100	100	100	100	100
nd middle bottom flexion-extension	0	47.31	100	100	100	100	100	100	100	100	100	100	100	100	100
d index bottom flexion-extension	5.52	62.07	100	51.72	100	100	100	100	100	100	100	100	100	100	100
nd index bottom flexion-extension	0	39.31	100	100	100	100	100	100	100	100	100	100	100	100	100

Participant Restriction Level by Standard Deviation of Test

Participant #	Participant Gender	Participant Age	BBT Dom	BBT ND	9HPT Dom	9HP T ND	Grip Dom	Grip ND	Key Pinch Dom	Key Pinch ND
2	m	61-70	2	2	0	1	3	2	1	1
3	f	51-60	1	2	2	1	3	3	2'	3
4	m	20	3	3	3	3	1	1	1'	1'
5	m	21-30	2	3	0	3	2'	3	2'	3
6	m	19	3	3	3	3	2	2	1	1
7	f	19	3	3	3	3	2	1	1'	1'
8	f	41-50	3	3	3	3	3'	2	1	1'
9	m	51-60	2	1	0	1	2'	NA	3	3
10	m	19	3	2	3	3	3	3	3'	3'
11	m	18	3	3	3	2	2	3	2	2
12	f	19	2	3	3	3	2	3	1'	2'
13	f	20-29	2	2	2	3	2	3	1'	1'
14	m	30-39	2	2	1	2	1'	1'	3'	3'
15	m	20-29	2	2	3	3	1	1	2'	1'
16	m	20-29	1	2	3	2	0	1	1	1'

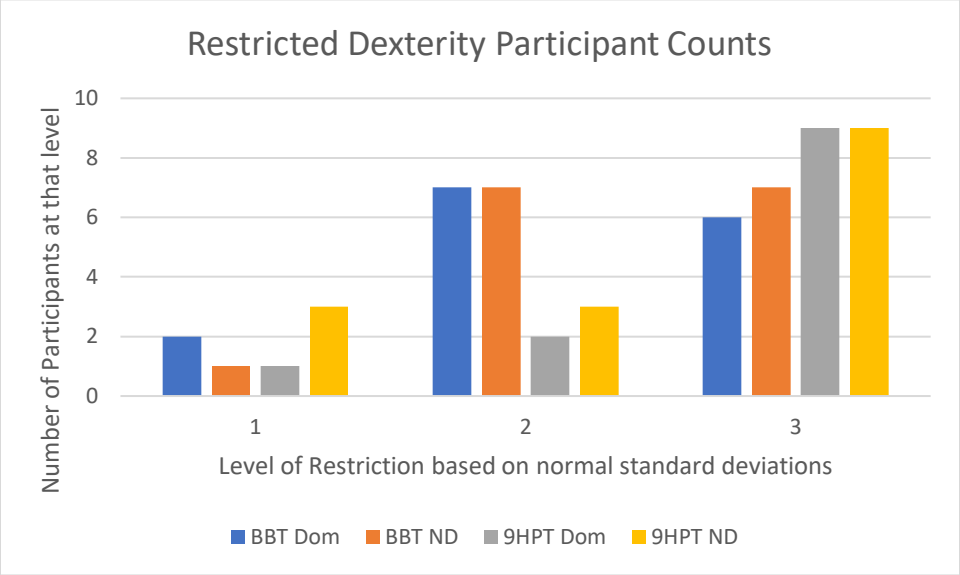
#' indicates higher than average functioning where # indicates a restriction compared to average.

Counts of Participant Restriction Levels by Standard Deviation of Test

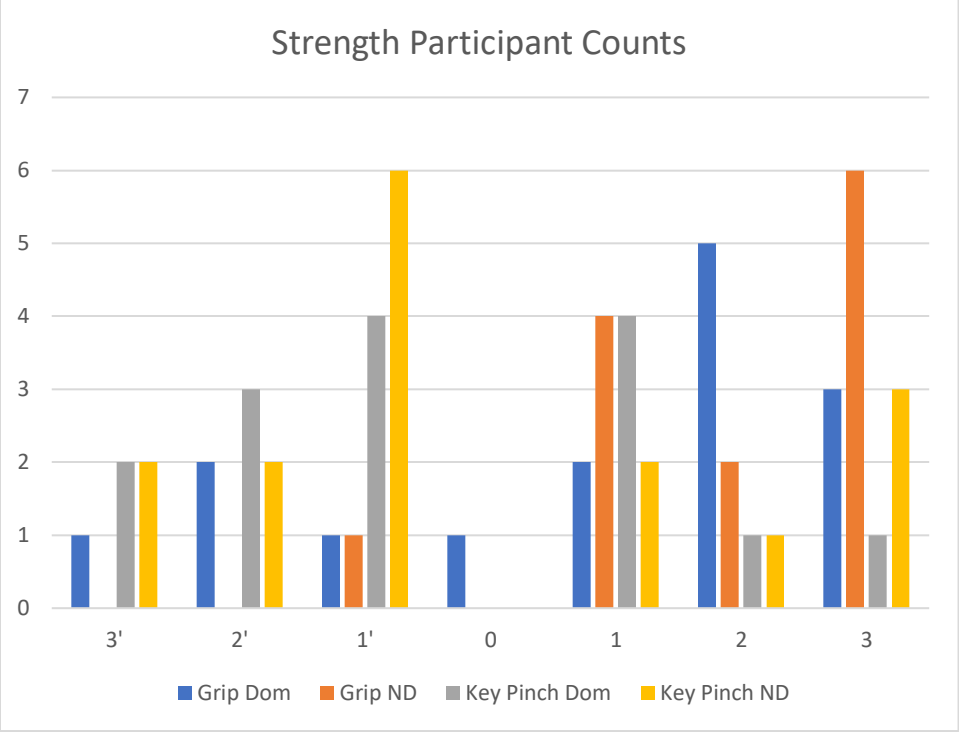
All Participants	Counts							
Restrictions	BBT Dom	BBT ND	9HPT Dom	9HPT ND	Grip Dom	Grip ND	Key Pinch Dom	Key Pinch ND
3'	0	0	0	0	1	0	2	2
2'	0	0	0	0	2	0	3	2
1'	0	0	0	0	1	1	4	6
0	0	0	3	0	1	0	0	0
1	2	1	1	3	2	4	4	2
2	7	7	2	3	5	2	1	1
3	6	7	9	9	3	6	1	3
PMR(2,3,5,9)	Counts							
Restrictions	BBT Dom	BBT ND	9HPT Dom	9HPT ND	Grip Dom	Grip ND	Key Pinch Dom	Key Pinch ND
3'	0	0	0	0	0	0	0	0
2'	0	0	0	0	2	0	2	0
1'	0	0	0	0	0	0	0	0
0	0	0	3	0	0	0	0	0
1	1	0	0	3	0	0	1	1
2	3	2	1	0	0	1	0	0
3	0	1	0	1	2	2	1	3
SSU(4,6,7,8,10, 11,12,13,14,15, 16)	Counts							
Restrictions	BBT Dom	BBT ND	9HPT Dom	9HPT ND	Grip Dom	Grip ND	Key Pinch Dom	Key Pinch ND
3'	0	0	0	0	1	0	2	2
2'	0	0	0	0	0	0	1	1
1'	0	0	0	0	1	1	4	6
0	0	0	0	0	1	0	0	0
1	1	0	1	0	2	4	3	1
2	4	5	1	3	5	2	1	1
3	6	6	9	8	1	4	0	0

Participant Restriction Charts

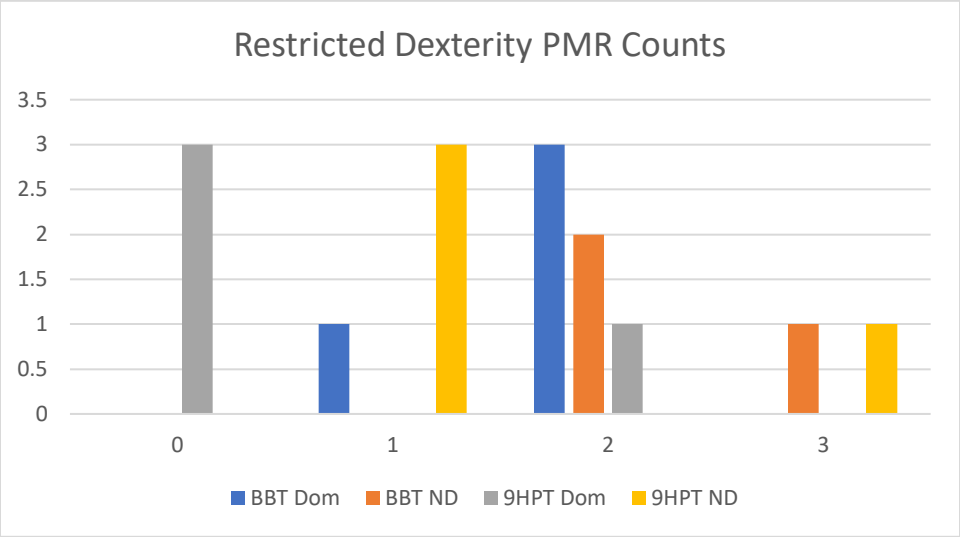
Dexterity Restriction Counts: 1 means within 1 standard deviation of normal functioning, 2 is within 2 stdev, 3 is within 3 stdev.



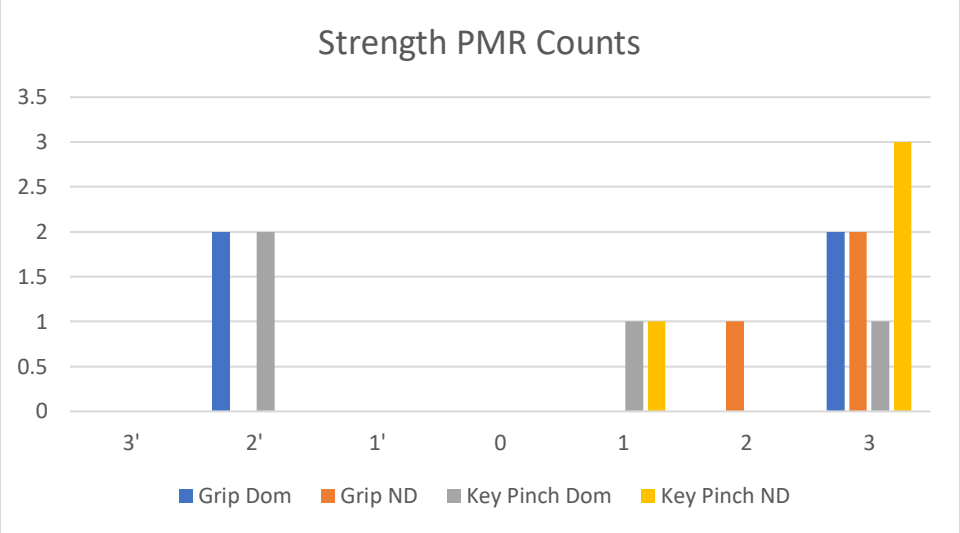
Strength Restriction Counts: All (‘) indicate participants stronger than the average normal strength, numbers indicate which standard deviation they are greater than.



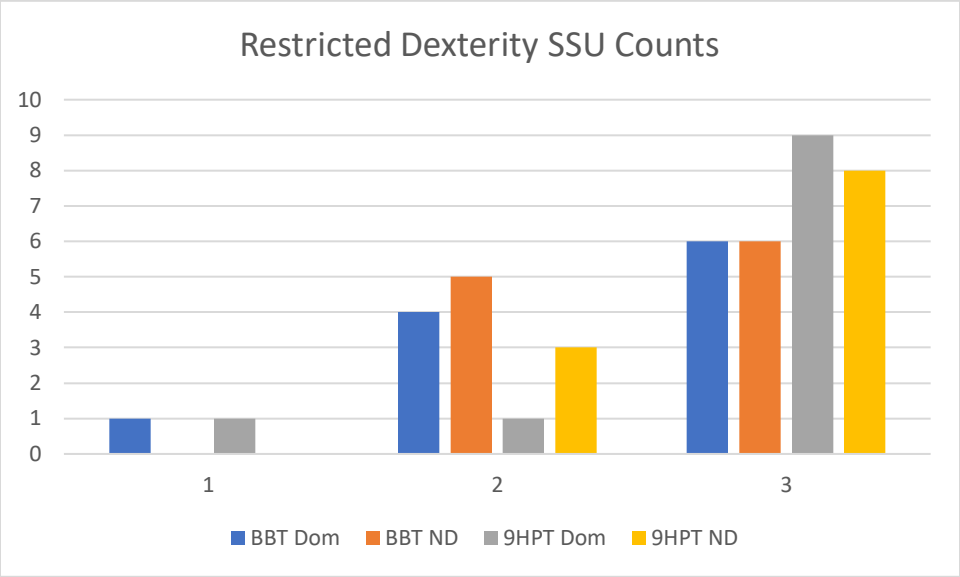
Dexterity Restriction Counts for PMR Subgroup:



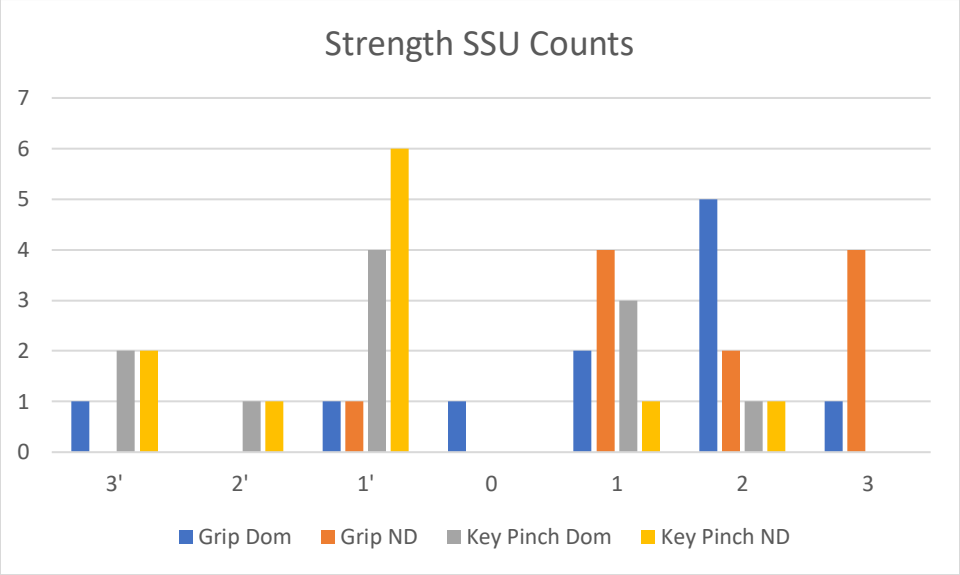
Strength Restriction Counts for PMR Subgroup:



Dexterity Restriction Counts for SSU Subgroup:



Strength Restriction Counts for SSU Subgroup:



WHODAS Results

	PLEASE NOTE: When scoring WHODAS, the following numbers are assigned to responses:				
	0 = No Difficulty				
	1 = Mild Difficulty				
	2 = Moderate Difficulty				
	3 = Severe Difficulty				
	4 = Extreme Difficulty or Cannot Do	Part 2	Part 3	Part 5	Add1
D1.1	Concentrating on doing something for ten minutes?	2	0	0	2
D1.2	Remembering to do important things?	2	1	0	0
D1.3	Analyzing and finding solutions to problems in day-to-day life?	1	1	0	1
D1.4	Learning a new task, for example, learning how to get to a new place?	0	1	0	3
D1.5	Generally understanding what people say?	3	0	0	0
D1.6	Starting and maintaining a conversation?	0	0	0	2
		33.33%	8.33%	0.00%	33.33%
D2.1	Standing for long periods such as 30 minutes?	3	0	0	4
D2.2	Standing up from sitting down?	1	2	0	1
D2.3	Moving around inside your home?	1	0	0	1
D2.4	Getting out of your home?	1	1	0	1
D2.5	Walking a long distance such as a kilometre [or equivalent]?	1	0	0	4
		35.00%	15.00%	0.00%	55.00%
D3.1	Washing your whole body?	0	3	1	2
D3.2	Getting dressed?	2	3	0	1.5
D3.3	Eating?	0	2	0	2
D3.4	Staying by yourself for a few days?	0	2	0	3
		12.50%	62.50%	6.25%	53.13%
D4.1	Dealing with people you do not know?	0	0	0	3
D4.2	Maintaining a friendship?	0	1	0	1
D4.3	Getting along with people who are close to you?	0	0	0	0
D4.4	Making new friends?	0	1	0	0
D4.5	Sexual activities?	3	2	0	0.5
		15.00%	20.00%	0.00%	22.50%
D5.1	Taking care of your household responsibilities?	1	2	0	2
D5.2	Doing most important household tasks well?	1	3	0	2
D5.3	Getting all the household work done that you needed to do?	2	2	0	3.5
D5.4	Getting your household work done as quickly as needed?	3	4	0	4
D5.5	Your day-to-day work/school?	2	1	0	1
D5.6	Doing your most important work/school tasks well?	2	1	0	0
D5.7	Getting all the work done that you need to do?	2	1	0	1
D5.8	Getting your work done as quickly as needed?	3	2	0	3
		50.00%	50.00%	0.00%	51.56%

D6.1	How much of a problem did you have in joining in community activities (for example, festivities, religious or other activities) in the same way as anyone else can?	1	2	0	0
D6.2	How much of a problem did you have because of barriers or hindrances in the world around you?	1	1	0	3
D6.3	How much of a problem did you have living with dignity because of the attitudes and actions of others?	0	1	0	1
D6.4	How much time did you spend on your health condition, or its consequences?	3	2	0	0
D6.5	How much have you been emotionally affected by your health condition?	2	2	1	1.5
D6.6	How much has your health been a drain on the financial resources of you or your family?	3	2	0	0
D6.7	How much of a problem did your family have because of your health problems?	0	1	0	0
D6.8	How much of a problem did you have in doing things by yourself for relaxation or pleasure?	0	3	0	1.5
		31.25%	43.75%	3.13%	21.88%
		29.51%	33.26%	1.56%	39.57%
H1	Overall, in the past 30 days, how many days were these difficulties present?	6	16		2
H2	In the past 30 days, for how many days were you totally unable to carry out your usual activities or work because of any health condition?	0	3		0
H3	In the past 30 days, not counting the days that you were totally unable, for how many days did you cut back or reduce your usual activities or work because of any health condition?	10	7		5

Appendix O: Taxonomy Information Tables

FSU Taxonomy Breakdowns

All FSU	What		Performance		Message		Market	
Code	Counts	Percents	Counts	Percents	Counts	Percents	Counts	Percents
1	18	19.1%	6	6.4%	16	22.3%	77	81.9%
2	32	34.0%	55	58.5%	21	50.0%	18	19.1%
3	10	10.6%	22	23.4%	47	11.7%		
4	33	35.1%	12	12.8%	11	0.0%		
5	2	2.1%						
CO2	What		Performance		Message		Market	
Code	Counts	Percents	Counts	Percents	Counts	Percents	Counts	Percents
1	6	16.2%	2	5.4%	6	21.6%	30	81.10%
2	14	37.8%	21	56.8%	8	51.4%	7	18.90%
3	4	10.8%	6	16.2%	19	10.8%		
4	12	32.4%	8	21.6%	4	16.2%		
5	1	2.7%						
GP2	What		Performance		Message		Market	
Code	Counts	Percents	Counts	Percents	Counts	Percents	Counts	Percents
1	6	16.2%	2	5.4%	5	18.9%	25	67.6%
2	12	32.4%	18	48.6%	7	40.5%	5	13.5%
3	2	5.4%	8	21.6%	15	8.1%		
4	9	24.3%	2	5.4%	3	13.5%		
5	1	2.7%						
JO2	What		Performance		Message		Market	
Code	Counts	Percents	Counts	Percents	Counts	Percents	Counts	Percents
1	6	16.2%	2	5.4%	5	16.2%	22	59.5%
2	6	16.2%	16	43.2%	6	35.1%	6	16.2%
3	4	10.8%	8	21.6%	13	10.8%		
4	12	32.4%	2	5.4%	4	13.5%		
5	0	0.0%						

PWD Taxonomy Breakdowns

All PWD	Market	Market	Message	Message	Performance	Performance	What	What
Code	Counts	Percents	Counts	Percents	Counts	Percents	Counts	Percents
1	61	79.2%	15	27.3%	9	11.7%	12	15.6%
2	17	22.1%	21	40.3%	41	53.2%	29	37.7%
3			31	14.3%	21	27.3%	6	7.8%
4			11	0.0%	7	9.1%	29	37.7%
5							2	2.6%
JO1	Market	Market	Message	Message	Performance	Performance	What	What
Code	Counts	Percents	Counts	Percents	Counts	Percents	Counts	Percents
1	18	48.6%	7	13.5%	4	10.8%	6	16.2%
2	4	10.8%	5	24.3%	13	35.1%	6	16.2%
3			9	2.7%	4	10.8%	2	5.4%
4			1	18.9%	1	2.7%	8	21.6%
5							0	0.0%
CO1	Market	Market	Message	Message	Performance	Performance	What	What
Code	Counts	Percents	Counts	Percents	Counts	Percents	Counts	Percents
1	23	62.2%	5	27.0%	1	2.7%	3	8.1%
2	6	16.2%	10	27.0%	14	37.8%	11	29.7%
3			10	10.8%	12	32.4%	3	8.1%
4			4	13.5%	2	5.4%	11	29.7%
5							1	2.7%
GP1	Market	Market	Message	Message	Performance	Performance	What	What
Code	Counts	Percents	Counts	Percents	Counts	Percents	Counts	Percents
1	20	54.1%	3	16%	4	11%	3	8.1%
2	7	18.9%	6	32%	14	38%	12	32.4%
3			12	16%	5	14%	1	2.7%
4			6	8%	4	11%	10	27.0%
5							1	2.7%

All Exp1 Taxonomy Breakdowns

All Exp 1	Market		Message			Performance			What		
Percents	Counts	Code	Percents	Counts	Code	Percents	Counts	Code	Percents	Counts	Code
75.4%	138	1	18%	31	1	9%	15	1	17.3%	30	1
19.1%	35	2	24%	42	2	55%	96	2	35.3%	61	2
			45%	78	3	25%	43	3	9.2%	16	3
			13%	22	4	11%	19	4	35.8%	62	4
									2.3%	4	5

RCO Taxonomy Breakdowns by Subgroup

RCO	Subgroup SSU							
	Market		Message		Performance		What	
Code	Percents	Counts	Percents	Counts	Percents	Counts	Percents	Counts
1	75.0%	18	25.0%	6	8.3%	2	12.5%	3
2	25.0%	6	20.8%	5	45.8%	11	29.2%	7
3			50.0%	12	25.0%	6	12.5%	3
4			4.2%	1	16.7%	4	37.5%	9
5							8.3%	2
RCO	Subgroup PMR							
	Market		Message		Performance		What	
Code	Percents	Counts	Percents	Counts	Percents	Counts	Percents	Counts
1	83.3%	10	25.0%	3	0.0%	0	16.7%	2
2	16.7%	2	25.0%	3	25.0%	3	58.3%	7
3			25.0%	3	41.7%	5	8.3%	1
4			25.0%	3	33.3%	4	8.3%	1
5							8.3%	1
RCO	Subgroup Both							
	Market		Message		Performance		What	
Code	Percents	Counts	Percents	Counts	Percents	Counts	Percents	Counts
1	71.4%	5	14.3%	1	0.0%	0	28.6%	2
2	28.6%	2	42.9%	3	42.9%	3	42.9%	3
3			28.6%	2	42.9%	3	14.3%	1
4			14.3%	1	14.3%	1	0.0%	0
5							14.3%	1

Taxonomy Breakdowns for Different Lists

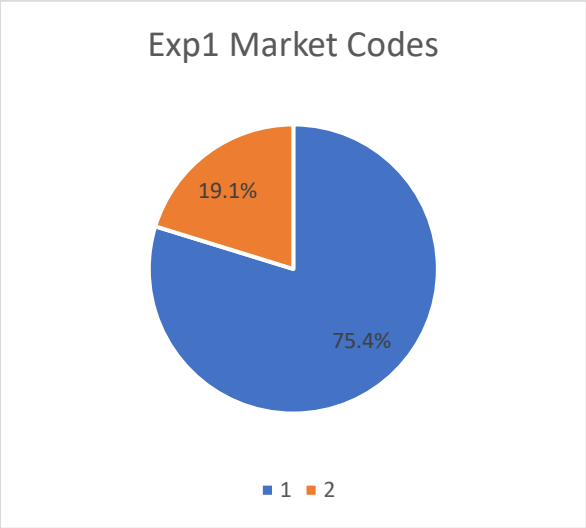
total code count	List Names	Mark 1	Mark 2	Mess 1	Mess 2	Mess 3	Mess 4	Perf 1	Perf 2	Perf 3	Perf 4	What 1	What 2	What 3	What 4
7	J1	7	0	0	2	5	0	0	7	0	0	3	2	0	2
14	C1	12	2	0	8	6	0	0	9	5	0	3	4	2	5
8	G1	8	0	0	0	6	2	2	6	0	0	3	2	0	3
12	J2	12	0	0	2	10	0	0	12	0	0	4	0	3	6
19	C2	17	2	0	2	15	2	0	13	2	4	5	7	0	7
17	G2	15	2	0	4	11	2	2	11	2	2	5	6	0	6
47	All 1 (FSU)	43	4	0	8	35	4	4	39	0	4	14	14	4	15
32	All 2 (PWD)	28	4	0	12	20	0	0	27	5	0	9	4	4	15
78	All Exp1	72	6	0	21	57	0	0	70	8	0	23	20	9	26
77	All Exp2	57	20	10	16	42	0	0	52	15	10	21	26	6	24

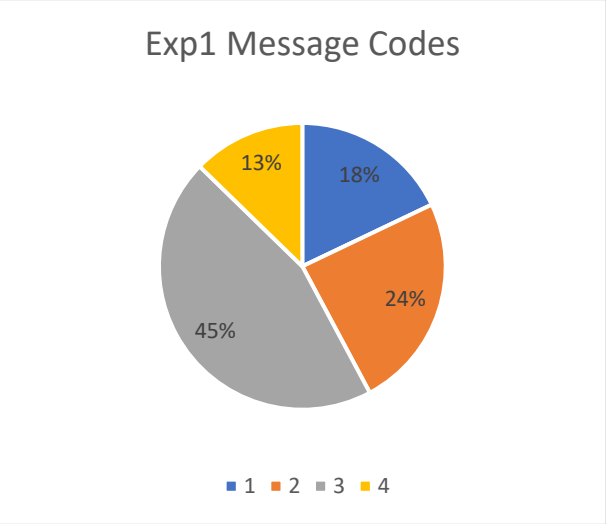
Human Factors Category Results

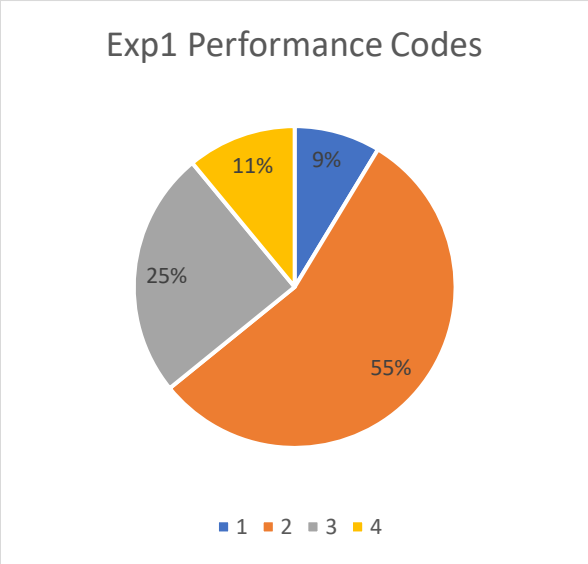
Data Set Name	Total	HF	HF%
FSU	47	39	83
CO2	19	13	68.4
GP2	17	13	76.5
JO2	12	12	100
PWD	32	27	84.4
CO1	14	9	64.3
GP1	8	6	75
JO1	7	7	100
Exp1	78	70	89.7
Exp2	77	52	67.5
BJO	15	9	60
TJO	5	5	100
SGP	14	7	50
CGP	10	4	40
RCO	13	5	38.5
WCO	20	16	80
C	19	13	68.4
G	10	6	60
J	13	13	100

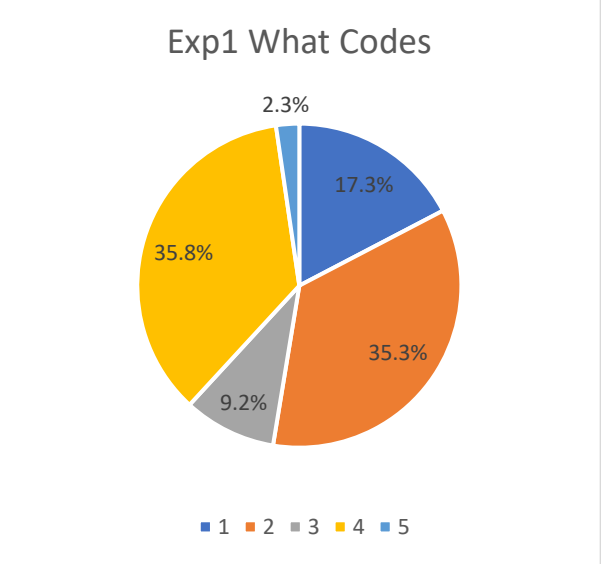
Appendix P: Taxonomy Information Charts

Experience 1 Taxonomy Code Breakdowns:

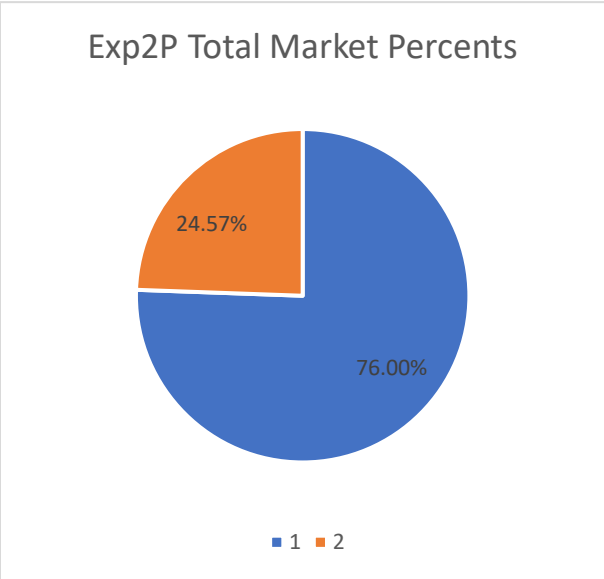


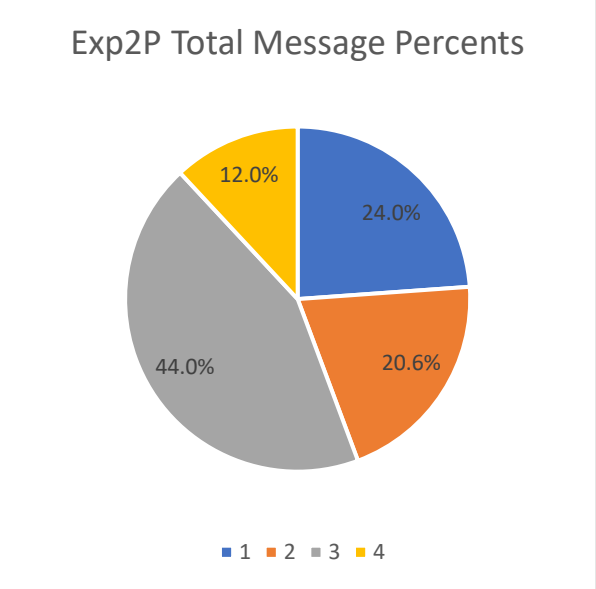


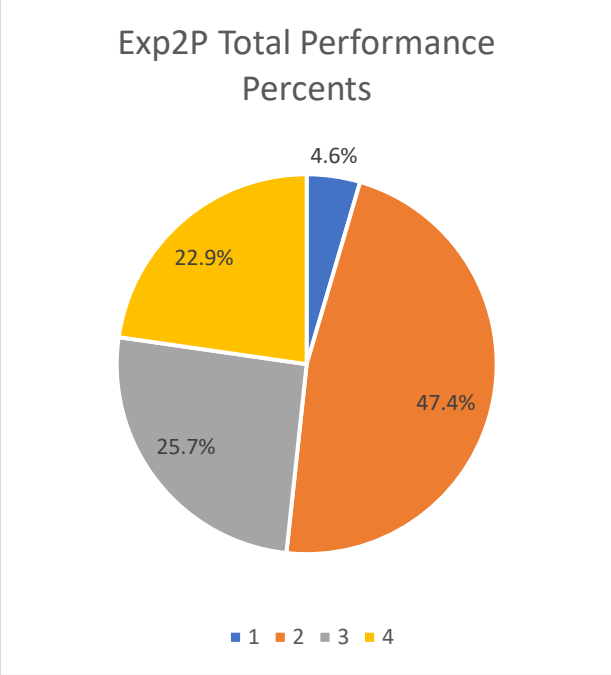


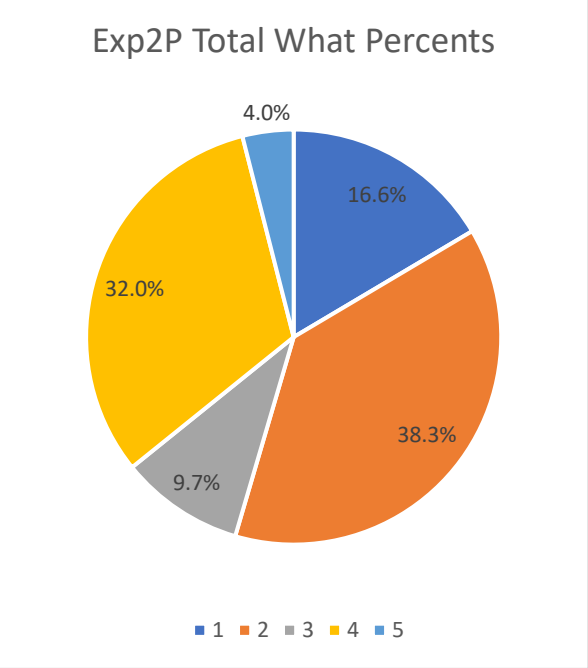


Taxonomy Code Breakdowns for all of Experience 2 using the product lists:

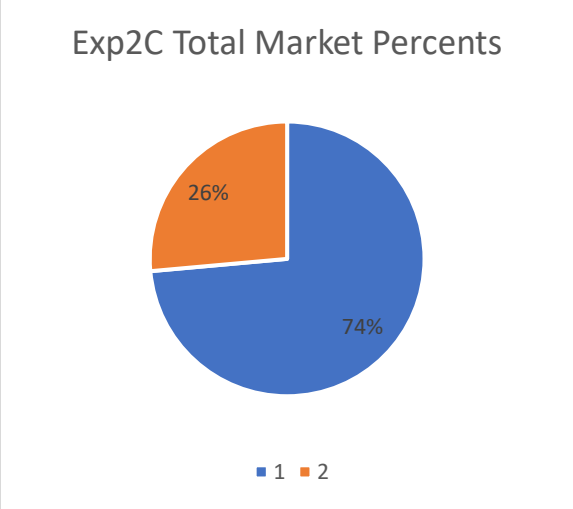


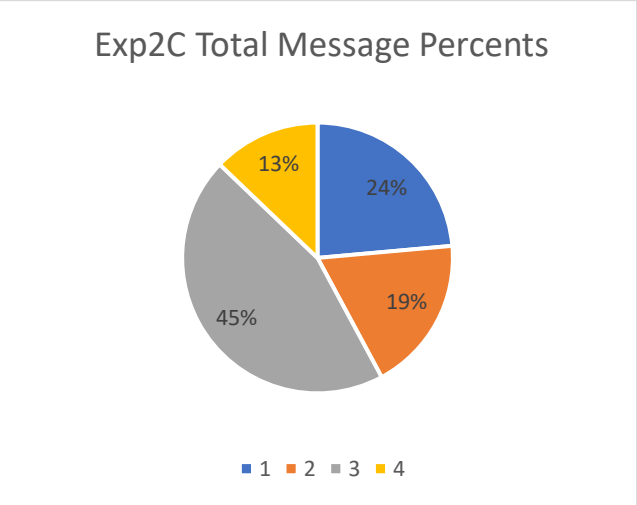


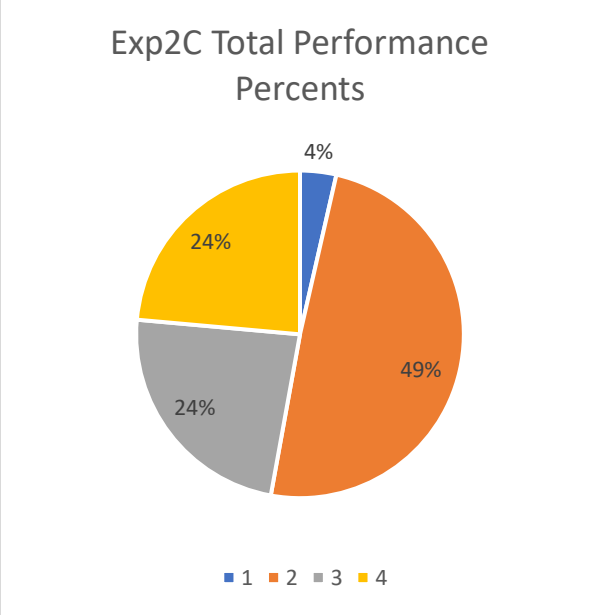


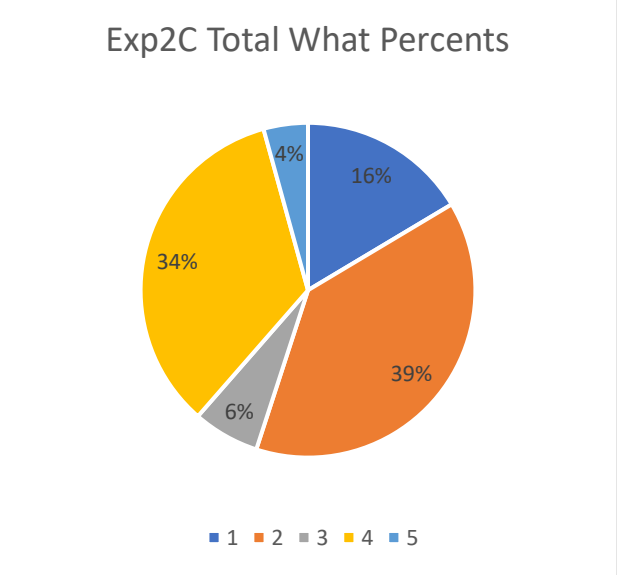


Taxonomy Code Breakdowns for all of Experience 2 using combined product pair lists:

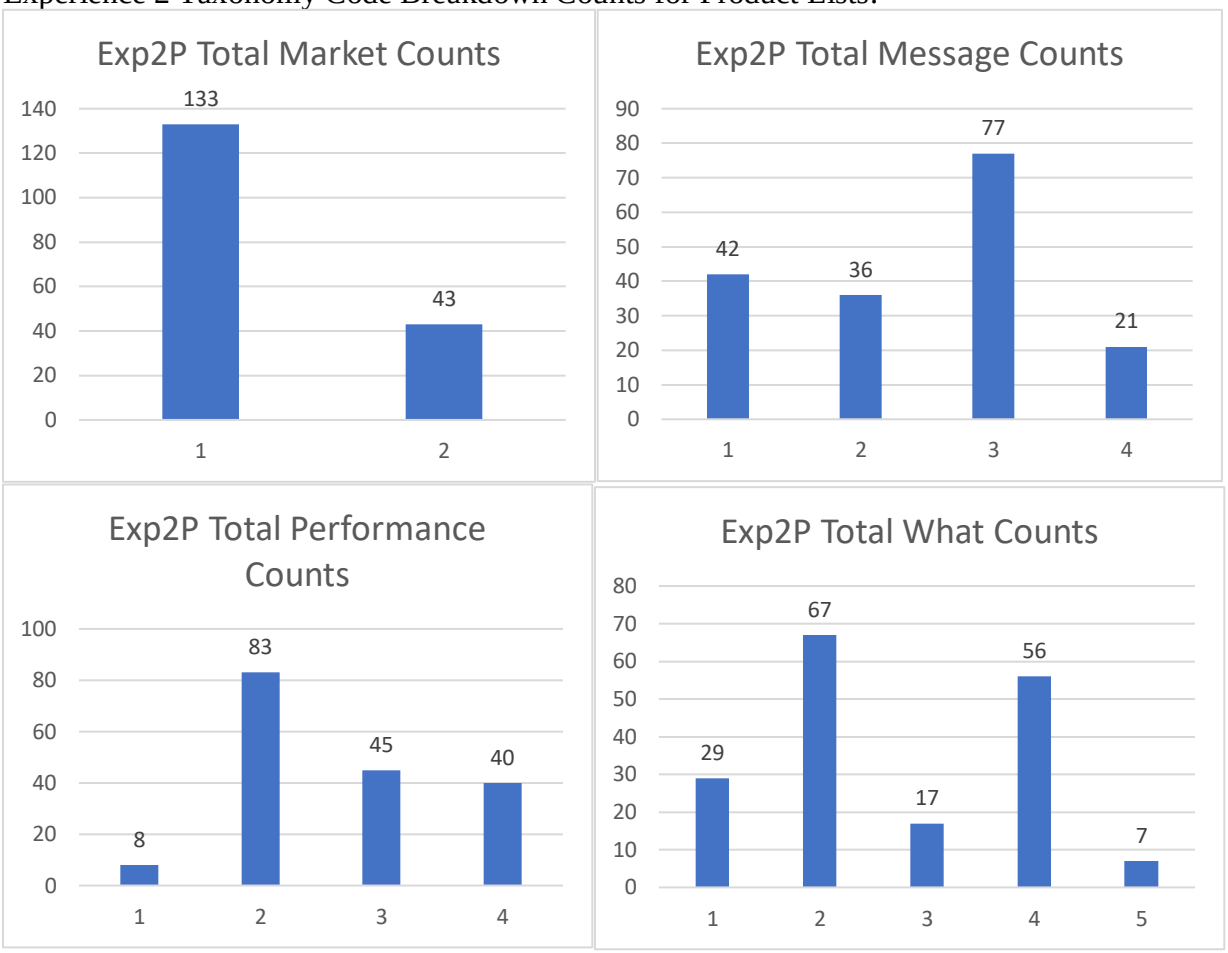




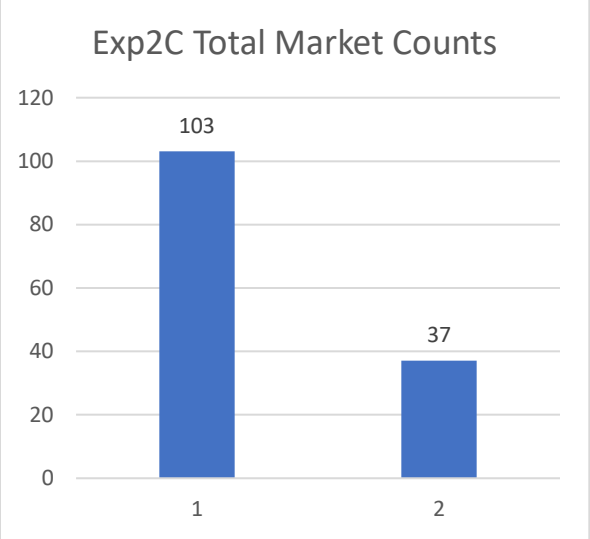


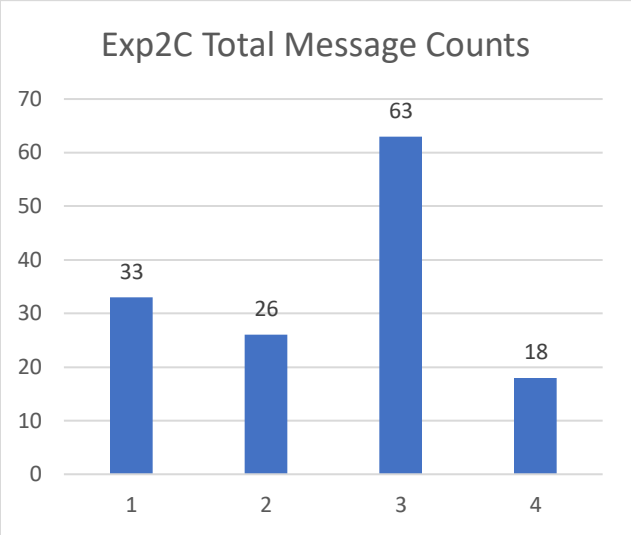


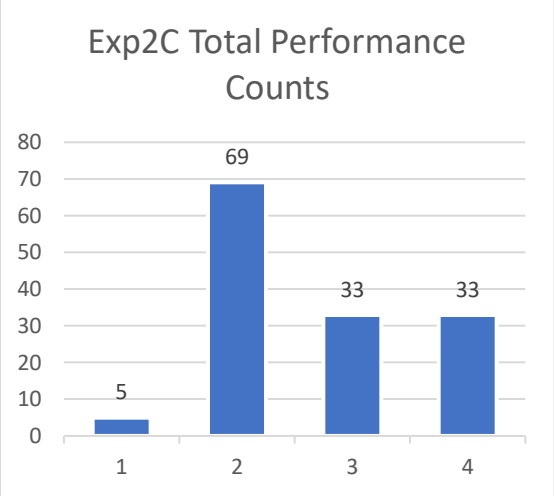
Experience 2 Taxonomy Code Breakdown Counts for Product Lists:

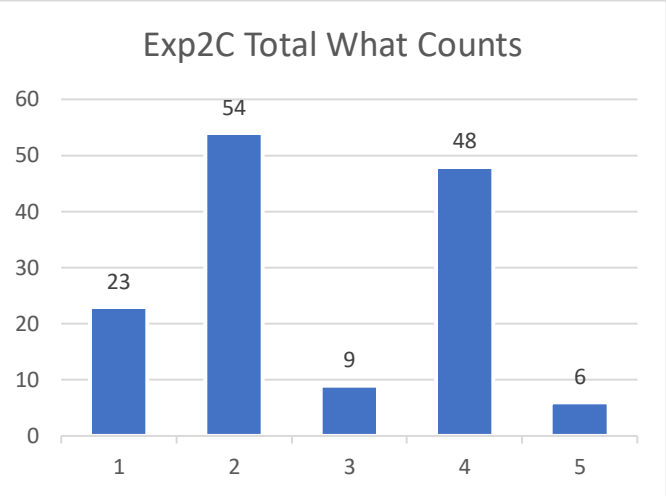


Experience 2 Taxonomy Code Breakdown Counts for Combined Lists:

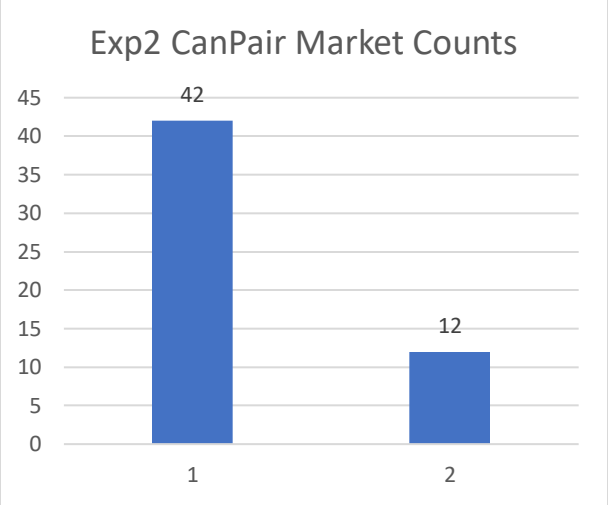


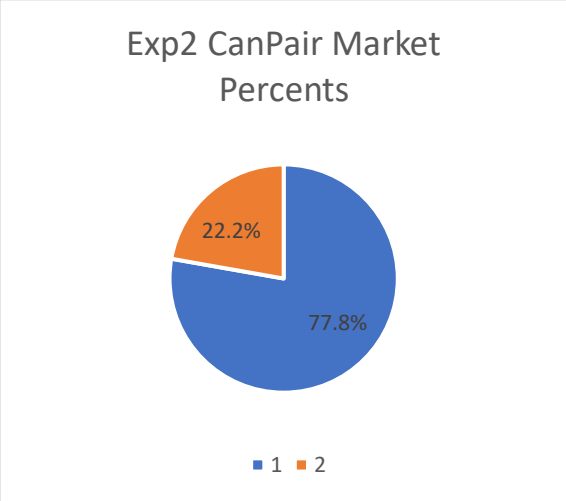


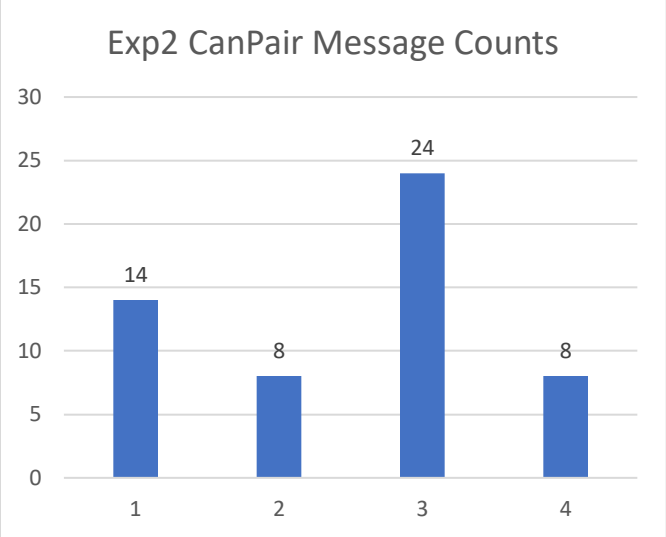


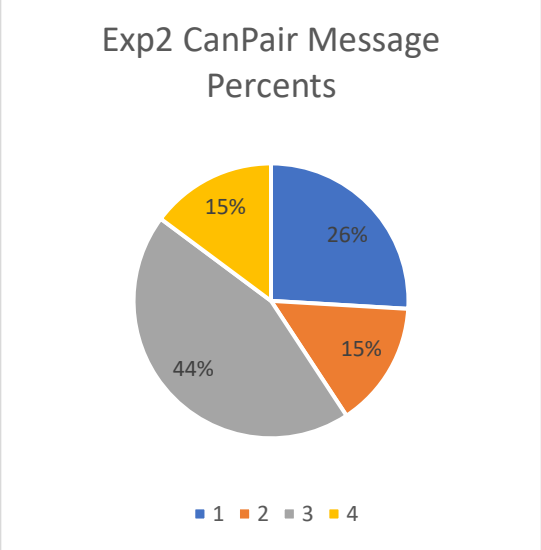


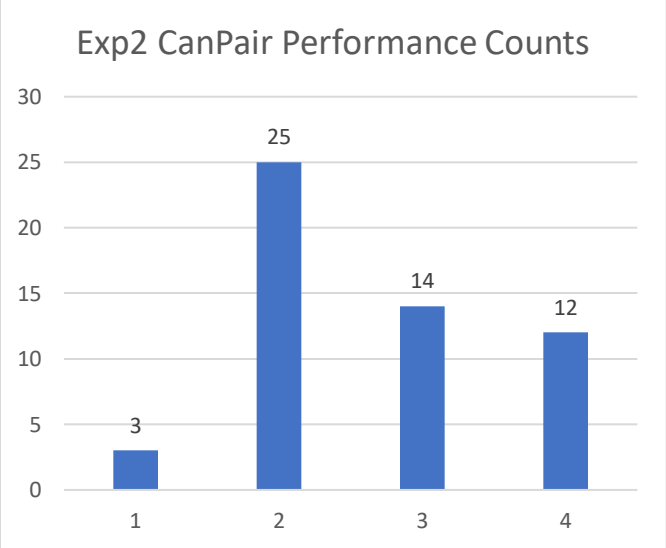
Experience 2 Taxonomy Code Breakdowns by Count and Percent for the Can Opener Pair List:

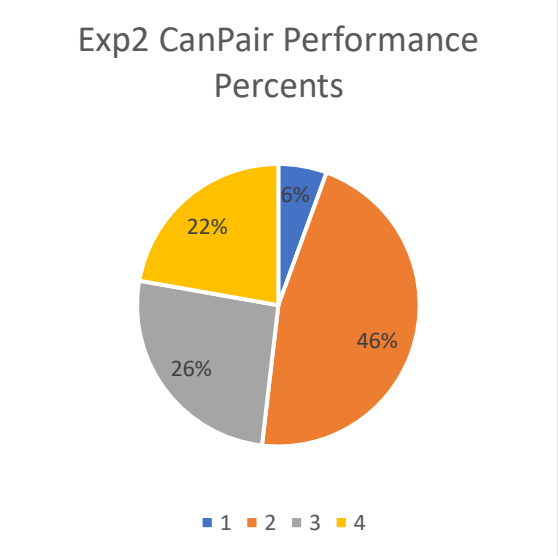


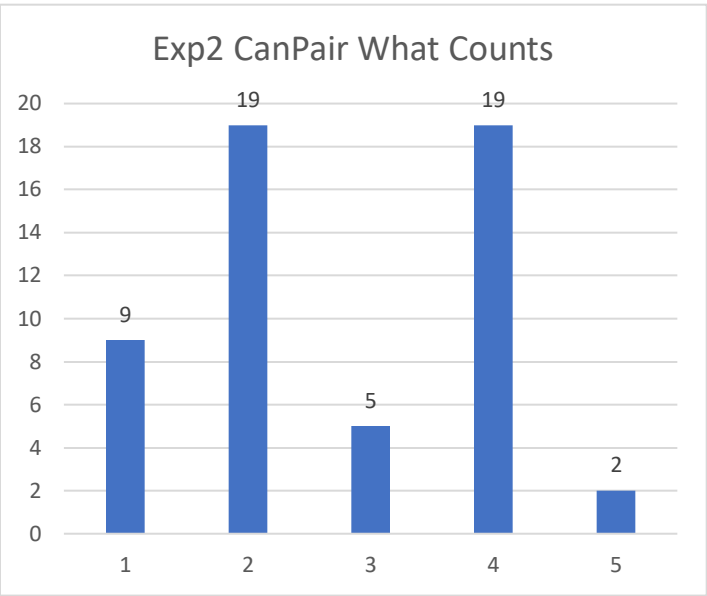


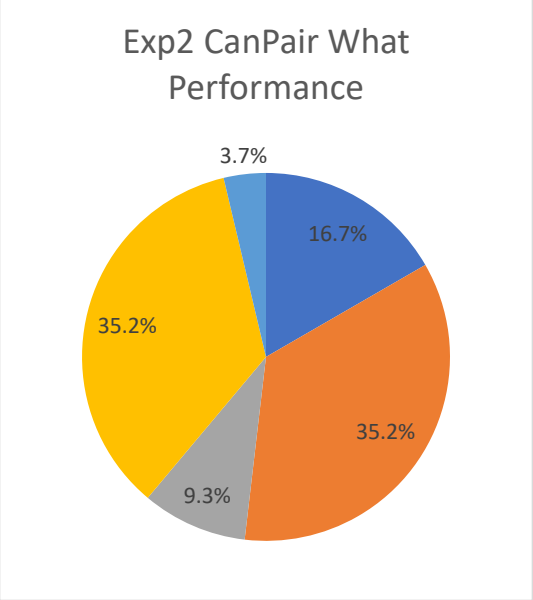




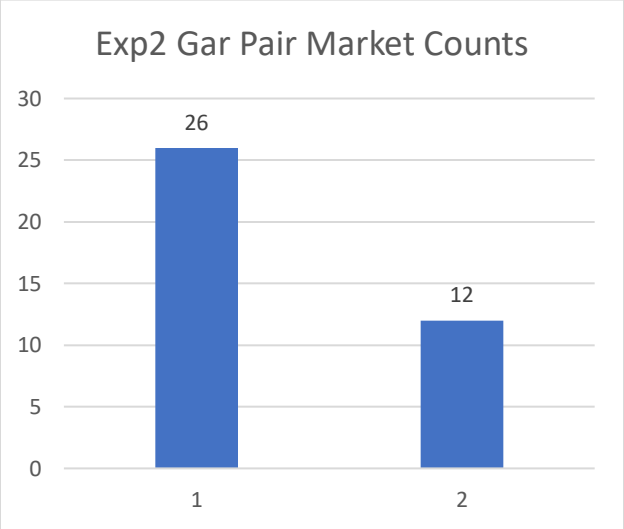


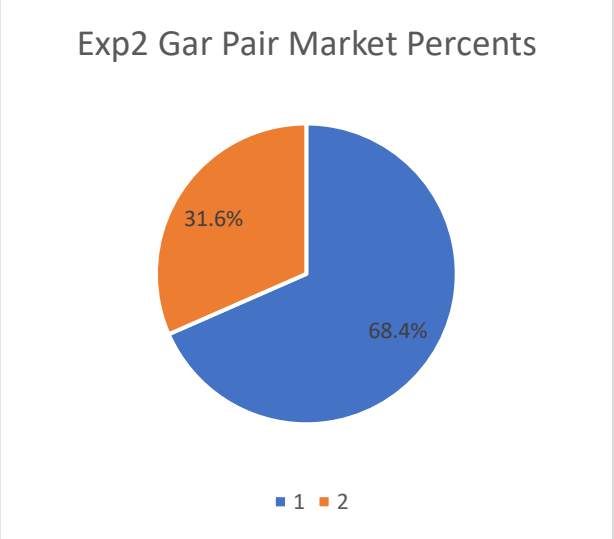


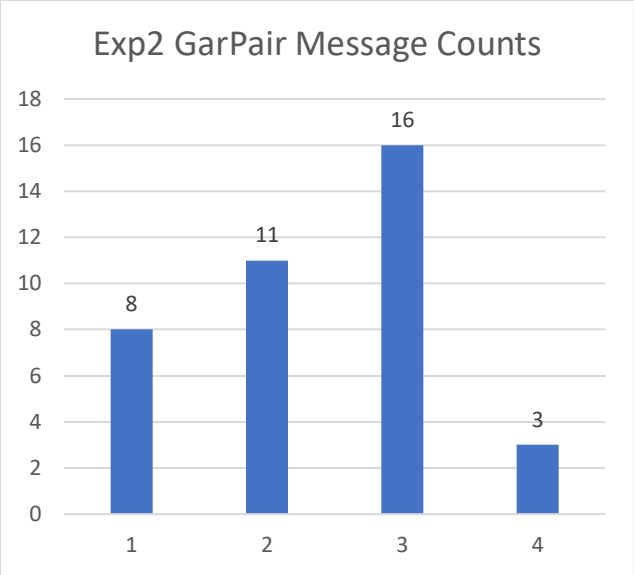


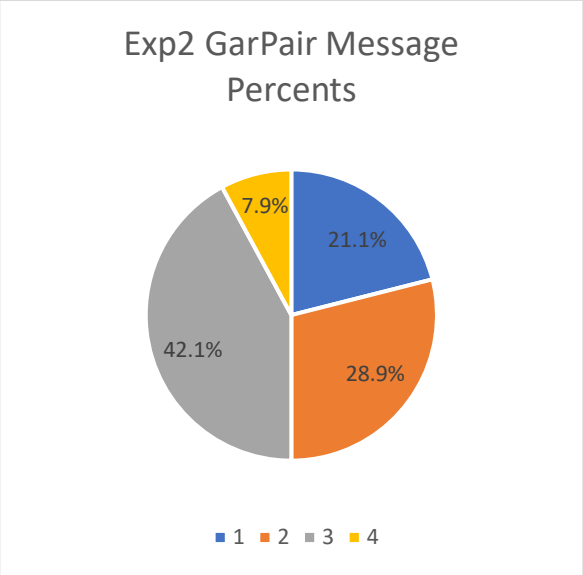


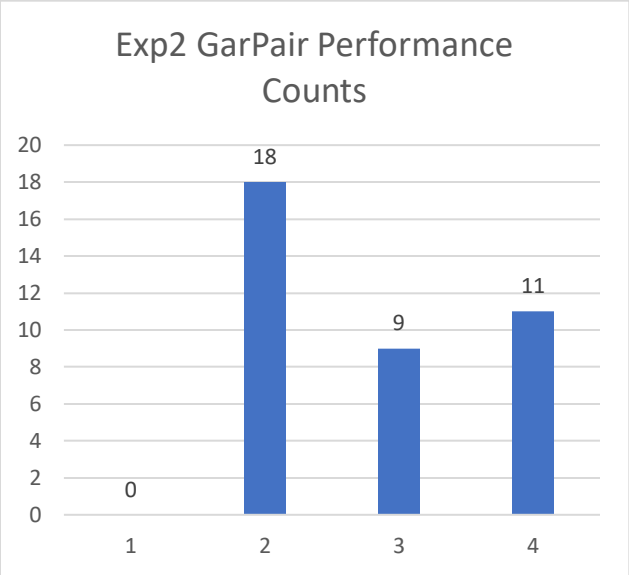
Experience 2 Taxonomy Code Breakdowns for Garlic Press Pair List:

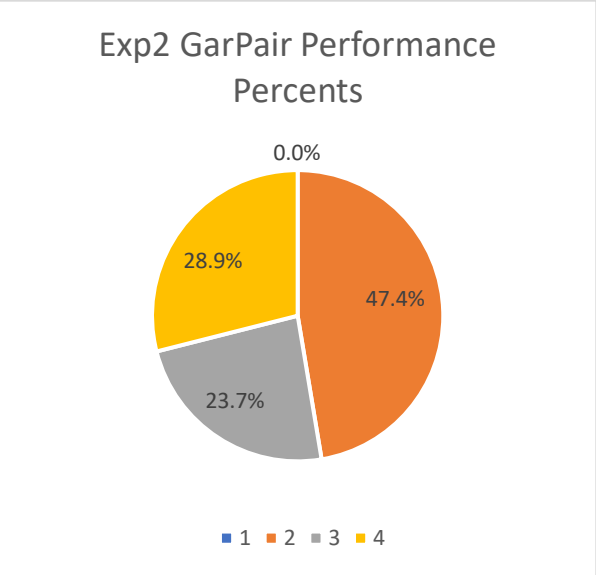


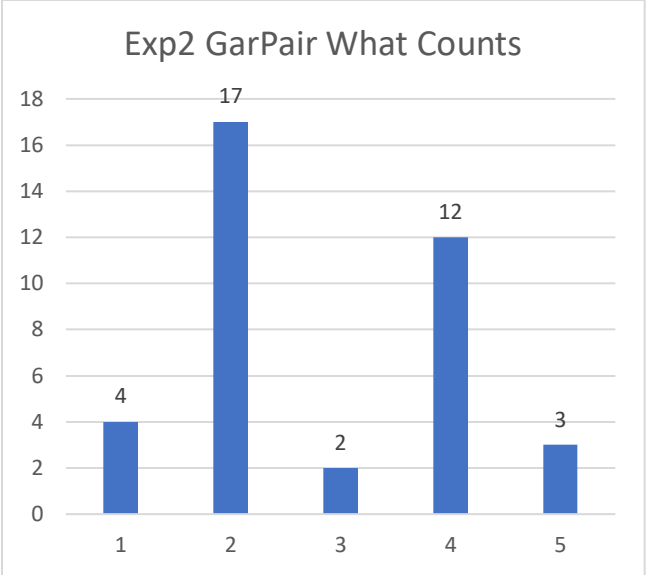


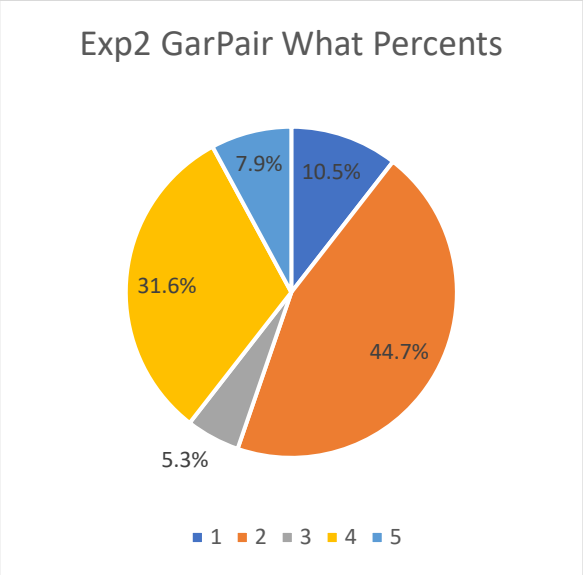

Exp2 GarPair Message Counts
18
16
14
12
10
8
6
4
2
0
8
11
16
3
1
2
3
4


Exp2 GarPair Message Percents
7.9%
21.1%
42.1%
28.9%
1
2
3
4

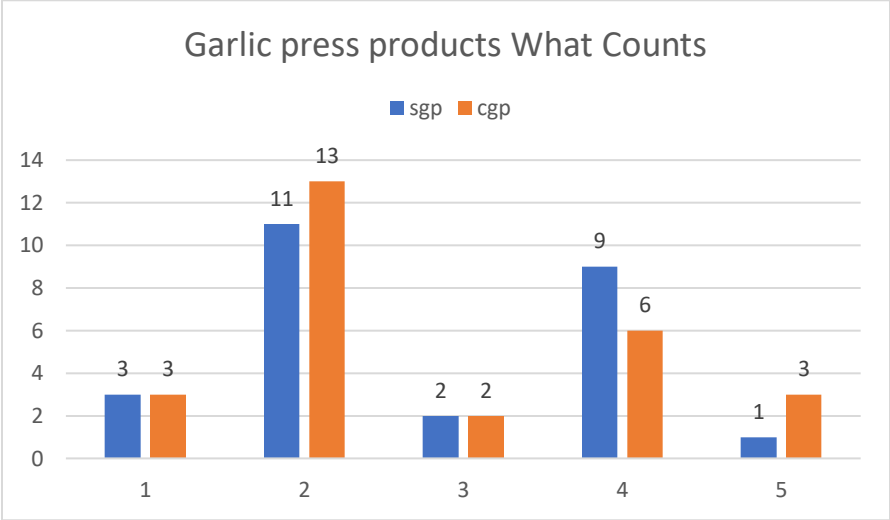

Exp2 GarPair Performance Counts
20
18
16
14
12
10
8
6
4
2
0
0
18
9
11
1
2
3
4

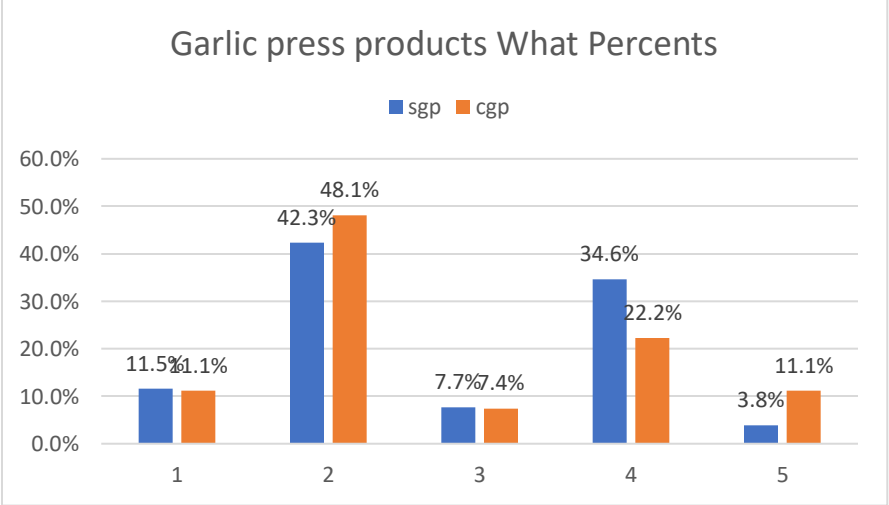

Exp2 GarPair Performance Percents
0.0%
28.9%
47.4%
23.7%
1
2
3
4



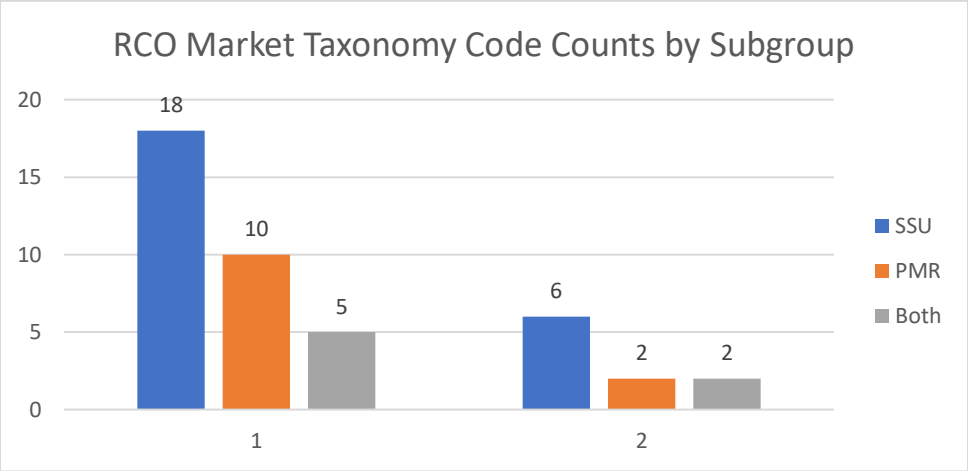


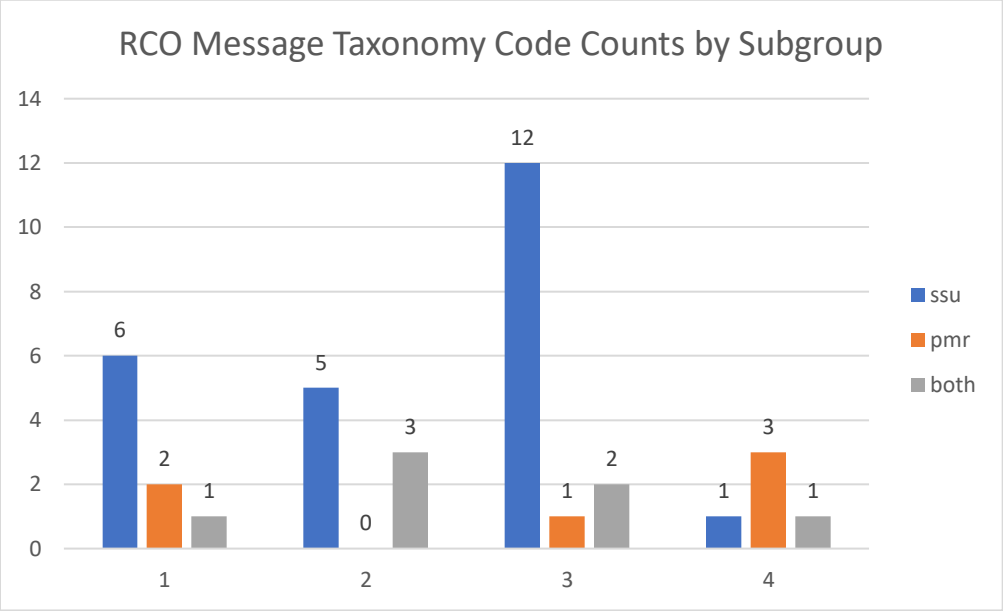
Experience 2 Garlic Press What Taxonomy Breakdowns by Subgroups

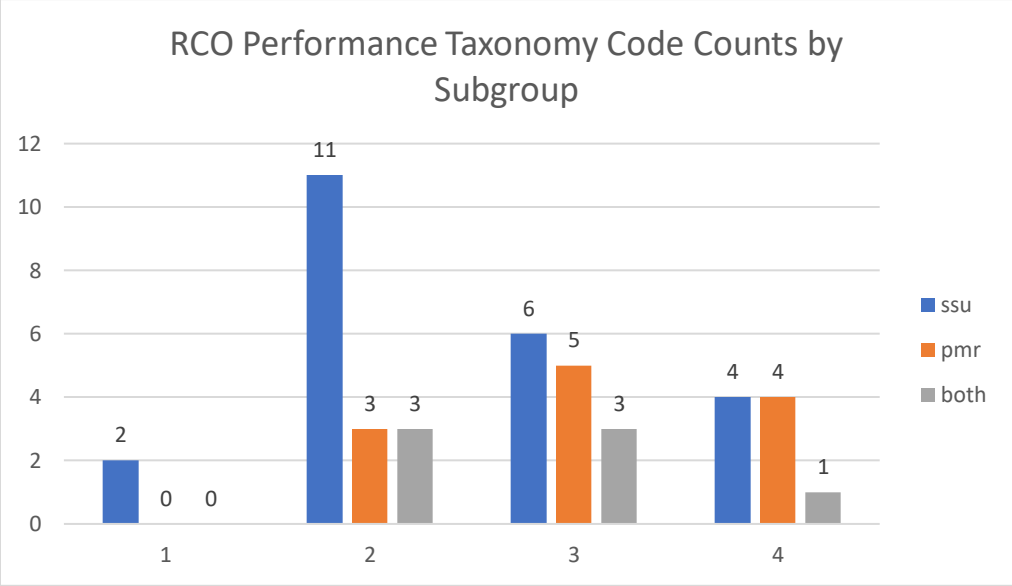


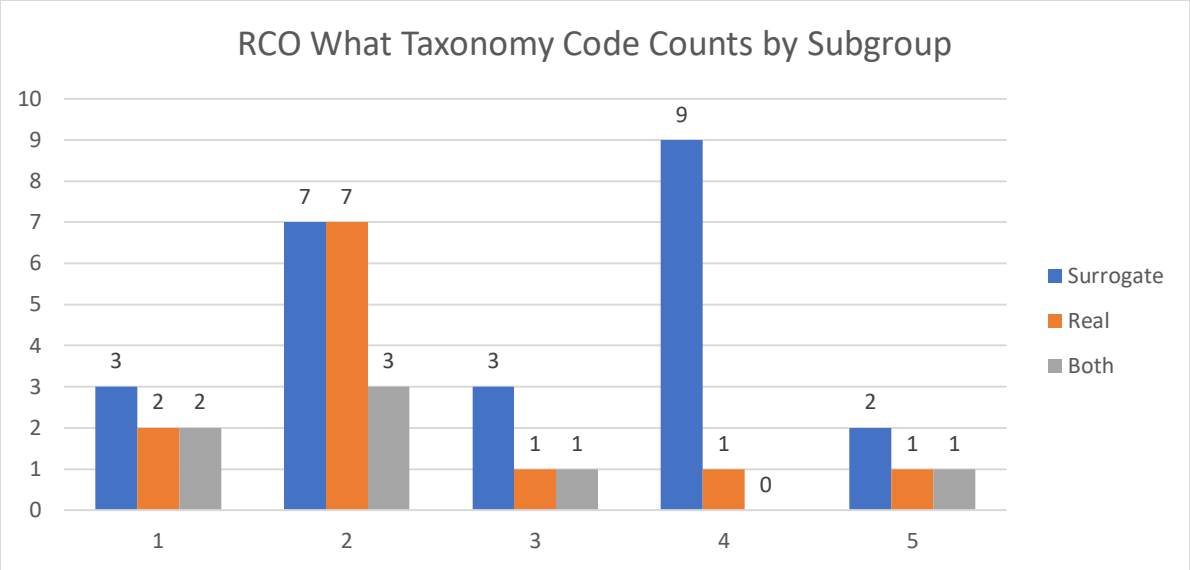


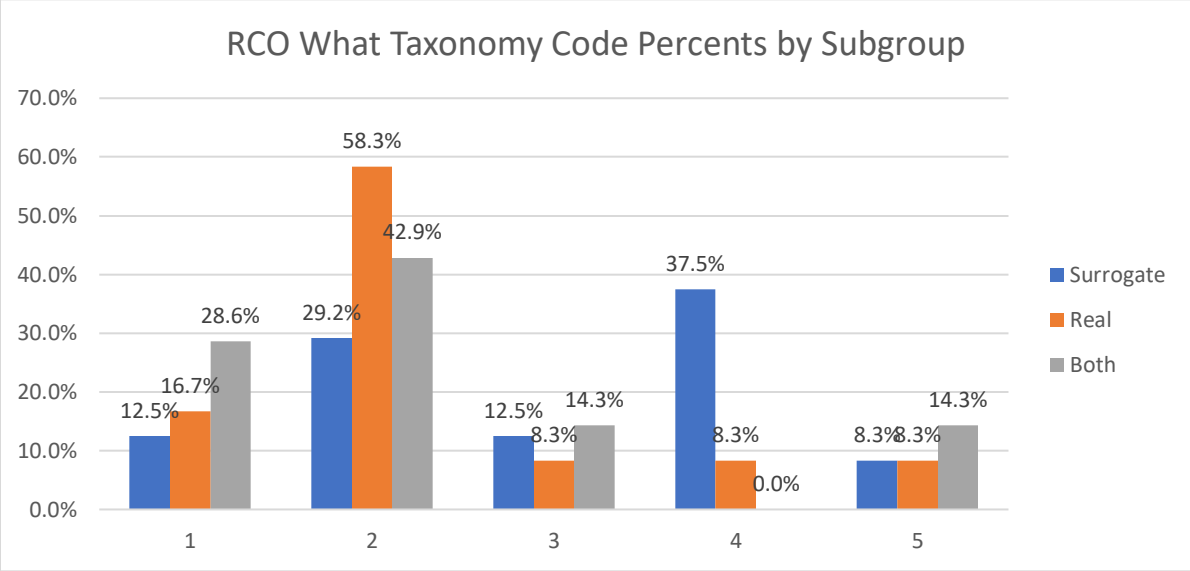
Exp2 Taxonomy Code Breakdowns by Subgroup for RCO Product:



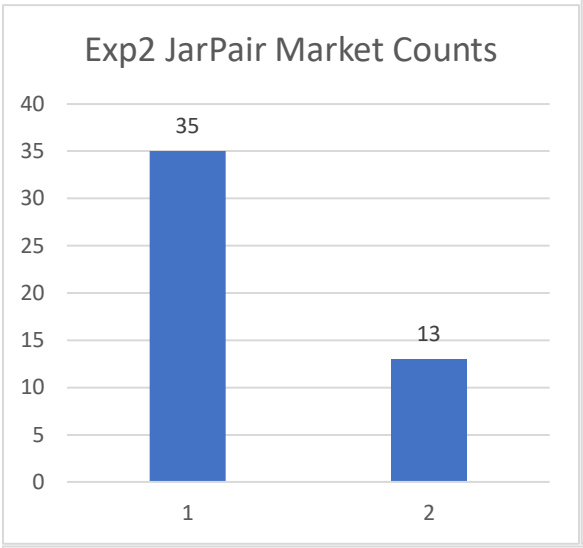


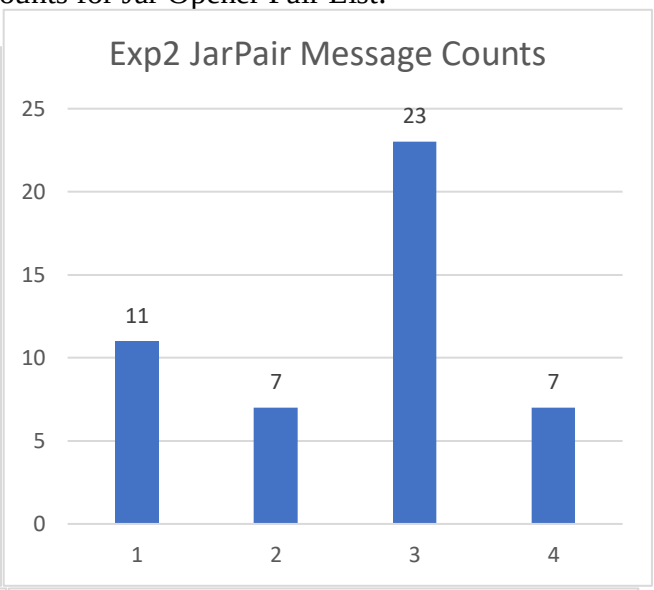


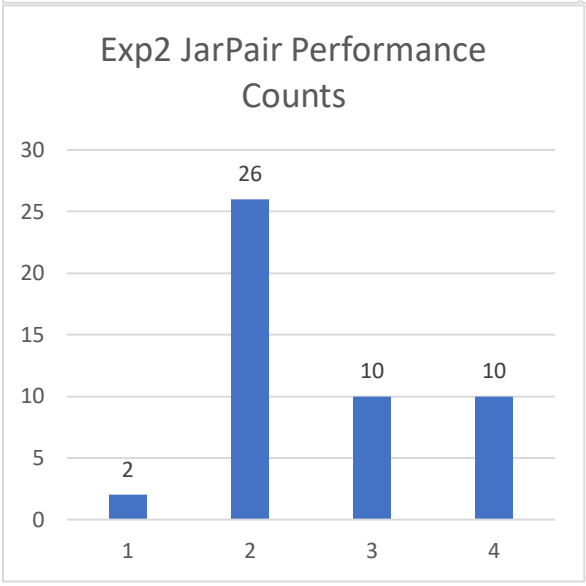

RCO What Taxonomy Code Counts by Subgroup
10
9
8
7
6
5
4
3
2
1
0
3
2
2
7
7
3
3
1
1
9
1
0
2
1
1
1
2
3
4
5
Surrogate
Real
Both

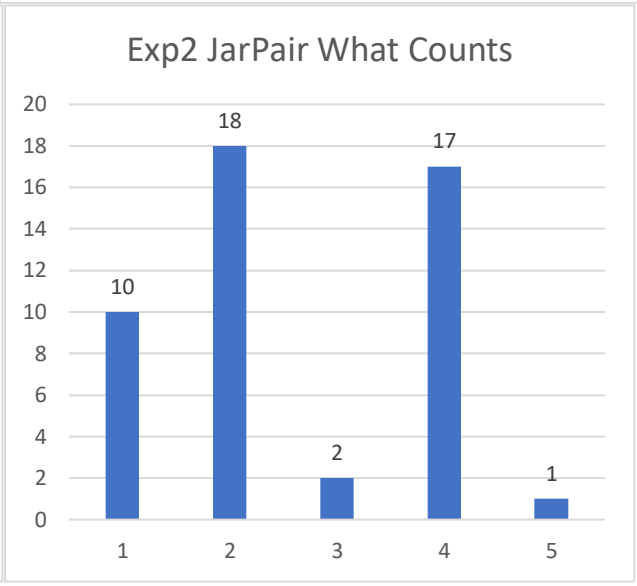

RCO What Taxonomy Code Percents by Subgroup
70.0%
60.0%
50.0%
40.0%
30.0%
20.0%
10.0%
0.0%
12.5%
16.7%
28.6%
29.2%
58.3%
42.9%
12.5%
8.3%
14.3%
37.5%
8.3%
0.0%
8.3%
8.3%
14.3%
1
2
3
4
5
Surrogate
Real
Both

Experience 2 Taxonomy Code Breakdown Counts for Jar Opener Pair List:

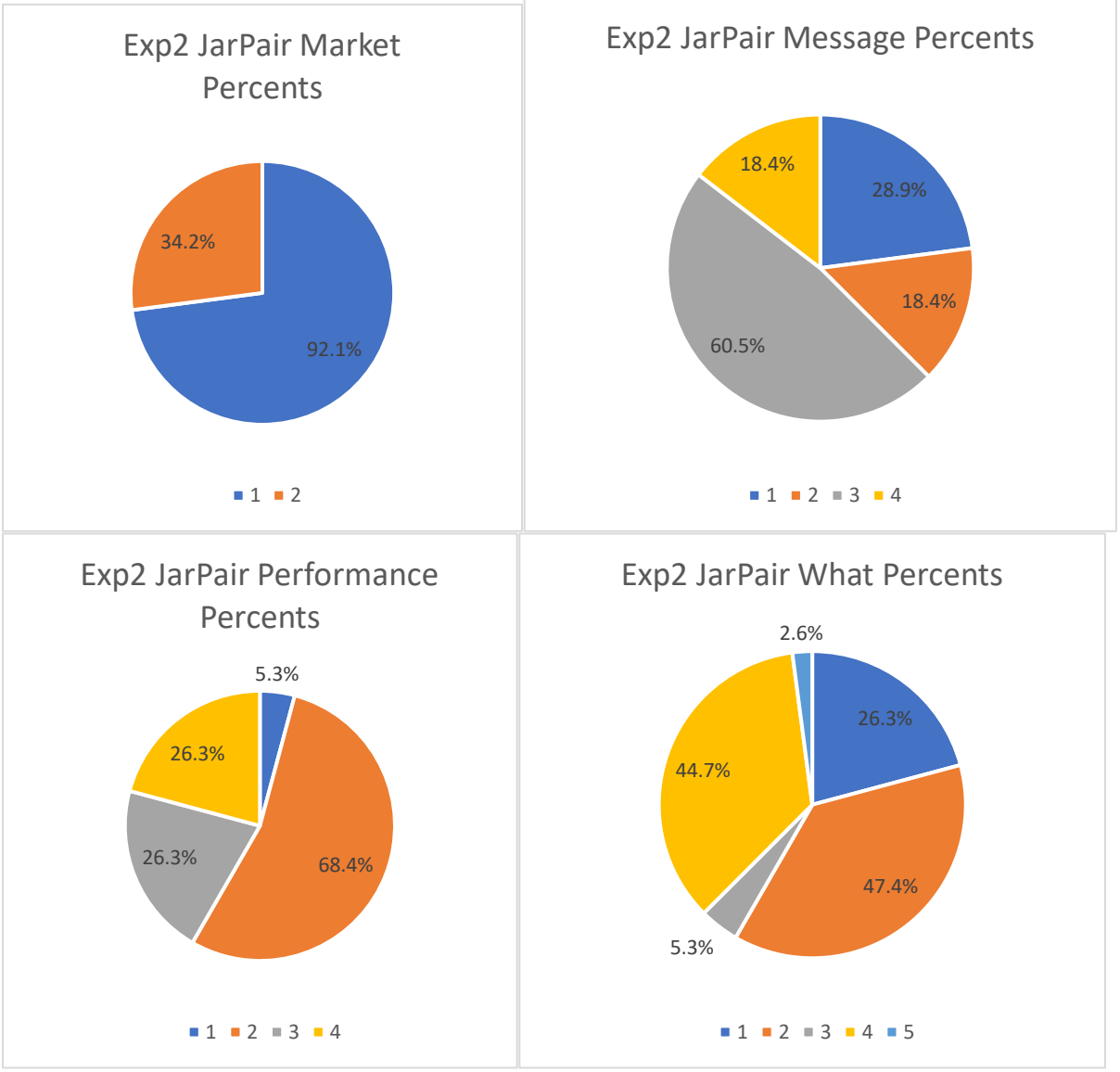




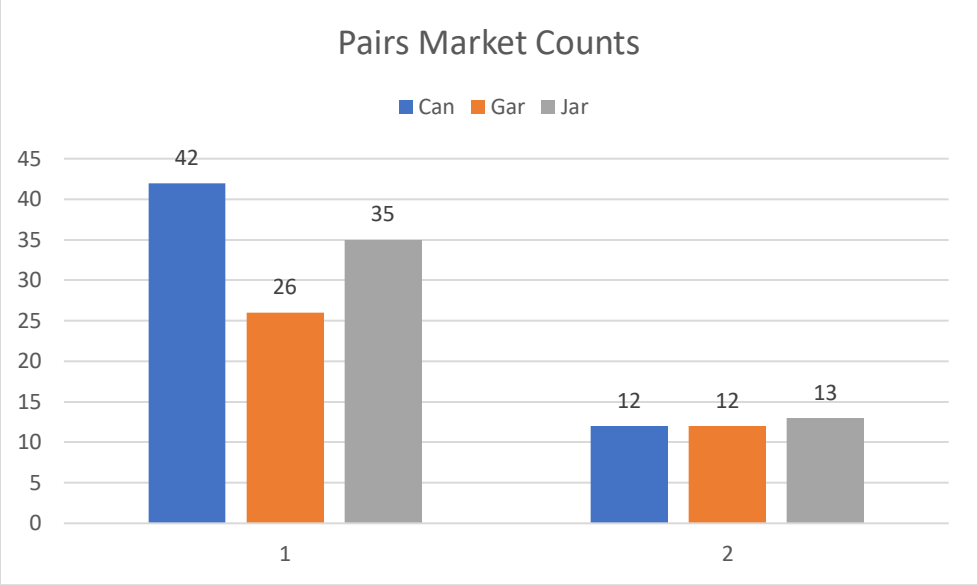


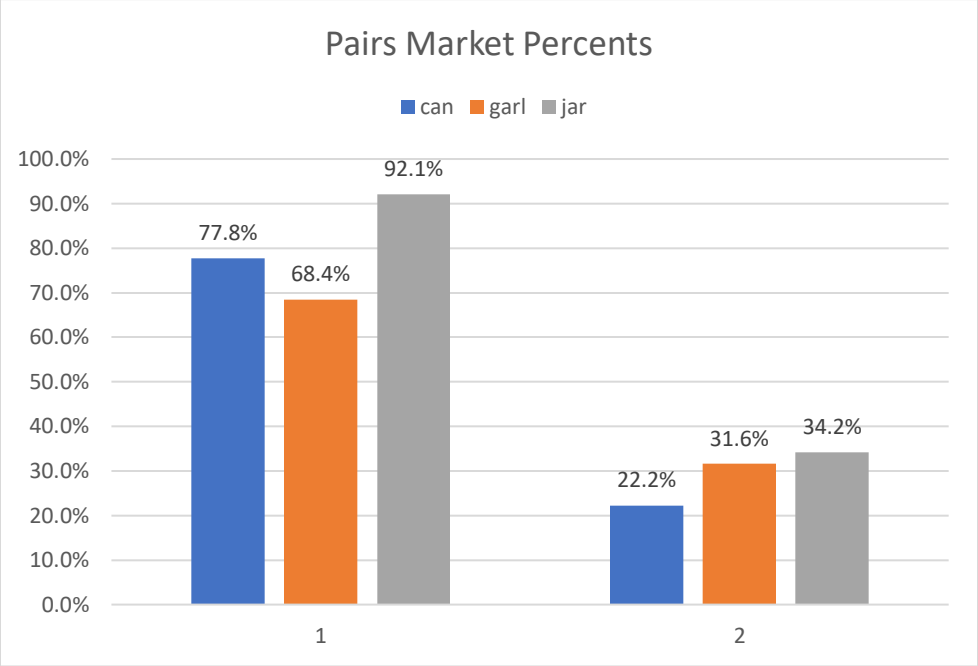


Experience 2 Taxonomy Code Breakdown Percentages for Jar Opener Pair List:



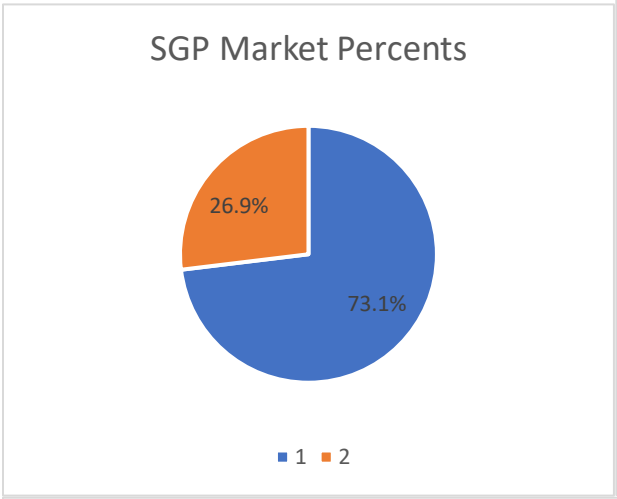
All of Exp2 Market Taxonomy Code Count and Percent Breakdowns by Product Pair:

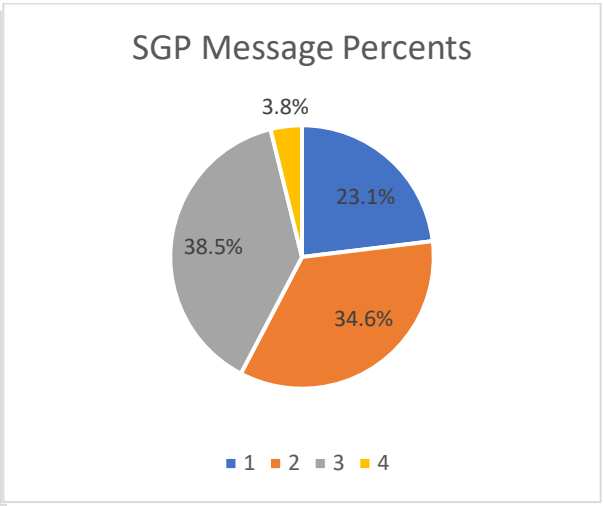


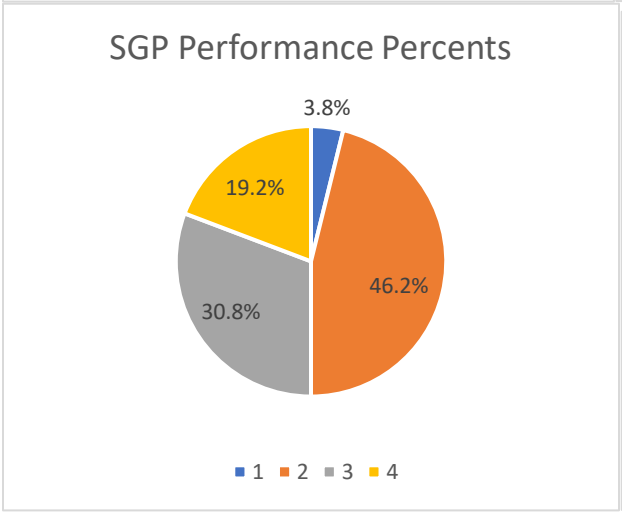


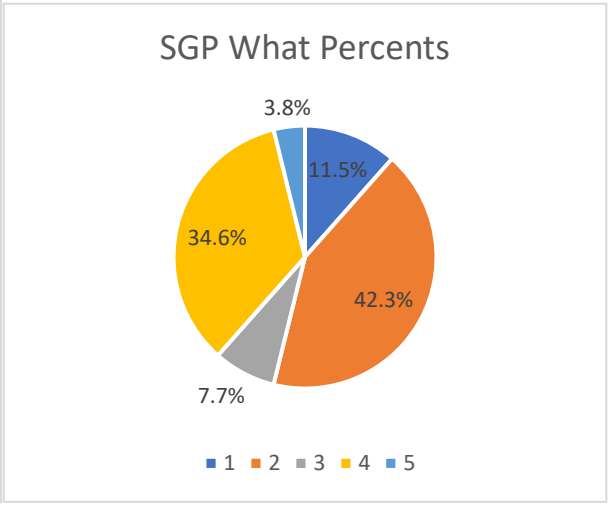
Pie Charts for Taxonomy Code Breakdowns by Percent of List for all 6 individual product lists:

SGP

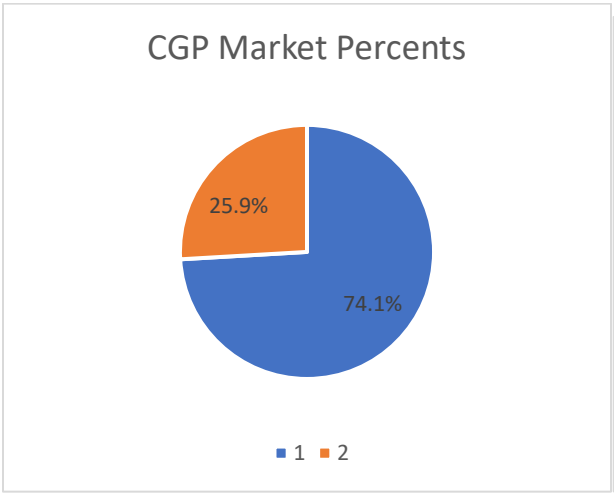


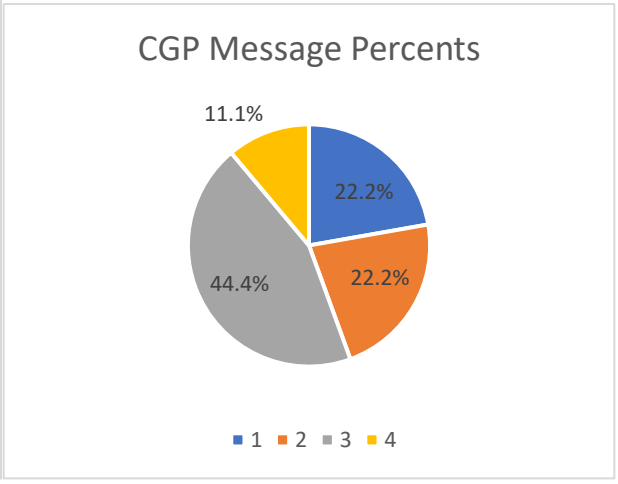


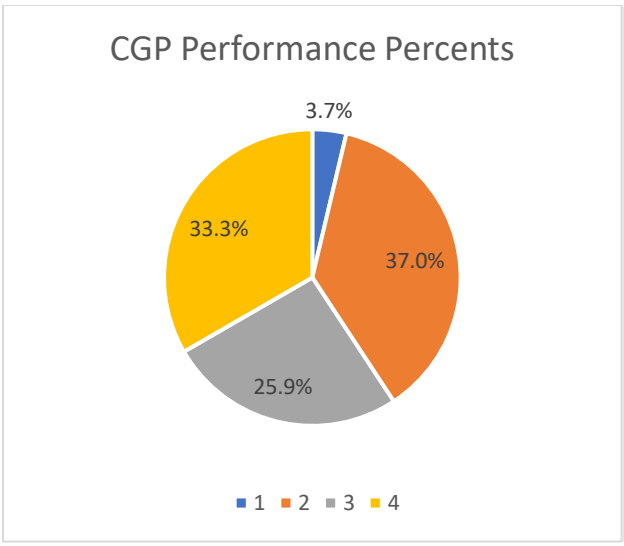


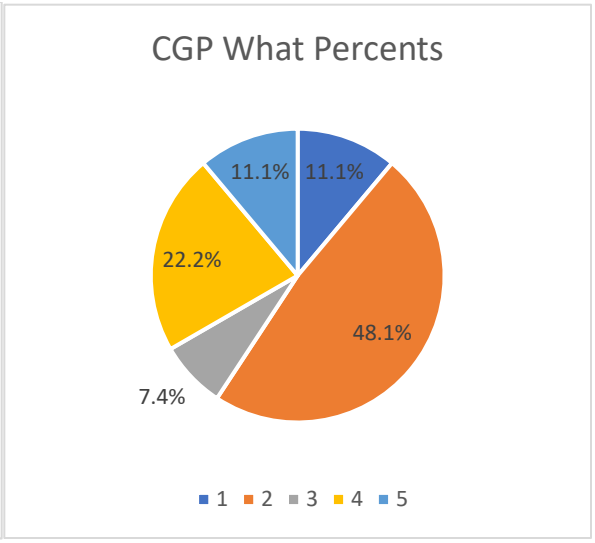


CGP

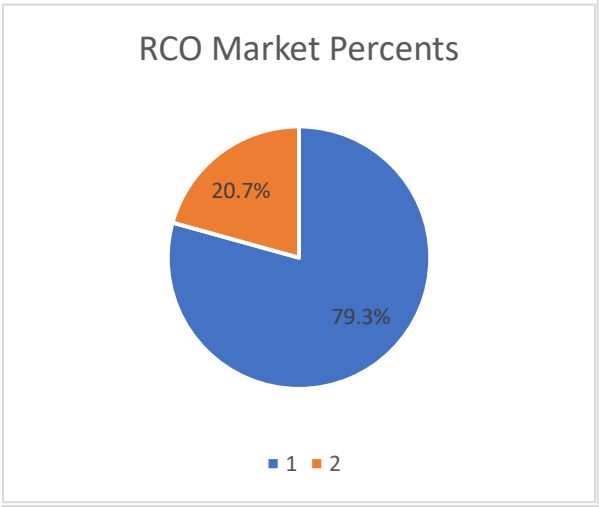


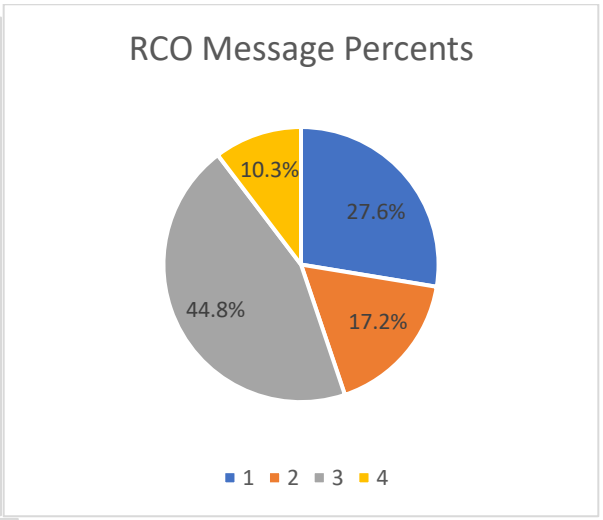


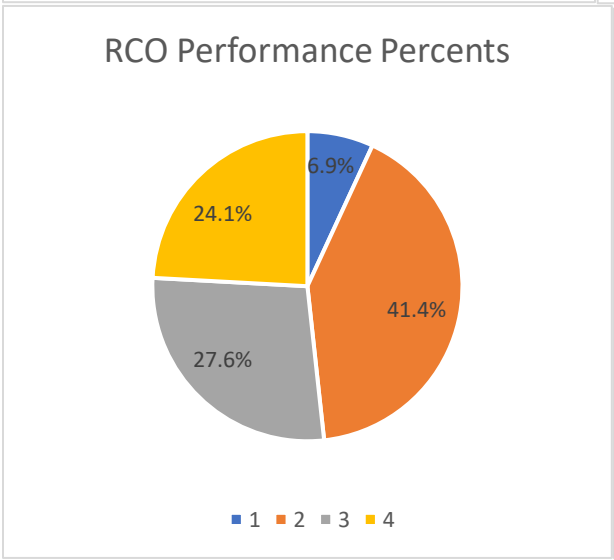

CGP Performance Percents
3.7%
37.0%
25.9%
33.3%
1 2 3 4

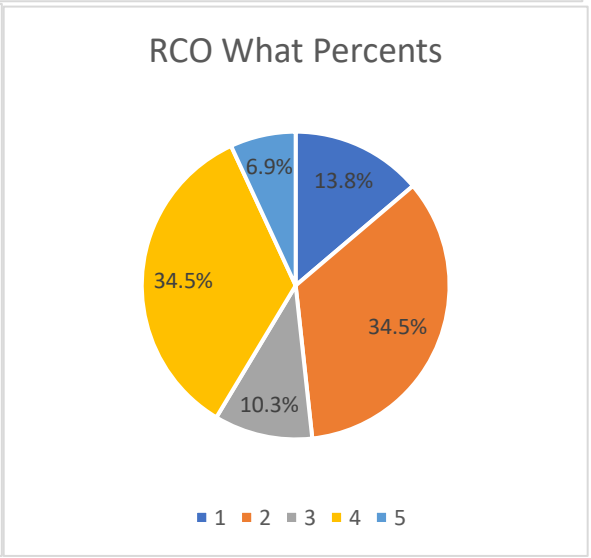

CGP What Percents
11.1%
11.1%
48.1%
7.4%
22.2%
1 2 3 4 5

RCO

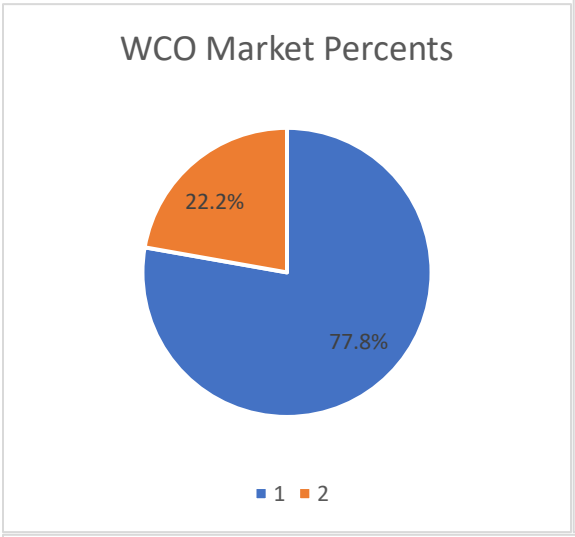

RCO Market Percents
20.7%
79.3%
1 2

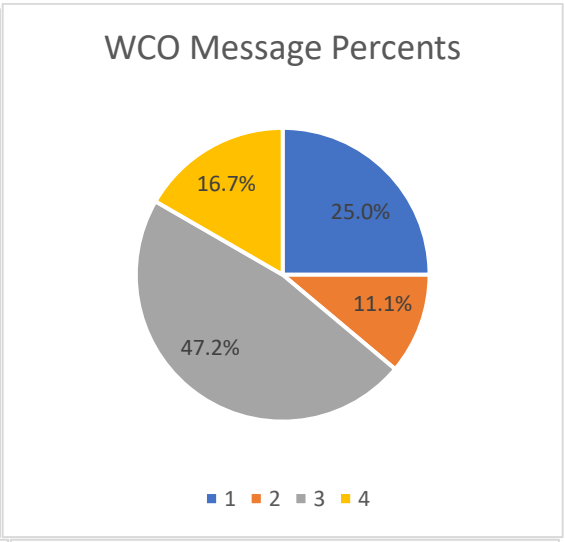

RCO Message Percents
10.3%
27.6%
44.8%
17.2%
1 2 3 4

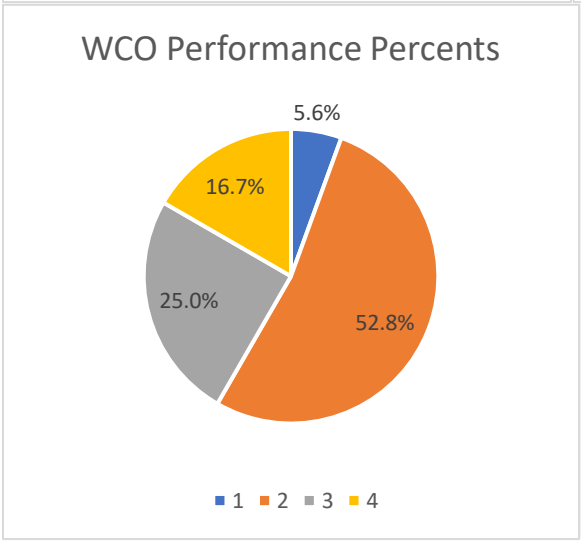

RCO Performance Percents
6.9%
24.1%
41.4%
27.6%
1 2 3 4

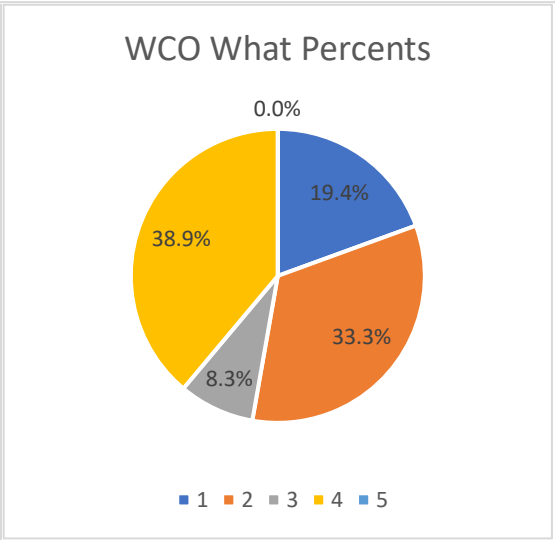

RCO What Percents
6.9%
13.8%
34.5%
34.5%
10.3%
1 2 3 4 5

WCO

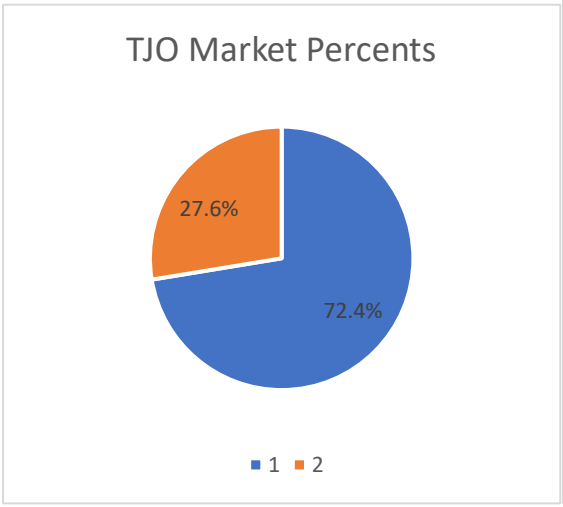

WCO Market Percents
22.2%
77.8%
1 2

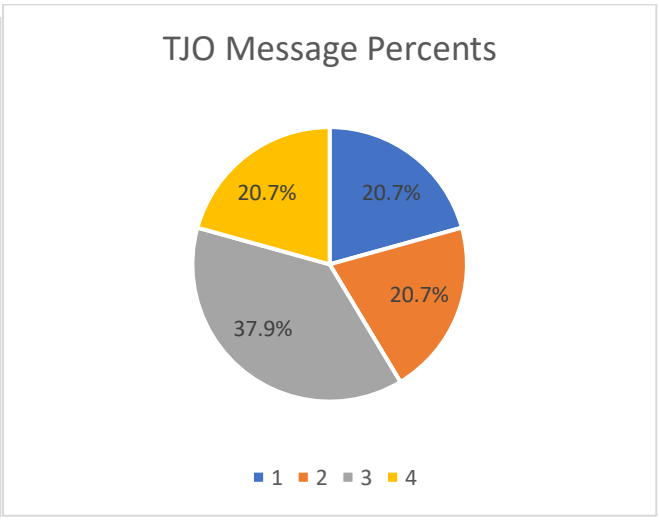

WCO Message Percents
16.7%
25.0%
11.1%
47.2%
1 2 3 4

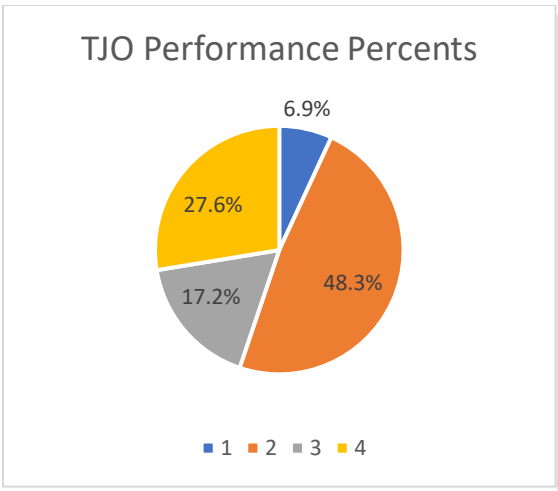

WCO Performance Percents
5.6%
16.7%
25.0%
52.8%
1 2 3 4

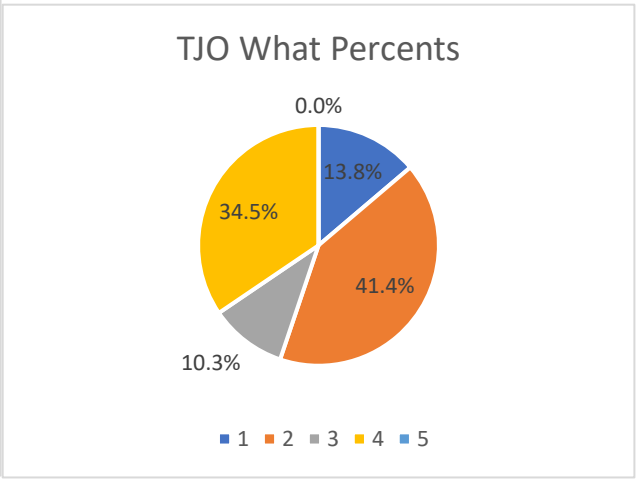

WCO What Percents
0.0%
19.4%
38.9%
33.3%
8.3%
1 2 3 4 5

TJO

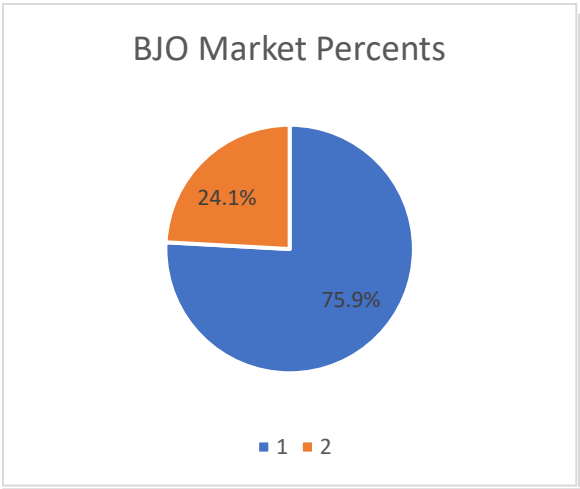

TJO Market Percents
27.6%
72.4%
1 2

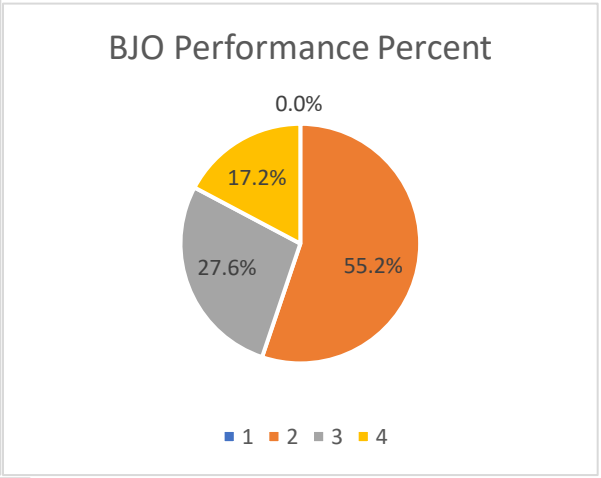

TJO Message Percents
20.7%
20.7%
20.7%
37.9%
1 2 3 4

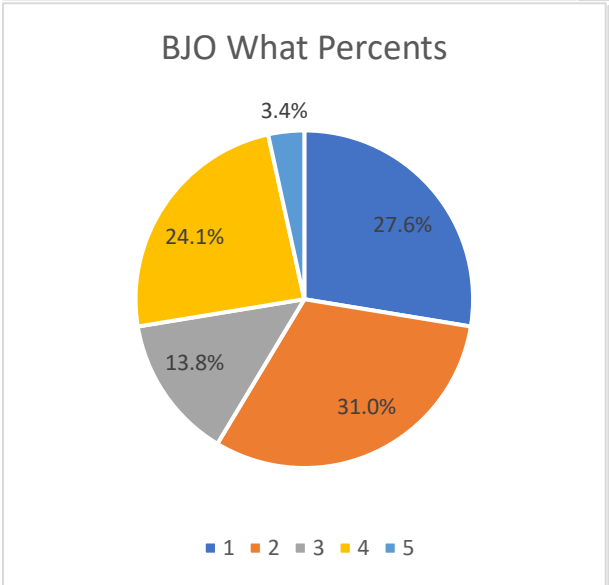

TJO Performance Percents
6.9%
27.6%
48.3%
17.2%
1 2 3 4

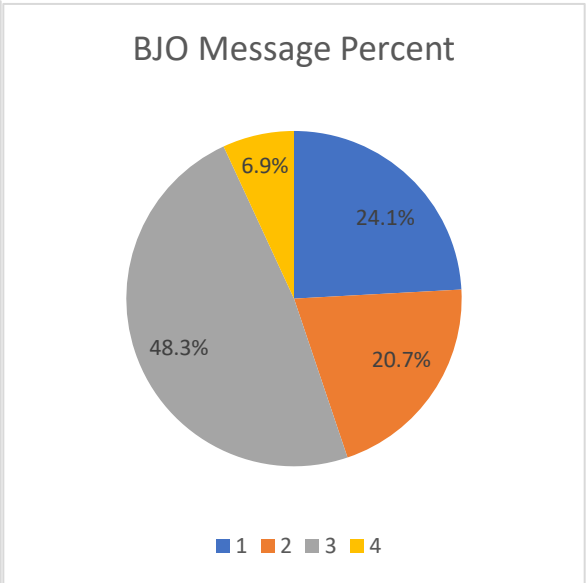

TJO What Percents
0.0%
13.8%
34.5%
41.4%
10.3%
1 2 3 4 5

BJO


BJO Market Percents
24.1%
75.9%
1 2

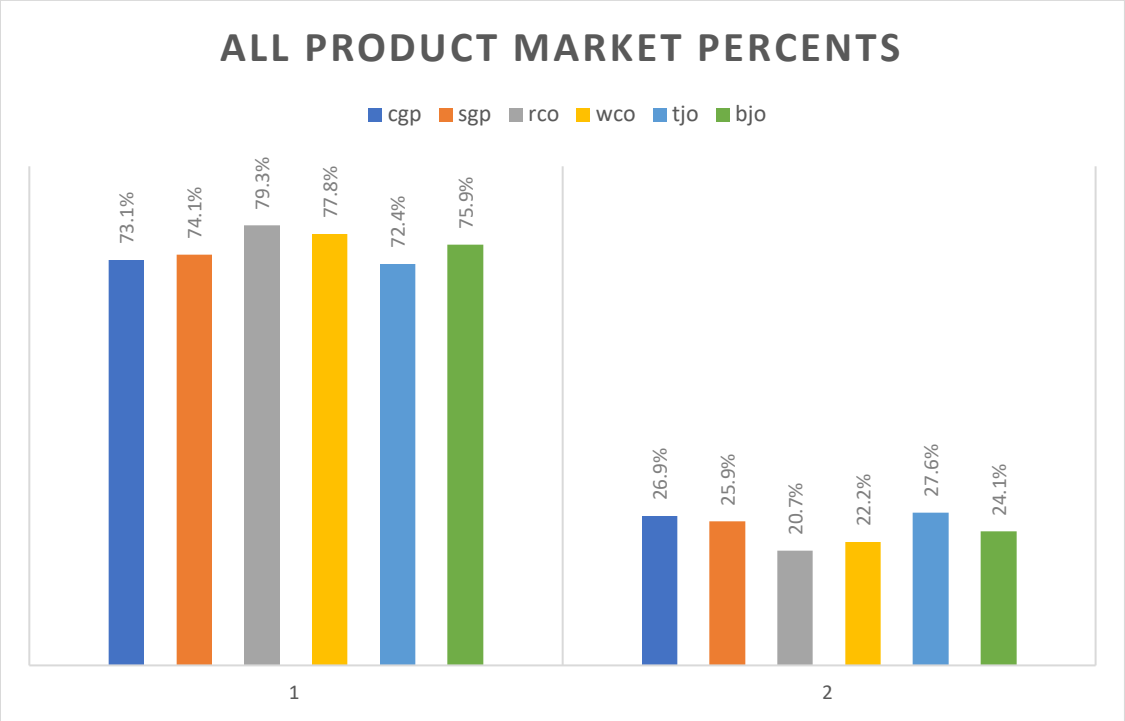

BJO Performance Percent
0.0%
17.2%
27.6%
55.2%
1 2 3 4

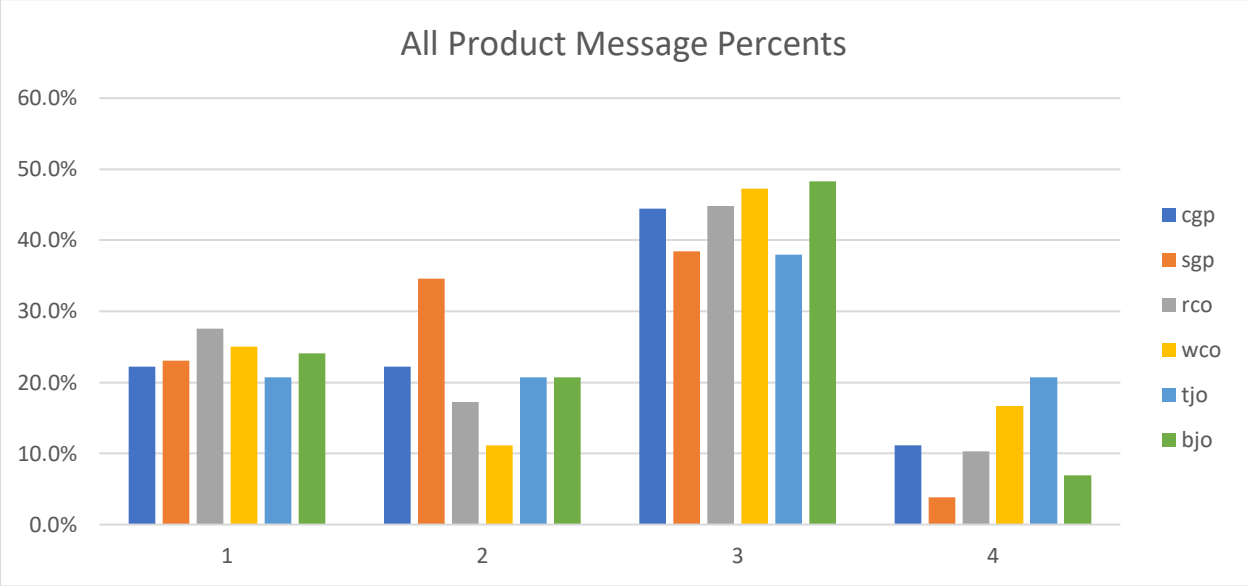

BJO What Percents
3.4%
24.1%
27.6%
13.8%
31.0%
1 2 3 4 5

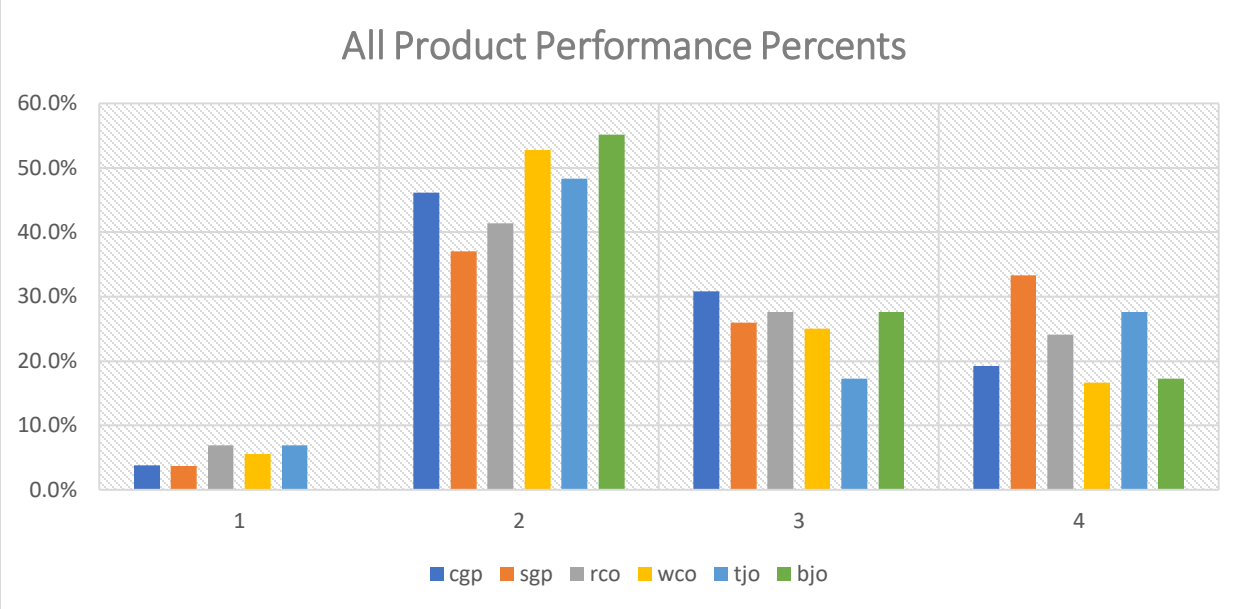

BJO Message Percent
6.9%
24.1%
48.3%
20.7%
1 2 3 4

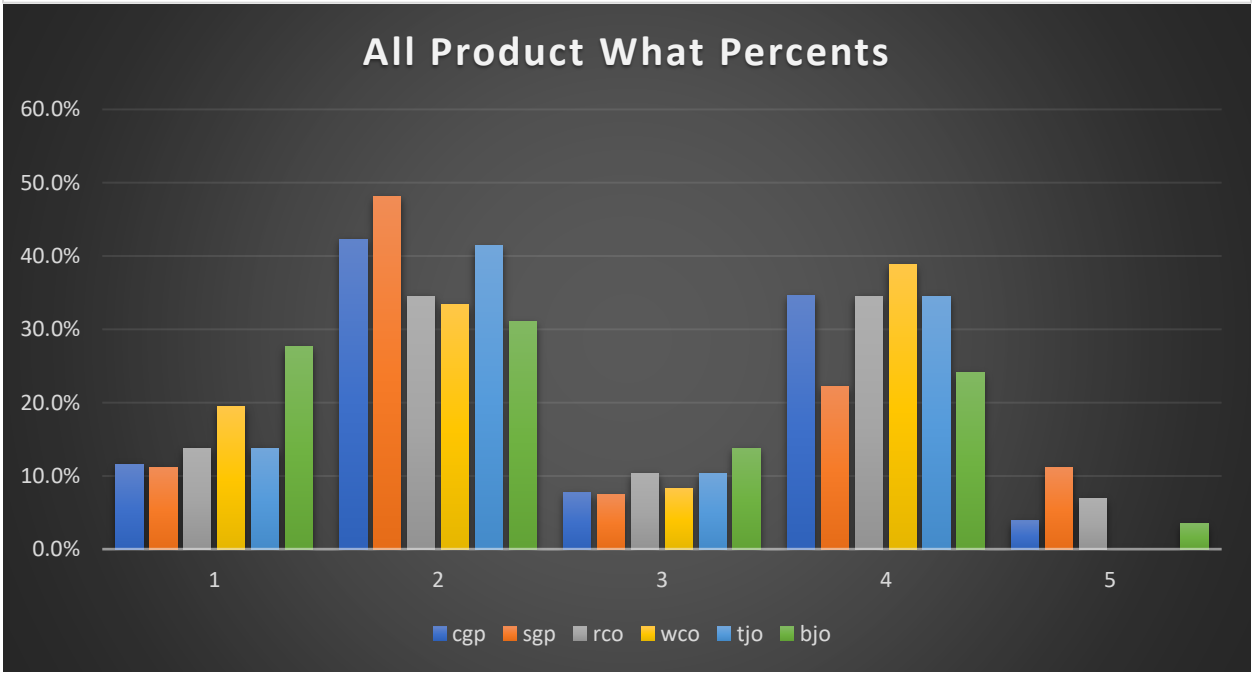
Appendix Q: Taxonomy Breakdowns by Products

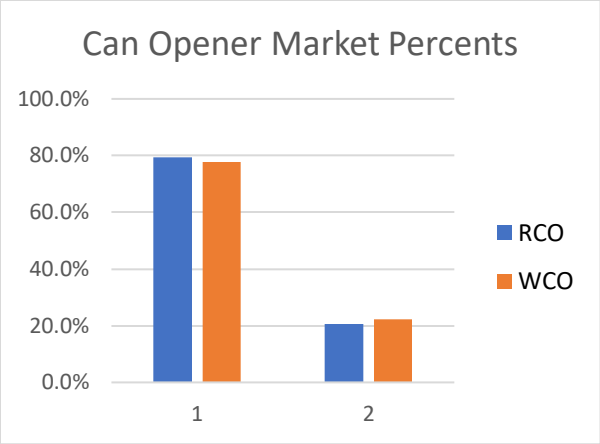
All of Exp2 Taxonomy Code Percent Breakdowns by Product:

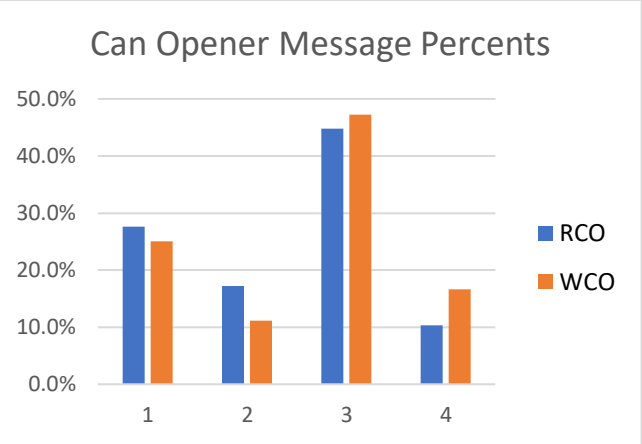


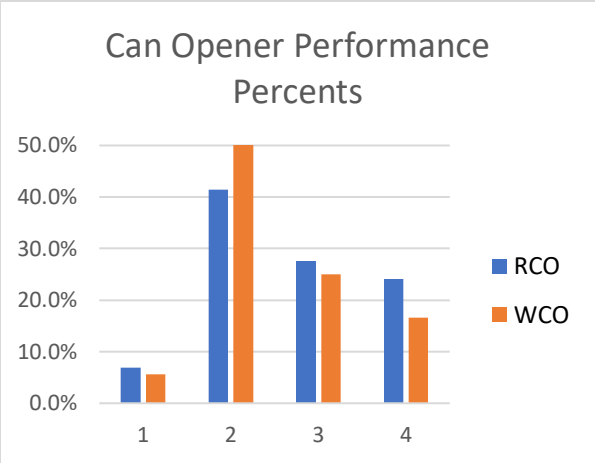


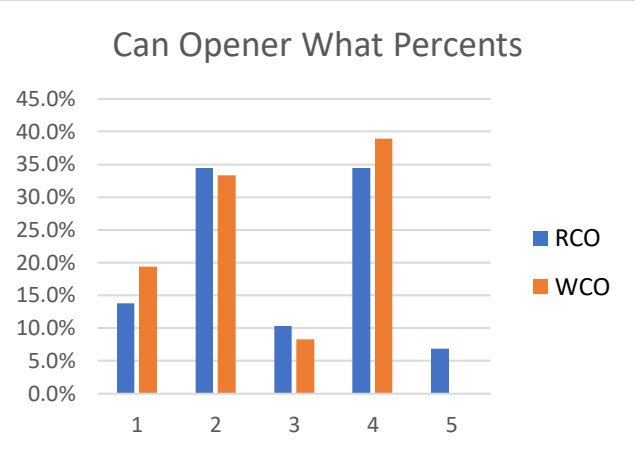

All Product Performance Percents
60.0%
50.0%
40.0%
30.0%
20.0%
10.0%
0.0%
1
2
3
4
cgp
sgp
rco
wco
tjo
bjo

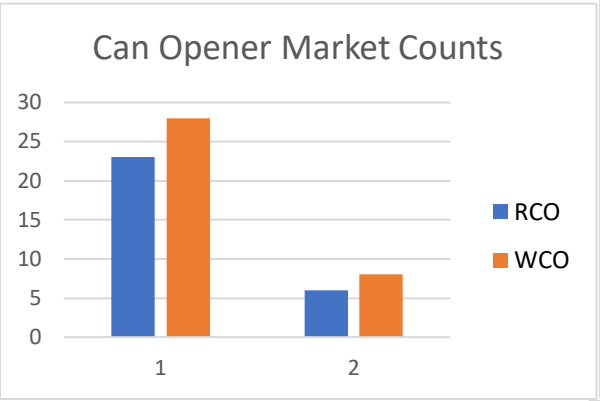

All Product What Percents
60.0%
50.0%
40.0%
30.0%
20.0%
10.0%
0.0%
1
2
3
4
5
cgp
sgp
rco
wco
tjo
bjo

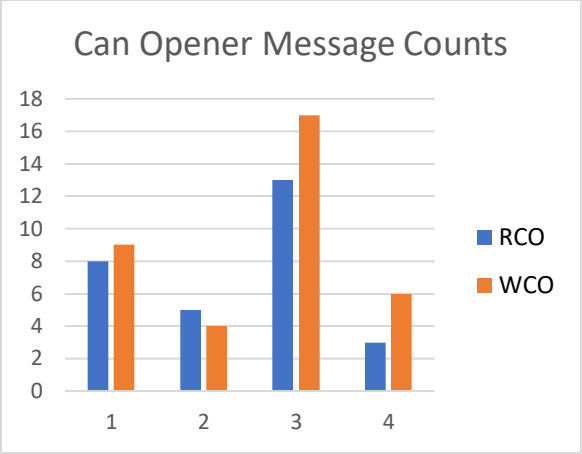

Can Opener Market Percents
100.0%
80.0%
60.0%
40.0%
20.0%
0.0%
1
2
RCO
WCO

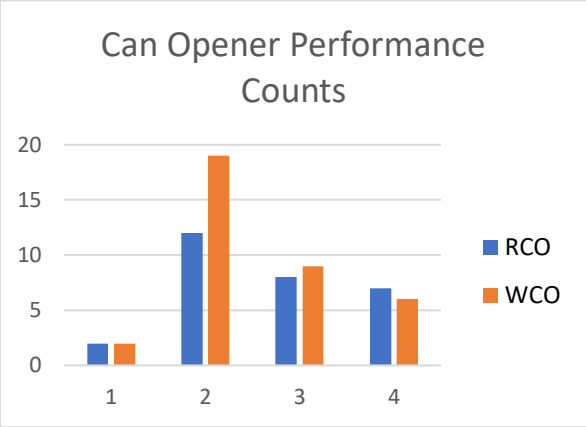

Can Opener Message Percents
50.0%
40.0%
30.0%
20.0%
10.0%
0.0%
1
2
3
4
RCO
WCO

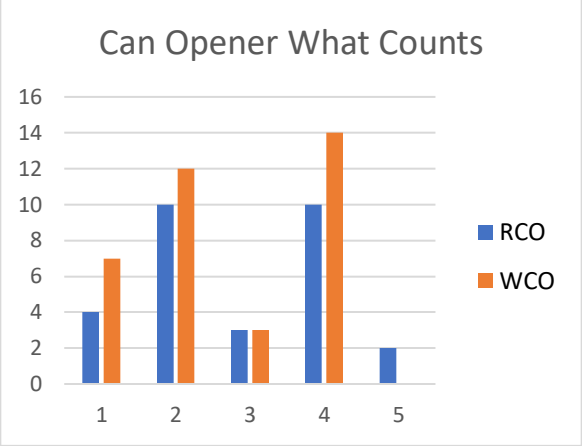

Can Opener Performance Percents
50.0%
40.0%
30.0%
20.0%
10.0%
0.0%
1
2
3
4
RCO
WCO

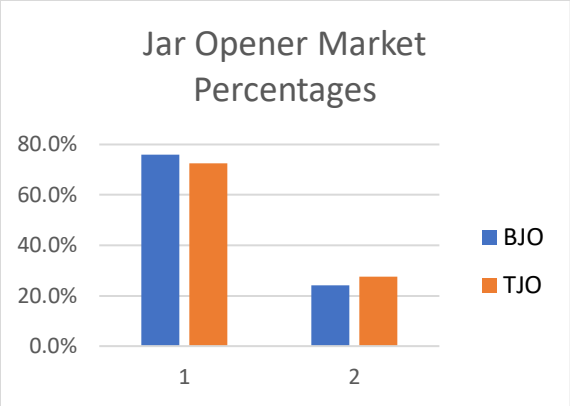

Can Opener What Percents
45.0%
40.0%
35.0%
30.0%
25.0%
20.0%
15.0%
10.0%
5.0%
0.0%
1
2
3
4
5
RCO
WCO

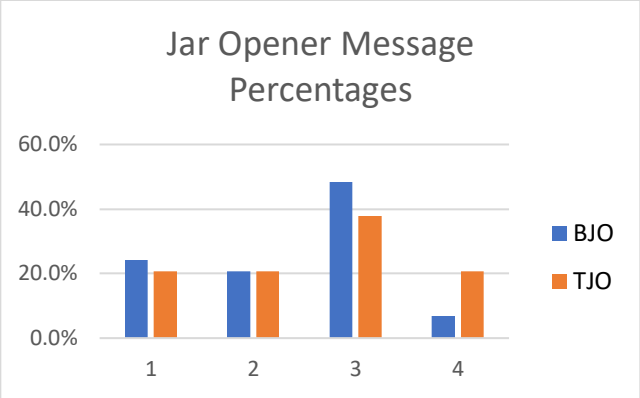

Can Opener Market Counts
30
25
20
15
10
5
0
1
2
RCO
WCO

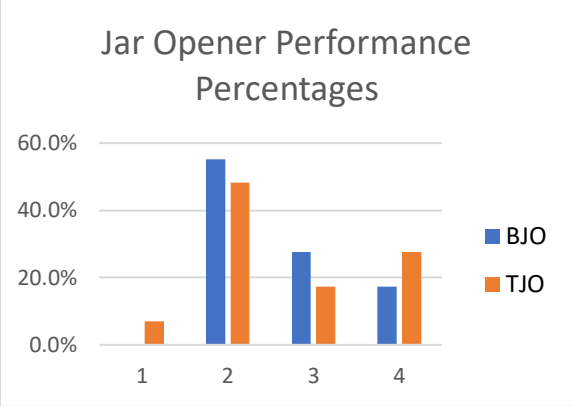

Can Opener Message Counts
18
16
14
12
10
8
6
4
2
0
1
2
3
4
RCO
WCO

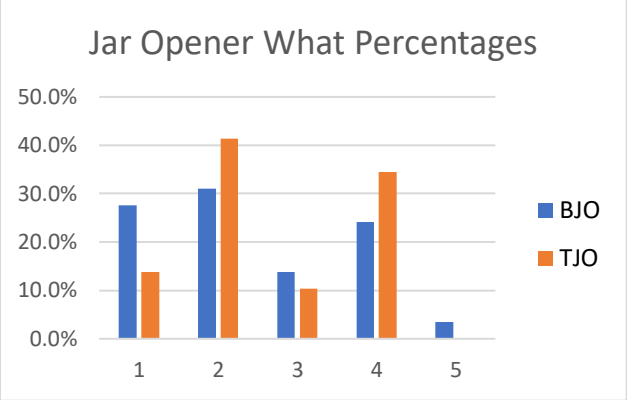

Can Opener Performance Counts
20
15
10
5
0
1
2
3
4
RCO
WCO

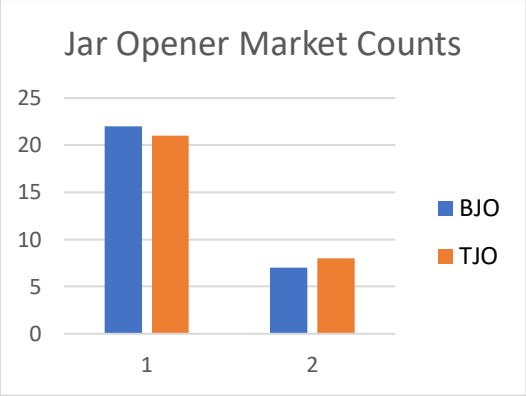

Can Opener What Counts
16
14
12
10
8
6
4
2
0
1
2
3
4
5
RCO
WCO

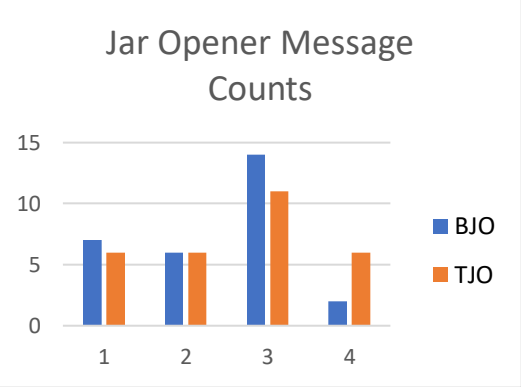

Jar Opener Market Percentages
80.0%
60.0%
40.0%
20.0%
0.0%
1
2
BJO
TJO

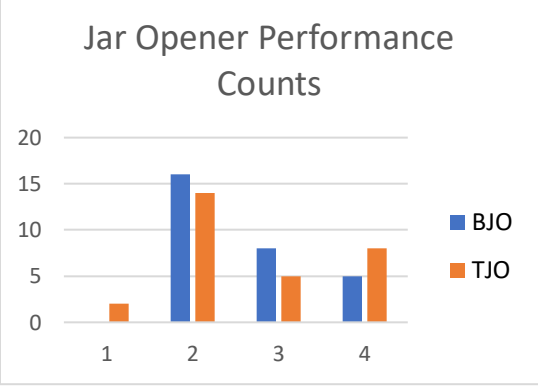

Jar Opener Message Percentages
60.0%
40.0%
20.0%
0.0%
1
2
3
4
BJO
TJO

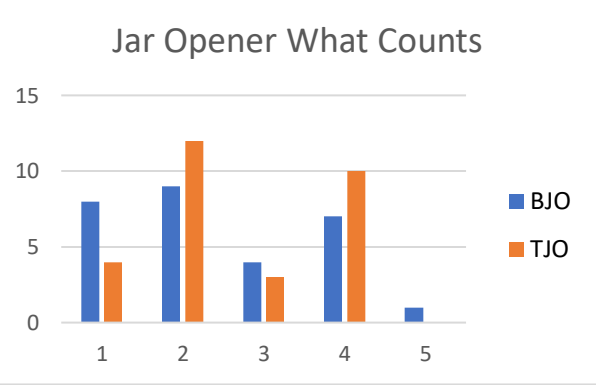

Jar Opener Performance Percentages
60.0%
40.0%
20.0%
0.0%
1
2
3
4
BJO
TJO

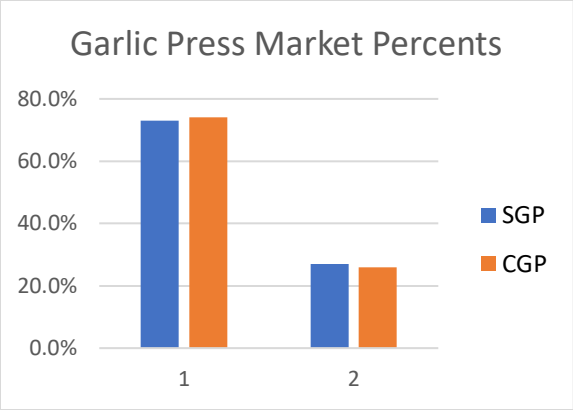

Jar Opener What Percentages
50.0%
40.0%
30.0%
20.0%
10.0%
0.0%
1
2
3
4
5
BJO
TJO

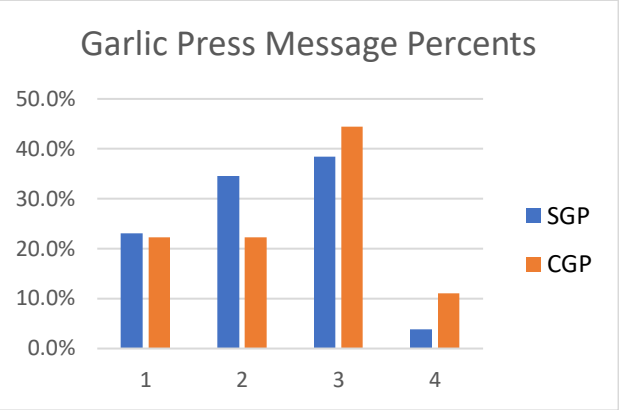

Jar Opener Market Counts
25
20
15
10
5
0
1
2
BJO
TJO

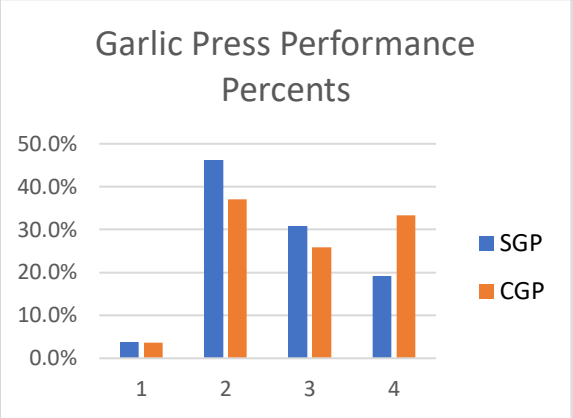

Jar Opener Message Counts
15
10
5
0
1
2
3
4
BJO
TJO

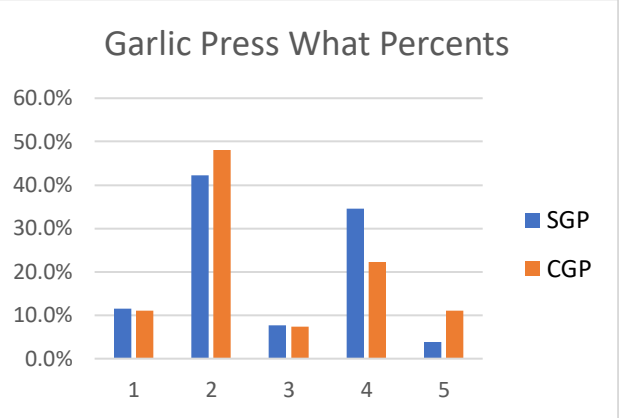

Jar Opener Performance Counts
20
15
10
5
0
1
2
3
4
BJO
TJO

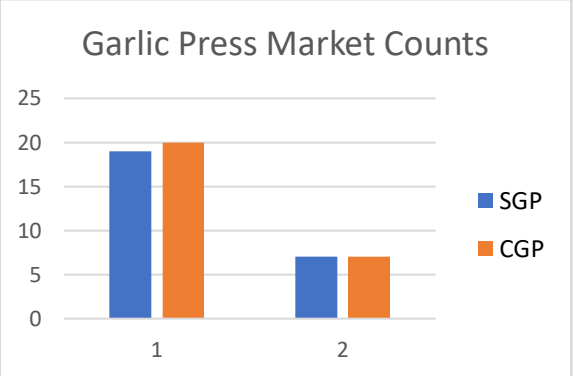

Jar Opener What Counts
15
10
5
0
1
2
3
4
5
BJO
TJO

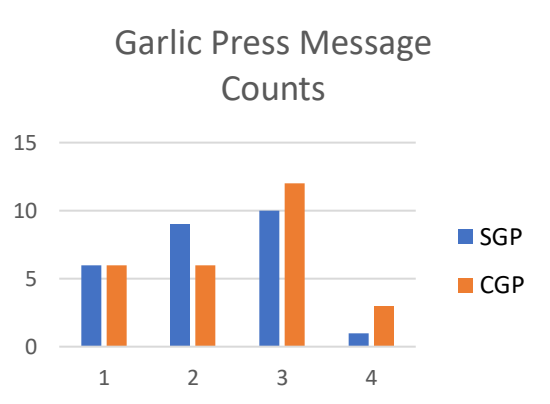

Garlic Press Market Percents
80.0%
60.0%
40.0%
20.0%
0.0%
1
2
SGP
CGP

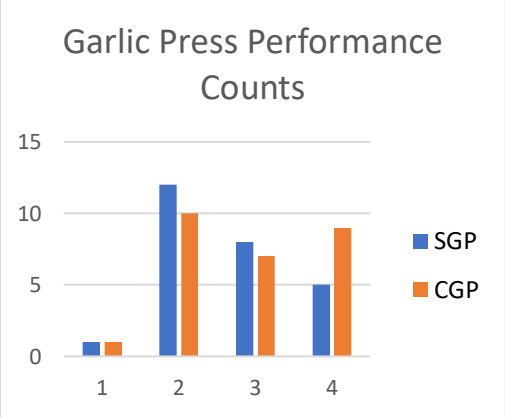

Garlic Press Message Percents
50.0%
40.0%
30.0%
20.0%
10.0%
0.0%
1
2
3
4
SGP
CGP

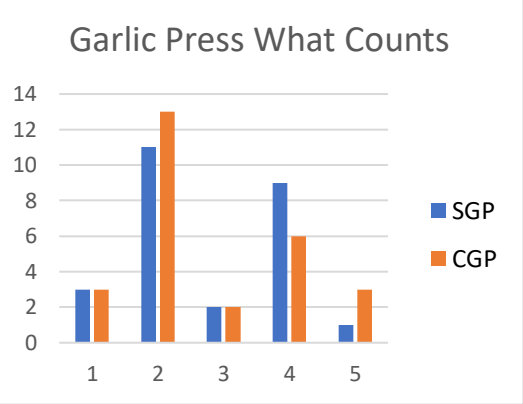

Garlic Press Performance Percents
50.0%
40.0%
30.0%
20.0%
10.0%
0.0%
1
2
3
4
SGP
CGP


Garlic Press What Percents
60.0%
50.0%
40.0%
30.0%
20.0%
10.0%
0.0%
1
2
3
4
5
SGP
CGP


Garlic Press Market Counts
25
20
15
10
5
0
1
2
SGP
CGP


Garlic Press Message Counts
15
10
5
0
1
2
3
4
SGP
CGP


Garlic Press Performance Counts
15
10
5
0
1
2
3
4
SGP
CGP


Garlic Press What Counts
14
12
10
8
6
4
2
0
1
2
3
4
5
SGP
CGP

Appendix R: Participant Experience Info Tables and Charts

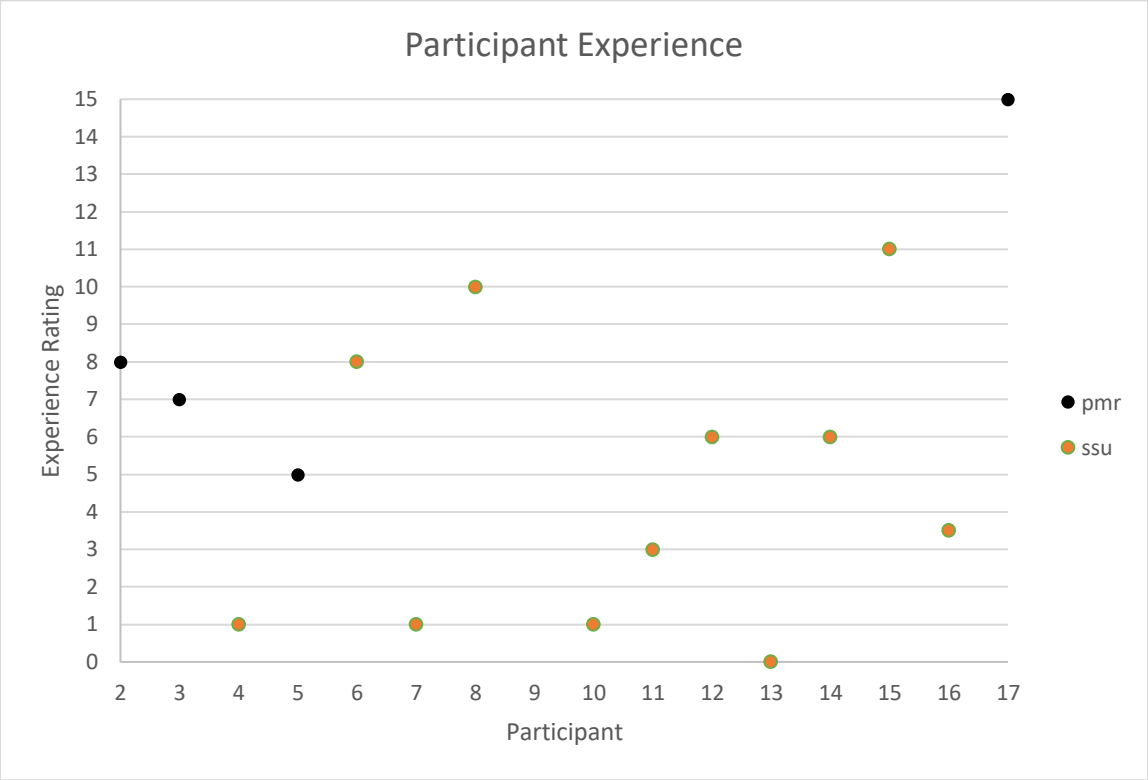
Experience Factors

Participant #	Explicit answer	Implicit answer	Perceived Difficulty	Experience Points	Self-assessment	Incl.Design knowledge	Aggregated
4	yes	yes	5	1	Not well at all	no	1
6	no data	no data	no data	5	Well	no	8
7		yes	4	0	A little bit	no	1
8	yes		4	5	Well	Yes	10
10		no	3	0	A little bit	no	1
11		yes	4	2	A little bit	no	3
12	yes		5	5	A little bit	no	6
13		no	2	0	Not well at all	no	0
14	yes		3.5	4	A little bit	Some	6
15	yes		5	9	A little bit	Some	11
16	maybe		3	0.5	A little bit	Yes	3.5
9	na	na	low	3	a little bit	no	4
17	na	na	na	11	very well	some	15
2	na	na	na	5	well	no	8
3	na	na	na	6	a little bit	no	7
5	na	na	na	1	very well	no	5

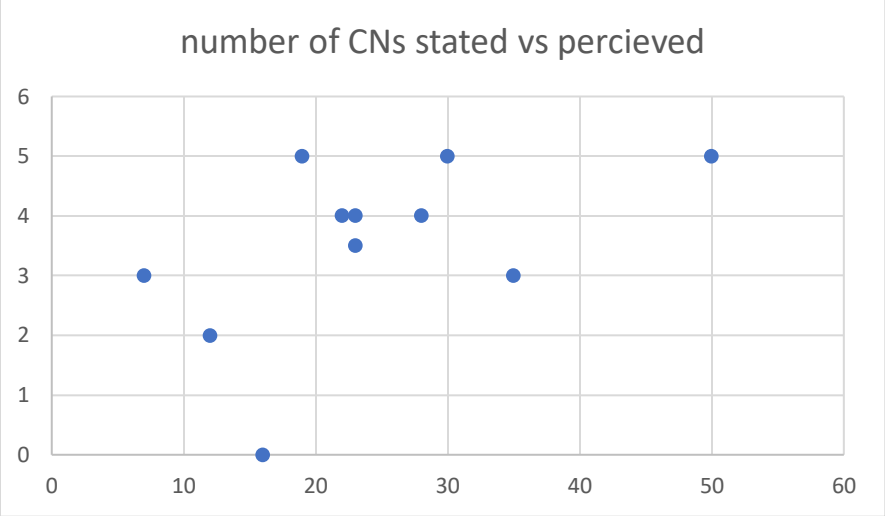
Experience Analysis

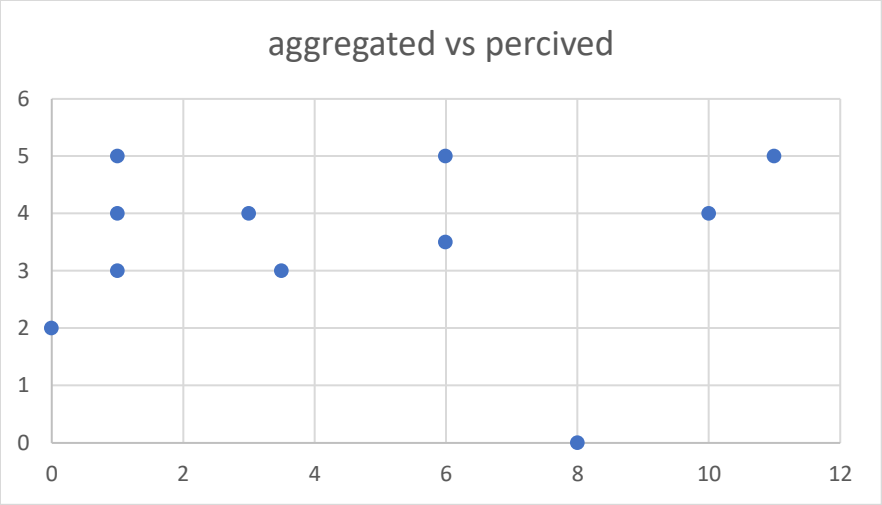
Aggregated Experience	Scaled	combined effects add	combined effects mult	number of CNs stated	Correlation	
1	0.33	5.33	1.67	19	0.480568	pva
8	2.67	3.00	3.00	16	0.542293	pvc
1	0.33	4.33	1.33	22	0.659019	avc
10	3.33	7.33	13.33	28	0.795305	cvca
1	0.33	3.33	1.00	7	0.814559	cvcm
3	1.00	5.00	4.00	23		
6	2.00	7.00	10.00	30		
0	0.00	2.00	0.00	12		
6	2.00	5.50	7.00	23		
11	3.67	8.67	18.33	50		
3.5	1.17	4.17	3.50	35		

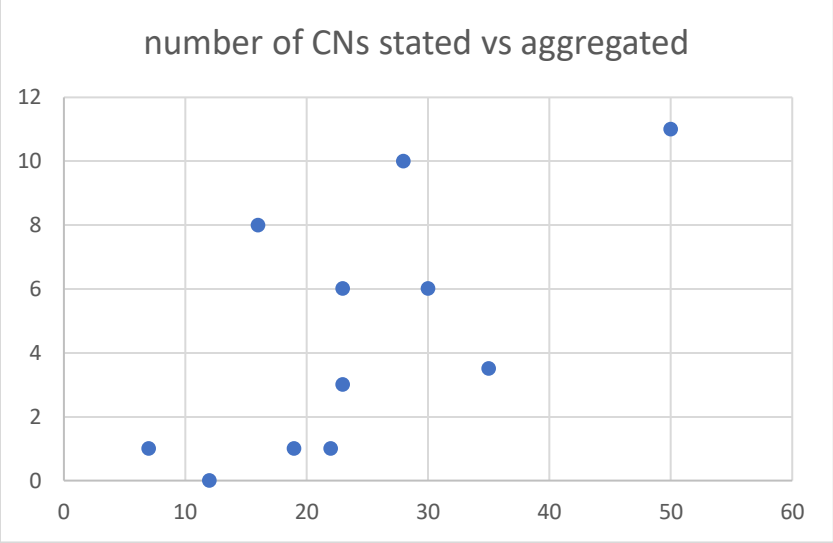
Experience Rating by individual and subgroup:

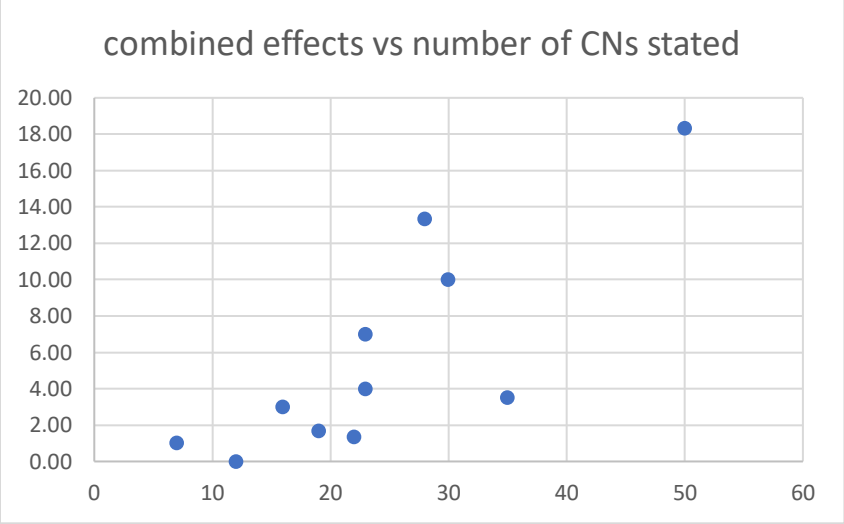


Correlation Charts for Experience(s) vs CN counts:




aggregated vs percived
6
5
4
3
2
1
0
0
2
4
6
8
10
12


number of CNs stated vs aggregated
12
10
8
6
4
2
0
0
10
20
30
40
50
60


combined effects vs number of CNs stated
20.00
18.00
16.00
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
0
10
20
30
40
50
60

Appendix S: Participant Demographics

Participant Demographic Breakdown

Participant #	Gender	Age Range	Age #	Previous Experience Score
2	m	61-70	65	12
3	f	51-60	55	11
4	m	20	20	1
5	m	21-30	25	9
6	m	19	19	8
7	f	19	19	1
8	f	41-50	45	10
9	m	51-60	55	7
10	m	19	19	1
11	m	18	18	3
12	f	19	19	6
13	f	20-29	25	0
14	m	30-39	35	6
15	m	20-29	25	11
16	m	20-29	25	3.5
17	f	18	18	15

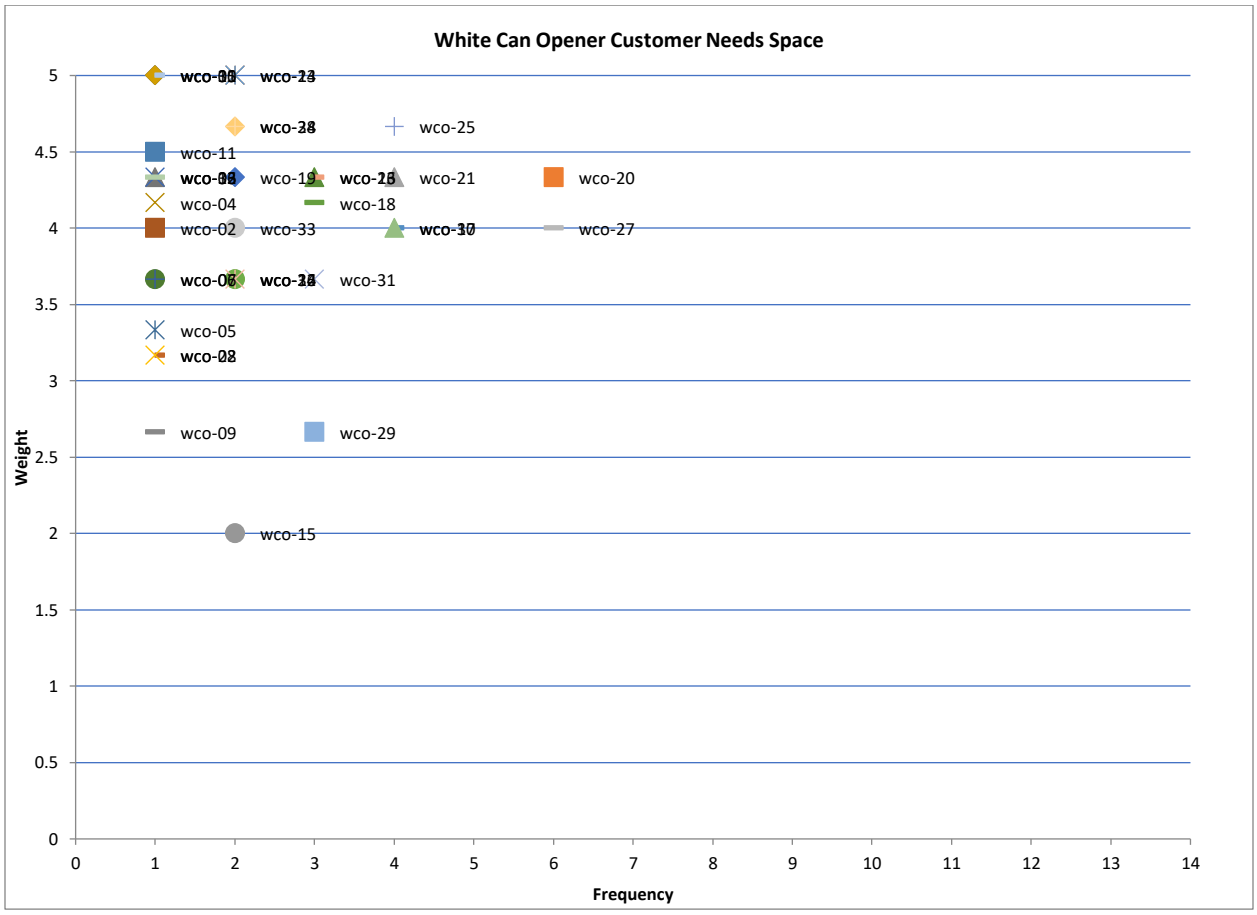
Subgroup Age and Experience Stats

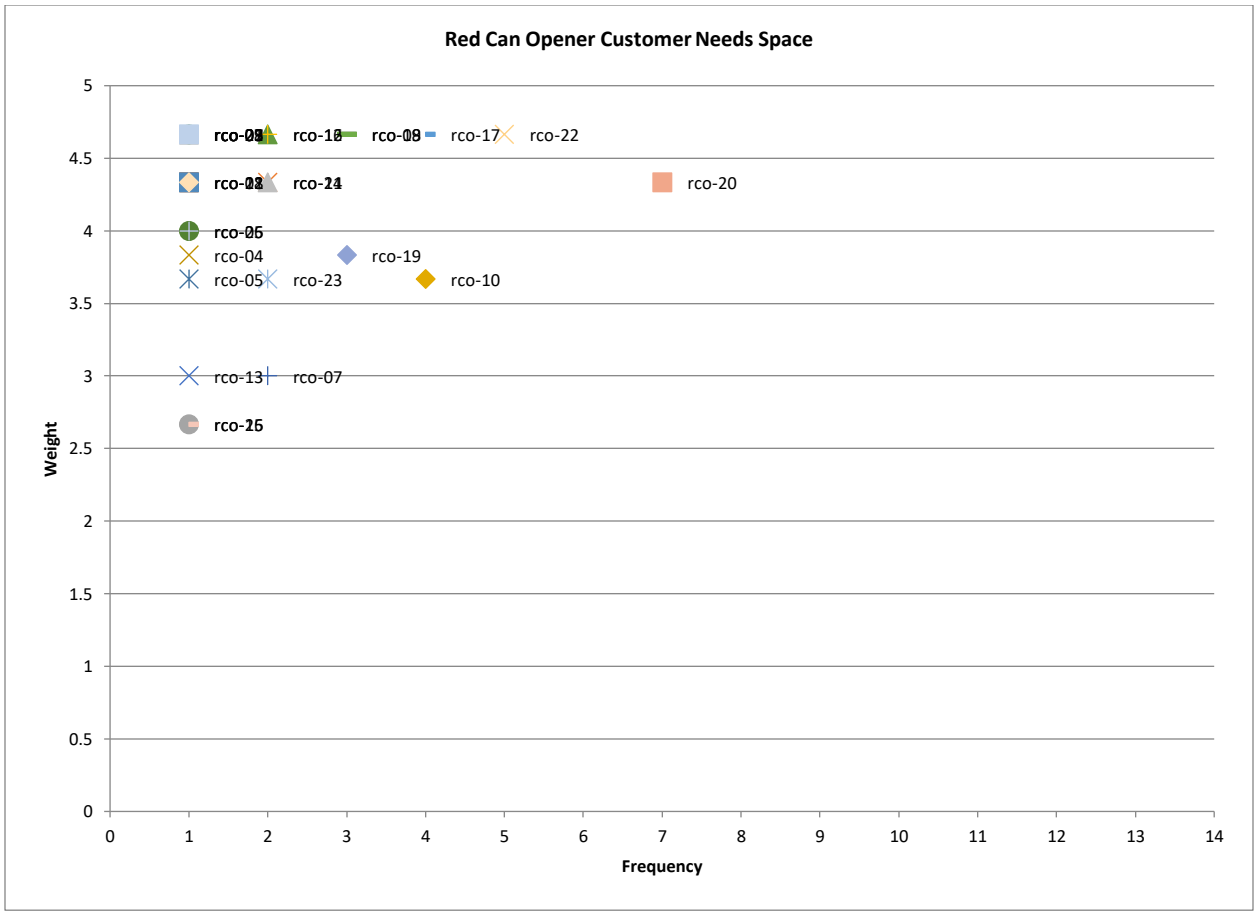
PMR	Customer Need List Group (2,3,5)	with 17	with 9	with both
genders	1f/2m	2f/2m	1f/3m	2f/3m
age range	25-65	18-65	25-65	18-65
age avg	48.33	40.75	50	43.6
age med	55	40	55	55
age stdev	20.82	22.78	17.32	20.73
exp range	9-12	9-15	7-12	7-15
exp avg	10.67	11.75	9.75	10.8
exp stdev	1.53	2.5	2.22	3.03

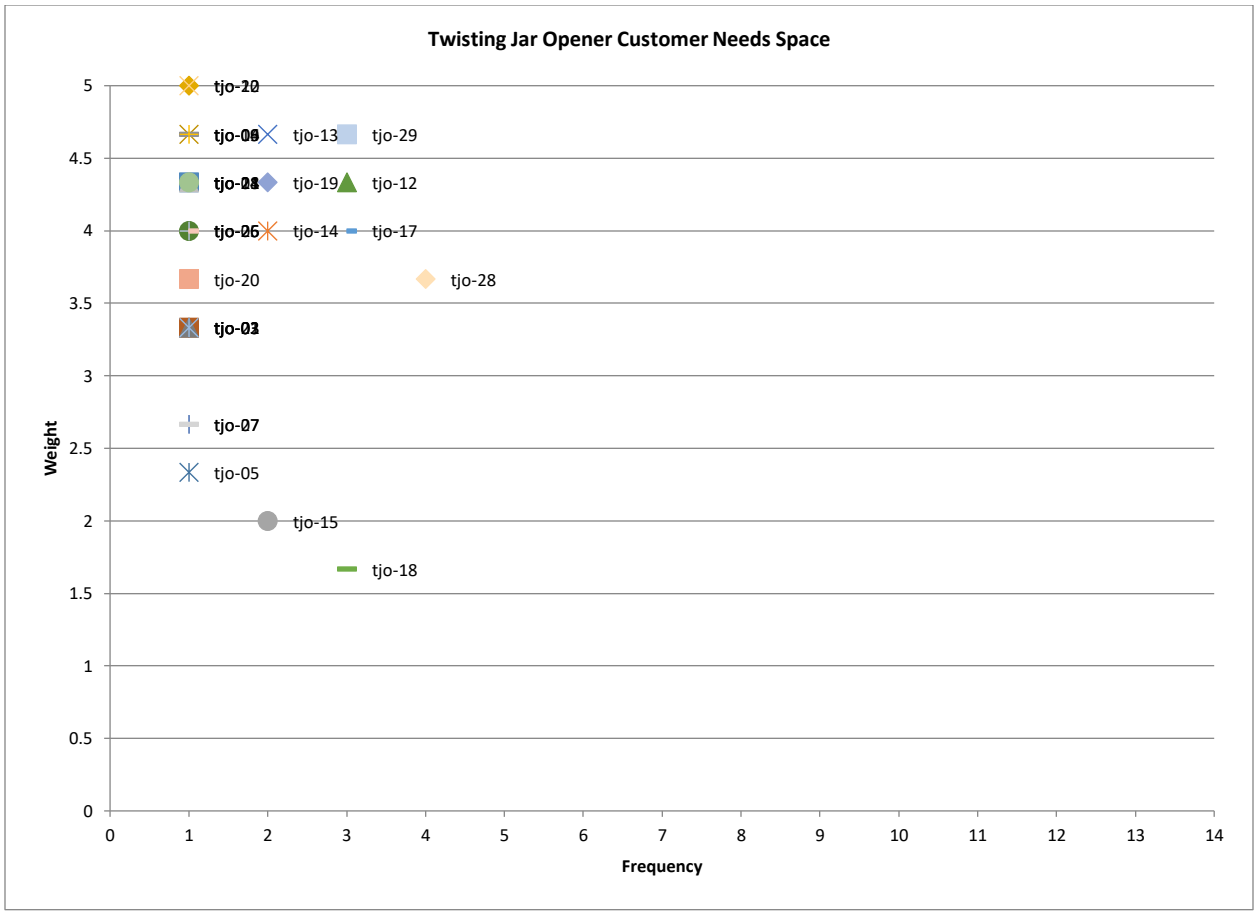
SSU	Participants 4,6,7,8,10,11,12,13,14,15
genders	7m/4f
age range	18-45
age avg	24.45
age med	20
age stdev	8.45
exp range	1-11
exp avg	4.59
exp stdev	3.87

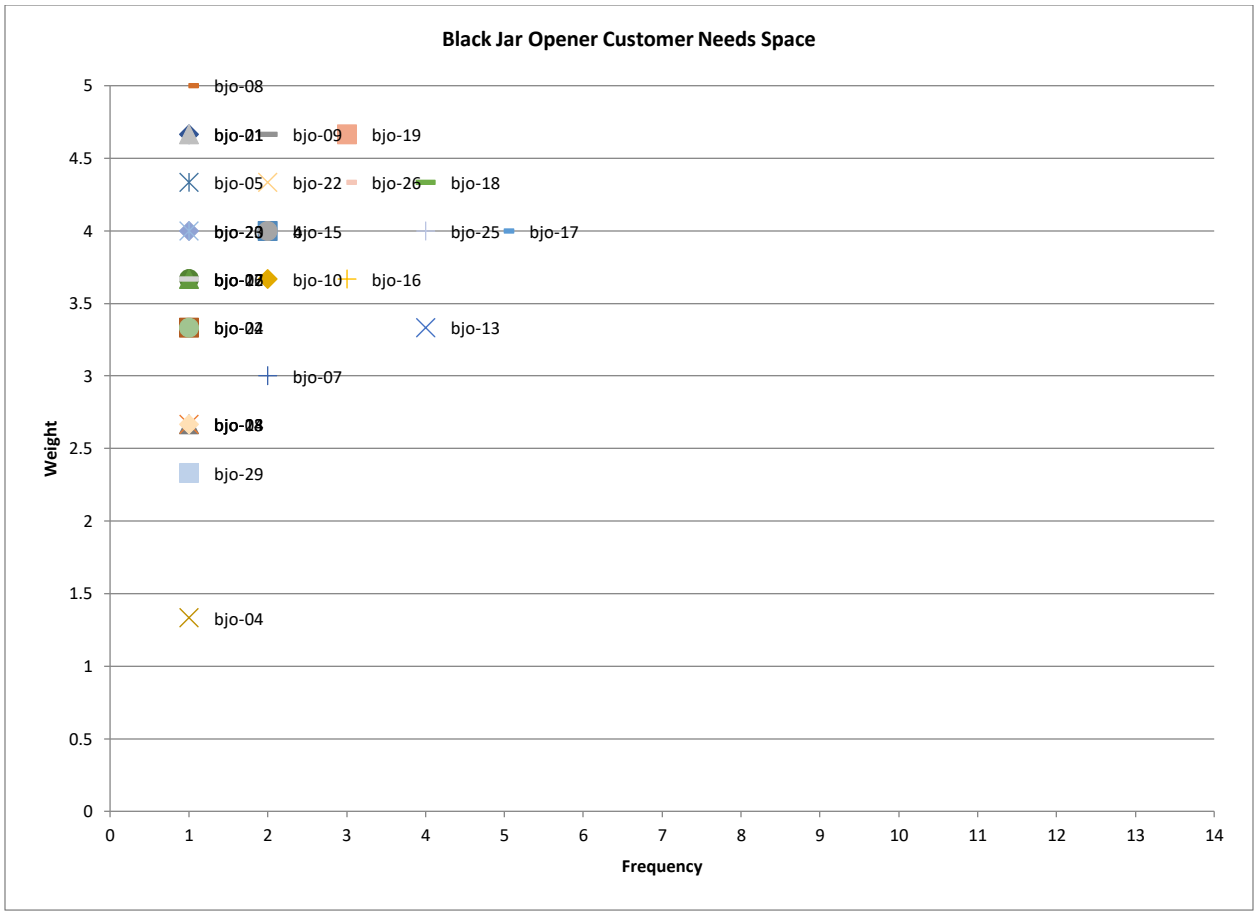
Full Demographic Breakdowns Available for analysis upon request…

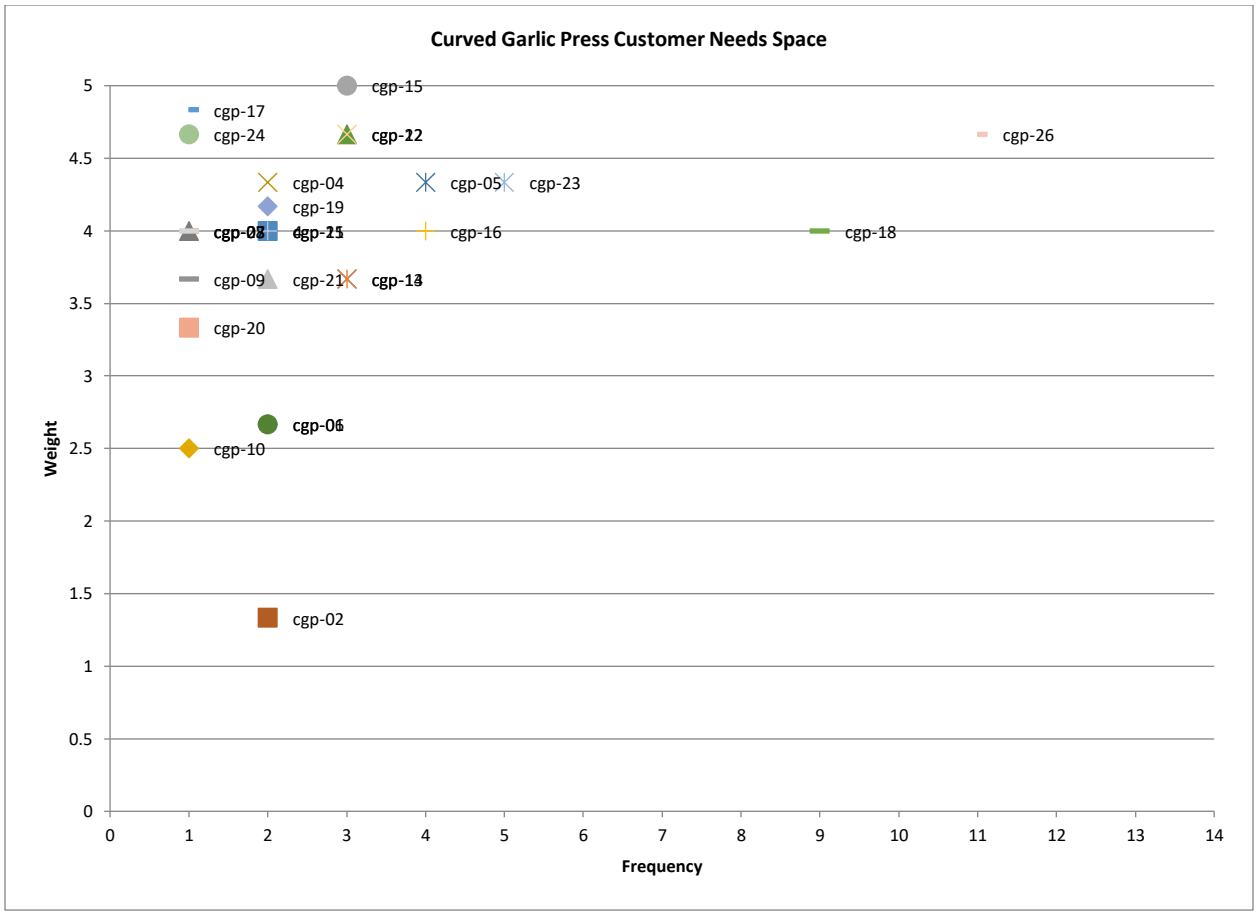
Appendix T: CN Space Graphs

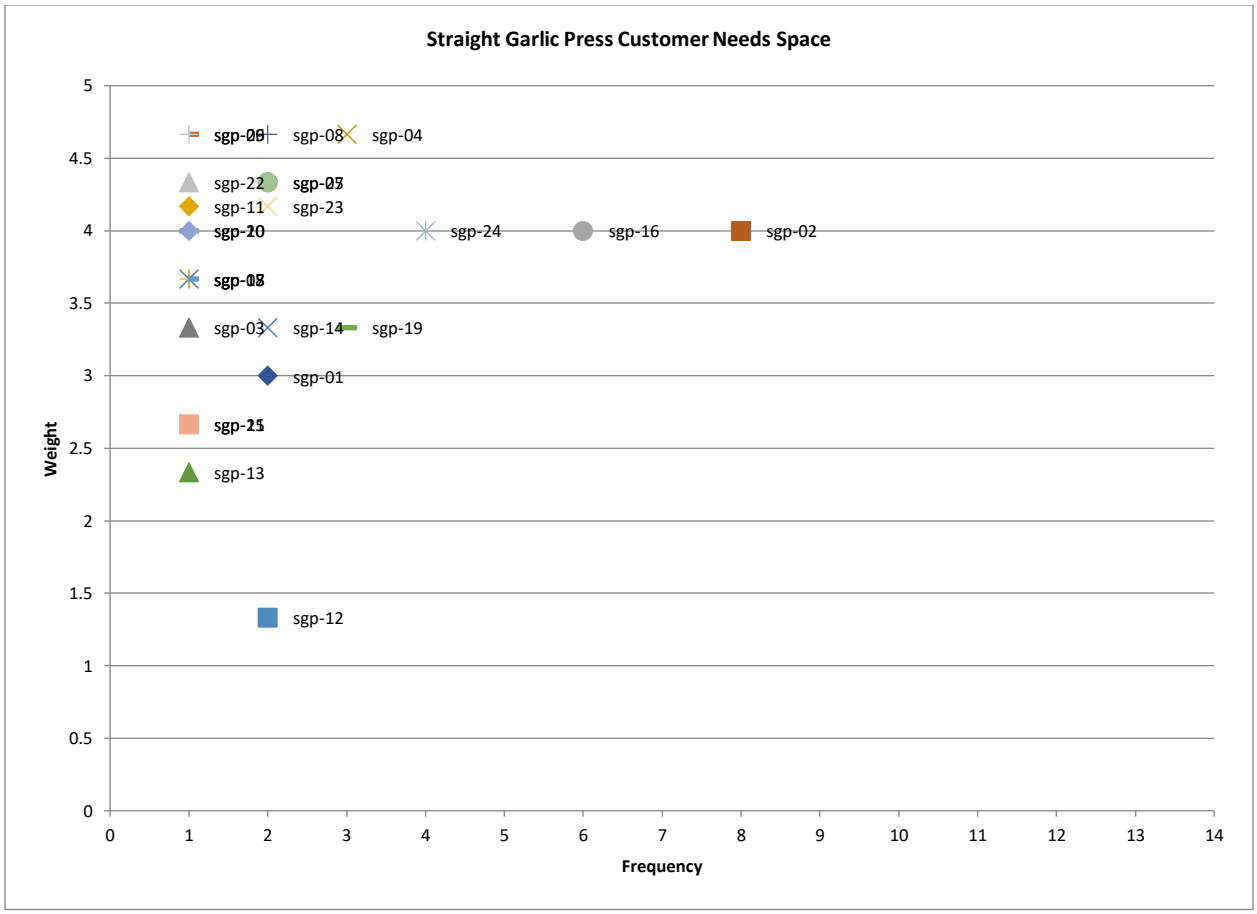


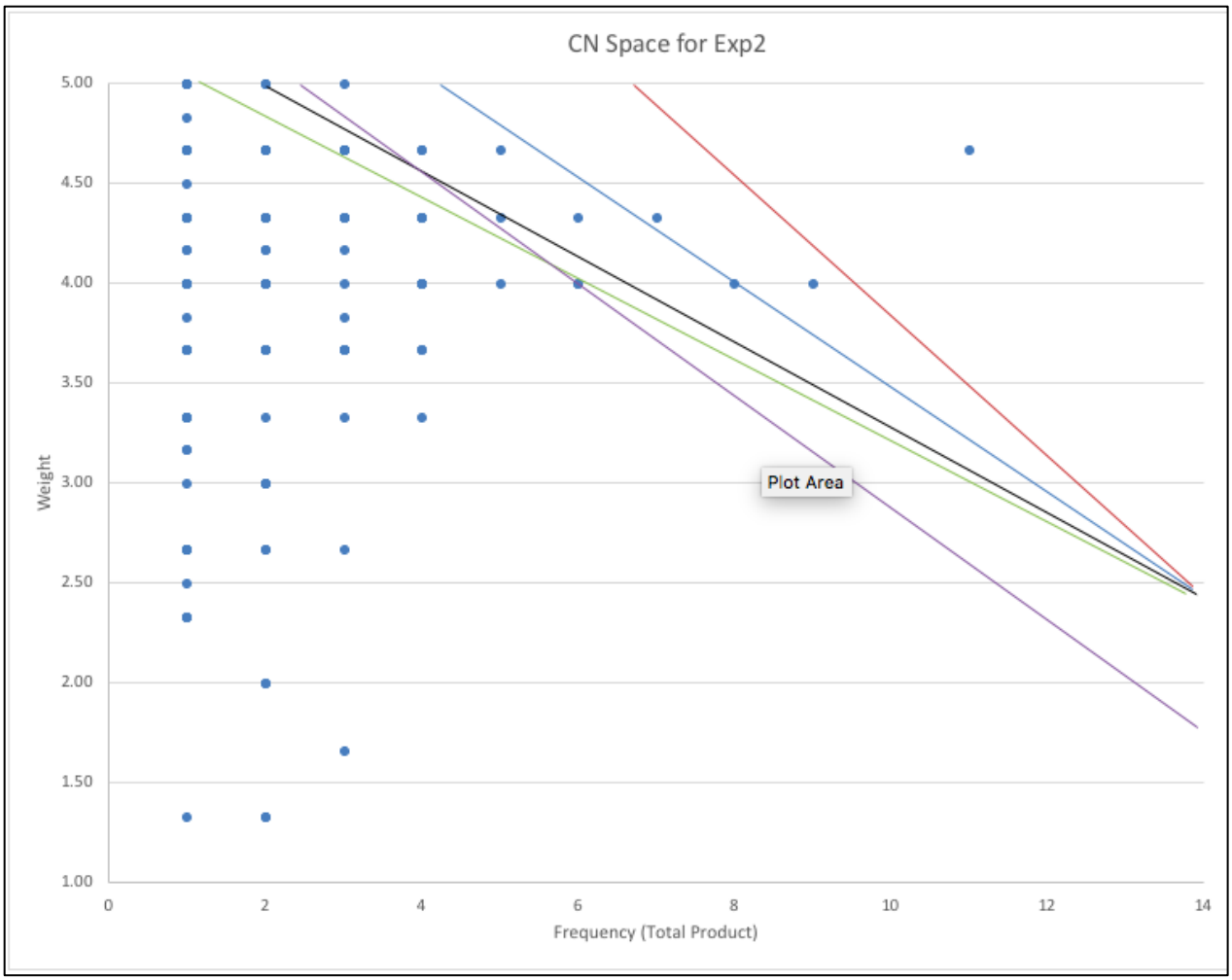

Red Can Opener Customer Needs Space
Weight
Frequency
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
rco-17
rco-22
rco-20
rco-04
rco-19
rco-05
rco-23
rco-10
rco-13
rco-07


Twisting Jar Opener Customer Needs Space
tjo-13
tjo-29
tjo-19
tjo-12
tjo-14
tjo-17
tjo-20
tjo-28
tjo-05
tjo-15
tjo-18
Weight
Frequency
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14


Black Jar Opener Customer Needs Space
bjo-08
bjo-21
bjo-09
bjo-19
bjo-05
bjo-22
bjo-26
bjo-18
bjo-20
bjo-15
bjo-25
bjo-17
bjo-10
bjo-16
bjo-13
bjo-07
bjo-29
bjo-04
Weight
Frequency
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14


Curved Garlic Press Customer Needs Space
Weight
Frequency
cgp-15
cgp-17
cgp-24
cgp-22
cgp-26
cgp-04
cgp-05
cgp-23
cgp-19
cgp-16
cgp-18
cgp-09
cgp-21
cgp-20
cgp-06
cgp-10
cgp-02


Straight Garlic Press Customer Needs Space
Weight
Frequency
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
sgp-08
sgp-04
sgp-22
sgp-11
sgp-23
sgp-24
sgp-16
sgp-02
sgp-03
sgp-14
sgp-19
sgp-01
sgp-13
sgp-12


CN Space for Exp2
5.00
4.50
4.00
3.50
3.00
2.50
2.00
1.50
1.00
Weight
Plot Area
0
2
4
6
8
10
12
14
Frequency (Total Product)

Appendix U: Common Module Information

Common?	Match	CN Statement	Ptag	Ctag	Product type	Total Prod Freq	Weight Partic Avg
y	1	Product should be easy to clean	cgp-18	G19	Inclusive	9	4.00
y	2	Product should be easy (require little effort to) squeeze closed	cgp-26	G33	Inclusive	11	4.67
y	4	Product should be easy to turn	rco-20	C42	Exclusive	7	4.33
y	1	Product should be easy to clean	sgp-02	G19	Exclusive	8	4.00
		blue					
y		Product should Not open too far / Not need full extension of hands to use	cgp-15	G16	Inclusive	3	5.00
?		Product should help release the garlic	cgp-23	G24	Inclusive	5	4.33
y		Product should not allow contents to spill	rco-01	C01	Exclusive	1	4.67
y	2?	Product should not need a lot of grip force to puncture can	rco-22	C18	Exclusive	5	4.67
y		Product should work quickly	wco-14	C02	Inclusive	2	5.00
y		Product should have comfy rubber grips on handles	wco-20	C44	Inclusive	6	4.33
?		Product should not feel flimsy	wco-23	C08	Inclusive	2	5.00
y	2?	Product should take little pressure to press closed	wco-25	C18	Inclusive	4	4.67
		black					
y	2	Product should require little pressure to squeeze closed	sgp-16	G33	Exclusive	6	4.00
y		Product should stay locked in place on can	wco-27	C52	Inclusive	6	4.00
		close to black					
y	5	Product should have instructions that are easy to read	bjo-19	J17	Exclusive	3	4.67
y		Products' parts should all align automatically	cgp-12	G13	Inclusive	3	4.67
y	3	Product should be easy/comfy to grasp/grip	cgp-22	G23	Inclusive	3	4.67
y		Product should be simple	rco-09	C03	Exclusive	3	4.67
y	3?	Product should be easy to grasp/grip	rco-18	C39	Exclusive	3	4.67
y		Product should be durable	sgp-04	G26	Exclusive	3	4.67
y	4?	Product should have knobs that are easy to turn	tjo-29	J43	Inclusive	3	4.67
		green					
y	5?	Product should have clear directions	bjo-18	J16	Exclusive	4	4.33
?		Product should have an easy to access container to load garlic	cgp-05	G04	Inclusive	4	4.33
n		Product should have big enough handles for two hands	wco-21	C48	Inclusive	4	4.33
		close to green					

Appendix V: Knowledge Tracking Information

participants	# CNs Stated	# Unique CNs	knowledge progression
2	26	26	26
3	16	12	38
4	18	10	48
5	44	31	79
6	14	5	84
7	21	7	91
8	27	11	102
9	10	3	105
10	6	0	105
11	20	6	111
12	31	11	122
13	11	1	123
14	20	5	128
15	47	7	135
16	32	5	140
totals	343	140	

PMR Group Entire Study Actual Order			
participants	# CNs Stated	# Unique CNs	knowledge progression
2	26	26	26
3	16	12	38
5	44	33	71

PMR Group Entire Study Ideal Order			
participants	# CNs Stated	# Unique CNs	knowledge progression
5	44	44	44
2	26	18	62
3	16	9	71

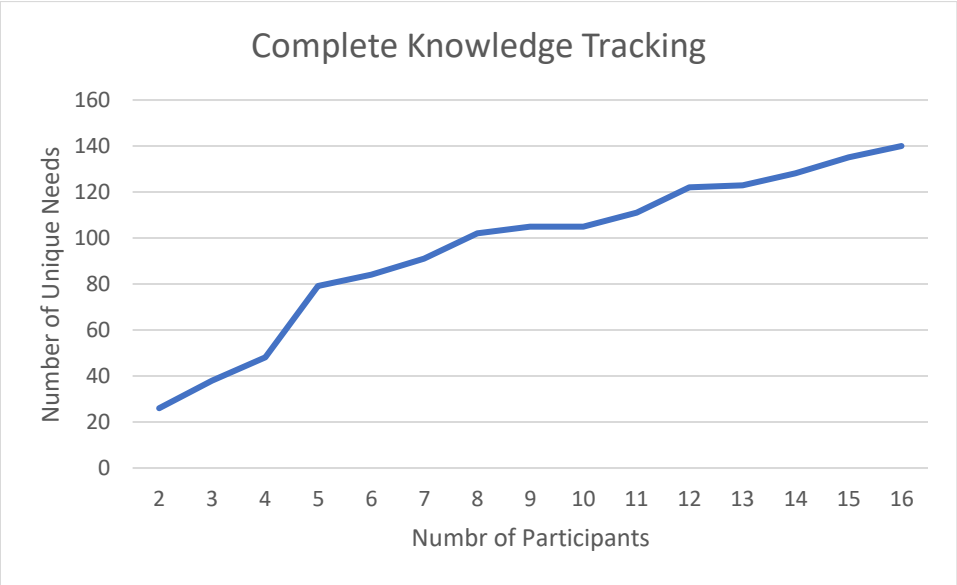
SSU Group Entire Study Actual Order			
participants	SUMS	Uniques	unique totals
4	18	18	18
6	14	11	29
7	21	15	44

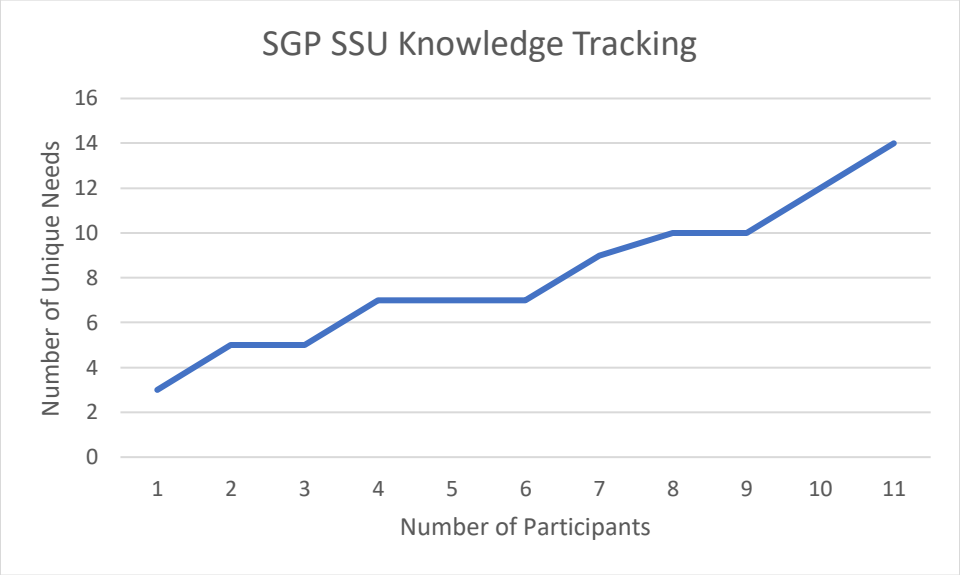
8	27	17	61
10	6	1	62
11	20	10	72
12	31	17	89
13	11	1	90
14	20	6	96
15	47	15	111
16	32	9	120

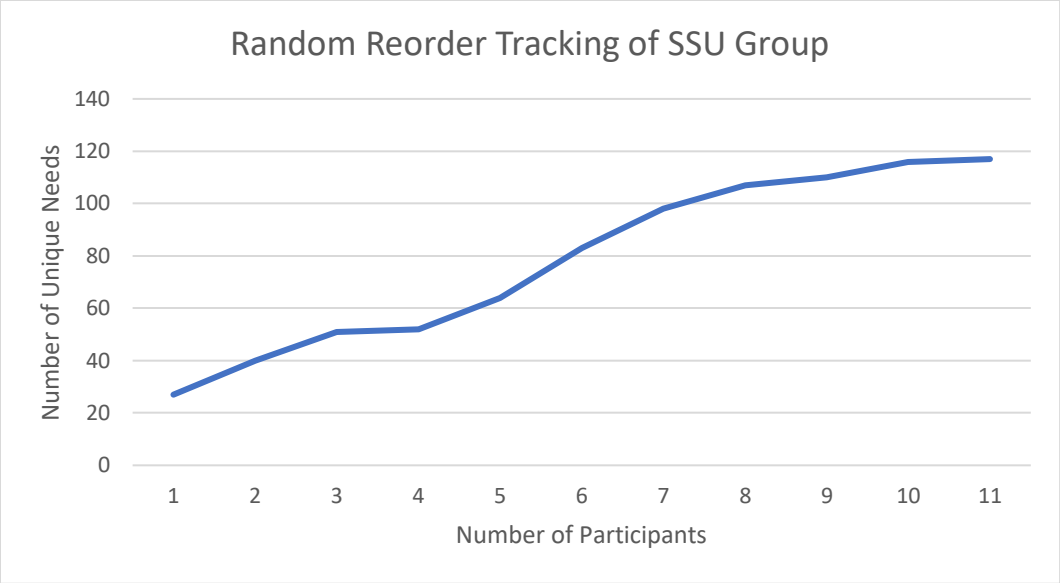
SSU Group Entire Study Random Order			
participants	SUMS	Uniques	unique totals
8	27	27	27
4	18	13	40
14	20	11	51
10	6	1	52
11	20	12	64
15	47	19	83
12	31	15	98
16	32	9	107
6	14	3	110
7	21	6	116
13	11	1	117

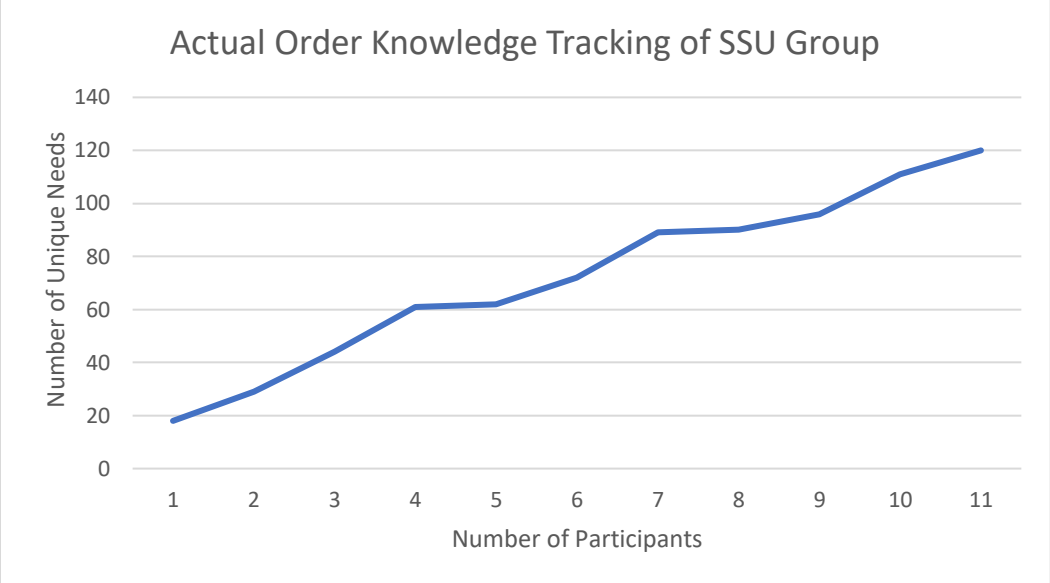
SSU Group One Product Actual Order			
participants	# CNs Stated	# Unique CNs	knowledge progression
4	5	3	3
6	4	2	5
7	2	0	5
8	5	2	7
10	3	0	7
11	2	0	7
12	3	2	9
13	2	1	10
14	2	0	10
15	7	2	12
16	4	2	14

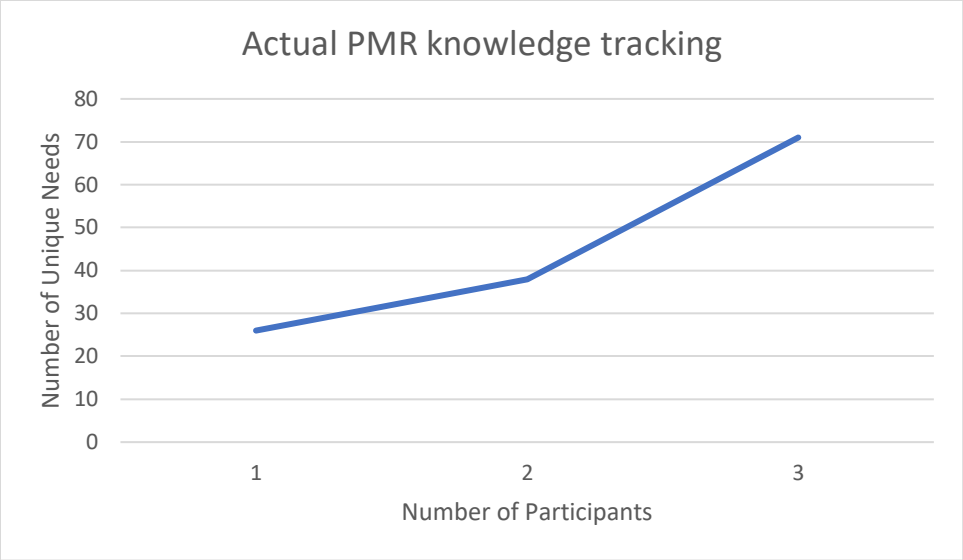
Appendix W: Knowledge Tracking Graphs

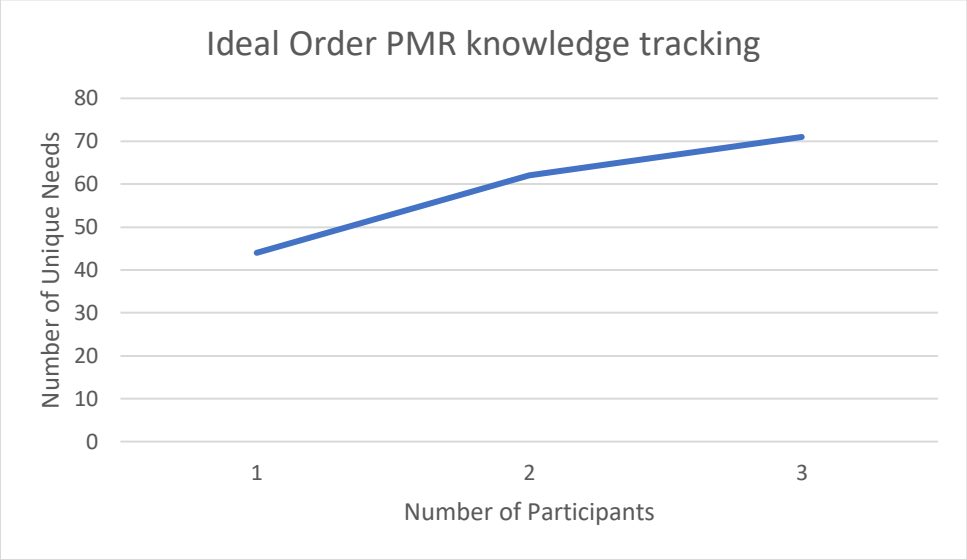


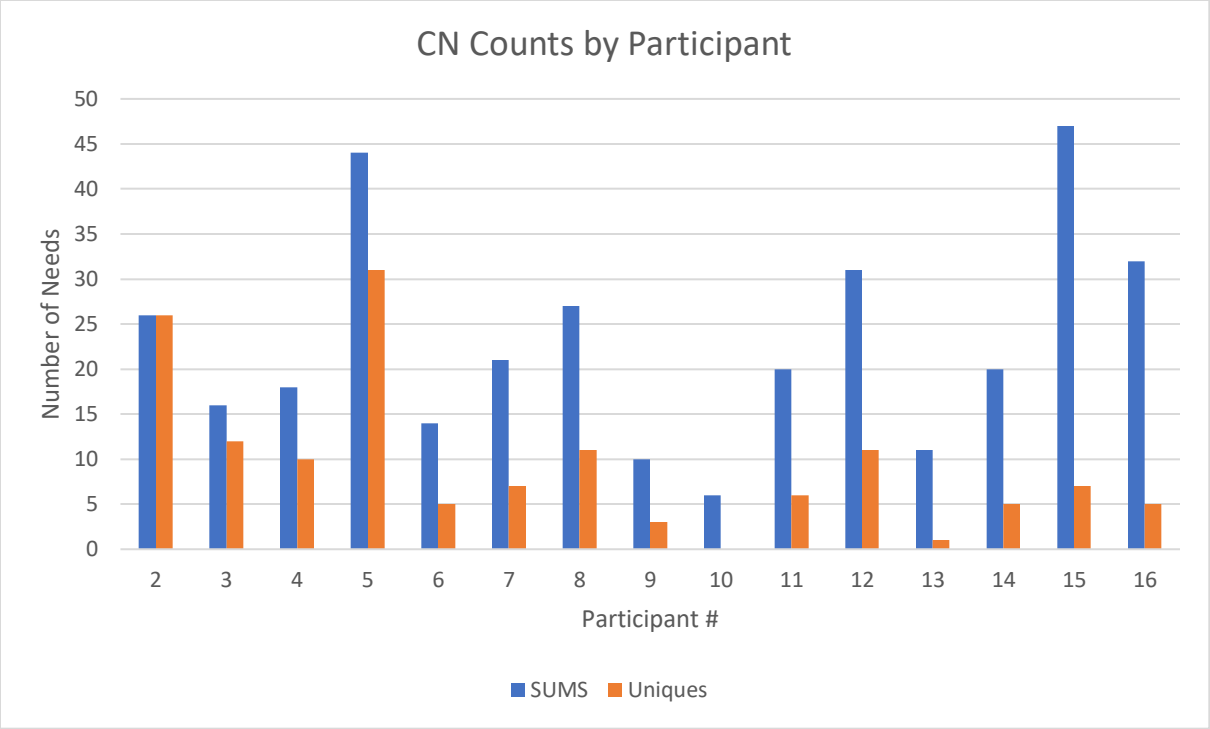



Random Reorder Tracking of SSU Group
Number of Unique Needs
140
120
100
80
60
40
20
0
1
2
3
4
5
6
7
8
9
10
11
Number of Participants


Actual Order Knowledge Tracking of SSU Group
Number of Unique Needs
140
120
100
80
60
40
20
0
1
2
3
4
5
6
7
8
9
10
11
Number of Participants


Actual PMR knowledge tracking
Number of Unique Needs
80
70
60
50
40
30
20
10
0
1
2
3
Number of Participants


Ideal Order PMR knowledge tracking
Number of Unique Needs
80
70
60
50
40
30
20
10
0
1
2
3
Number of Participants


CN Counts by Participant
Number of Needs
50
45
40
35
30
25
20
15
10
5
0
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
Participant #
SUMS
Uniques

Appendix X: CN Coverage tables

Data Set Name	#s	#r	#both	SSU totals	PMR totals	List CN Totals	s%	r%	both%	% MR Coverage
TJO	19	5	5	24	10	29	65.5	17.2	17.2	50.0
BJO	15	7	7	22	14	29	51.7	24.1	24.1	50.0
J	25	9	14	39	23	48	52.1	18.7	29.2	60.9
CGP	15	4	8	23	12	27	55.6	14.8	29.6	66.7
SGP	14	3	8	22	11	26	53.8	11.5	30.8	72.7
G	17	3	16	33	19	38	44.7	7.9	42.1	84.2
WCO	17	8	11	28	19	36	47.2	22.2	30.6	57.9
RCO	17	5	7	24	12	29	58.6	17.2	24.1	58.3
C	25	11	18	43	29	54	46.3	20.4	33.3	62.1
EXP2										

Number of CNs	Total	PMR	SSU
SGP	25	11	22
CGP	27	12	23
WCO	36	19	28
RCO	29	12	24
BJO	29	14	22
TJO	29	10	24
	group totals	78	143
G	37	19	33
C	54	29	44
J	48	23	39
	group totals	71	116
EXP2	175 prod/139 pair/357 total	92	265
Number of CNs	Total	PWD	FSU
GP	57	27	30
CO	66	29	37
JO	50	22	28
IT	29	13	16
Exp1	202	91	111

number CNs	sgp lists	number CNs	cgp lists	number CNs	G list
14	s	15	s	17	s
3	r	4	r	3	r
8	b	8	b	16	b
25	total	27	total	37	total
56.0%	%s	55.6%	%s	45.9%	%s
12.0%	%r	14.8%	%r	8.1%	%r
32.0%	%shared	29.6%	%shared	43.2%	%shared
22	CNs in S	23	CNs in S	33	CNs in S
11	Cns in R	12	Cns in R	19	Cns in R
27.3%	%uniqueR	33.3%	%uniqueR	15.8%	%uniqueR
63.6%	%uniqueS	65.2%	%uniqueS	51.5%	%uniqueS
number CNs	wco lists	number CNs	rco list	number CNs	C list
17	s	17	s	25	s
8	r	5	r	11	r
11	b	7	b	18	b
36	total	29	total	54	total
47.2%	%s	58.6%	%s	46.3%	%s
22.2%	%r	17.2%	%r	20.4%	%r
30.6%	%shared	24.1%	%shared	33.3%	%shared
28	CNs in S	24	CNs in S	43	CNs in S
19	Cns in R	12	Cns in R	29	Cns in R
42.1%	%uniqueR	41.7%	%uniqueR	37.9%	%uniqueR
60.7%	%uniqueS	70.8%	%uniqueS	58.1%	%uniqueS
number CNs	tjo lists	number CNs	bjo lists	number CNs	J list
19	s	15	s	25	s
5	r	7	r	9	r
5	b	7	b	14	b
29	total	29	total	48	total
65.5%	%s	51.7%	%s	52.1%	%s
17.2%	%r	24.1%	%r	18.8%	%r
17.2%	%shared	24.1%	%shared	29.2%	%shared
24	CNs in S	22	CNs in S	39	CNs in S
10	Cns in R	14	Cns in R	23	Cns in R
50.0%	%uniqueR	50.0%	%uniqueR	39.1%	%uniqueR
79.2%	%uniqueS	68.2%	%uniqueS	64.1%	%uniqueS

Appendix Y: Top Code CNs

These are the lists used to create the guidelines.

EXP1 Top Codes by List

(Each List Provides: Tag, Statement and Code, sorted by Code)

Exp1 All surrogate users (FSU) CNs for Top codes		
Tag	CN Statement "Product should…_"	Code
C-2-13	pierce the can with little effort	1223
J-2-07	require only low forces to operate	1223
G-2-01	require only small force to squeeze closed	1223
J-2-25	take off the seal with little force	1223
C-2-01	operation should be clear / obvious	1321
G-2-23	be aesthetically pleasing	1321
C-2-04	be attractive	1321
J-2-01	be easy to understand / intuitive	1321
C-2-18	be familiar	1321
G-2-16	feel durable	1321
J-2-21	feel secure	1321
G-2-30	fit in the hand comfortably / well	1321
J-2-14	handle should fit nicely in the hand	1321
J-2-17	have clear directions	1321
C-2-25	have nice feeling knob and handles	1321
G-2-13	look simple	1321
C-2-23	operation should be easy to learn	1321
G-2-22	operation should be obvious / intuitive	1321
C-2-34	be easy to grip	1322
C-2-07	be made of a material that feels nice to hold	1322
G-2-14	have a nice grip	1322
C-2-19	have easy to press buttons	1322
J-2-10	be easy to assemble	1324
J-2-15	be easy to attach to lid	1324
G-2-15	be easy to insert/load garlic into place	1324
C-2-15	be easy to maneuver	1324
G-2-24	be easy to maneuver / manipulate	1324
G-2-08	be easy to pick up	1324
J-2-19	be easy to push	1324
C-2-06	be easy to remove from can	1324
C-2-10	be easy to squeeze	1324
C-2-08	be easy to turn / twist	1324

J-2-08	be easy to twist	1324
J-2-12	operate with as few steps as possible	1324
J-2-03	require only a little dexterity / coordination	1324
C-2-36	requires as few steps as possible to use	1324
G-2-09	have a non-slip surface	1412
J-2-02	have a non-slip surface	1412
G-2-29	have rounded edges so as not to dig into the hand	1412
C-2-14	not dig into the hand	1412
G-2-04	have a large gripping surface	2242
G-2-03	have large handles	2242
C-2-29	have small handles	2242
C-2-22	have thick handles	2242
Exp1 FSU Can Opener CNs for Top codes		
Tag	CN Statement "Product should…_"	Code
C-2-01	operation should be clear / obvious	1321
C-2-04	be attractive	1321
C-2-18	be familiar	1321
C-2-23	operation should be easy to learn	1321
C-2-25	have nice feeling knob and handles	1321
C-2-07	be made of a material that feels nice to hold	1322
C-2-19	have easy to press buttons	1322
C-2-34	be easy to grip	1322
C-2-06	be easy to remove from can	1324
C-2-08	be easy to turn / twist	1324
C-2-10	be easy to squeeze	1324
C-2-15	be easy to maneuver	1324
C-2-36	requires as few steps as possible to use	1324
C-2-11	remain sharp for a long time	1334
C-2-35	remain closed easily	1334
C-2-05	have a rubber gripping surface	1442
C-2-26	have sharp blade	1442
C-2-22	have thick handles	2242
C-2-29	have small handles	2242
Exp1 FSU Garlic Press CNs for Top codes		
Tag	CN Statement "Product should…_"	Code
G-2-12	transfer energy efficiently	1234
G-2-26	be efficient (material vs. effort)	1234
G-2-13	look simple	1321
G-2-16	feel durable	1321

G-2-22	operation should be obvious / intuitive	1321
G-2-23	be aesthetically pleasing	1321
G-2-30	fit in the hand comfortably / well	1321
G-2-02	be easy to grip/grasp	1322
G-2-14	have a nice grip	1322
G-2-08	be easy to pick up	1324
G-2-15	be easy to insert/load garlic into place	1324
G-2-18	require only low dexterity	1324
G-2-24	be easy to maneuver / manipulate	1324
G-2-09	have a non-slip surface	1412
G-2-29	have rounded edges so as not to dig into the hand	1412
G-2-03	have large handles	2242
G-2-04	have a large gripping surface	2242
Exp1 FSU Jar Opener CNs for Top codes		
Tag	CN Statement "Product should…_"	Code
J-2-07	require only low forces to operate	1223
J-2-25	take off the seal with little force	1223
J-2-01	be easy to understand / intuitive	1321
J-2-14	handle should fit nicely in the hand	1321
J-2-17	have clear directions	1321
J-2-21	feel secure	1321
J-2-03	require only a little dexterity / coordination	1324
J-2-08	be easy to twist	1324
J-2-10	be easy to assemble	1324
J-2-12	operate with as few steps as possible	1324
J-2-15	be easy to attach to lid	1324
J-2-19	be easy to push	1324
Exp1 All People With Disabilities (PWD) CNs for Top codes		
Tag	CN Statement "Product should…_"	Code
J-1-14	require low torque to twist off lid	1223
C-1-15	be easy to turn	1223
C-1-25	require only minimal squeeze force to puncture can	1223
G-1-14	require only low grip force / pressure to close	1223
J-1-08	require only small forces to use	1224
C-1-20	require only low force to hold closed	1224
C-1-29	put user at the right height	1224
G-1-2	require only modest hand spans	1224
J-1-01	look simple	1321
J-1-04	be easy to understand	1321

J-1-18	have a nice grip	1321
C-1-19	have a nice gripping surface	1321
C-1-22	be familiar	1321
C-1-28	be easy to understand	1321
G-1-01	have an obvious holder	1321
G-1-12	have obvious operation	1321
G-1-20	have a familiar shape	1321
J-1-03	be easy to assemble	1324
J-1-22	be easy to attach to lid	1324
C-1-11	operation should be simple	1324
G-1-13	have simple garlic insertion method	1324
G-1-24	be conducive to apply pressure	1324
G-1-26	be easy to manipulate / maneuver	1324
J-1-17	work on multiple jar sizes	1334
C-1-08	be efficient	1334
C-1-14	function with pressure from multiple angles	1334
C-1-23	remain in position easily	1334
G-1-07	be efficient	1334
J-1-20	have large gripping surface	2222
C-1-04	allow sufficient grip with one hand	2222
C-1-07	have large handles	2222
G-1-25	have large handles	2222
Exp1 PWD Can Opener CNs for Top codes		
Tag	CN Statement "Product should…_"	Code
C-1-15	be easy to turn	1223
C-1-25	require only minimal squeeze force to puncture can	1223
C-1-20	require only low force to hold closed	1224
C-1-29	put user at the right height	1224
C-1-24	be lightweight	1232
C-1-27	remain sharp as long as possible	1232
C-1-19	have a nice gripping surface	1321
C-1-22	be familiar	1321
C-1-28	be easy to understand	1321
C-1-10	position user's hands comfortably	1322
C-1-11	operation should be simple	1324
C-1-08	be efficient	1334
C-1-14	function with pressure from multiple angles	1334
C-1-23	remain in position easily	1334
C-1-04	allow sufficient grip with one hand	2222

C-1-07	have large handles	2222
Exp1 PWD Garlic Press CNs for Top codes		
Tag	CN Statement "Product should…_"	Code
G-1-01	have an obvious holder	1321
G-1-12	have obvious operation	1321
G-1-20	have a familiar shape	1321
G-1-13	have simple garlic insertion method	1324
G-1-24	be conducive to apply pressure	1324
G-1-26	be easy to manipulate / maneuver	1324
G-1-05	have a non-slip grip surface	1412
G-1-11	be rounded so as not to cut into the hand	1412
Exp1 PWD Jar Opener CNs for Top codes		
Tag	CN Statement "Product should…_"	Code
J-1-12	have an easy to turn knob	1222
J-1-19	operate with as few steps as possible	1222
J-1-01	look simple	1321
J-1-04	be easy to understand	1321
J-1-18	have a nice grip	1321
J-1-03	be easy to assemble	1324
J-1-22	be easy to attach to lid	1324

EXP2 Top Codes by List

(Each List Provides: Tag, Statement and Code, sorted by Code)

EXP 2: CN Lists for Top Codes: Separated by Lists: For All Participants		
Exp2 All CNs for Top codes		
Tag	CN Statement	Code
bjo-12	Product should provide good leverage	1233
bjo-20	Product should grip lid easily	1233
cgp-24	Product should provide good leverage	1233
sgp-22	Product should provide good leverage	1233
tjo-09	Product should provide good leverage	1233
wco-10	Product should provide good leverage	1233
bjo-03	Product should Not be too unfamiliar	1321
bjo-04	Product should Not look scary	1321
bjo-06	Product operation should be visible	1321
bjo-09	Product should have a simple design	1321
bjo-17	Product should be easy to understand	1321
bjo-18	Product should have clear directions	1321
bjo-19	Product should have instructions that are easy to read	1321
cgp-16	Product should be easy to understand	1321
rco-10	Product should be familiar	1321
rco-15	Product should look simple	1321
rco-29	Product should have comfortably curved handles	1321
sgp-17	Product should be intuitive	1321
sgp-23	Product should be comfortable to hold	1321
tjo-01	Product should have a simple design	1321
tjo-26	Product should Not be clunky	1321
tjo-28	Product should be easy to understand/intuitive/obvious	1321
wco-13	Product should have an ergonomic shape	1321
wco-15	Product should look good	1321
wco-17	Product should be easy to understand	1321
wco-19	Product's extra features should be visible/obvious	1321
wco-23	Product should not feel flimsy	1321
bjo-15	Product should be easy to grip/grasp	1322
cgp-05	Product should have an easy to access container to load garlic	1322
cgp-22	Product should be easy/comfy to grasp/grip	1322
rco-18	Product should be easy to grasp/grip	1322
sgp-07	Product should have easy to grip handles	1322
tjo-21	Product should Not be hard to grip	1322
wco-35	Product should Not need awkward angles to use	1322
bjo-08	Product should be easy/simple to attach	1324

bjo-10	Product should Not need precision/complex movements	1324
cgp-04	Product should open Easily	1324
rco-06	Product should be easy to maneuver	1324
rco-20	Product should be easy to turn	1324
sgp-20	Product should be easy to insert garlic	1324
sgp-25	Product should be easy to manipulate	1324
tjo-08	Product should give the user good control	1324
tjo-16	Product should be easy to detach from lid	1324
wco-01	Product should require only low dexterity to operate	1324
wco-04	Product should be easy to detach from can	1324
wco-06	Product should Not require a lot of actions	1324
wco-30	Product should be easy to turn	1324
wco-36	Product should Not need large movements	1324
bjo-01	Product should be durable	1332
bjo-11	Product should work quickly	1332
cgp-13	Product should be compact	1332
cgp-25	Product should be heavyduty	1332
rco-24	Product should not be flimsy	1332
sgp-04	Product should be durable	1332
sgp-13	Product should be compact	1332
wco-02	Product should be durable	1332
wco-14	Product should work quickly	1332
bjo-29	Product should work towards user instead of away	2124
cgp-15	Product should Not open too far / Not need full extension of hands to use	2124
cgp-20	Product should be usable with only one hand	2124
rco-13	Product should be usable with only one hand	2124
sgp-03	Product should Not need two hands to use	2124
sgp-06	Product should be usable with either hand	2124
sgp-21	Product should signal that the crunch is complete	2124
tjo-06	Product should tell user when it is attached	2124
wco-07	Product should work with only one hand	2124
wco-24	Product should indicate when it is engaged/closed	2124
bjo-13	Product should have big handles	2242
cgp-10	Product should Not have thick handles	2242
cgp-11	Product should have big handles	2242
rco-07	Product should not have thin/narrow handles	2242
rco-27	Product should have large handles	2242
sgp-10	Product should Not have small handles	2242
sgp-11	Product should Not have short handles	2242

sgp-12	Product should have small handles	2242
tjo-25	Product should have large handles	2242
wco-32	Product should have large turning handle	2242
Exp2 Individual Product Lists CNs Top Codes		
Exp2 Twisting Jar Opener CNs for Top codes		
Tag	CN Statement	Code
tjo-01	Product should have a simple design	1321
tjo-26	Product should Not be clunky	1321
tjo-28	Product should be easy to understand/intuitive/obvious	1321
tjo-08	Product should give the user good control	1324
tjo-16	Product should be easy to detach from lid	1324
Exp2 Black Jar Opener CNs for Top codes		
Tag	CN Statement	Code
bjo-21	Product should Not slide on lid	1134
bjo-22	Product should Not strip the lid	1134
bjo-12	Product should provide good leverage	1233
bjo-20	Product should grip lid easily	1233
bjo-03	Product should Not be too unfamiliar	1321
bjo-04	Product should Not look scary	1321
bjo-06	Product operation should be visible	1321
bjo-09	Product should have a simple design	1321
bjo-17	Product should be easy to understand	1321
bjo-18	Product should have clear directions	1321
bjo-19	Product should have instructions that are easy to read	1321
bjo-08	Product should be easy/simple to attach	1324
bjo-10	Product should Not need precision/complex movements	1324
bjo-01	Product should be durable	1332
bjo-11	Product should work quickly	1332
Exp2 Straight Garlic Press CNs for Top codes		
Tag	CN Statement	Code
sgp-09	Product should get a lot of garlic per effort (efficient)	1234
sgp-15	Product should Not waste much garlic	1234
sgp-17	Product should be intuitive	1321
sgp-23	Product should be comfortable to hold	1321
sgp-20	Product should be easy to insert garlic	1324
sgp-25	Product should be easy to manipulate	1324
sgp-04	Product should be durable	1332
sgp-13	Product should be compact	1332
sgp-03	Product should Not need two hands to use	2124

sgp-06	Product should be usable with either hand	2124
sgp-21	Product should signal that the crunch is complete	2124
sgp-10	Product should Not have small handles	2242
sgp-11	Product should Not have short handles	2242
sgp-12	Product should have small handles	2242
Exp2 Curved Garlic Press CNs for Top codes		
Tag	CN Statement	Code
cgp-17	Product should be food sanitary	1145
cgp-19	Product should be dishwasherable	1145
cgp-05	Product should have an easy to access container to load garlic	1322
cgp-22	Product should be easy/comfy to grasp/grip	1322
cgp-13	Product should be compact	1332
cgp-25	Product should be heavyduty	1332
cgp-15	Product should Not open too far / Not need full extension of hands to use	2124
cgp-20	Product should be usable with only one hand	2124
cgp-10	Product should Not have thick handles	2242
cgp-11	Product should have big handles	2242
Exp2 Red Can Opener CNs for Top codes		
Tag	CN Statement	Code
rco-05	Product should work being turned in both directions	1144
rco-28	Product should not have any wiggle in it	1144
rco-10	Product should be familiar	1321
rco-15	Product should look simple	1321
rco-29	Product should have comfortably curved handles	1321
rco-06	Product should be easy to maneuver	1324
rco-20	Product should be easy to turn	1324
rco-03	Product should be easy to align the blade	1334
rco-19	Product should not need to be held closed	1334
rco-04	Product should have a sharp blade	1442
rco-26	Product should have nonslip handles	1442
rco-07	Product should not have thin/narrow handles	2242
rco-27	Product should have large handles	2242
Exp2 White Can Opener CNs for Top codes		
Tag	CN Statement	Code
wco-12	Product should have instructions	1122
wco-18	Product should Not have unfamiliar extra features	1122
wco-25	Product should take little pressure to press closed	1224
wco-28	Product should take little or no pressure to stay closed	1224
wco-13	Product should have an ergonomic shape	1321

wco-15	Product should look good	1321
wco-17	Product should be easy to understand	1321
wco-19	Product's extra features should be visible/obvious	1321
wco-23	Product should not feel flimsy	1321
wco-01	Product should require only low dexterity to operate	1324
wco-04	Product should be easy to detach from can	1324
wco-06	Product should Not require a lot of actions	1324
wco-30	Product should be easy to turn	1324
wco-36	Product should Not need large movements	1324
wco-02	Product should be durable	1332
wco-14	Product should work quickly	1332
wco-05	Product should have efficient twisting mechanism with no play	1432
wco-31	Product should have smooth turning mechanism	1432
wco-07	Product should work with only one hand	2124
wco-24	Product should indicate when it is engaged/closed	2124
Exp2 Combined List Top Codes		
Exp2 C List CNs for Top Codes		
Tag	CN Statement	Code
C04	Product should look simple	1321
C05	Product should be familiar	1321
C06	Product should look good	1321
C08	Product should not feel flimsy	1321
C12	Product should be easy to understand	1321
C27	Product’s extra features should be visible/obvious	1321
C46	Product should have comfortably curved / ergonomic handles	1321
C16	Product should be easy to detach from can	1324
C34	Product should be easy to maneuver	1324
C35	Product should Not require a lot of actions	1324
C40	Product should Not need large movements	1324
C41	Product should require only low dexterity to operate	1324
C42	Product should be easy to turn	1324
C21	Product should have a sharp blade	1442
C44	Product should have comfy rubber grips on handles	1442
C45	Product should have nonslip handles	1442
C47	Product should not have thin/narrow handles	2242
C49	Product should have large turning handle	2242
C54	Product should have large handles	2242
Exp2 G List CNs for Top codes		
Tag	CN Statement	Code

G04	Product should have an easy to access container to load garlic	1322
G23	Product should be easy/comfy to grasp/grip	1322
G37	Product should have easy to grip handles	1322
G05	Product should open Easily	1324
G27	Product should be easy to manipulate	1324
G38	Product should be easy to insert garlic	1324
G11	Product should Not have thick handles	2242
G12	Product should have big handles	2242
G29	Product should Not have short handles	2242
G30	Product should have small handles	2242
Exp2 J List CNs for Top Codes		
Tag	CN Statement	Code
J03	Product should Not be too unfamiliar	1321
J04	Product should Not look scary	1321
J06	Product operation should be visible	1321
J15	Product should be easy to understand	1321
J16	Product should have clear directions	1321
J17	Product should have instructions that are easy to read	1321
J18	Product should grip lid easily	1321
J20	Product should have a simple design	1321
J41	Product should Not be clunky	1321
J08	Product should be easy/simple to attach	1324
J09	Product should Not need precision/complex movements	1324
J27	Product should give the user good control	1324
J34	Product should be easy to detach from lid	1324

Appendix Z: Top Code Info Charts

Top Codes FSU	Count	Top Codes PWD	Count	Top Codes Exp1	FSU	PWD
1223	4	1223	4	1223	4	4
1321	14	1224	4	1224	1	4
1322	6	2222	4	1321	14	9
1324	15	1334	5	1322	6	1
1412	4	1324	6	1324	15	6
2242	4	1321	9	1334	3	5
				1412	4	2
				2222	1	4
				2242	4	1

21 non top codes in C	13 non top codes in J
15 non top codes in G	16 non top codes in C
15 non top codes in J	17 non top codes in G

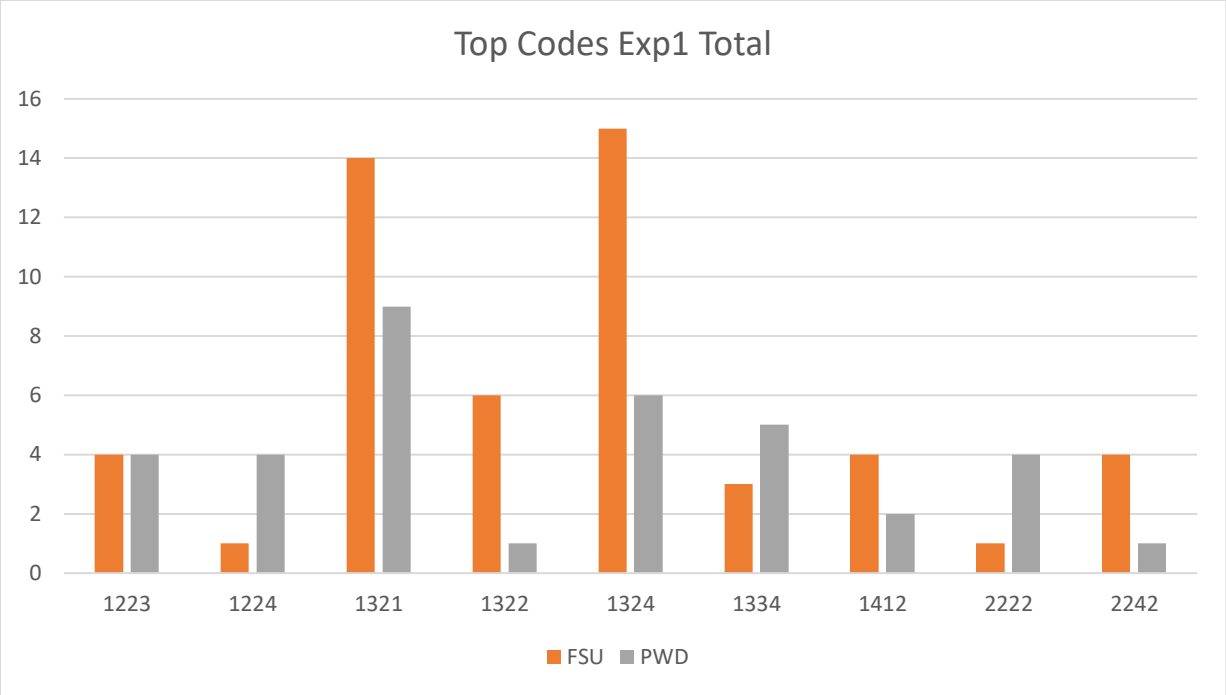
Top Codes Exp1	FSU	PWD
1223	4	4
1224	1	4
1321	14	9
1322	6	1
1324	15	6
1334	3	5
1412	4	2
2222	1	4
2242	4	1
Top Codes Exp 1 JO	FSU	PWD
1324	6	2
1321	4	3
1223	2	1
1222	1	2
Top Codes Exp 1 CO	FSU	PWD
1223	2	2
1224	1	2
1232	1	2
1321	5	3
1322	2	1
1324	5	1
1334	3	3
1412	2	1
2222	1	2
2242	2	0
Top Codes Exp 1 GP	FSU	PWD
1234	2	1
1321	5	3
1322	2	1
1324	4	3
1412	2	2
2242	2	1

Tags	Statement	Final Codes	Internal Matches	ICF Codes	ICF Descriptions
G-1-24	be conducive to apply pressure	**1324**		b7101/d498/ s730	mobility and structure of the upper extremity
J-1-01	look simple	**1321**		b156	Perceptual functions?/
C-1-22	be familiar	**1321**	3?	b156/d199	perceptual functions/ mental functions
G-1-01	have an obvious holder	**1321**		b156/d199	perceptual functions/ mental functions
G-1-12	have obvious operation	**1321**		b156/d199	perceptual functions/ mental functions
G-1-20	have a familiar shape	**1321**	3?	b156/d199	perceptual functions/ mental functions
G-1-13	have simple garlic insertion method	**1324**		b156/d199/ d440	perceptual functions/ mental functions/fine hand use
C-1-28	be easy to understand	**1321**	1	b164	higher level cognitive functions?
J-1-04	be easy to understand	**1321**	1	b164	higher level cognitive functions?
C-1-29	put user at the right height	**1224**		b7102?	Mobility of joints generalized?
C-1-25	require only minimal squeeze force to puncture can	**1223**	6	b730	muscle power functions
G-1-14	require only low grip force / pressure to close	**1223**	6	b730	muscle power functions
J-1-08	require only small forces to use	**1224**		b730	muscle power functions
J-1-14	require low torque to twist off lid	**1223**		b730	muscle power functions
C-1-20	require only low force to hold closed	**1224**		b730/b7401	muscle power functions/Endurance of muscle groups
C-1-11	operation should be simple	**1324**		b7601/b176	control of complex voluntary motions/mental functions of sequencing complex movements
J-1-03	be easy to assemble	**1324**		d440	fine hand use
C-1-19	have a nice gripping surface	**1321**	4	d4401	grasping
J-1-18	have a nice grip	**1321**	4	d4401	grasping
J-1-20	have large gripping surface	**2222**	5?	d4401	grasping
G-1-26	be easy to manipulate / maneuver	**1324**		d4402	manipulating
J-1-22	be easy to attach to lid	**1324**		d4402	manipulating
C-1-15	be easy to turn	**1223**		d4453	turning or twisting the hands or arms
C-1-04	allow sufficient grip with one hand	**2222**		s7302	structure of the hand

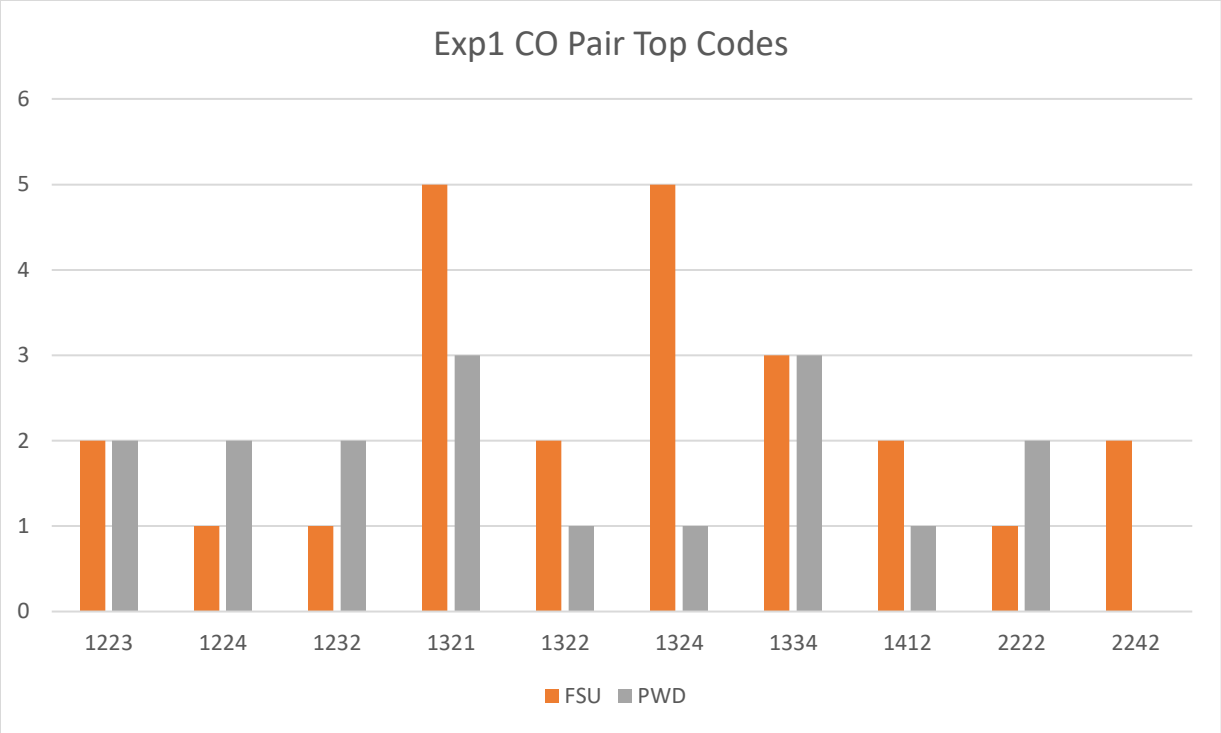
C-1-07	have large handles	**2222**	5	s7302	structure of the hand
G-1-02	require only modest hand spans	**1224**		s7302	structure of the hand
G-1-25	have large handles	**2222**	5	s7302	structure of the hand
C-1-08	be efficient	**1334**	2		
C-1-14	function with pressure from multiple angles	**1334**		b7101/d498/ s730	mobility and structure of the upper extremity
C-1-23	remain in position easily	**1334**		d440	fine hand use
G-1-07	be efficient	**1334**	2		
J-1-17	work on multiple jar sizes	**1334**			

Tags	**Statement**	**Final Codes**	**Internal Matches**	**ICF Codes**	**ICF Description**
C-2-07	be made of a material that feels nice to hold	1322		b156	perceptual functions
C-2-25	have nice feeling knob and handles	1321		b156	perceptual functions
G-2-13	look simple	1321		b156	Perceptual functions?/
G-2-16	feel durable	1321		b156	Perceptual functions?/
G-2-23	be aesthetically pleasing	1321		b156	Perceptual functions?/
J-2-21	feel secure	1321		b156	Perceptual functions?/
C-2-18	be familiar	1321		b156/d199	perceptual functions/mental functions
C-2-01	operation should be clear / obvious	1321	5	b164	higher level cognitive functions?
G-2-22	operation should be obvious / intuitive	1321	5	b164	higher level cognitive functions?
J-2-01	be easy to understand / intuitive	1321		b164	higher level cognitive functions?
J-2-17	have clear directions	1321		b164/b1640/d166 /b210-279	higher level cognitive functions/abstraction/reading/ sensory functions
C-2-04	be attractive	1321		b210/b1649	seeing functions/higher level cognitive functions unspecified
C-2-08	be easy to turn / twist	1223	3	b710/s73011	mobility of joint functions/wrist joint
G-2-01	require only small force to squeeze closed	1223	7	b730	muscle power functions
J-2-07	require only low forces to operate	1223	7	b730	muscle functions
J-2-25	take off the seal with little force	1223		b730	muscle power functions
C-2-10	be easy to squeeze	1324		b730/b7300	muscle power functions/power of isolated muscle groups
C-2-13	pierce the can with little effort	1223		b730/b7300	muscle power functions/power of isolated muscle groups
C-2-23	operation should be easy to learn	1321		d131/d155/d159/ d160/d199	learning
C-2-19	have easy to press buttons	1322		d440	fine hand use
G-2-15	be easy to insert/load garlic into place	1324		d440	fine hand use

G-2-18	require only low dexterity	1324	6	d440	fine hand use
J-2-03	require only a little dexterity / coordination	1324	6	d440	fine hand use
J-2-10	be easy to assemble	1324		d440	fine hand use
G-2-08	be easy to pick up	1324		d4400	picking up
C-2-34	be easy to grip	1322	1	d4401	grasping
G-2-02	be easy to grip/grasp	1322	1	d4401	grasping
G-2-14	have a nice grip	1322		d4401	grasping
J-2-09	be easy to grip	1322	1	d4401	grasping
C-2-15	be easy to maneuver	1324	2	d4402	manipulating
G-2-24	be easy to maneuver / manipulate	1324	2	d4402	manipulating
J-2-15	be easy to attach to lid	1324		d4402	manipulating
C-2-06	be easy to remove from can	1324		d4402/d4403	
J-2-19	be easy to push	1324		d4451	Pushing
J-2-08	be easy to twist	1324	3	d4453	turning or twisting the hands or arms
G-2-30	fit in the hand comfortably / well	1321		s7302	structure of the hand
J-2-14	handle should fit nicely in the hand	1321		s7302	structure of the hand
C-2-14	not dig into the hand	1412		s7302	structure of the hand?
C-2-22	have thick handles	2242			sort of hand
C-2-29	have small handles	2242			sort of hand
G-2-04	have a large gripping surface	2242			sort of hand
G-2-09	have a non-slip surface	1412	4		
G-2-29	have rounded edges so as not to dig into the hand	1412		s7302	structure of the hand?
J-2-02	have a non-slip surface	1412	4		


Top Codes Exp1 Total
16
14
12
10
8
6
4
2
0
1223
1224
1321
1322
1324
1334
1412
2222
2242
FSU
PWD


Exp1 JO Pair Top Codes
7
6
5
4
3
2
1
0
1324
1321
1223
1222
FSU
PWD


Exp1 CO Pair Top Codes
6
5
4
3
2
1
0
1223
1224
1232
1321
1322
1324
1334
1412
2222
2242
FSU
PWD


Exp1 GP Pair Top Codes
6
5
4
3
2
1
0
1234
1321
1322
1324
1412
2242
FSU
PWD

Top Codes 6 prods Exp2	Count
1233	6
1321	21
1322	7
1324	14
1332	9
2124	10
2242	10

TJO Top Codes	Count
1321	3
1324	2

BJO Top Codes	Count
1321	7
1134	2
1233	2
1324	2
1332	2

SGP Top Codes	Count
2124	3
2242	3
1234	2
1321	2
1324	2
1332	2

CGP Top Codes	Count
1145	2
1322	2
1332	2
2124	2
2242	2

RCO Top Codes	Count
1321	3
1144	2
1324	2
1334	2
1442	2
2242	2

WCO Top Codes	Count
1321	5
1324	5
1122	2
1224	2
1332	2
1432	2
2124	2

WCO TOP CODES CNs	Statement	Ont Code	group	ICF Code	ICF Description	Total Product Frequency
wco-01	Product should require only low dexterity to operate	1324	s	d4402	manipulating	1
wco-02	Product should be durable	1332	s			1
wco-04	Product should be easy to detach from can	1324	s	d4402/d4403/ d445(0/1)	manipulating/releasing/pushpull	1
wco-05	Product should have efficient twisting mechanism w/ no play	1432	s			1
wco-06	Product should Not require a lot of actions	1324	s	d7601/2/b176	control/coordination of complex voluntary movements / mental functions of sequencing complex movements	1
wco-07	Product should work with only one hand	2124	s	?	?	1
wco-12	Product should have instructions	1122	r	d166	Reading??	1
wco-13	Product should have an ergonomic shape	1321	s	s7302	structure of the hand	3

wco-14	Product should work quickly	1332	s			2
wco-15	Product should look good	1321	s	b210/b1649	seeing functions/higher level cognitive functions unspecified	2
wco-17	Product should be easy to understand	1321	b	b164	higher level cognitive functions?	4
wco-18	Product should Not have unfamiliar extra features	1122	s	b156/b199	Perceptual functions?/ mental functions unspecified	3
wco-19	Product's extra features should be visible/obvious	1321	b	b210/b156	seeing functions/perceptual functions	2
wco-23	Product should not feel flimsy	1321	r	b156/b260/b265/b1649	Perceptual functions ETC	2
wco-24	Product should indicate when it is engaged/closed	2124	s	b156	Perceptual functions?	2
wco-25	Product should take little pressure to press closed	1224	b	b730/b7300	muscle power functions/power of isolated muscle groups	4
wco-28	Product should take little or no pressure to stay closed	1224	s	b740	muscle endurance functions	2
wco-30	Product should be easy to turn	1324	b	d4453	turning or twisting the hands or arms	4
wco-31	Product should have smooth turning mechanism	1432	b			3
wco-36	Product should Not need large movements	1324	r	b715/b7101?	stability of joint functions/mobility of several joints	1

RCO TOP CODES CNs	Statement	Ont Code	group	ICF Code	ICF Description	Total Product Frequency
rco-03	Product should be easy to align the blade	1334	s			1
rco-04	Product should have a sharp blade	1442	r			1
rco-05	Product should work being turned in both directions	1144	s			1
rco-06	Product should be easy to maneuver	1324	s	d4402	manipulating	1
rco-07	Product should not have thin/narrow handles	2242	b			2
rco-10	Product should be familiar	1321	b	b156/b199	Perceptual functions?/ mental functions unspecified	4
rco-15	Product should look simple	1321	s	b156/b199	Perceptual functions?/ mental functions unspecified	1
rco-19	Product should not need to be held closed	1334	s	b7401	endurance of muscle groups	3
rco-20	Product should be easy to turn	1324	s	d4453	turning or twisting the hands or arms	7

rco-26	Product should have nonslip handles	1442	r			1
rco-27	Product should have large handles	2242	s			1
rco-28	Product should not have any wiggle in it	1144	r			1
rco-29	Product should have comfortably curved handles	1321	s	s7302	Structure of the hand	1

CGP TOP CODES CNs	Statement	Ont Code	group	ICF Code	ICF Description
cgp-05	Product should have an easy to access container to load garlic	1322	s	d4402	manipulating
cgp-10	Product should Not have thick handles	2242	r		
cgp-11	Product should have big handles	2242	s		
cgp-13	Product should be compact	1332	s		
cgp-15	Product should Not open too far / Not need full extension of hands to use	2124	s	s7302	structure of the hand
cgp-17	Product should be food sanitary	1145	s		
cgp-19	Product should be dishwasherable	1145	s		
cgp-20	Product should be usable with only one hand	2124	s	?	?
cgp-22	Product should be easy/comfy to grasp/grip	1322	b	d4401	Grasping
cgp-25	Product should be heavyduty	1332	r		

SGP TOP CODES CNs	Statement	Ont Code	group	ICF Code	ICF Description
sgp-03	Product should Not need two hands to use	2124	s	s7308	Structure of upper extremity, other specified
sgp-04	Product should be durable	1332	b		
sgp-06	Product should be usable with either hand	2124	g		
sgp-09	Product should get a lot of garlic per effort (efficient)	1234	r		
sgp-10	Product should Not have small handles	2242	s		
sgp-11	Product should Not have short handles	2242	s		
sgp-12	Product should have small handles	2242	b		
sgp-13	Product should be compact	1332	s		
sgp-15	Product should Not waste much garlic	1234	r		
sgp-17	Product should be intuitive	1321	s	b164	higher level cognitive functions

sgp-20	Product should be easy to insert garlic	1324	s	d440/d4402	fine hand use/manipulating
sgp-21	Product should signal that the crunch is complete	2124	s	b210-b279	sensory functions
sgp-23	Product should be comfortable to hold	1321	s	d430	lifting and carrying objects
sgp-25	Product should be easy to manipulate	1324	s	d4402	manipulating

BJO TOP CODES CNs	Statement	Ont Code	group	ICF Code	ICF Description
bjo-01	Product should be durable	1332	r		
bjo-03	Product should Not be too unfamiliar	1321	s	b156/b199	Perceptual functions?/ mental functions unspecified
bjo-04	Product should Not look scary	1321	s	b156/b199	Perceptual functions?/ mental functions unspecified
bjo-06	Product operation should be visible	1321	s	b210/d110	seeing functions/watching?
bjo-08	Product should be easy/simple to attach	1324	s	d440	fine hand use
bjo-09	Product should have a simple design	1321	r	b164/b1640	higher level cognitive functions/abstraction
bjo-10	Product should Not need precision/complex movements	1324	s	b7601	control of complex movements
bjo-11	Product should work quickly	1332	b		
bjo-12	Product should provide good leverage	1233	s		
bjo-17	Product should be easy to understand	1321	b	b164	higher level cognitive functions?
bjo-18	Product should have clear directions	1321	s	b164/b1640/ d166/b210-279	higher level cognitive functions/abstraction/reading /sensory functions
bjo-19	Product should have instructions that are easy to read	1321	b	d166/b210	Reading/seeing functions
bjo-20	Product should grip lid easily	1233	r		
bjo-21	Product should Not slide on lid	1134	r		
bjo-22	Product should Not strip the lid	1134	b		

TJO TOP CODES CNs	Statement	Ont Code	group	ICF Code	ICF Description
tjo-01	Product should have a simple design	1321	r	b164/b1640	higher level cognitive functions/abstraction
tjo-08	Product should give the user good control	1324	s	b760/d4402	control of voluntary movements/manipulating
tjo-16	Product should be easy to detach from lid	1324	s	d4402/d4305	manipulating/putting down objects

tjo-26	Product should Not be clunky	1321	s	b210/b1649??	seeing functions/higher level cognitive functions unspecified
tjo-28	Product should be easy to understand/intuitive/obvious	1321	s	b164	higher level cognitive functions?

All EXP2 Top Codes	Accompanying CNs	Code	Freq SSU	Freq PMR	Total Freq	ICF Code	HF	group
bjo-01	Product should be durable	1332	0	1	1		0	r
bjo-03	Product should Not be too unfamiliar	1321	1	0	1	b156/b199	1	s
bjo-04	Product should Not look scary	1321	1	0	1	b156/b199	1	s
bjo-06	Product operation should be visible	1321	1	0	1	b210/d110	1	s
bjo-08	Product should be easy/simple to attach	1324	1	0	1		1	s
bjo-09	Product should have a simple design	1321	1	1	2	b164/b1640	1	b
bjo-10	Product should Not need precision/complex movements	1324	2	0	2	b7601	1	s
bjo-11	Product should work quickly	1332	1	1	2		0	b
bjo-12	Product should provide good leverage	1233	1	0	1		0	s
bjo-13	Product should have big handles	2242	3	1	4		0	s
bjo-15	Product should be easy to grip/grasp	1322	2	0	2	d4401	1	s
bjo-17	Product should be easy to understand	1321	3	2	5	b164	1	b
bjo-18	Product should have clear directions	1321	4	0	4	b164/b1640/ d166/b210-279	1	s
bjo-19	Product should have instructions that are easy to read	1321	2	1	3	d166/b210	1	b
bjo-20	Product should grip lid easily	1233	0	1	1		0	p
bjo-29	Product should work towards user instead of away	2124	1	0	1	d4450	1	s
cgp-04	Product should open Easily	1324	1	1	2	d4402	1	b
cgp-05	Product should have an easy to access container to load garlic	1322	4	0	4		1	s
cgp-10	Product should Not have thick handles	2242	0	1	1		0	p
cgp-11	Product should have big handles	2242	2	0	2		0	s
cgp-13	Product should be compact	1332	3	0	3		0	s
cgp-15	Product should Not open too far / Not need full extension of hands to use	2124	3	0	3	s7302	1	s
cgp-16	Product should be easy to understand	1321	4	0	4	b164/b199	1	s
cgp-20	Product should be usable with only one hand	2124	1	0	1	?	1	s
cgp-22	Product should be easy/comfy to grasp/grip	1322	2	1	3		1	b
cgp-24	Product should provide good leverage	1233	0	1	1		0	p
cgp-25	Product should be heavyduty	1332	0	2	2		0	p

rco-06	Product should be easy to maneuver	1324	2	0	2	d4402	1	s
rco-07	Product should not have thin/narrow handles	2242	1	1	2		0	b
rco-10	Product should be familiar	1321	2	2	4	b156/b199	1	b
rco-13	Product should be usable with only one hand	2124	1	0	1		1	s
rco-15	Product should look simple	1321	1	0	1	b156/b199	1	s
rco-18	Product should be easy to grasp/grip	1322	3	0	3	d4401	1	s
rco-20	Product should be easy to turn	1324	7	0	7	d4453	1	s
rco-24	Product should not be flimsy	1332	0	1	1		0	p
rco-27	Product should have large handles	2242	2	0	2		0	s
rco-29	Product should have comfortably curved handles	1321	1	0	1	s7302	1	s
sgp-03	Product should Not need two hands to use	2124	1	0	1	s7308	1	s
sgp-04	Product should be durable	1332	2	1	3		0	b
sgp-06	Product should be usable with either hand	2124	0	0	0	s7302	1	g
sgp-07	Product should have easy to grip handles	1322	1	1	2	d4401	1	b
sgp-10	Product should Not have small handles	2242	1	0	1		0	s
sgp-11	Product should Not have short handles	2242	1	0	1		0	s
sgp-12	Product should have small handles	2242	1	1	2		0	b
sgp-13	Product should be compact	1332	1	0	1		0	s
sgp-17	Product should be intuitive	1321	1	0	1	b164	1	s
sgp-20	Product should be easy to insert garlic	1324	1	0	1	d440/d4402	1	s
sgp-21	Product should signal that the crunch is complete	2124	1	0	1	b210-b279	1	s
sgp-22	Product should provide good leverage	1233	1	0	1		0	s
sgp-23	Product should be comfortable to hold	1321	2	0	2	d430	1	s
sgp-25	Product should be easy to manipulate	1324	2	0	2	d4402	1	s
tjo-01	Product should have a simple design	1321	0	1	1	b164/b1640	1	p
tjo-06	Product should tell user when it is attached	2124	1	0	1	b210-b279	1	s
tjo-08	Product should give the user good control	1324	1	0	1	b760/d4402	1	s
tjo-09	Product should provide good leverage	1233	0	1	1		0	p
tjo-16	Product should be easy to detach from lid	1324	1	0	1	d4402/d4305	1	s
tjo-21	Product should Not be hard to grip	1322	1	0	1	d4401	1	s
tjo-25	Product should have large handles	2242	1	0	1		0	s
tjo-26	Product should Not be clunky	1321	1	0	1	b210/b1649??	1	s
tjo-28	Product should be easy to understand/intuitive/obvious	1321	4	0	4	b164	1	s
wco-01	Product should require only low dexterity to operate	1324	1	0	1	d4402	1	s

wco-02	Product should be durable	1332	1	0	1		0	s
wco-04	Product should be easy to detach from can	1324	1	0	1	d4402/d4403/d445(0/1)	1	s
wco-06	Product should Not require a lot of actions	1324	1	0	1	d7601/2/b176	1	s
wco-07	Product should work with only one hand	2124	1	0	1	?	1	s
wco-10	Product should provide good leverage	1233	0	1	1		0	p
wco-13	Product should have an ergonomic shape	1321	3	0	3	s7302	1	s
wco-14	Product should work quickly	1332	2	0	2		0	s
wco-15	Product should look good	1321	2	0	2		1	s
wco-17	Product should be easy to understand	1321	3	1	4	b164	1	b
wco-19	Product's extra features should be visible/obvious	1321	1	1	2	b210/b156	1	b
wco-23	Product should not feel flimsy	1321	0	2	2	b156/b260/b265/b1649	1	p
wco-24	Product should indicate when it is engaged/closed	2124	2	0	2	b156	1	s
wco-30	Product should be easy to turn	1324	3	1	4	d4453	1	b
wco-32	Product should have large turning handle	2242	1	1	2		0	b
wco-35	Product should Not need awkward angles to use	1322	1	0	1	b710	1	s
wco-36	Product should Not need large movements	1324	0	1	1	b715/b7101?	1	p

Can Opener Pair Exp2 Top Code Info

Top Codes	Count					
1321	7					
1324	6					
1442	3					
2242	3	HF% = 0.684210526				
Code	**CTag**	**Statement**	**ICF Code**	**ICF Description**	**Group**	**Total Comb Freq**
1321	C04	Product should look simple	b156/b199	Perceptual functions?/ mental functions unspecified	s	1
1321	C05	Product should be familiar	b156/b199	Perceptual functions?/ mental functions unspecified	b	4
1321	C06	Product should look good	b210/b1649	seeing functions/higher level cognitive functions unspecified	s	2
1321	C08	Product should not feel flimsy	b156/b260/b265/b1649	Perceptual functions ETC	r	2
1321	C12	Product should be easy to understand	b164	higher level cognitive functions?	b	4
1324	C16	Product should be easy to detach from can	d4402/d4403/d445(0/1)	manipulating/releasing/pushpull	s	1

1442	C21	Product should have a sharp blade			r	1
1321	C27	Product's extra features should be visible/obvious	b210/b156	seeing functions/perceptual functions	b	2
1324	C34	Product should be easy to maneuver	d4402	manipulating	s	2
1324	C35	Product should Not require a lot of actions	d7601/2/b176	control/coordination of complex voluntary movements / mental functions of sequencing complex movements	s	1
1324	C40	Product should Not need large movements	b715/b7101?	stability of joint functions/mobility of several joints	r	1
1324	C41	Product should require only low dexterity to operate	d4402	manipulating	s	1
1324	C42	Product should be easy to turn	d4453	turning or twisting the hands or arms	s	8
1442	C44	Product should have comfy rubber grips on handles			b	6
1442	C45	Product should have nonslip handles			r	1
1321	C46	Product should have comfortably curved / ergonomic handles	s7302	Structure of the hand	s	4
2242	C47	Product should not have thin/narrow handles			b	2
2242	C49	Product should have large turning handle			b	2
2242	C54	Product should have large handles			s	2

Garlic Press Pair Exp2 Top Code Info

Top Codes	Count				
1322	3				
1324	3				
2242	4	HF% = .60			
Code	**CTag**	**Statement**	**ICF Code**	**ICF Description**	**Group**
1322	G04	Product should have an easy to access container to load garlic	d4402	manipulating	s
1324	G05	Product should open Easily	d4402/d445(0/1)?	manipulating/pushing/pulling	b
2242	G11	Product should Not have thick handles			r
2242	G12	Product should have big handles			s
1322	G23	Product should be easy/comfy to grasp/grip	d4401	Grasping	b
1324	G27	Product should be easy to manipulate	d4402	manipulating	s
2242	G29	Product should Not have short handles			s

2242	G30	Product should have small handles			b
1322	G37	Product should have easy to grip handles	d4401	Grasping	b
1324	G38	Product should be easy to insert garlic	d440/d4402	fine hand use/manipulating	s

Jpair					
Top codes	Count	100%			
1321	9				
1324	4				
Code	**CTag**	**Statement**	**ICF Code**	**ICF Description**	**Group**
1321	J03	Product should Not be too unfamiliar	b156/b199	Perceptual functions?/ mental functions unspecified	s
1321	J04	Product should Not look scary	b156/b199	Perceptual functions?/ mental functions unspecified	s
1321	J06	Product operation should be visible	b210/d110	seeing functions/watching?	s
1324	J08	Product should be easy/simple to attach	d440	fine hand use	s
1324	J09	Product should Not need precision/complex movements	b7601	control of complex movements	s
1321	J15	Product should be easy to understand	b164	higher level cognitive functions?	b
1321	J16	Product should have clear directions	b164/b1640/ d166/b210-279	higher level cognitive functions/abstraction/reading/sensory functions	s
1321	J17	Product should have instructions that are easy to read	d166/b210	Reading/seeing functions	b
1321	J18	Product should grip lid easily			r
1321	J20	Product should have a simple design	b164/b1640	higher level cognitive functions/abstraction	b
1324	J27	Product should give the user good control	b760/d4402	control of voluntary movements/manipulating	s
1324	J34	Product should be easy to detach from lid	d4402/d4305	manipulating/putting down objects	s
1321	J41	Product should Not be clunky	b210/b1649??	seeing functions/higher level cognitive functions unspecified	s

Appendix ZZ: Weight Difference Analysis Starts

Straight Garlic Press Need Statements	Weight from PMR	Weight from SSU	Diff	Weight Add1	Add1 Matches Where
Product should Not have to open very far to access	2	3	-1	4	higher than both
Product should be easy to clean	4	4	0	4	same as both
Product should Not need two hands to use	3	2	1	5	higher than both
Product should be durable	5	4	1	5	pmr
Product should Not have a lot of moving parts	3	3	0	5	higher than both
Product should be usable with either hand	5	4	1	5	pmr
Product should have easy to grip handles	5	4	1	4	ssu
Product should have tapered edges so it can't catch on the hand	4	5	-1	5	ssu
Product should get a lot of garlic per effort (efficient)	4	5	-1	5	ssu
Product should Not have small handles	4	4	0	4	both
Product should Not have short handles	4	4	0	4.5	both
Product should have small handles	1	2	-1	1	pmr
Product should be compact	2	3	-1	2	pmr
Product should be easy to apply pressure (angle)	4	5	-1	1	lower than both
Product should Not waste much garlic	4	2	2	2	ssu
Product should require little pressure to squeeze closed	4	4	0	4	both
Product should be intuitive	4	3	1	4	pmr
Product should be simple	4	2	2	5	higher than both
Product should have a chamber big enough for all garlic	2	3	-1	5	higher than both
Product should be easy to insert garlic	3	4	-1	5	higher than both
Product should signal that the crunch is complete	3	1	2	4	higher than both
Product should provide good leverage	5	4	1	4	ssu
Product should be comfortable to hold	5	4	1	3.5	lower than both
Product's parts should not misalign	4	3	1	5	higher than both
Product should be easy to manipulate	5	3	2	5	pmr
Product should Not be too small	5	4	1	5	pmr
Analysis of ssu vs pmr = 8 with ssu higher by 1, 9 with pmr higher by 1, 3 with pmr higher by 2, 5 agree					

Curved Garlic Press Need Statements	**Weight from PMR**	**Weight from SSU**	**Diff**	**Weight Add1**	**Add1 Matches Where**
Product should be lightweight	3	1	2	4	higher than both
Product should look cool	NA	1	X	3	higher than both
Product should have an adequate sized container	4	3	1	5	higher than both
Product should open Easily	4	4	0	5	higher than both
Product should have an easy to access container to load garlic	3	5	-2	5	ssu
Product should have curved handles	3	3	0	2	lower than both
Product should Not be too complicated	3	4	-1	5	higher than both
Product should have few moving parts	3	4	-1	5	higher than both
Product should have rubber nonslip grip on handles	4	5	-1	2	lower than both
Product should Not have thick handles	2	3	-1	2.5	between
Product should have big handles	4	4	0	4	both
Products' parts should all align automatically	4	5	-1	5	ssu
Product should be compact	2	4	-2	5	higher than both
Product should fit small hands easily	4	3	1	4	pmr
Product should Not open too far / Not need full extension of hands to use	5	5	0	5	both
Product should be easy to understand	4	5	-1	3	lower than both
Product should be food sanitary	5	5	0	4.5	lower than both
Product should be easy to clean	4	5	-1	3	lower than both
Product should be dishwasherable	4	5	-1	3.5	lower than both
Product should be usable with only one hand	4	3	1	3	ssu
Product should be efficient (lots separated, none wasted)	4	3	1	4	pmr
Product should be easy/comfy to grasp/grip	5	4	1	5	pmr
Product should help release the garlic	4	5	-1	4	pmr
Product should provide good leverage	5	5	0	4	lower than both
Product should be heavyduty	2	5	-3	5	ssu
Product should be easy / require little effort to squeeze closed	5	4	1	5	pmr
Product should have rounded edges	2	5	-3	5	ssu
SSU/PMR Difference Analysis = 6 agree, 6 with pmr higher by 1, 1 with pmr higher by 2, 9 with ssu higher by 1, 2 with ssu higher by 2, 2 with ssu higher by 3, 1 NA					

Twisting Jar Opener Need Statements	Weight from PMR	Weight from SSU	Diff	Weight Add1	Add1 Matches Where
Product should have a simple design	3	2	1	5	higher than both
Product should have a clear center of rotation	3	2	1	5	higher than both
Product should hold onto the jar as well	3	4	-1	3	pmr
Product should Not allow contents to spill upon opening	4	5	-1	5	ssu
Product should be made of stainless steel	2	3	-1	2	pmr
Product should tell user when it is attached	3	4	-1	5	higher than both
Product should Not require a turning motion	2	2	0	4	higher than both
Product should give the user good control	4	4	0	5	higher than both
Product should provide good leverage	5	4	1	5	pmr
Product should Not deform the lid	5	5	0	5	both
Product should grip the lid easily and not slip	5	4	1	4	ssu
Product should lock onto the lid	5	4	1	4	ssu
Product should adjust to all lid sizes	4	5	-1	5	ssu
Product should maintain control of the lid	4	4	0	4	both
Product should also assist with putting the lid back on	2	2	0	2	both
Product should be easy to detach from lid	5	4	1	5	pmr
Product should have a low chance of mechanical failure (durable/heavyduty)	4	5	-1	3	lower than both
Product should indicate direction of turn	1	3	-2	1	pmr
Product should make it so that very little effort will remove the lid	4	5	-1	4	pmr
Product should have a good turning angle	4	3	1	4	pmr
Product should Not be hard to grip	5	4	1	4	ssu
Product should Not have sharp edges on turning knobs	5	5	0	5	both
Product should have a place to hold on both sides	3	4	-1	3	pmr
Product should work with small hands	5	3	2	5	pmr
Product should have large handles	5	2	3	5	pmr
Product should Not be clunky	4	4	0	4	both
Product should Not have too many moving parts	3	4	-1	1	lower than both
Product should be easy to understand/intuitive/obvious	3	5	-2	3	pmr
Product should have knobs that are easy to turn	5	4	1	5	pmr
SSU/PMR Difference Analysis = 7 agree, 9 with pmr higher by 1, 1 with pmr higher by 2, 1 with pmr higher by 3, 9 with ssu higher by 1, 2 with ssu higher by 2					

Black Jar Opener Need Statements	Weight from PMR	Weight from SSU	Diff	Weight Add1	Add1 Matches Where
Product should be easy to clean	5	1	4	4	between
Product should Not be too unfamiliar	3	3	0	2	
Product should Not look scary	1	1	0	2	
Product should Not have parts that can be lost	3	5	-2	5	ssu
Product operation should be visible	3	3	0	5	
Product operation should be one step	4	2	2	3	between
Product should be easy/simple to attach	5	5	0	5	both
Product should have a simple design	4	5	-1	5	ssu
Product should Not need precision/complex movements	3	4	-1	4	ssu
Product should work quickly	4	5	-1	3	
Product should provide good leverage	5	2	3	4	between
Product should have big handles	4	1	3	5	
Product should have small enough handles to hold	4	3	1	1	
Product should be easy to grip/grasp	4	4	0	4	both
Product should have rubber nonslip grip on handle	3	4	-1	4	pmr
Product should be easy to understand	3	4	-1	5	
Product should have clear directions	4	5	-1	4	pmr
Product should have instructions that are easy to read	4	5	-1	5	ssu
Product should grip lid easily	5	4	1	3	
Product should Not slide on lid	5	4	1	5	pmr
Product should Not strip the lid	5	3	2	5	pmr
Product should remove all sizes of lids	4	4	0	4	both
Product should indicate direction of turn	2	5	-3	3	between
Product should hold onto the jar as well	2	5	-3	5	ssu
Product should need only low strength to use	5	3	2	5	pmr
Product should Not need constant application of force	5	4	1	2	
Product should only work in one direction (the intended direction)	na	4	###	4	ssu
Product should work towards user instead of away	1	4	-3	2	between
SSU/PMR Weight Diff Analysis = 6 agree, 1 pmr higher by 1, 3 pmr higher by 2, 3 pmr higher by 2, 2 pmr higher by 3, 1 pmr higher by 4, 7 ssu higher by 1, 1 ssu higher by 1, 3 ssu higher by 3					

Red Can Opener Need Statements	**Weight from PMR**	**Weight from SSU**	**Diff**	**Weight Add1**	**Add1 Matches Where**
Product should not allow contents to spill	4	5	-1	5	ssu
Product should Not be free swinging	4	4	0	5	
Product should be easy to align the blade	5	4	1	5	pmr
Product should have a sharp blade	5	4	1	2.5	
Product should work being turned in both directions	3	3	0	5	
Product should be easy to maneuver	4	3	1	5	
Product should not have thin/narrow handles	1	4	-3	4	ssu
Product should cut consistently	5	5	0	4	
Product should be simple	5	4	1	5	pmr
Product should be familiar	3	4	-1	4	ssu
Product should be easy to clean	5	5	0	3	
Product should not require large wrist motions to operate	5	4	1	5	pmr
Product should be usable with only one hand	4	2	2	3	between
Product should assist with removal of the lid after cutting	4	4	0	5	
Product should look simple	2	1	1	5	
Product should work at comfortable arm/wrist angles	5	4	1	5	pmr
Product should be easy to attach to can	5	4	1	5	pmr
Product should be easy to grasp/grip	5	5	0	4	ssu
Product should not need to be held closed	4	5	-1	2.5	
Product should be easy to turn	5	5	0	3	
Product should have mechanisms that turn smoothly/fluidly	5	3	2	5	pmr
Product should not need a lot of grip force to puncture can	5	4	1	5	pmr
Product should not rust	2	5	-3	4	between
Product should not be flimsy	5	5	0	4	
Product should not catch the teeth in the blade	5	4	1	3	
Product should have nonslip handles	3	3	0	2	
Product should have large handles	5	4	1	5	pmr
Product should not have any wiggle in it	4	4	0	5	
Product should have comfortably curved handles	4	4	0	5	

White Can Opener Need Statements	W Part# from PMR	W Part# from SSU	**Diff**	**Weight Add1**
Product should require only low dexterity to operate	5	5	0	5
Product should be durable	4	5	-1	3
Product should provide enough clearance from the can	4	5	-1	4
Product should be easy to detach from can	5	3	2	4.5
Product should have efficient twisting mechanism with no play	5	3	2	2
Product should Not require a lot of actions	4	4	0	3
Product should work with only one hand	3	3	0	5
Product should Not squeak	3	2	1	4.5
Product should turn and cut in both directions	1	2	-1	5
Product should provide good leverage	5	5	0	5
Product should keep the blades touching	NA	4	#	5
Product should have instructions	3	5	-2	5
Product should have an ergonomic shape	4	4	0	5
Product should work quickly	5	5	0	5
Product should look good	1	1	0	4
Product should look safe	4	2	2	5
Product should be easy to understand	4	3	1	5
Product should Not have unfamiliar extra features	4	4	0	4.5
Product's extra features should be visible/obvious	4	4	0	5
Product should have comfy rubber grips on handles	3	5	-2	5
Product should have big enough handles for two hands	4	4	0	5
Product should have curved handles	5	3	2	1.5
Product should not feel flimsy	5	5	0	5
Product should indicate when it is engaged/closed	4	2	2	5
Product should take little pressure to press closed	5	4	1	5
Product should be easy to attach to can	5	4	1	4
Product should stay locked in place on can	5	3	2	4
Product should take little or no pressure to stay closed	5	4	1	5XX
Product should Not require user to push a button	2	1	1	5
Product should be easy to turn	5	3	2	4
Product should have smooth turning mechanism	5	4	1	2
Product should have large turning handle	3	3	0	5
Product should help remove the lid after cutting	4	3	1	5
Product should cut through the can well	5	4	1	5
Product should Not need awkward angles to use	5	5	0	5
Product should Not need large movements	4	5	-1	4
1 NA / 13 agree / 9pmr higher by1, 7 pmr higher by2, 4 ssu higher by1, 2 ssu higher by2				