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BIOMECHANICAL ANALYSIS OF OPENING GLASS JARS:
USING KINEMATICES TO INFORM DESIGN FOR
IMPROVED ACCESSIBILITY

presented by

JOSEPH ROBERT FAIR

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of the requirements for the

M.S. degree in PACKAGING

Laura Bix

Major Professor's Signature

5/8/09

Date

BIOMECHANICAL ANALYSIS OF OPENING GLASS JARS: USING KINEMATICS TO INFORM DESIGN FOR IMPROVED ACCESSIBILITY

By

Joseph Robert Fair

A THESIS

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ABSTRACT

BIOMECHANICAL ANALYSIS OF OPENING JARS: USING KINEMATICS TO INFORM DESIGN FOR IMPROVED ACCESSIBILITY

By

Joseph Robert Fair

The research presented in this thesis theorizes that there are three styles of hand movement which can be used when removing a lug style closure from a glass jar. These movements include closure hand movement alone (either right or left hand), jar hand movement alone (either right or left hand), or the movement of both hands (either right hand or left on the closure or jar). However, it is hypothesized that experimental set up will significantly impact how participants move as they remove lug closures; that an unrestrained subject will move differently than if restrained for ease of experimental set up. Each study participant will open glass jars with lug style closures in two fashions: restrained so that the test jar remains on the table and unrestrained so that the jar begins in a comfortable height above the table.

In order to be able to accurately capture the opening movement when subjects are not restrained, the system must be fixtured, creating a "reference point." Twenty one subjects without a history of injury to the hands, wrists, arms, or shoulders were used in the study in order to create the fixturing system, refine the methodology and test the hypothesis that restraining subjects influences the movement used in order to open the jars. This information can help guide future studies' experimental set ups along with providing vital information for the design of jars related to the motion used to open jars.

DEDICATION PAGE

For Katie

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Chapter 1

LITERATURE REVIEW

Having trouble opening packaging is by no means a new phenomenon, and jars have been noted to be particularly problematic for consumers, especially if they have a disability or as they increase in age [1 – 4]. The success or failure of a jar opening seems to be strongly related to a consumer's prior knowledge of the package, their understanding of new opening features, and their ability to meet the physical requirements necessary [1].

Torque Studies

Most research that looks at the trouble associated with opening glass jars has been related to consumers' physical abilities to overcome the torque applied to the closure [1 – 4]. However, torque is a single factor of many that impact utility, or lack thereof, for these packages.

A commonly used industry practice is to apply a closure at a torque equal to one half the finish diameter of the closure [5]. For example, a jar with an 82mm finish would be torqued to 41 in – lbs, or 4.63Nm. This industry "rule of thumb" presents concerns in light of the available usability research. Voorbij and Steenbekkers (2002) indicate that although consumers under 30 generally do not have trouble opening glass jars; subjects over 50 do. Further, the research team suggests that opening torques should be limited to 2Nm (17.7 in – lbs) for maximum usability of subjects over 50 years of age. Their team makes note of the lack of enthusiasm from packaging professionals for this finding, indicating, "It is strange, therefore, that the packaging industry has not yet addressed the problem by changing this type of packaging" [3].

A study conducted by the UK Department of Trade and Industry (DTI) [2] investigated the torque that a consumer could apply to three different diameters aluminum "jars" while sitting or standing. The study did not indicate if subjects where restricted to opening on a table. Smooth and knurled closures were used in the study and included a non - disabled population along with a disabled population. The study had several interesting findings. The non – disabled population could apply a torque 2 to 2.5 times greater than the disabled population for both closure styles. The greater the diameter, the greater the applied torque. Also, the knurled closure allowed for a greater applied torque. However, the research did not investigate the motion associated with opening closures. The data allows for an understanding of how torque limits the ability of a person to open a jar and suggests that knurled closures improve the ability of someone who has less strength to successfully open a jar. However, knurled closures alone cannot overcome the application torque and vacuum applied to closures.

Unlike most studies related to this topic, Voorbij and Steenbekkers (2002) allowed the subjects to replicate opening in a less controlled environment. Subjects were allowed to stand and either open the jar on the table surface or open the jar in an unrestricted fashion. However, their research examined the forces associated with the use of an aluminum jar and subjects could only apply a force to the jar, not open the jar, as did the UK Department of Trade and Industry study in 2002 [3, 2].

Crawford, Wanibe, and Nayak (2002) examined the torque subjects could apply by, again, using a restrained opening location for jar and closure. The test population included healthy younger and older adults and subjects were allowed to use either hand on the closure. Standard glass jars were used but nylon closure were created in round (20mm, 50mm and 80mm) and square test (50mm) pieces. This, again, creates a situation that does not completely relate to real life. However, an interesting conclusion of the study is that the square closures allowed users to generate a greater torque. The research found that males could apply more torque than females, and that younger subjects were able to apply more torque than older subjects. Another interesting finding from this study relates to anthropometrics. There were significant correlations between hand length and grip strength, along with hand breadth and grip strength [4].

Research conducted by Yoxall et. al. (2006) investigated the torque applied to 75mm jars and employed a glass jar. This was done in an effort to ensure that the torque values would not be altered due to frictional differences between glass and aluminum, which they had seen in previous studies, allowing for a more realistic test. However, the closures could not be removed from the jars. Subjects were allowed to stand or sit and could hold the jar in any way they wanted. Subjects were also required to open the jar bolted to a table for comparison. Multiple tries were allowed. Several interesting findings came from this work. Male subjects were able to apply a greater amount of torque to the jar, consistent with that of Crawford, Wanibe, and Nayak (2002) [1, 4]. Also, the torque applied to the bolted down jar were lower than the un – restricted jar. The research did not investigate the effect of the movement, or motion employed by the user as it related to torque.

Motion Studies

Much of the research that measures motion restricts the subject, providing potentially unrealistic scenarios [6, 7]. Studies that have restrained subject motion very well may alter the way subjects perform opening procedures and, as a result, may or may not provide value for designers.

Fowler and Nicol (1999) collected strength data and assessed both the force and motion of opening jars, specifically aimed at the loading forces on the interphalangeal joint of the dominant hand index finger. However, their study design did not accurately replicate reality. Their jar was not made of glass, and subjects were required to keep the jar on the table. Second, and more importantly, subjects were instructed to always use their dominant hand on the closure of the jar. Requiring subjects to place their dominant hand on the closure makes the assumption that this would be the most common placement used when opening a jar [6].

Murgia et. al. (2004) used motion capture technology to investigate wrist kinematics during jar opening. Subjects had to press a timer prior to opening a jar with a 70mm closure. Subjects were asked to remove the closure and placed the jar and closure back on the table and press the timer again. However, the subjects were seated and required to open the jar closure with their dominant hand, again assuming that this would be the desired placement [7].

Laterality

An interesting explanation for hand placement during tasks such as opening jars may be related to laterality, a research area that examines postural preferences. Mohr et.al. (2003, 2006) examined postural preferences using arm – folding and hand – clasping. Their research identified four possible groups for these two behaviors. Left thumb or arm on top was coded with an L and right thumb or arm on top was coded with an R. Therefore, the four possible groups were coded LL, LR, RL or RR (hand preference followed by arm preference). People who placed either both left or right on top were considered congruent whereas people who placed a combination of left or right were considered incongruent [8, 9]. In their 2003 study all subjects (n = 362) were right handed [8]. In their 2006 study 86.8 percent (442 of 509 subjects) were right handed [9]. For the 2006 study, handedness was based on a 13 item questionnaire. They found that the greatest number of people prefer their left hand on top for both hand clasping and arm crossing, but that this did not relate to their dominate hand.

In research related to packaging, specifically jars, handedness was found to be significantly related to the closure and jar hand placement. Voorbij and Steenbekkers (2002) studied 743 subjects and found that most right handed subjects placed their left hand on the closure (511 of 534 subjects) and left handed subjects placed their right hand on the closure (147 of 209 subjects) [3], going against the assumption used by Fowler and Nicol (1999) [6]. This finding coincides with those of Mohr et. al. (2003, 2006) [8, 9]. However, they did not investigate factors that explained the positioning of the hand on the jar or closure; perhaps, handedness, postural preferences (laterality), injury or just random placement are likely causative factors for hand placement and motion. As part of the study presented here, researchers will examine data for possible correlations between postural preference and grip positioning.

Physical setup of the experiment

A review of the literature indicates that the physical set up of the experiment is also crucial. Stins, Kadar, and Costall (2001) noted that the contents of a glass, along with the location of the glass, relative to the subjects' dominant hand, were significant factors in which hand the subject used to reach for the glass. Glasses set directly in front of a subject were most likely to be grasped with the dominant hand of the subject as opposed to the hand closest to the glass. Fixing the test stimulus, as compared to allowing users to move freely, as mentioned, has been shown to impact user ability [10]. Yoxall et. al. (2006) noted that the torque applied to a bolted down jar was lower than the jar opening where users were unrestricted [1]. This suggests that there could also be differences in the opening motion used between these two conditions.

For the purposes of this research, we will explore how people open lug style closures from a motion perspective when constrained to a table surface and when opening in an unrestricted manor. Perhaps people open jars differently when constrained to an x, y coordinate system than when allowed the freedom to open in an unrestricted x, y, z coordinate system.

Research that investigates the unhindered motion of the user when opening jars is needed because: (1) pilot studies conducted by the team indicate that restraining subjects may affect their motion (2) limited research into biomechanics and packaging is available, and what is frequently restrains subjects while opening packaging to aid data collection and analysis, not necessarily representing a real life situation (3) methodologies that characterize opening motions need to be developed (4) little is known about opening motions used for glass jars, yet it is widely understood that they are difficult to open [1 – 4].

Chapter 2

OBJECTIVE

The overall objective of this study was to create and refine a methodology for using motion capture in packaging applications. Glass jars with smooth style metal lug style closures were used to create the methodology, but it is anticipated that the techniques employed can be used to characterize the opening motions associated with varied package types in future work. Additionally, this research investigates the impact of experimental setup, restrained or unrestrained, on the motions employed during opening and begins to explore how people move when opening jars.

HYPOTHESIS

It was hypothesized that the physical positioning of the subject had the potential to impact the opening motion employed. Therefore, two opening positions were incorporated into the experiment; opening "restrained" to a counter set at a standard height of 91 cm (36 inches) [11] the other opening in the air at a height comfortable to the subject, "unrestrained opening."

It was also hypothesized that the motion used by a subject to open glass jars with lug style closures would take one of three forms;

1. Closure Hand Supplies Motion
2. Jar Hand Supplies Motion
3. Both Hands Supply Motion

Chapter 3

MATERIALS AND METHODOLOGY

Subjects were recruited by word of mouth and represented a convenience sample. Data was collected at the Biomechanical Design Research Laboratory (BDRL) in the department of mechanical engineering at Michigan State University. Data was collected from 25 subjects using procedures approved under IRB 06-981. Subjects were screened prior to testing to ensure they did not have a history of injury to their hands, wrists, arms or shoulders, or if they indicated allergies to surgical tape or rubbing alcohol. Subjects without a history of injury were used. Since there is little research into this area a healthy population is needed to create a baseline for future studies In exchange for participation, subjects were compensated with a twenty five dollar gift certificate to Meijer ®. Once informed consent had been obtained, data was collected as outlined.

Demographics

Following the screening process and signing of the consent form, a member of the research team collected demographic data from subjects, see Appendix B for a copy of the Data Collection Form. Demographic data included gender, age and preferred dexterity. Subject under the age of 30 were targeted based on studies related to torque that indicated subjects in this age range would not have difficulty overcoming the torque applied to closures on glass jars [3]. Preferred dexterity was determined by asking each subject which hand they considered to be their dominant prior to collecting any data. The subject was also asked about having a history or allergic reaction or irritation to rubbing alcohol or surgical tape as well as a history or injury to the hands, shoulder, arms or wrists. If the subject indicated a positive response to either of the previous questions they were thanked for their time, given the gift card and excused from the remainder of the testing. All other subjects moved forward with the testing procedure.

Anthropometrics

Using a photographic method employed by previous studies [2], researchers characterized each subject's hand size. Subjects were asked to place the hands, first right, then left hand, on a flat base that had a grid consisting of 10 mm squares. The base was equipped with an articulated arm that served as a mount for a digital camera (Canon PowerShot G6, PC1089, 7.1 Megapixels, No. 9121102252) mounted parallel to the base at a fixed distance from the hands, see Figure 1.

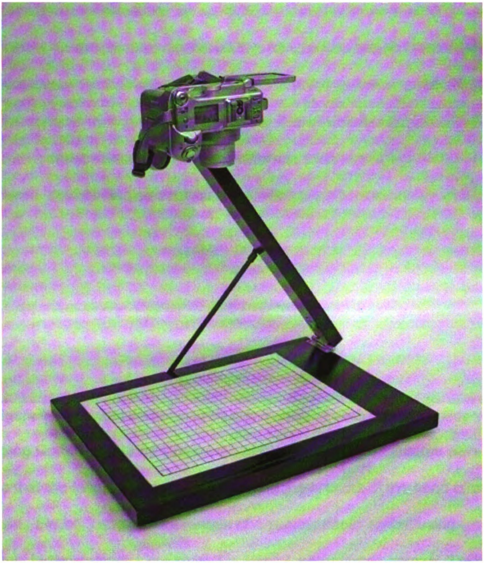


Figure 1 – Camera mounting rig for digital pictures

Photographs were taken of the right and left hand in two different positions for a total of four different photographs, see Figure 2. No preference was given to which order subjects placed their hands on the grid

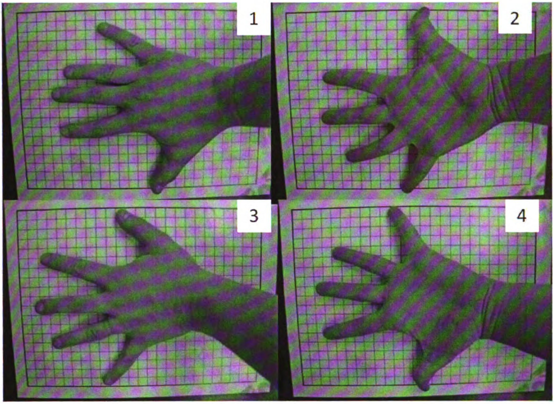


Figure 2 – Photographs taken to classify the size of each subject's hands

Using CorelDraw X3 for Windows (Version 13.0.0.739), pictures were scaled so that the length of the index finger and the breadth of the hand could be determined. Figure 3 shows an example of a subject photo scaled using CorelDraw. Measurement 1 in Figure 3 is Hand Length, measurement 2 is Wrist – Index Finger Length and measurement 3 is Hand Breadth.

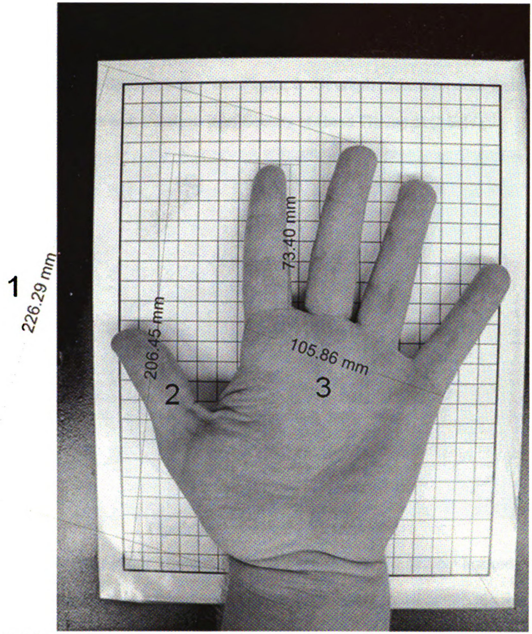


Figure 3 – CorelDraw X3 measurement example, 1 – hand length, 2 – index finger length, 3 – hand breadth

Strength Measurements

Following the collection of anthropometric data, the subjects went through a series of strength measurements. Strength measurements were taken to determine grip strength and palm to palm squeeze strength. Grip strength was collected using a Jamar® grip dynamometer, see Figure 4, and the subject's bilateral palm-to-palm squeeze strength was collected using a Baseline® pneumatic squeeze dynamometer, see Figure 5. Strength measurements were taken in accordance with the American Society of Hand Therapist (ASHT).

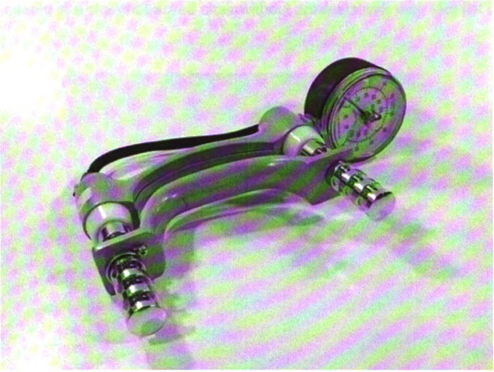


Figure 4 – Jarmar® grip dynamometer

For collection of grip strength subjects were seated in a straight backed chair without armrests and their feet flat on the floor. Subjects were handed the Jamar® grip dynamometer and instructed to hold the dynamometer so that their elbow was at a 90 degree angle and that their arm was not resting on any part of them or the chair. Subjects were instructed by a member of the research team to squeeze as hard as they could for a total of 3 seconds. Time was kept by the tester through a verbal command of, "Squeeze as hard as you can…harder, harder, relax." In order to avoid fatigue, each subject began with the dynamometer in their right hand and then switched back and forth between their right and left hand for a total until there were a total of three repetitions for each hand.

For collection of the bilateral palm to palm squeeze strength subjects remained seated in a straight backed chair without armrests with their feet flat on the floor.

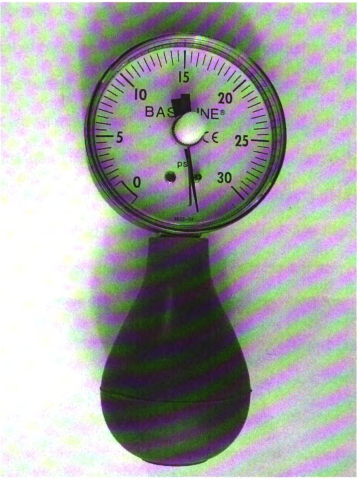


Figure 5 –Baseline ® pneumatic squeeze dynamometer

Subjects were handed the Baseline® pneumatic squeeze dynamometer and instructed to hold the dynamometer at chest level between their palms. Subjects were instructed to hold their hands at a 90 degree angle from each other and to not lock their hands or fingers. Subjects were asked to squeeze as hard as they could for a total of 3 seconds. Time was again kept by the tester through a verbal command, "Squeeze as hard as you can…harder, harder, relax."

Laterality Measurements

The last data collected prior to the collection of the motion data were measurements of laterality or "postural preference." Subjects were asked to stand in front of a set of curtains so that a series of photographs could be taken. Subjects were first instructed to lace or clasp their hands together. Photograph 1, see Figure 6, shows an example of a subject demonstrating hand clasping with the left thumb on top. The picture had to be taken at an angle that allowed the research team to determine which thumb was on top during data processing. Subjects were then asked to fold their arms. Photograph 2, see Figure 6, shows an example of a subject demonstrating arm folding with the left arm on top.

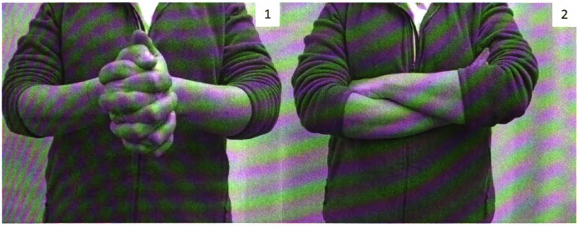


Figure 6 – "Postural Preferences," 1 shows hand clasp and 2 shows arm fold

Jars and Closures Used During Motion Capture

Two jar sizes were selected and subjects opened them using two opening orientations, restrained and unrestrained. The jars selected for testing are shown in Figure 7 and accompanying specifications are shown in Table 1. The jars used in the study were donated by Saint – Gobain and closures were donated by Silgan through the assistance of the Glass Packaging Institute.

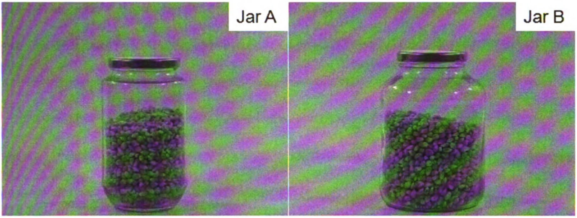


Figure 7 – Photographs of the two jar sizes used for testing; Jar A and Jar B

Jar Specifications				
Jar	Mold #	Finish Designation	Height (cm)	Diameter (cm)
A	5175023	70 - 2030	15.08252	8.73252
B	3456037	70 - 2030	15.63624	10.95502

Table 1 – Jar specifications for the two jars used for motion capture

Jar A and Jar B were chosen for testing in order to limit the differences between the two. The heights of the two jars are nearly the same and both jars have a finish designation of 70 – 2030 (the jars have a closure diameter of 70 mm). The closures were "Regular Twist – Off TM" style containing 4 lugs. Due to the potential for glare off of the closure white matte finish circular labels, see

Figure 8, were placed on each closure. The glare from the closure could account for false targets in the Qualisys software.

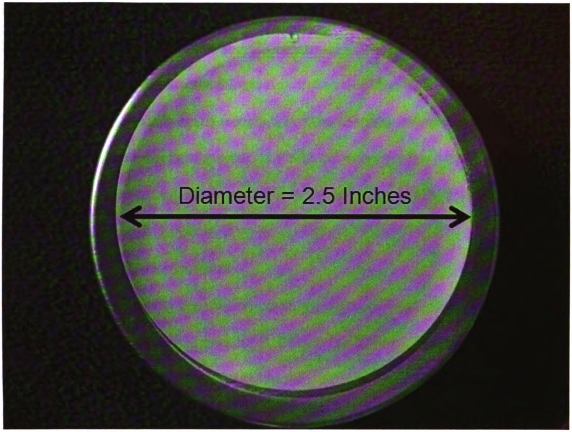


Figure 8 – 70 – 2030 closure with 2.5 inch white matte label

The main difference between Jar A and Jar B is the diameter of the jar, see Table 1. The difference between the two jar diameters is 2.2225 cm. Additionally, the jars were filled to two thirds of their overflow capacity with pop corn kernels. The overflow capacity was determined using;

$$Bv = \frac{(Bf - Be)}{0.997}$$

Where Bv is the volume in fluid ounces, Bf is the full container weight in grams, Be is the empty container weight in grams. Popcorn kernels were used as a way to create contents that resembled liquid without having to bring liquids into the test lab where they presented a danger to the testing equipment. Overflow capacity was calculated for gram weight with water. The equal weight in popcorn kernels was then added to the jars and used throughout the testing. Jar A had a two thirds overflow weight of 963.88 grams and Jar B had a two thirds overflow weight of 1507.37 grams. It was decided that full jars would not be used since a vacuum could not be drawn on the jars for each opening. A full jar would represent the first opening in which case a vacuum would be present along with the applied torque. Using a two thirds full jar also reduced the risk that the subject would spill popcorn kernels during the opening trial.

Grip Style Determination

Prior to beginning the motion capture portion of the research, subjects were asked to pick up Jar A and Jar B, from a table, and open them one at a time. This demonstrated how the subject would open each in the unrestrained position. Two opening styles were used by the subjects for the unrestrained openings, a side grip and a bottom grip. Some subjects demonstrated the same grip for both Jar A and Jar B and some subjects demonstrated both styles this seemed to vary with the diameter, and will be discussed in greater detail in Chapter 4. The two grip styles are shown in Figure 9.

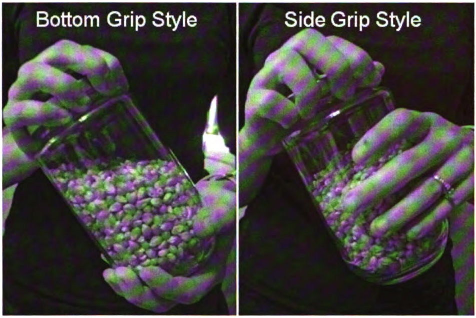


Figure 9 – Grip styles used for unrestrained openings

Based on the two grip styles demonstrated by the subjects, two jar rigs were created for testing during the unrestricted motion capture. The rigs are shown in Figure 16. The rigs will be discussed in greater detail in the Unrestricted Opening section.

Biomechanical Motion Capture

Following the demonstration of grip style, subjects were prepped for motion capture testing. Subjects were asked to remove any jewelry or clothing that incorporated reflective material. Subjects who wore long sleeves were allowed to use a bathroom located next to the lab to change into a short sleeved shirt provided by the research team. The next step consisted of swabbing the hands and forearms of the subject where the reflective targets would be attached using a rubbing alcohol pad, this assisted in removing dirt that could interfere with the adhesion of the targets to the skin of the subject.

The targets were attached, using surgical tape, to three anatomical points on the hands. The first target was attached to the scaphoid bone (located at the center of the base of the hand), the second to the proximal interphalangeal (PIP) joint of the index finger (the middle joint of the index finger) and the third target to the metacarpophalangeal (MCP) joint (bottom of the pinky) of the small finger [12]. Two additional targets were placed on the forearms so that data could be collected for potential future testing along with a target on the right shoulder. The target on the right shoulder was used to identify the right hand versus the left hand in the software. Figure 10 shows the location of the hand targets on a subject.

(A) Scaphoid Bone
(B) Proximal Interphalangeal (PIP) Joint
(C) Metacarpophalangeal (MCP) Joint

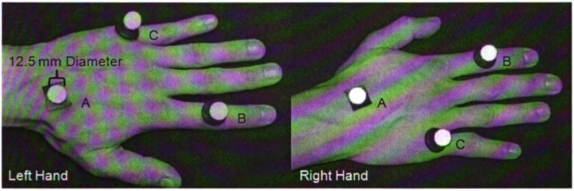


Figure 10 – Location of hand targets on a subject

Motion Capture Design

The motion capture system used for testing consisted of five infrared cameras connected to a computer running Qualisys software. Reflective targets, made from wooden spheres with a diameter of 12.5 mm covered in 3M reflective tape (7610 WS, silver "High Gain Sheeting"), were taped to the subjects and attached to the jars, see Figures 10, 13 and 16. The infrared light from the cameras reflected off the targets and allows for the software to identify the targets in 3 – Dimensional space, resulting in x, y, z coordinate data for each target.

Setup of Openings

Jar A and Jar B were each opened three times in the restricted and unrestricted positions for a total of 12 openings by each subject as shown in Figure 11.

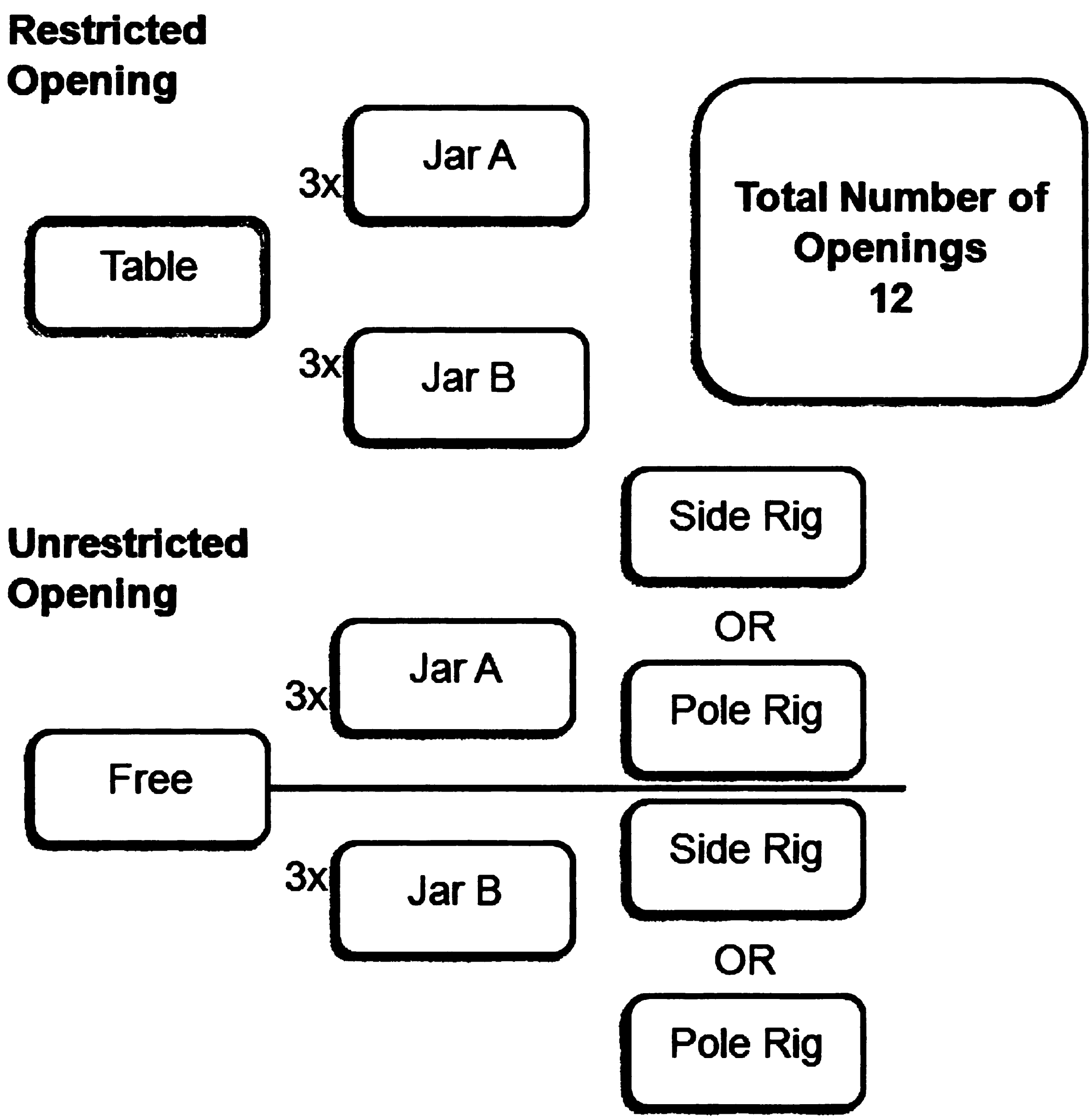


Figure 11 – Sequence diagram for the 12 openings

To balance the effect of fatigue across treatments, the order in which subjects opened the jars was rotated. Subject one began the sequence Jar A table, Jar B table, Jar A free then Jar B free. Subject two began the sequence Jar A table, Jar B table, Jar B free then Jar A free. This rotation sequence continued allowing for a different opening sequence for all subjects, see Appendix E. For the restricted openings, the subjects reused the same jar three times and a new closure was applied for each trial, the jars were only used for one subject before being removed from the testing. Subjects had time to rest between each opening while a member of the research team applied the new closure. For the unrestricted openings, two of each of the rigs were created by the research team. The same rig was used for every subject; the secondary rig was only to be used if there was a failure of the original rig.

Restricted Opening

In preparation for restricted opening, two foam board placement mats were created, see Figure 12.

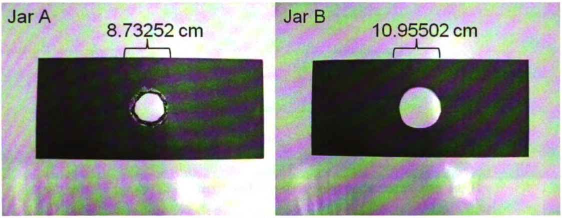


Figure 12 – Foam boards created for restricted opening

The mats allowed the research team to ensure that the jar openings performed on the table in the restricted position were done in the same position for each trial. Velcro attached the boards to the table so that the mats were placed in the same location from subject to subject. This also helped to prevent the jar from sliding out of position during motion trials. The holes cut into the mats were sized to the diameter of the jar creating a fit, but not to the point of creating friction between the jar and the mat.

Prior to testing each subject, the Qualisys software was calibrated using a calibration structure Appendix D describes this process.

A member of the research team placed a reference jar on the table prior to the collection of the data. Figure 13 shows the reference jars for the table openings. The reference jars were the jars the subject was going to use for the restricted table openings with a special reference closure, with a target adhered to the center, in place of the closure that would be used for the opening trials. These jars were then placed on the table in the foam board shown in Figure 12.

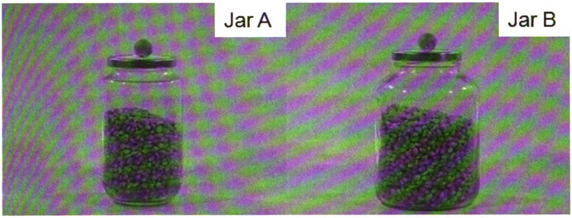


Figure 13 – Restricted opening reference Jar A and Jar B

The software was set to collect at 60 Hz (for every second of capture 60 pictures were taken by the cameras). Five cameras were set up around the table to capture the motion. Of the five cameras, a target had to be in view of two cameras in order for the software to identify the marker and produce x, y, z coordinate data. An overhead schematic of the camera setup around the table is shown in Figure 14. The schematic also identifies the subject location along with the foam board and jar (shown with the reference target on the closure).

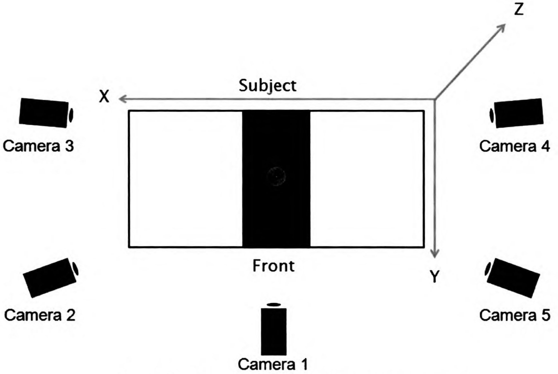


Figure 14 – Overhead view of table and camera setup

The reference file was collected to identify the height and center point for the jar on the table. This height and center of the jar was then coupled with the opening file to determine rotation; this process will be outlined in Data Processing. Figure 15 shows a schematic setup of the table with a jar ready for referencing from the front.

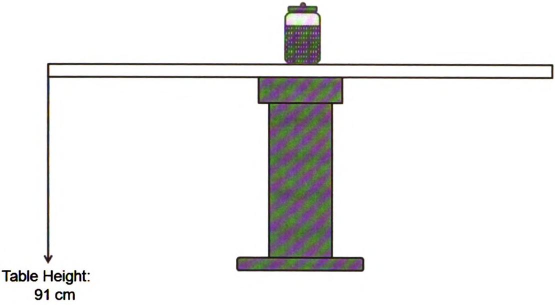


Figure 15 – Front view of table with restricted reference jar

Table height was fixed at 91 cm for each subject. For both restricted and unrestricted openings, the subjects were guided to the table by a member of the research team ensuring both the safety of the subject and so that no cameras or cables would be moved. If the cameras were moved in any manner after calibration, the system was re – calibrated and testing continued.

Subjects were instructed to stand with their shoulders parallel to the table. A member of the research team placed the jar on the table in the foam board and then instructed the subject to place their hands on the jar in the opening position they felt was comfortable. If a subject wanted to alter their hand placement from trial to trial they were allowed to do so. Subjects were given a verbal instruction of, "ready, set, open." Additionally subjects were asked to rotate the closure until the jar was open, but not to remove the closure from the jar.

Unrestricted Opening

Before beginning motion capture testing, subjects had been asked to pick up a standard Jar, both A and B, see Figure 13 and asked to open each of them. This identified their grip style, see Figure 9, and determined which of two rigs would be used during the motion capture testing, see Figures 16. Figure 16 shows the pole rigs and side rigs for both Jar A and Jar B set up for the reference file. When the pole and side rigs were ready for motion capture with a subject the closure with the target was replaced with an unused closure without a target.

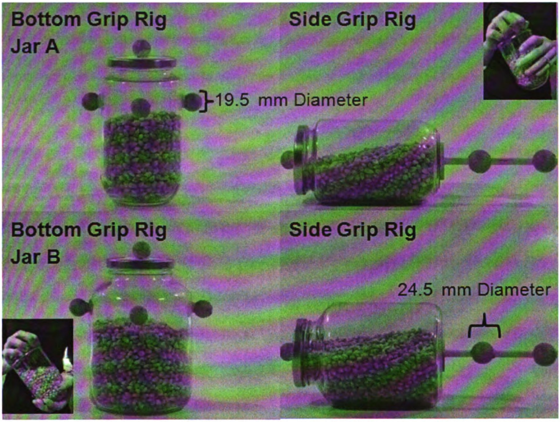


Figure 16 – Unrestricted open rigs for bottom and side grips

The jars were placed on the table in the orientation shown in Figure 16. The foam boards were not used during the unrestrained openings. The reference file was used to collect a center axis point of jar. This was then coupled with the opening file to have a point in order to determine rotation about. A sample of how the of the pole rig and side rig appear in the Qualisys software is shown in Figure 17.

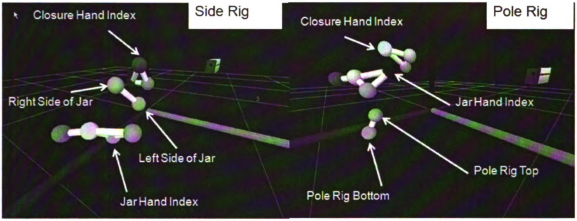


Figure 17 – Qualisys screen shot of side rig and pole rig opening

Subjects were asked to stand with shoulders parallel to the table and hold the jar in a position that was comfortable to them. For the unrestrained opening, subjects were asked to pick up the jar and hold it as they would prior to opening without opening it. Subjects were also instructed to try to hold the jar closure in place once opening had occurred, see Figure 18. Once the jar was held at a comfortable position above the table, the subjects were given a verbal instruction of, “ready, set, open.”

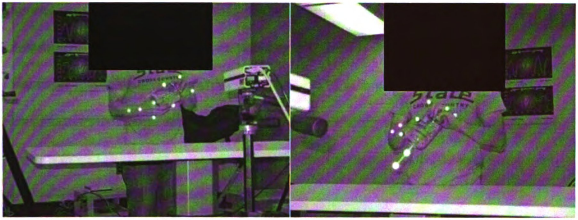


Figure 18 – Subject opening side rig (left) and pole rig (right)

Data Transfer

The total capture time was 4 seconds for each opening. The capture time of 4 seconds was based on knowledge gained in pilot studies of the time needed to successfully open the jars in an injury free population. This coincides with the study by Fowler and Nicol (1999) in that their range of time required for opening a jar was 0.6 – 3.7 seconds [6]. Therefore, each opening trial provided 240 data points (60 Hz x 4 seconds) for calculating rotation. After each opening the trial was reviewed in the Qualisys software to make sure it did not need to be recaptured. During the review of each trial several tasks were preformed. First the targets were labeled, see Figure 10, which included; left base (target A), left pinky (target C), left index (target B), right base (target A), right pinky (target C), right index (target B), right reference for the target on the shoulder along with the jar targets for the free openings only. The next step was to remove any false targets (usually reflections) that appeared during the opening. If a target was lost for an extended period usually 10 frames or more the opening trial was recaptured using a new closure. If the trial was considered to be good the file was saved as a .QTM and a .TSV. After completion of all 12 opening trials the .TSV files were then opened in a word pad one at a time and from the word pad they were copied into Microsoft Excel.

Data Processing

Table Openings

For each trial, two data sets were utilized (the table reference and the opening file) to calculate the rotation angle. An Excel file was created to be used with all table openings. First the reference file was copied from the word pad to a worksheet in the table opening Excel file. The sheet was used to calculate the average x, y, and z coordinate of the center of the closure. Target coordinates were calculated at the center of each retro – reflective marker by the Qualisys software. In order to identify the top surface of the closure, 10 mm was removed from the average z coordinate, placing the z coordinate on the surface of the closure. Using the reference target from the surface of the closure a second point was calculated at the middle of the jar half way between the closure point and the bottom of the jar. This point was calculated by subtracted one half of the measured jar height from the z coordinate value, see Figure 19.

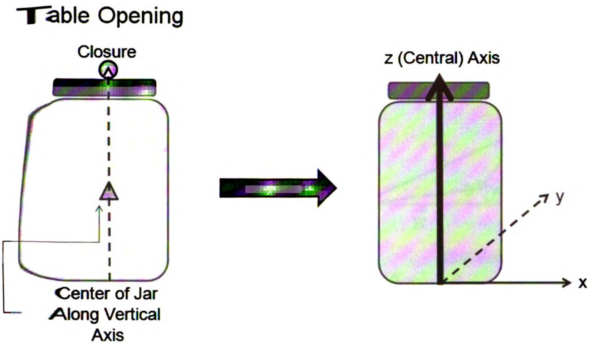


Figure 19 – Central rotation axis for restricted openings

While multiple targets were collected as part of each motion capture, only the targets on the index fingers were used, in addition to the targets used from the reference file, for calculating the rotation of the index finger around the center of the jar in the restricted orientation

Rotation of the closure was computed by evaluating the movement of the index finger about the center of the closure in the x y plane. Rotation of the hand on the jar was computed about the mid – point of the jar in the x y plane.

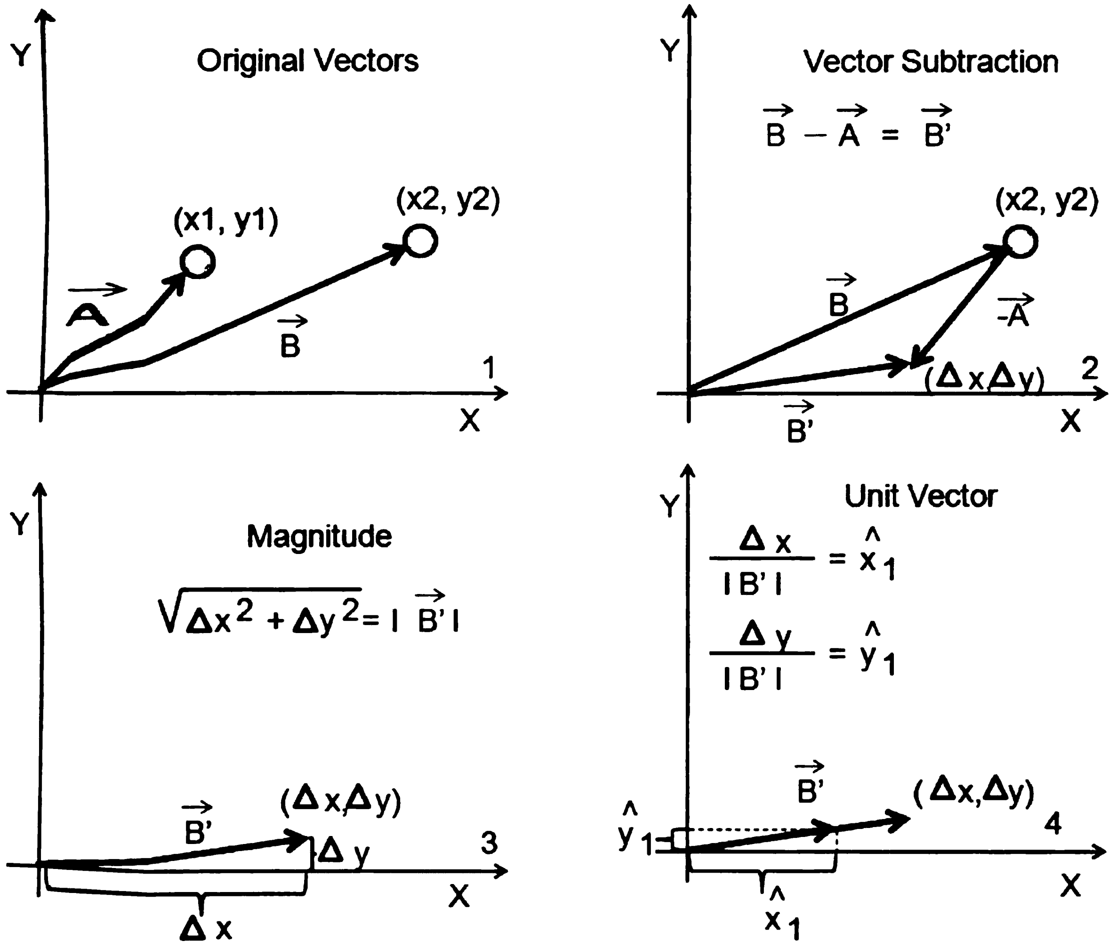


Figure 20 – Vector analysis of targets

In the first graph of Figure 20, top left graph, coordinate point (x_1, y_1) represents the closure center or the jar center about which coordinate point (x_2, y_2), the target on the corresponding index finger is rotating. In the second graph $\vec{A}$ has been subtracted from $\vec{B}$ resulting in $\vec{B'}$ with coordinate point $(\Delta x, \Delta y)$. This was done by using:

$$x_2 - x_1 = \Delta x$$
$$y_2 - y_1 = \Delta y$$

Next the magnitude of $\overrightarrow{B'}$ was calculated using the Pythagorean Theorem, shown in graph 3 of Figure 20. Using the magnitude along with $(\Delta x, \Delta y)$ a unit vector was calculated, this is shown in graph 4 of Figure 20. This process was repeated across all 240 opening frames of each capture resulting in a unit vector at each frame with coordinates:

$$\hat{x}_1, \hat{x}_2, \hat{x}_3, \ldots, \hat{x}_{240}$$
$$\hat{y}_1, \hat{y}_2, \hat{y}_3, \ldots, \hat{y}_{240}$$

Next the change in $\overrightarrow{B'}$ from frame 1 to frame 240 was found using radians, which were then converted to degrees. The following equation (note that R was chosen to represent radians) shows this calculation:

$$\cos^{-1}(\hat{x}_1 \bullet \hat{x}_{240} + \hat{y}_1 \bullet \hat{y}_{240}) = R_{240} radians \times \frac{180^\circ}{\pi}$$

This calculation was equal to the angle in degrees between frame 1 and frame 240. Therefore, the degrees value is the rotation of the index finger about the center of the closure (or jar). This equation was then applied to compute the angle in degrees between frame 1 and every other capture frame (2 thru 239) giving the degrees rotation at all 240 frames, such as:

$$\cos^{-1}(\hat{x}_1 \bullet \hat{x}_2 + \hat{y}_1 \bullet \hat{y}_2) = R_2 radians \times \frac{180^\circ}{\pi}$$

$$\cos^{-1}(\hat{x}_1 \bullet \hat{x}_3 + \hat{y}_1 \bullet \hat{y}_3) = R_3 radians \times \frac{180^\circ}{\pi}$$

$$\cdots$$

$$\cos^{-1}(\hat{x}_1 \bullet \hat{x}_{239} + \hat{y}_1 \bullet \hat{y}_{239}) = R_{239} radians \times \frac{180^{\circ}}{\pi}$$

The degrees calculated at every frame were then plotted in a scatter plot, see Figure 23 and Determination of Degrees Rotation below.

Unrestricted Openings

As with the restricted orientation (table opening), for the unrestricted to be processed in Excel, two files had to be imported. For unrestricted openings the table reference file along with an opening file were needed to calculate the rotation angle. Unrestricted openings were calculated in 3 – dimensions.

Pole Rig Openings

Determination of rotation for the pole rig openings began by using the reference file to calculate the jar length. This was accomplished using two of the three targets on the pole rig jar, see Figure 21.

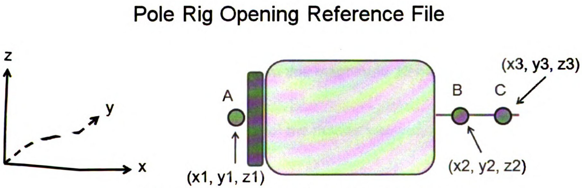


Figure 21 – Central rotation axis for pole rig openings

The closure target, (x_1, y_1, z_1) in Figure 21, and the top pole target, (x_2, y_2, z_2) in Figure 21, were used to calculate the distance from B to the surface of the closure from the reference file. The following equations were used when analyzing the pole rig data, prior to computing the following calculations it was confirmed that the axis formed through BC was straight and went through point A.

STEP 1: Creating a vector between points A and B – directed along the center axis of the jar and closure.

The same calculations used in the table restricted method were performed for the pole rig, but in three-dimensions. The following calculations are performed on the jar while it is stationary:

$$\vec{A} = x_1\hat{i} + y_1\hat{j} + z_1\hat{k}$$

$$\vec{B} = x_2\hat{i} + y_2\hat{j} + z_2\hat{k}$$

The vectors were then subtracted to find a new vector

$\vec{AB} = \vec{B} - \vec{A} = (x_2 - x_1)\hat{i} + (y_2 - y_1)\hat{j} + (z_2 - z_1)\hat{k}$ written

as $\vec{AB} = \Delta x_{ab}\hat{i} + \Delta y_{ab}\hat{j} + \Delta z_{ab}\hat{k}$. Next the magnitude was calculated as,

$\left|\vec{AB}\right| = \sqrt{\Delta x_{ab}^2 + \Delta y_{ab}^2 + \Delta z_{ab}^2}$ from this magnitude 10 mm was subtracted to account for the fact that the center of the marker was located 10 mm above the closure.

STEP 2: Creation of a unit vector along the center axis of the jar.

To compute an axis using the pole rig, the top and bottom targets for the poles were subtracted and the magnitude found as shown.

$C = (x_3, y_3, z_3)$ $B = (x_2, y_2, z_2)$

$$\vec{BC} = \vec{C} - \vec{B} = (x_3 - x_2)\hat{i} + (y_3 - y_2)\hat{j} + (z_3 - z_2)\hat{k} = \Delta x_{bc}\hat{i} + \Delta y_{bc}\hat{j} + \Delta z_{bc}\hat{k}$$

$$\left|\vec{BC}\right| = \sqrt{\Delta x_{bc}^2 + \Delta y_{bc}^2 + \Delta z_{bc}^2}$$

Next a unit vector for $\vec{BC}$ was calculated. $\frac{\Delta x_{bc}}{\left|\vec{BC}\right|} = \hat{x}_{bc}, \frac{\Delta y_{bc}}{\left|\vec{BC}\right|} = \hat{y}_{bc}, \frac{\Delta z_{bc}}{\left|\vec{BC}\right|} = \hat{z}_{bc}$

STEP 3: Locating closure surface and jar midpoint in free space.

To track the position of the jar and closure in 3 – dimensional space, the jar axis (developed in Step 2) was used in conjunction with the distance from the closure to point B and the distance from the middle of the jar (1/2 height) to point B.

From point $B = (x_2, y_2, z_2)$ the x-value $\hat{x}_{bc}$ was multiplied by the magnitude $\left|\vec{AB}\right|$, and then added to the respective component for all three components (x, y and z).

$$x_2 + (\hat{x}_{bc} \bullet \left|\vec{AB}\right|) = x_{closure}$$

$$y_2 + (\hat{y}_{bc} \bullet \left|\vec{AB}\right|) = y_{closure}$$

$$z_2 + (\hat{z}_{bc} \bullet \left|\vec{AB}\right|) = z_{closure}$$

This results in the center point of the top of the closure located at $(x_{closure}, y_{closure}, z_{closure})$. The process was repeated for half of the magnitude in order to find the coordinate of the point in the center of the jar, termed mid jar, about which the rotation or the jar index finger would be calculated.

$$x_2 + (\hat{x}_{bc} \bullet \tfrac{1}{2}\left|\overrightarrow{AB}\right|) = x_{mid}$$

$$y_2 + (\hat{y}_{bc} \bullet \tfrac{1}{2}\left|\overrightarrow{AB}\right|) = y_{mid}$$

$$z_2 + (\hat{z}_{bc} \bullet \tfrac{1}{2}\left|\overrightarrow{AB}\right|) = z_{mid}$$

STEP 4: Both the top of the closure as well as the jar midpoint were computed for each frame of data.

The rotation of each hand was computed around the center of the closure (closure hand) and the midpoint of the jar (jar hand). Now the rotation for each hand was calculated following the same steps as performed for the table restricted method shown previously, except in the three-dimensional coordinates. The index finger of the hand on the top of the jar was given coordinates $(x_{index1}, y_{index1}, z_{index1})$. The difference between this point and the top center of the jar was calculated:

$$x_{index1} - x_{closure,1} = \Delta x_1,\ y_{index1} - y_{closure,1} = \Delta y_1, z_{index1} - z_{closure,1} = \Delta z_1$$

$(\Delta x_1, \Delta y_1, \Delta z_1)$ gives vector $\overrightarrow{AB_r}$

Magnitude $\left|\overrightarrow{AB_r}\right| = \sqrt{\Delta x_1{}^2 + \Delta y_1{}^2 + \Delta z_1{}^2}$

Unit vector coordinates $\dfrac{\Delta x_1}{\left|\overrightarrow{AB_r}\right|} = \hat{x}_{1r}, \dfrac{\Delta y_1}{\left|\overrightarrow{AB_r}\right|} = \hat{y}_{1r}, \dfrac{\Delta z_1}{\left|\overrightarrow{AB_r}\right|} = \hat{z}_{1r}$

Using the midpoint of the jar $(x_{mid,1}, y_{mid,1}, z_{mid,1})$ and the index finger of the jar, a unit vector was computed from the jar center to the index finger of jar hand. The same process was used for the hand on the closure.

STEP 5

Steps 3 and 4 were repeated for each camera frame 1 to frame 240, since the jar and hand were moving, each frame had new index finger and new jar coordinates that had to be computed.

STEP 6: Computing degrees of rotation.

Next the degree of rotation for each frame was found using:

$$\cos^{-1}(\hat{x}_{1r} \bullet \hat{x}_{240r} + \hat{y}_{1r} \bullet \hat{y}_{240r} + \hat{z}_{1r} \bullet \hat{z}_{240r}) = R_{240} radians \times \frac{180^\circ}{\pi} = angle$$

The angle between the first frame and every consecutive frame was computed.

$$\cos^{-1}(\hat{x}_{1r} \bullet \hat{x}_{2r} + \hat{y}_{1r} \bullet \hat{y}_{2r} + \hat{z}_{1r} \bullet \hat{z}_{2r}) = R_2 radians \times \frac{180^\circ}{\pi}$$

$$\cdots \qquad \cdots$$

$$\cos^{-1}(\hat{x}_{1r} \bullet \hat{x}_{240r} + \hat{y}_{1r} \bullet \hat{y}_{240r} + \hat{z}_{1r} \bullet \hat{z}_{240r}) = R_{240} radians \times \frac{180^\circ}{\pi}$$

The degrees calculated at every frame were then plotted in a scatter plot, see Figure 23 and Determination of Degrees Rotation below.

Side Rig

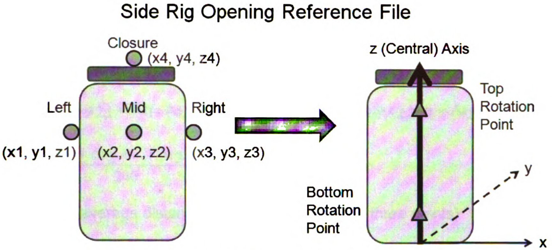


Figure 22 – Side rig opening reference file

STEP 1: Computing average jar target heights.

The side rig jar had three target locations as shown in Figure 22. The first calculation was to find the average of the z coordinates at each frame when the jar was stationary on the table. Let z_, _ where the first subscript represents the left (1), middle (2), right (3), or top (4) point and the second subscript is the frame number. For example $z_{1,1}$ represents the z coordinate of the left target at frame 1.

Frame 1: $\frac{z_{1,1} + z_{2,1} + z_{3,1}}{3} = z_{avg,1}$ continue for each frame up to

Frame 240: $\frac{z_{1,240} + z_{2,240} + z_{3,240}}{3} = z_{avg,240}$

Next the 240 frames just found were averaged:

$$\frac{z_{avg,1} + z_{avg,2} \cdots + z_{avg,240}}{240} =$$ Average vertical location of the three target points on the jar. Still working with the jar stationary, the middle target coordinate (z_2) on the jar was subtracted from the top coordinate (z_4) on the closure for each frame. Next the average distance to the closure from all 240 frames was found.

$$z_{4,1} - z_{2,1} = \Delta z_1,\ z_{4,2} - z_{2,2} = \Delta z_2, \ldots, z_{4,240} - z_{2,240} = \Delta z_{240}$$

$$\frac{\Delta z_1 + \Delta z_2 + \ldots + \Delta z_{240}}{240} = z_{vertavg}$$

(The average distance from the closure to the three points)

STEP 2: Creating a local coordinate system that rides with the jar.

The next steps were calculated when the jar was moving. First the left target coordinates were subtracted from the right target coordinates for all 240 frames, see Figure 22. This produced vector $\overrightarrow{LR}$.

$$\begin{array}{lcl} x_{3,1} - x_{1,1} = \Delta x_1 & & x_{3,240} - x_{1,240} = \Delta x_{240} \\ y_{3,1} - y_{1,1} = \Delta y_1 & \cdots & y_{3,240} - y_{1,240} = \Delta y_{240} \\ z_{3,1} - z_{1,1} = \Delta z_1 & & z_{3,240} - z_{1,240} = \Delta z_{240} \end{array}$$

The magnitude for each frame was calculated: $\sqrt{\Delta x_1^2 + \Delta y_1^2 + \Delta z_1^2} = \left|\overrightarrow{LR_1}\right|$

$$\cdots$$

$$\sqrt{\Delta x_{240}^2 + \Delta y_{240}^2 + \Delta z_{240}^2} = \left|\overrightarrow{LR_{240}}\right|$$

Next the unit vector was calculated for each frame:

$$\left(\frac{\Delta x_1}{\left|\overrightarrow{LR_1}\right|}, \frac{\Delta y_1}{\left|\overrightarrow{LR_1}\right|}, \frac{\Delta z_1}{\left|\overrightarrow{LR_1}\right|}\right) \quad \cdots \quad \left(\frac{\Delta x_{240}}{\left|\overrightarrow{LR_1}\right|}, \frac{\Delta y_{240}}{\left|\overrightarrow{LR_{240}}\right|}, \frac{\Delta z_{240}}{\left|\overrightarrow{LR_{240}}\right|}\right)$$

$$(\hat{x}_1, \hat{y}_1, \hat{z}_1) \quad \cdots \quad (\hat{x}_{240}, \hat{y}_{240}, \hat{z}_{240})$$

The next step was to calculate a point in the center of the jar at the level of the targets on the outside of the jar. Calculations for the center of the jar for each frame:

1) Find an average magnitude $\dfrac{\left|\overrightarrow{LR_1}\right| + \left|\overrightarrow{LR_2}\right| + \ldots + \left|\overrightarrow{LR_{240}}\right|}{240} = \left|\overrightarrow{LR_{avg}}\right|$

2) Calculate coordinates for the center (center of diameter between L and R target) of the jar at the level of the targets:

$$x_{left,1} + \tfrac{1}{2}(\hat{x}_1 \bullet \left|\overrightarrow{LR_{avg}}\right|) = x_{center,1}$$

$$x_{left,2} + \tfrac{1}{2}(\hat{x}_2 \bullet \left|\overrightarrow{LR_{avg}}\right|) = x_{center,2}$$

$$\cdots$$

$$x_{left,240} + \tfrac{1}{2}(\hat{x}_{240} \bullet \left|\overrightarrow{LR_{avg}}\right|) = x_{center,240}$$

(Repeat for y and z coordinates)

Again working with each frame a vector $\overrightarrow{CL}$ (center to left) was created by subtracting the left target minus the center point computed above.

$$\begin{array}{lcl} x_{left,1} - x_{center,1} = \Delta x_{left,1} & & x_{left,240} - x_{center,240} = \Delta x_{left,240} \\ y_{left,1} - y_{center,1} = \Delta y_{left,1} & \cdots & y_{left,240} - y_{center,240} = \Delta y_{left,240} \\ z_{left,1} - z_{center,1} = \Delta z_{left,1} & & z_{left,240} - z_{center,240} = \Delta z_{left,240} \end{array}$$

Repeat this process for the subtraction of the right target from the center target to get: $\left(\Delta x_{right,1}, \Delta y_{right,1}, \Delta z_{right,1}\right)$ for each frame of data. Next the magnitude for each frame was calculated. A cross product was computed between CL and CR:

$$\overrightarrow{CR} \times \overrightarrow{CL} = \overrightarrow{Z}$$

This resulted in an z axis that ran through the center of the jar directed downward toward the base of the jar.

Find the unit vector of the cross:

$$\hat{\overrightarrow{Z}} = (\hat{x}_{cross}, \hat{y}_{cross}, \hat{z}_{cross})$$

Repeat Step 5 of Pole Rig Method for each frame (2 through 240)

STEP 3: Bottom of jar (center point, moved down 70 mm) calculation.

Frame 1: $x_{2,1} + \hat{x}_{cross,1} \bullet 70mm$

$\cdots$

Frame 240: $x_{2,240} + \hat{x}_{cross,240} \bullet 70mm$

Repeat for the y and z coordinates. This point was then used for calculating the rotation of the jar hand index finger about the jar, see Figure 22.

STEP 4: Rotation point (center point, moved up 35 mm) calculation of closure.

Frame 1: $x_{2,1} - \hat{x}_{cross,1} \bullet 35mm$

. . .

Frame 240: $x_{2,240} - \hat{x}_{cross,240} \bullet 35mm$

Repeat for the y and z coordinates. This point was then used for calculation the rotation of the closure hand index finger about the jar, see Figure 22.

Next the process for the Pole Rig Method Steps 4 through 6 was used to calculate the degrees for every frame. All 240 frames where graphed using the corresponding degrees, see Figure 23 and Determination of Degrees Rotation below.

Determination of Degrees Rotation

In order to determine the degree of rotation supplied by each hand at the determined point of opening, see Appendix C, the calculated degrees for each hand at each frame collected were graphed. In order to determine the motion that correlated with package opening, graphs consisting of the entire set of data points (240 points) were created. Figure 23, a representative sample provided by one subject for a single jar, depicts a restricted opening (table bound) for jar B. In Figure 23 there is an additional data point at frame 1. This point represents the angle calculated between frame 1 and frame 240. Researchers identified opening through the use of the slope of the data, with the area of greater slope representing the period of opening.

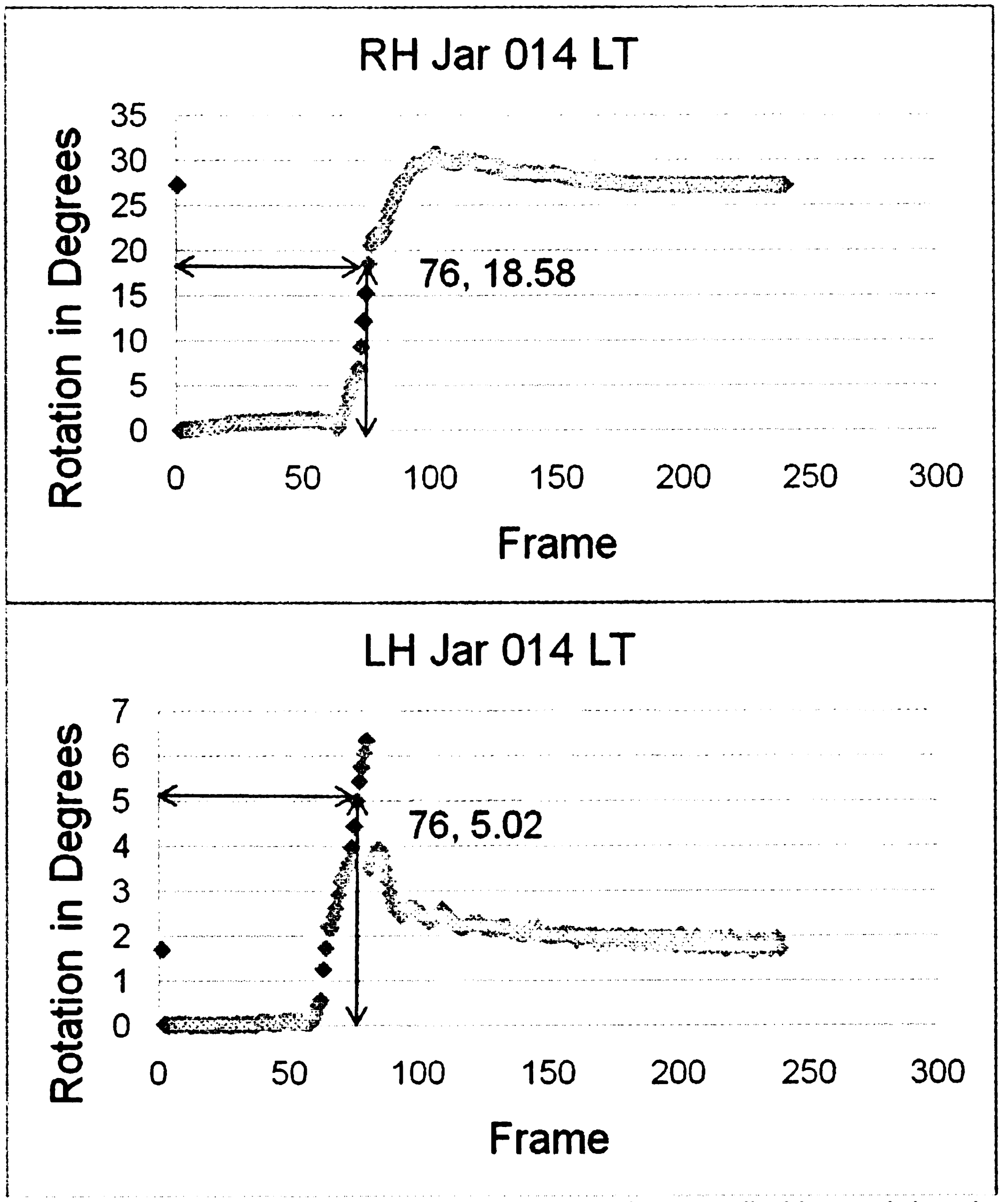


Figure 23 – Graphs used for calculating rotation supplied by each hand

Appendix C shows how the degrees of rotation needed to remove the closure form the jar were calculated for both Jar A and Jar B. Jar A was determined to require an average of 30 degrees of rotation for an opening to occur while Jar B was calculated to need an average of 25 degrees. Using Figure 23 where subject 014 is opening Jar B there should be one data point where the left hand (LH) and the right hand (RH) together account for a degree of opening near degrees. At data point 76 the right hand on the jar rotates 18.58 degrees and the left hand on the closure rotates 5.02 degrees for a total combined rotation of 23.06 degrees. For all of the openings collected from the subjects the data point closest to the calculated average, in the area of the graph where the increase was seen, was determined to be the point at which the closure was removed from the jar. These degrees were then calculated into a percentage of the opening degree. In continuing the example demonstrated by Figure 22 the right hand on the jar supplied 18.58 degrees of the total 23.60 degrees (18.58 + 5.02) for an opening percentage of 78.73 percent (18.58/23.60). The left hand (in this case the closure hand) supplied 5.02 degrees of the total 23.60 (18.58 + 5.02) degrees for an opening percentage of 21.27 percent (5.02/23.60).

Data was categorized in an attribute fashion by grouping the openings into three categories; closure hand only, jar hand only and both hands. The categories were determined by computing percentages from the angles calculated from the Qualisys data as outlined above. Parameters were set by the researchers as to what would qualify, based on percent, as one hand supplying the rotation necessary to open the jar, either closure hand or jar hand, or if both hands were involved in supplying the rotation need to open the jar. In order to determine whether one hand or both hands were involved in the opening all of the opening percents were first graphed to see if a trend would emerge showing a clear break between one hand, either closure or jar hand, or both hands being used for opening, see Figure 30.

Chapter 4

RESULTS AND DISCUSSION

Subject Information

Researchers collected data on 25 subjects, all of whom attended Michigan State University. Of the 25 subjects, the first twelve had to be collected two times due to a collection error, and all subjects were compensated for both testing sessions. This error was created by incorrect calibration of the motion capture system; see Appendix D for correct calibration. Of the first twelve subjects only nine were available for the second session. As such, only 22 subjects had usable data collected.

One of the factors of interest in the data analysis was the effect of laterality on motion. A single participant, subject number 024, clasped their hands with their thumbs in a side by side orientation. As a result, researchers could not code the laterality for this subject, whose results were subsequently eliminated.

Of the usable 21 subjects, 14 were male and 7 female. The average age of these subjects was 24 ± 3.1 years, and subjects ranged in age from 18 to 30.

Twenty of the 21 indicated that they were right handed, and one subject indicated himself to be left handed. Table 2 gives an overview of the preferred dexterity and information about which hand was placed on the closure hand placement indicated/used by subject and gender.

Overview of subjects included in analysis			
	Female	Male	Total
Total Number of Subjects	7	14	21
Indicated Right Handed	7	13	20
Indicated Left Handed	0	1*	1
Right Hand on Closure	6	10	16
Left Hand on Closure	1	3	4
Alternated Closure Hand	0	1*	1
*Left handed male subject alternated closure hand placement			

Table 2 – Overview of subjects participating in study

Data was collected on which hand each subject placed on the jar closure for each opening trial during testing. Of the 21 subjects tested, 16 placed their right hand on the closure, or 76.2% of the subjects. All 16 of the subjects placing their right hand on the closure indicated that they were right-hand dominant. Of these, 10 were male and 6 were female. This finding is not consistent with that of Voorbij and Steenbekkers (2002) who found that 511 or 534 or roughly 96 percent of subjects that are right handed place their left hand on the closure [3]. Of the remaining subjects, 4 placed their left hand (non – dominant) on the closure (19.1% of the subjects); of these 3 were male and 1 was female. One subject, a male that had indicated himself to be left-handed, alternated which hand was placed on the closure during opening (4.7%).

Hand Size

Anthropometric data (size) was collected for all test subjects. This data included: Hand Breadth, Wrist – Index Finger Length and Hand Length, see Figure 3 in Chapter 3 and Table 3.

Table of Average Size of the Hand (Anthropometric Data)			
Population (number of people)	Measurement	Average (mm)	Standard Dev.
Overall (21)	Hand Breadth Left	96.63	8.75
	Wrist - Index Finger Length Left	188.15	12.87
	Hand Length Left	202.83	14.55
	Hand Breadth Right	96.74	8.23
	Wrist - Index Finger Length Right	189.85	12.71
	Hand Length Right	203.07	13.74
Male (14)	Hand Breadth Left	101.10	5.34
	Wrist - Index Finger Length Left	192.79	9.68
	Hand Length Left	209.10	10.23
	Hand Breadth Right	100.84	5.00
	Wrist - Index Finger Length Right	195.02	9.14
	Hand Length Right	208.91	9.98
Female (7)	Hand Breadth Left	87.71	7.35
	Wrist - Index Finger Length Left	178.88	14.08
	Hand Length Left	190.30	14.28
	Hand Breadth Right	88.54	7.35
	Wrist - Index Finger Length Right	179.53	13.09
	Hand Length Right	191.39	13.23

Table 3 – Anthropometric data

Hand size was then categorized based on size in mm in accordance with the data collected by a division of the United States Department of Commerce called the National Technical Information Service (NTIS) [13]. Figure 24 shows the current study compared to the NTIS data for hand breadth. NTIS data recorded the average measurements so the current study right hand and left hand measurements are compared to the averages of the NTIS data.

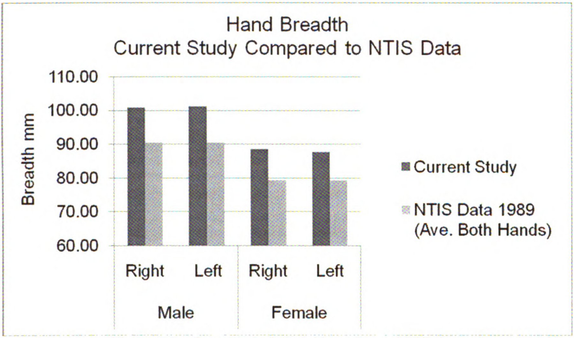


Figure 24 – Current study hand breadth vs. NTIS data

In the current study, hand breadth measurements for both male and female, left and right hand, are larger than the average measurements from the NTIS data. This could be related to the very small sample that came from a single population presented in our study, which had 14 males and 7 females. The NTIS data consisted of 1,774 males and 2,208 females. Another possibility could be the 20 year gap in data collection. If the current study left and right hand data is averaged then using the percentiles compiled by the NTIS [13] the average subject in the current study had a hand breadth in the 99th percentile for males and the 98th percentile for females.

Figure 25 shows the current study compared to the NTIS data for wrist – index finger length. Again, the NTIS data recorded the average measurements so the current study right hand and left hand measurements are compared to the averages of the NTIS data [13].

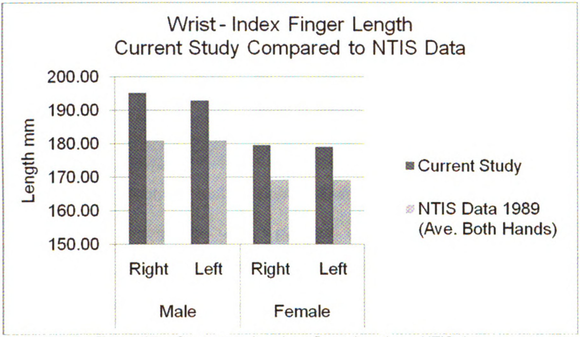


Figure 25 – Current study wrist – finger length vs. NTIS data

Wrist – index finger length data again demonstrates that the current study subjects had measurements above the average data collected by the NTIS [13]. If the current study left and right hand data is averaged then using the percentiles compiled by the NTIS the average subject in the current study had a wrist – index finger length in the 90th percentile for males and the 85th percentile for females [13].

Figure 26 shows the current study compared to the NTIS data for hand length. Again the NTIS data recorded the average measurements so the current study right hand and left hand measurements are compared to the averages of the NTIS data.

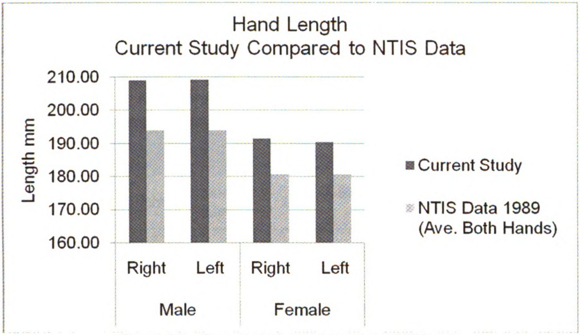


Figure 26 – Current study hand length vs. NTIS data

Measurements of hand length were found to be greater than the average measurements collected for the NTIS study [13]. If the current study left and right hand data is averaged then using the percentiles compiled by the NTIS the average subject in the current study had a hand length in the 90th percentile for males and the 85th percentile for females. The results for anthropometrics of the current study compared to the data from the NTIS show that, on average, the subjects used in the current study had relatively large hands [13]. Researchers examined the data for correlations on the collected anthropometric data.

Analysis of Strength Data

Strength data was also collected for each subject. The hand strength measurements collected were grip strength and bilateral palm to palm squeeze strength. Table 4 shows the average results.

Table of Strength Measurements						
Population (number of people)	Grip Strength (lbs)				Bilateral Palm to Palm Squeeze (psi)	
	Right	Standard Dev.	Left	Standard Dev.	Right/Left	Standard Dev.
Overall (20)	37.69	13.62	36.60	13.06	7.04	5.80
Men (14)	42.10	14.63	41.46	13.29	8.88	6.16
Women (7)	28.88	4.27	26.87	4.50	3.36	2.49

Table 4 – Table of strength measurements

The results for the right and left hands within gender were quite similar for the grip strength. This finding could be related to the fact that all subjects were free of injuries to the hands, wrist, arms and shoulders. However, this finding suggests that with relatively equal strength measurements in both hands subjects might not favor the strength in one hand over the other for opening purposes. Figure 27 is a graphical representation of the strength measurements.

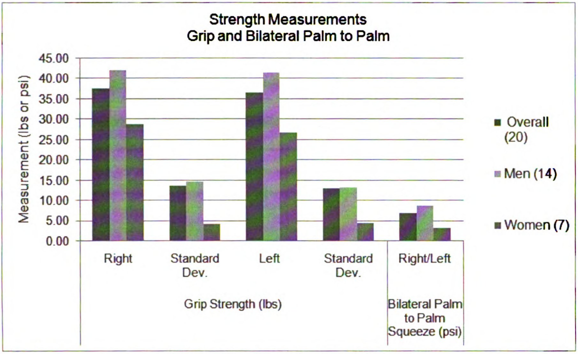


Figure 27 – Strength measurements

Laterality

Laterality was of special interest for the research team. Table 5 shows an overview of the laterality results observed in the 21 subjects.

Laterality Results by Gender and Dexterity						
Gender	Dexterity		Laterality (Hand)		Laterality (Arm)	
	Right	Left	Right	Left	Right	Left
Male	13	1	6	8	4	10
Female	7	0	3	4	3	4
Total	20	1	9	12	7	14

Table 5 – Laterality results by gender and dexterity

Table 6 shows the breakdown of the four laterality coding possibilities with the statistical analysis that examines the relationship between hand clasping and arm folding.

Table of Laterality (Hand) by Laterality (Arm)		
Laterality (Hand)	Laterality (Arm)	
	Right	Left
Right	3 (RR)	6 (LR)
Left	4 (RL)	8 (LL)
Fisher's Exact Test		
Cell (1, 1) Frequency (F)		3
Left - sided Pr <= F		0.6811
Right - sided Pr > = F		0.6765
Table Probability (P)		**0.3576**
Two - sided Pr <= P		1.0000
Sample Size		21

Table 6 – Laterality hand by laterality arm statistics

Based on the results of a Fisher's Exact Test, see Table 6, the data suggests no evidence of an association between hand clasp and arm folding (P = 0.35). This indicates that the two measures of laterality are independent of each other. This is consistent with other researcher's findings Mohr et. al. (2003, 2006) [8, 9] that indicate that there is close to equal distribution of subjects between the four possible codes (LL, LR, RR, RL). Distribution of the sample population based on laterality is expressed in Figure 28.

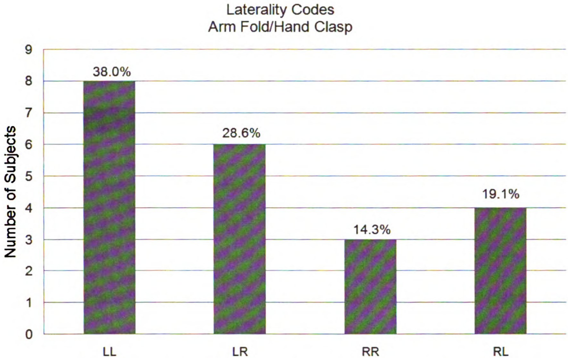


Figure 28 – Number of subjects representing each of the four laterality codes

Opening Data

Simple analysis of the opening data shows that, across all openings (restricted or unrestricted), on average, whichever hand was on the closure had an average opening rotation percentage greater than that of the jar hand; see Table 7 and Figure 29. However, not every subject had a greater percentage of rotation for the closure hand, 80 of the 252 openings had a greater percentage rotation of for the jar hand. For the unrestricted openings the subjects placed their hands in the same positions. The left handed male subject alternated his hand placements on the closure for both restricted and unrestricted openings.

Overview of Rotation in Percent and Degrees All Openings N = 252				
	Average	Standard Deviation	Minimum	Maximum
Rotation Closure Hand %	59.60	25.34	0.20	99.79
Rotation Closure Hand Degrees	16.07	7.23	0.05	30.78
Rotation Jar Hand %	40.40	25.34	0.21	99.80
Rotation Jar Hand Degrees	11.25	9.08	0.05	97.07
Unrestricted Openings N = 126				
	Average	Standard Deviation	Minimum	Maximum
Rotation Closure Hand %	54.20	20.46	3.15	94.38
Rotation Closure Hand Degrees	14.31	5.81	1.00	30.35
Rotation Jar Hand %	45.80	20.46	5.62	96.85
Rotation Jar Hand Degrees	12.73	9.59	1.41	97.07
Restricted Openings N = 126				
	Average	Standard Deviation	Minimum	Maximum
Rotation Closure Hand %	66.75	28.12	0.20	99.79
Rotation Closure Hand Degrees	18.35	7.96	0.05	30.78
Rotation Jar Hand %	33.25	28.12	0.21	99.80
Rotation Jar Hand Degrees	9.28	8.03	0.05	30.10

Table 7 – Overview of rotation by percent and degrees

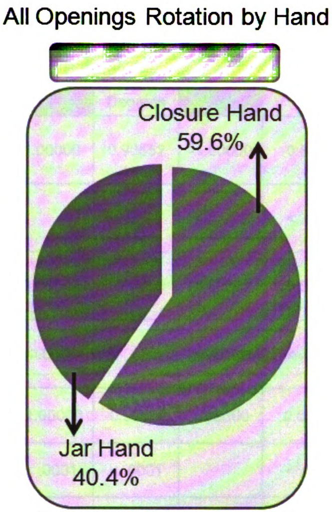


Figure 29 – Openings by rotation hand

A Pearson Correlation Coefficient was applied to the opening rotation in percent and degree for both the closure and jar hands in all openings, see Table 8.

Pearson Correlation Coefficients, N = 252					
Prob > I r I under HO: Rho = 0					
	Rotation Closure Hand %	Rotation Closure Hand Degrees	Rotation Jar Hand %	Rotation Jar Hand Degrees	Total Degrees Rotation
Rotation Closure Hand %	1.00000	0.90552	-1.00000	-0.81302	-0.10750
Rotation Closure Hand %		< .0001	< .0001	< .0001	0.0886
Rotation Closure Hand Degrees	0.90552	1.00000	-0.90552	-0.56924	0.26651
Rotation Closure Hand Degrees	< .0001		< .0001	< .0001	< .0001
Rotation Jar Hand %	-1.00000	-0.90552	1.00000	0.81302	0.10750
Rotation Jar Hand %	< .0001	< .0001		< .0001	0.0886
Rotation Jar Hand Degrees	-0.81302	-0.56924	0.81302	1.00000	0.64073
Rotation Jar Hand Degrees	< .0001	< .0001	< .0001		< .0001
Total Degrees Rotation	-0.10750	0.26651	0.10750	0.64073	1.00000
Total Degrees Rotation	0.0886	< .0001	0.0886	< .0001	

Table 8 – Pearson correlation coefficients

Note the perfect correlation between percent rotation of jar hand and percent rotation of the closure hand (Correlation = -1), thus indicating that modeling of one variable is a mirror complement to the modeling of the other. Also, note the high correlation between rotation of each hand expressed in degrees or percent (Correlation > 0.90), thus suggesting reliable representation of one with the other.

Each subject opened 2 jars, see Table 1 and Figure 7, in both the restricted (table) and unrestricted (free motion) conditions of test three times each, for a total of 12 openings per subject, see Figure 11. Degrees of rotation were analyzed using techniques described previously. Figure 30 shows all of the opening trials for both restricted and unrestricted openings in percent degrees of rotation for the closure hand, which, as noted above, represents a mirror of jar hand opening.

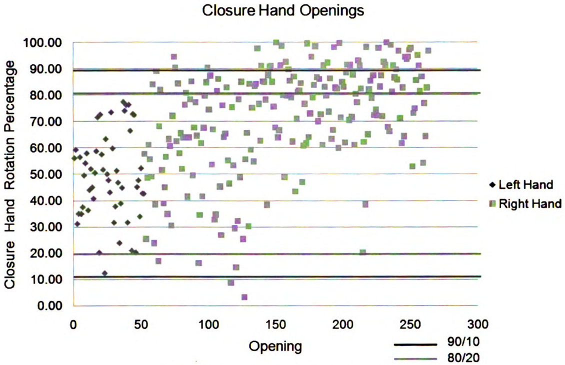


Figure 30 – Closure hand openings

The total opening trials, N = 252, can be broken down into restricted and unrestriced openings, each with N = 126. Beginning with the restricted openings, see Table 7, the trend of closure hand having a greater percentage of rotation compared to the jar hand, on average, remains. While this finding does not change compared to the overall average it is interesting that the closure hand is supplying a greater percent, on average, for the restricted openings then was seen across all 252 openings, both restrained and unrestrained.

When the restricted opening trials are graphed according to the percent of degrees of rotation of the closure hand, there appears to be a separation between left hand closure openings and right hand closure openings, see Figure 31. The openings where the subject placed their left hand on the closure account for twelve of the openings, three males and one female at 3 opening each.

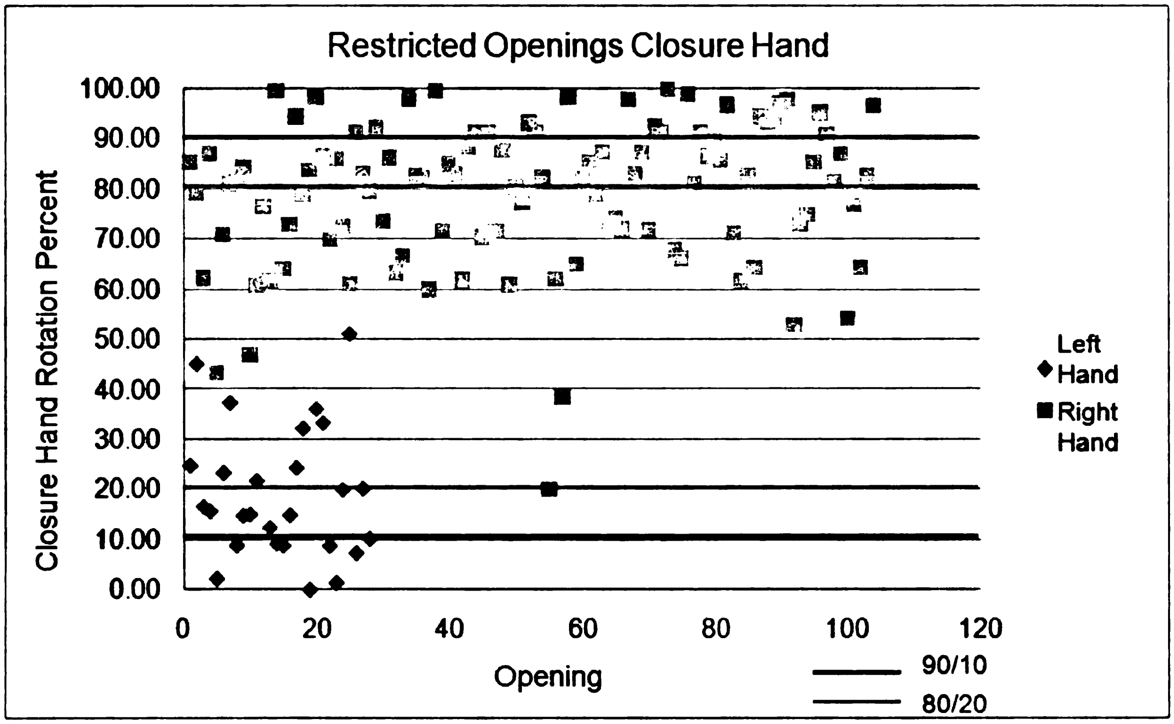


Figure 31 – Restricted closure hand openings

This may be explained by the fact that twenty of the twenty one subjects declared themselves to be of right hand dexterity. The right hand exhibited higher degrees of rotation, on average than did the left hand. In other words the left hand was on the closure, but it appears that the dominant (right) hand supplied a greater rotation percent, see Figure 34. Also, as noted by Voorbij and Steenbekkers (2002) the vast majority (nearly 96 %) of right hand dominate subjects place their left hand on the closure [3], so this trend may not apply to most subjects and could be a result of the subject population used in this study.

For the unrestricted openings, see Table 7 and Figure 32, the trend of closure hand having a greater percentage of rotation compared to the jar hand remains. However, the closure and jar hands result in averages of rotation percent that are more scattered than those seen in the restricted openings.

It appears that both hands tended to have a greater role in unrestricted openings than they did when motion was restricted, making it more difficult to predict the motion applied by either hand when opening jars in an unrestricted fashion.

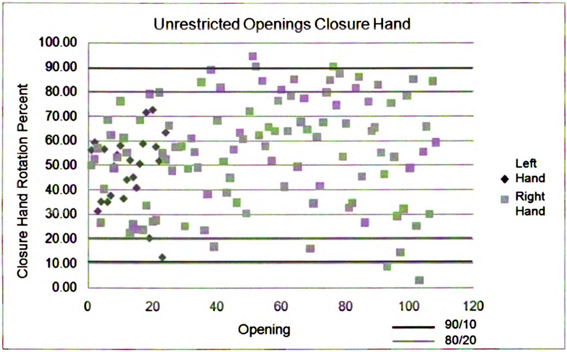


Figure 32 – Unrestricted closure hand openings

The degree of rotation of the closure hand for all openings was graphed in an attempt to identify whether or not discrete differences existed in how people used their hands (i.e. some a majority of the closure hand, others a majority of the jar hand and some both hands). However, no clear break was seen in the graphical data for the closure hand. Therefore, arbitrary values were set for the break in percent rotation for determination of one hand or both hands used for opening. Two arbitrary value boundaries were set for statistical analysis; 90 – 10 and 80 – 20, meaning that if either hand supplied 90 or greater, or 80 or greater of the percent rotation it was classified as a one hand opening, jar or closure, see Figures 30, 31 and 32 for the boundaries. Openings where one hand was not determined to have supplied 90 percent or greater or 80 percent or greater was coded as a two-handed opening (i.e. both closure and jar hands provided motion). There was a marginal disagreement between the two motion classifications (90_10 or 80_20), thus emphasizing the arbitrary nature of the boundaries, see Table 9.

Table of Closure Hand 90_10 and 80_20 Openings All Openings		
	80_20	90_10
Left	7	2
Right	84	34
Both	161	216

Table 9 – Total openings for 80_20 and 90_10 groupings

Rig Selection

The twenty-one subjects were asked to open 2 jars, see Figure 7 and Table 1, in two different orientations (restrained and unrestrained) a total of three times in each orientation; this totaled 12 observations per subject, or 252 observations for the entire experiment. The unrestricted openings required different experimental equipment, or "rigs." Two rigs were used to accommodate the differing grip styles employed by subjects, see Figure 16. A Chi – square test was run on rig type by gender with a sample size of 126, which account for the total number of openings performed by the 21 included subjects in the unrestricted positions (2 jars x 3 replicates x 21 subjects), see Table 10.

Table of Rig Type by Gender			
Gender	Rig Type		Total
	Pole	Side	
Male	72	12	84
Female	30	12	42
Total	102	24	126

Statistics for Table of Rig Type by Gender			
Statistic	DF	Value	Prob.
Chi - Square	1	3.7059	0.0542
Likelihood Ratio Chi - Square	1	3.5478	0.0596
Continuity Ad. Chi - Square	1	2.8373	0.0921
Mantel - Haenszel Chi - Square	1	3.6765	0.0552
Phi Coefficient		0.1715	
Contingency Coefficient		0.1690	
Cramer's V		0.1715	

Fisher's Exact Test	
Cell (1,1) Frequency (F)	72
Left - sided Pr <= F	0.9833
Right - sided Pr >= F	0.0481
Table Probability (P)	**0.0314**
Two - sided Pr <=P	0.0901
Sample Size	126

Table 10 – Rig type by gender statistics for unrestricted openings

Based on the Chi – Square analysis, see Table 10, male subjects were found to be more likely to use the pole rig than female subjects (P<0.05). This has ramifications for the grip style that they used. Male subjects were more likely to grip jars by the side than females (P<0.05), who more frequently gripped at the bottom of the jar than their male counterparts, see Table 10. Table 11 further investigates the use of the side and bottom grips, indicating that both male and female subjects tend to grip the larger jar from the bottom more frequently than the smaller jar.

Effect of Rig Type and Jar Size on % Rotation Degrees by Jar Hand

Effects of grip style were further examined using a general linear mixed model, which was fit to the continuous response variable "percentage of rotation degrees by the jar hand" using the MIXED procedure of SAS (version 9.1, SAS Institute, Cary, NC). Data were collected in a RCB design, such that subject was considered the blocking factor for assigning a 2x3 jar size by rig type treatment combination. Table 11 shows the breakdown of opening positions (table, pole rig and side rig) by jar size and gender. Pole rig openings accounted for 80.9% of the unrestricted openings, in other words, few people gripped the bottom of the jar during the opening process.

Table of Jar Size by Opening Position, Gender and Closure Hand									
	Male Openings (Closure Hand)			Female Openings (Closure Hand)			Total Openings (Closure Hand)		
	Right Hand	Left Hand	Total	Right Hand	Left Hand	Total	Right Hand	Left Hand	Total Both
Jar A Table	30	12	42	18	3	21	48	15	63
Jar A Pole Rig	30	9	39	15	3	18	45	12	57
Jar A Side Rig	3	*0*	3	3	*0*	3	6	*0*	6
Jar A Total Opening	63	21	84	36	6	42	99	27	126
Jar B Table	32	10	42	18	3	21	50	13	63
Jar B Pole Rig	24	9	33	9	3	12	33	12	45
Jar B Side Rig	9	*0*	9	9	*0*	9	18	*0*	18
Jar B Total Opening	65	19	84	36	6	42	101	25	126

Table 11 – Table of jar size by opening position, gender and closure hand

By design, the base statistical model included the categorical fixed effects of jar size (Jar A and Jar B), rig type (table, pole and side rig) and their 2-way interaction. Effects considered random included: subject, subject by rig type and subject by jar size. These random effects were intended to recognize subject as the blocking factor and the appropriate degrees of freedom for each of the treatment factors, correspondingly. Also, a random effect of subject by jar size by rig type was fitted to account for technical replications (sub sampling) within the design (each subject in each rig type by jar size combination was measured 3 times).

Potential additional explanatory variables of interest were recorded at the subject level, including gender, dexterity, laterality (both by arm cross and hand clasp) and a total of 9 morphometric continuous variables. Closure hand used in each jar-opening event was also recorded. In order to decide between these potential explanatory variables, stepwise model selection based on Bayesian Information Criteria (BIC) was used to select a model of best fit. The BIC-based model of best fit included, in addition to the base model described above, the effects of gender, hand breadth RIGHT, their 2-way interaction and hand length RIGHT. Degrees of freedom were computed using Kenward-Roger method, as implemented in SAS. Model assumptions were checked using standardized residuals and were considered to be appropriately met. Least square means and standard errors are provided, see Table 12. Post-hoc pairwise comparisons were performed using Bonferroni's adjustment to avoid inflation of type I error rate. It should be noted that the lack of observations for the combination of the side rig (rig type 3) and the left hand on the closure (closure hand 2), this is shown in bold and italics in Table 11, prevented simultaneous fitting of the two (rig type and closure hand) as explanatory variables in a given model.

Due to these limitations in the data structure, it was decided to continue with a model without closure hand as an explanatory variable.

Solution for Fixed Effects								
Effect	Gender	Rig Type	Jar Size	Estimate	Standard Error	DF	t Value	Pr > I t I
Intercept				-54.3064	67.5064	17	-0.8	0.4322
Jar Size			1 (Jar A)	1.7748	10.8928	44.3	0.16	0.8713
Jar Size			2 (Jar B)	0				
Rig Type		1 (Table)		-12.2533	12.5283	69.2	-0.98	0.3315
Rig Type		2 (Pole)		1.4902	12.7554	72	0.12	0.9073
Rig Type		3 (Side)		0				
Rig Type * Jar Size		1 (Table)		-5.387	11.4502	43.3	-0.47	0.6404
Rig Type * Jar Size		1 (Table)		0				
Rig Type * Jar Size		2 (Pole)		-13.1516	11.6691	43.1	-1.13	0.266
Rig Type * Jar Size		2 (Pole)		0				
Rig Type * Jar Size		3 (Side)		0				
Rig Type * Jar Size		3 (Side)		0				
Gender	1 (M)			225.15	91.0139	15.7	2.47	**0.0252**
Gender	2 (F)			0				
Hand Breadth Right				-0.7418	0.7991	16.3	-0.93	0.3667
Hand Breadth Right * Gender	1 (M)			-2.1779	0.9613	15.9	-2.27	**0.0378**
Hand Breadth Right * Gender	2 (F)			0				
Hand Length Right				0.8413	0.3342	16.5	2.52	**0.0225**

Table 12 – Solution for fixed effects

The fixed effect gender was found to be significant (P = 0.0252; α =0.05); a significant difference existed in the % of degrees of jar rotation of men and women, where men rotate their jar hand more than women. Additionally, the interaction term hand breadth x gender was found to be significant at α =0.05 (P = 0.0378 - See Table 12).

When using the variable data (% of rotation of the closure hand) as a dependent variable, men and women with large hand breadths (102 mm) behave similarly in terms of rotational behavior (P = 0.7898), while men and women of moderate hand breadths (92 mm) were significantly different (P = 0.0107). Those with the narrowest hands (82 mm) were also significantly different in rotation behaviors (P = 0.0057), see Table 13 and Figure 33.

Differences of Lease Squares Means									
Effect	Gender	Gender	Hand Breadth Right	Hand Length Right	Estimate	Standard Error	DF	t Value	Pr > I t I
Gender	1 (M)	2 (F)	82.00	203.07	46.5701	14.4389	15	3.23	0.0057*
Gender	1 (M)	2 (F)	92.00	203.07	24.7916	8.5929	16.2	2.89	0.0107*
Gender	1 (M)	2 (F)	102.00	203.07	3.0131	11.1356	18	0.27	0.7898
*Significant at Bonferroni - adjusted comparison - wise type I error rate of 5%									

Table 13 – Jar hand rotation by hand breadth and gender

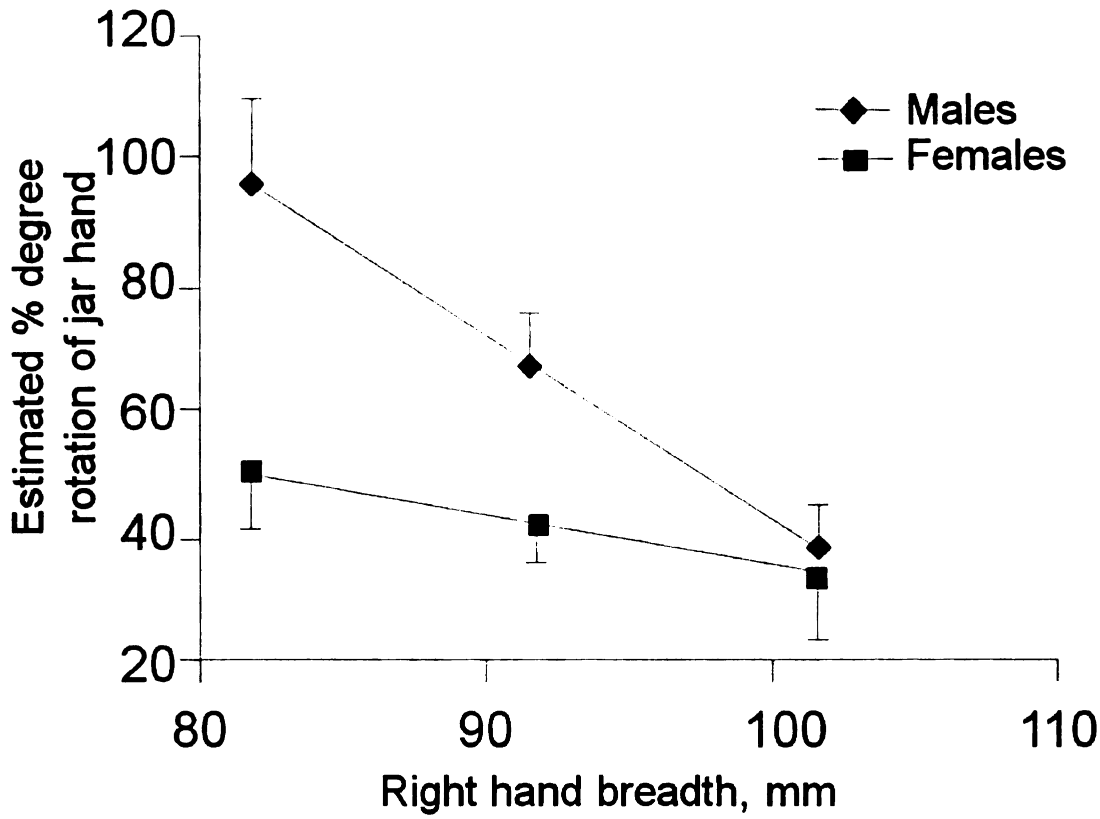


Figure 33 – Jar hand rotation by right hand breadth (mm)

Another significant effect when the variable of test was % of degrees of rotation of the jar hand, was hand length (P =0.0225; α=0.05, see Table 14). This relationship was such that each mm increase in length was associated with an increase of 0.84% in the degrees of rotation of the jar hand, In other words, people with longer hands tended to open a jar by rotating the jar hand more. Table 3 shows that, on average, males had longer hands than did females by nearly 20 mm.

Type 3 Tests of Fixed Effects				
Effect	Number Degrees Freedom	Den Degrees Freedom	F Value	Pr > F
Jar Size	1	42.8	1.18	0.2828
Rig Type	2	33.2	2.5	0.0974
Rig Type * Jar Size	2	39.8	1.32	0.2794
Gender	1	15.7	6.12	0.0252
Hand Breadth Right	1	16.8	8.19	0.0109
Hand Breadth Right * Gender	1	15.9	5.13	0.0378
Hand Length Right	1	16.5	6.34	0.0225

Table 14 – Type 3 tests of fixed effects

There was no evidence of an effect of jar size or rig type on the percentage degrees of rotation of the jar hand (P = 0.28 and 0.10, respectively) see Table 14.

Effect of Opening and Jar Size on % Rotation Degrees by Jar Hand

In order to include the effect closure hand, either left (opening 2) or right (opening 1), as an explanatory factor in the model, analysis of the opening rotation in percent was simplified. (Recall from the previous discussion that due to the lack of data for closure hand across the three opening positions (table, pole rig and side rig, closure hand could not be included in the analysis). Analysis was repeated to compare the restricted openings (opening 1 - table) to the unrestricted openings (opening 2) and the comparison between the pole and side rigs (grip style) were removed.

A general linear mixed models was fit to the continuous response variable "percentage of rotation degrees by the jar hand" using the MIXED procedure of SAS (version 9.1, SAS Institute, Cary, NC). Data were collected in a RCB design, such that subject was considered the blocking factor for assigning a 2x2 jar size by opening restriction treatment combination. By design, the base statistical model included the categorical fixed effects of jar size (2 levels), opening restriction (2 levels- unrestricted and table) and their 2-way interaction. The model included the random effects of subject, subject by opening and subject by jar size in order to recognize the blocking factor and the appropriate degrees of freedom for each of the treatment factors, respectively. In addition, a random effect of subject by jar size by opening restriction was fitted to account for technical replications within the design (each subject in each opening restriction by jar size combination was measured 3 times).

In addition, potential explanatory variables of interest were recorded at the subject level, including: gender, dexterity, laterality (both by arm cross and hand clasp) and a total of 9 morphometric continuous variables. Closure hand (left or right) used in each jar-opening event was also recorded. In order to decide between these potential explanatory variables, stepwise model selection based on Bayesian Information Criteria (BIC) was used to select a model of best fit. In this case, the model of best fit based on BIC included, in addition to the base model described above, the effects of gender, closure hand, its interaction with opening restriction, LEFT hand breadth and LEFT wrist – finger length. Degrees of freedom were computed using Kenward-Roger Method. Model assumptions were checked using standardized residuals and were considered to be appropriately met. Least square means and standard errors are provided, see Tables 18, 19 and 20. Post-hoc pairwise comparisons were performed using Bonferroni's adjustment to avoid inflation of type I error rate, see Table 19.

Solution for Fixed Effects									
Effect	Gender	Opening	Jar Size	Closure Hand	Estimate	Standard Error	DF	t Value	Pr > I t I
Intercept					90.8110	23.1989	16.3	3.91	0.0012
Jar Size			1		-8.5909	3.4507	59	-2.49	0.0156
Jar Size			2		0				
Opening		1			23.8171	5.8895	63.4	4.04	0.0001
Opening		2			0				
Opening * Jar Size		1	1		6.7273	4.8819	59	1.38	0.1734
Opening * Jar Size		1	2		0				
Opening * Jar Size		2	1		0				
Opening * Jar Size		2	2		0				
Gender	1				20.2015	4.0853	15.9	4.94	0.0001
Gender	2				0				
Closure Hand				1	-4.5686	4.5722	47.4	-1.00	0.3228
Closure Hand				2	0				
Opening * Closure Hand		1		1	-50.5138	6.0588	65.6	-8.34	<.0001
Opening * Closure Hand		1		2	0				
Opening * Closure Hand		2		1	0				
Opening * Closure Hand		2		2	0				
Hand Breadth Left					**-1.4275**	0.2974	15.9	-4.80	**0.002**
Finger Length Left					**0.4679**	0.1603	16	2.92	**0.0101**

Table 15 – Solution for fixed effects

Type 3 Tests of Fixed Effects				
Effect	Num DF	Den DF	F Value	Pr > F
Jar Size	1	59	4.59	**0.0364**
Opening	1	61.5	0.40	0.5272
Opening * Jar Size	1	59	1.90	0.1734
Gender	1	15.9	24.45	**0.0001**
Closure Hand	1	18.8	84.82	<.0001
Opening * Closure Hand	1	65.6	69.51	**<.0001**
Hand Breadth Left	1	15.9	**23.03**	**0.0002**
Finger Length Left	1	16	8.52	**0.0101**

Table 16 – Type 3 tests of fixed effects

Unlike the analysis that did not include the factor closure hand, the fixed effect of jar size was identified as having a significant effect on the % degrees of rotation of the jar hand (P = 0.04; α = 0.05). Jars of smaller size triggered, on average, a greater % of degrees of rotation by the jar hand, see Tables 15, 16, 17, 19 and 20.

Overview of Rotation in Percent and Degrees All Openings N = 252				
	Jar A (8.73252 cm)		Jar B (10.95502 cm)	
	Average	Standard Deviation	Average	Standard Deviation
Rotation Closure Hand %	57.46	24.40	63.49	25.99
Rotation Jar Hand %	42.54	24.40	36.51	25.99
Unrestricted Openings N = 126				
	Jar A (8.73252 cm)		Jar B (10.95502 cm)	
	Average	Standard Deviation	Average	Standard Deviation
Rotation Closure Hand %	49.96	18.18	58.44	21.84
Rotation Jar Hand %	50.04	18.18	41.56	21.84
Restricted Openings N = 126				
	Jar A (8.73252 cm)		Jar B (10.95502 cm)	
	Average	Standard Deviation	Average	Standard Deviation
Rotation Closure Hand %	64.96	27.48	68.54	28.85
Rotation Jar Hand %	35.04	27.48	31.46	28.85

Table 17 – Rotation by jar size

Further, the analysis indicated a significant effect of gender on % degrees of rotation by jar hand ($P = 0.0001$; $\alpha = 0.01$), such that males showed a greater % of degree of rotation by the jar hand than females, see Table 20. This finding follows the anthropometric data in that male subjects on average had left hand lengths that were nearly 20 mm longer then the female subjects see Table 3.

Differences of Least Squares Means									
Effect	Gender	Jar Size	Gender	Jar Size	Estimate	Standard Error	DF	t Value	Pr > I t I
Jar Size		1		2	-5.2272	2.441	59	-2.14	**0.0364**
Gender	1		2		20.2015	4.0853	16	4.94	**0.0001**

Table 18 – Differences of least square means

The two morphometric measures included in the model (hand breadth and finger length) were found to have a significant effect ($\alpha = 0.01$) on the % degrees of rotation by the jar hand ($P = 0.0002$ and $P = 0.0101$, respectively), see Tables 15 and 16. On average, each 1 mm increase in finger length of the left hand was associated with a 0.46% increase in degrees of rotation by the jar hand; each 1 mm increase in breadth of the left hand was associated with a 1.4% decrease in degrees of rotation by the jar hand.

The interaction term closure hand and opening restriction was also found to have a significant effect on the % rotation provided by the jar hand ($P < 0.0001$; $\alpha = 0.01$), see Tables 15, 16, 19 and 20. The nature of the interaction is depicted in the Figure 34.

Differences of Least Squares Means									
Effect	Opening	Closure Hand	Opening	Closure Hand	Estimate	Standard Error	DF	t Value	Pr > I t I
Opening * Closure Hand	1	1	1	2	-55.082	4.2924	56	-12.8	**<.0001***
Opening * Closure Hand	1	1	2	1	-23.333	2.7406	60	-8.51	**<.0001***
Opening * Closure Hand	1	2	2	2	27.1807	5.399	64	5.03	**<.0001***
Opening * Closure Hand	2	1	2	2	-4.5686	4.5722	47	-1.00	0.3228
(*) Significant at Bonferroni - adjusted comparison - wise type I error rate of 5%									

Table 19 – Differences of least square means

Least Square Means									
Effect	Gender	Opening	Jar Size	Closure Hand	Estimate	Standard Error	DF	t Value	Pr > I t I
Jar Size			1		42.7737	2.1712	34	19.70	<.0001
Jar Size			2		48.0009	2.1490	34	22.3	<.0001
Opening		1			46.3492	2.2713	44	20.4	<.0001
Opening		2			44.4254	2.4022	42	18.5	<.0001
Opening * Closure Hand		1		1	18.8080	2.0968	44	8.97	**<.0001**
Opening * Closure Hand		1		2	73.8904	3.8902	50	19	**<.0001**
Opening * Closure Hand		2		1	42.1411	2.0620	43	20.4	**<.0001**
Opening * Closure Hand		2		2	46.7097	4.2122	45	11.1	**<.0001**
Gender	1				55.4880	2.0257	16	27.4	<.0001
Gender	2				35.2865	3.2549	16	10.8	<.0001

Table 20 – Least square means

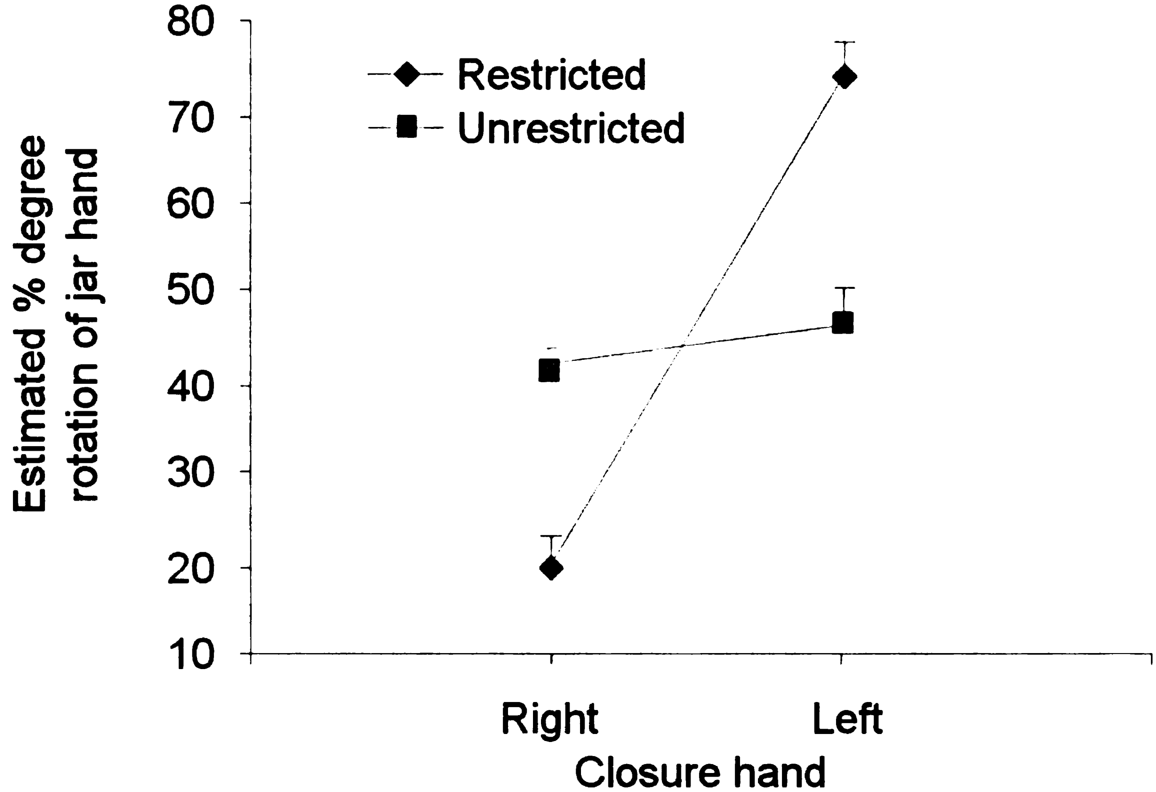


Figure 34 – Jar hand rotation by opening restriction

Figure 34 depicts the significant interaction term graphically. The interaction between closure hand and opening restriction indicates that the effect of opening restriction on % degrees of rotation differed depending on the closure hand used. For the restricted openings when the right hand is on the closure, the estimated % degrees rotation of the left hand (jar hand) is much lower than when the left hand is on the closure and the right hand is on the jar. This indicates that for this population of subjects, when restricted to the table, the right hand provided a greater % degree of rotation than the left hand, regardless of hand placement. In the unrestricted openings, the difference between left or right hand placement was not as pronouced but the same observation can be applied.

When compairing the closure hand between restricted and unrestricted openings the right hand on the closure supplied a greater % degrees rotation in the restricted than in the unrestricted meaning that the % degrees rotation estimated for the jar hand is lower in the restricted opening than in the unrestricted opening. For the left hand on the closure in the restricted opening there was a high % degrees of rotation of the jar hand indicating that the left hand did not supply as great a percentage as the jar hand. However, in the unrestricted openings the left hand on the closure supplied a greater % degrees rotation than in the restricted openings. Therefore, when restricting subjects to the table one hand, in this case the right, will tend to be used to a greater extent in opening compaired to the unrestricted opening where one hand does not tend to dominate on average.

These findings fit with the trend seen if the scatter plot of the restricted openings and the scatter plot of the unrestricted openings, see Figures 31 and 32, where restricted openings tend to clump together and urestricted openings do not.

Most important is the fact that the findings indicate a difference between restricted and unrestricted openings.

Rig Type under Unrestricted Movement Conditions

A generalized linear mixed models was also fit to the binary response variable "rig type under unrestricted conditions" (namely "side" vs. "bottom") using the GLIMMIX procedure of SAS (version 9.1, SAS Institute, Cary, NC). Data were collected in an RCB design, such that subjects (n = 21) were considered the blocking factor for assigning jar size (2 levels- A and B) under conditions of unrestricted movement only (data collected on table-restricted movement were not included in this analysis). By design, the base statistical model included the categorical fixed effects of jar size (2 levels) and the random blocking factor of subject. Thus, a total of 42 observations (subjects, 21 x jar size, 2) were available for analysis.

Additionally, potential explanatory variables of interest were recorded at the subject level, including gender, dexterity, laterality (both by arm cross and hand clasp), closure hand and a total of 9 morphometric continuous variables. All subject*jar size combinations were consistent in their "closure hand" under unrestricted movement conditions (i.e. people did not switch hands when opening in the unrestricted orientation). In order to decide between these potential explanatory variables, a stepwise model selection was used to select a model of best fit. The final model included, in addition to the base model described above, the effects of laterality arm cross and LEFT hand breadth. Least square mean probabilities of the pole rig (rig type =1), plus minus standard errors, are provided below in the columns labeled MEAN and ERROR MEAN, see Table 24. Post-hoc pairwise comparisons were performed using Tukey's adjustment to avoid inflation of type I error rate.

Solutions for Fixed Effects							
Effect	Lat Cross	Jar Size	Estimate	Standard Error	DF	t Value	Pr > I t I
Intercept			-14.5618	9.2302	18	-1.58	0.1321
Jar Size		1	-2.8461	1.4906	20	-1.91	**0.0707**
Jar Size		2	0				
Lat Cross	1		-2.9004	1.6347	20	-1.77	**0.0912**
Lat Cross	2		0				
Hand Breadth Left			0.2073	0.1034	20	2.00	**0.0588**

Table 21 – Solutions for fixed effects

Jar size was found to have a marginally significant effect (P =0.0707) on the selection of rig type, see Tables 11, 21 and 23. The least square mean probabilities of the use of the side rig (or a subject that gripped the jar from the bottom) under the unrestricted portion of testing were 98.2+- 2.5 % for Jar B versus 76.4 +- 17% for Jar A, see Tables 11 and 22. This finding indicates that subjects were marginally more likely to use the side rig, meaning they grasp the bottom of the jar, if the jar size was larger.

Jar Size Least Square Means							
Jar Size	Estimate	Standard Error	DF	t Value	Pr > I t I	Mean	Standard Error Mean
1	1.1730	0.9414	20	1.25	0.2271	**0.7637**	**0.16990**
2	4.0192	1.4753	20	2.72	0.0131	**0.9823**	**0.02558**

Table 22 – Jar size least square means

Difference of Jar Size Least Square Means Adjustment for Multiple Comparisons: Tukey - Kramer							
Jar Size	Jar Size	Estimate	Standard Error	DF	t Value	Pr > I t I	Adj. P
1	2	-2.8461	1.4906	20	-1.91	**0.0707**	**0.0707**

Table 23 – Tukey – Kramer jar size

A marginal association between arm cross laterality and the probability of the side rig (rig type = 2) under unrestricted movement was identified (P = 0.0912), see Table 25. The least square mean probabilities of the side rig (rig type = 2) under unrestricted movement were 98.3+- 2.4 % versus 75.9 +- 20% for laterality left arm top (arm cross 2) and right arm top (arm cross 1), respectively, see Table 24. This finding indicates that subjects whom placed their left arm on top were marginally more likely to use the side rig, meaning they grasp the bottom of the jar, than subjects who placed their right arm on top.

Lat Cross Least Squares Means							
Lat Cross	Estimate	Standard Error	DF	t Value	Pr > I t I	Mean	Standard Error Mean
1	1.1459	1.1313	20	1.01	0.3232	**0.7588**	**0.20710**
2	4.0463	1.4170	20	2.86	0.0098	**0.9828**	**0.02394**

Table 24 – Lat cross least squares means

Differences of Lat Cross Least Squares Means Adjustment for Multiple Comparisons: Tukey - Kramer							
Lat Cross	Lat Cross	Estimate	Standard Error	DF	t Value	Pr > I t I	Adj. P
1	2	-2.9004	1.6347	20	-1.77	**0.0912**	**0.0912**

Table 25 – Tukey – Kramer lat cross

A marginal association was identified between left hand breadth and the probability of the side rid (rig type 2) under unrestricted movement (P = 0.0588), see Table 21. Based on the estimated odd ratios, the odds of the side rig (rig type 2) increased by 23% for each mm increase in hand breadth of the left hand, see Table 16.

Chapter 5

CONCLUSIONS

One of the main goals of this research was to develop techniques for a methodology that could be used for unrestricted motion capture. This included creating a way to identify the rotational axis in order to evaluate and use the motion capture system for use in packaging applications that require the consumer to apply rotational movement. Data generated from this study also serves as pilot work in understanding the factors that impact the opening motions associated with two sizes of glass jars with lug style closures.

We hypothesized that the physical positioning of a subject had the potential to impact the opening motion employed. Therefore, two opening positions were incorporated into the experiment; opening "restrained" to a counter set at a standard height of 91 cm (36 inches) [11] the other opening in the air at a height comfortable to the subject, "unrestrained opening." Findings indicated a statistically significant interaction between closure hand and opening restriction on % degree of rotation by the jar hand ($P < 0.0001$), see Tables 15, 16, 19 and 20. The nature of the interaction is depicted in Figure 34. This suggests that restraining users will change their biomechanical approach to opening. This should be considered by future researchers that intend to collect data for the purpose of informing design.

It was also hypothesized that the motion used by a subject to open glass jars with lug style closures would take one of three forms;

1. Closure Hand Supplies Motion

2. Jar Hand Supplies Motion
3. Both Hands Supply Motion

Collected data suggest a spectrum of rotational behaviors, and no discrete breaks in the rotational behaviors. However, openings were not grouped by individual were breaks may have occurred from subject to subject if subjects displayed repeatability in opening motion.

In both the restricted and unrestricted openings the majority of subjects placed their right hand (dominant hand) on the closure, see Table 2. This finding is not consistent with that of Voorbij and Steenbekkers (2002) who found that 511 or 534 or roughly 96 percent of subjects that are right handed place their left hand on the closure [3].

There are several factors that give insight into why one hand may supply motion compared to the other hand.

1. Length of the jar hand (positive P = 0.02), people with longer hands tend to open the jar by rotating the jar hand more, see Table 14.
2. Gender and breadth of right hand (Significant P = 0.0378), men of narrow hands had significantly greater % degrees of rotation of the jar hand than women of narrow hands, see Table 14.
3. Gender (Significant P = 0.0001), males rotate jar hand more than females, see Table 20.
4. Jar Size (Significant P = 0.04), smaller jars lead to greater rotation of jar hand, see Tables 15, 16, 17, 19 and 20.

Data analysis of the variable data (% of rotation of the closure hand) indicated that men and women with large hand breadths (102 mm) behave similarly in terms of rotational behavior (P = 0.7898), while men and women of moderate hand breadths (92 mm) were significantly different (P = 0.0107). Those with the narrowest hands (82 mm) were also significantly different in rotation behaviors (P = 0.0057), see Table 13 and Figure 33.

It is interesting to note that as the jar size decreases essentially hand size, more specifically hand length in proportion to jar size, increases. Therefore, the finding that smaller jars lead to greater rotation of the jar hand seems rather intuitive when coupled with the finding that people with longer hands tend to open the jar by rotation the jar hand more. However, the ability to examine both the jar hand and the closure hand was constrained in that the research did not have any subjects whom grasped the side rig jar with their left hand on the closure, see Table 11. Due to this fact the closure hand was removed from the analysis and the ability to examine the unrestricted openings as pole rig and side rig was limited. Data analysis comparing restricted and unrestricted openings was therefore carried out combining pole rig and side rig openings.

One interesting point to take note of include the fact that both male and female subjects in the study had above average size hands in terms of hand length, hand breadth and wrist – finger length, see Figures 24, 25 and 26 . This fact, coupled with the fact that all subjects had no history of injury to the hands, wrists, arms or shoulders could have greatly influenced the results reported. This fact is interesting in that the general population should have smaller hand sizes on average compared to the subjects in this study. Further research, that recruits people with a spectrum of hand sizes, is needed to purposefully investigate the relationship between hand size and rotational behavior.

There are several factors that give insight into why a subject, during an unrestricted opening, chooses a particular grip.

1. Jar Size (Marginal P =0.0707), this finding indicates that subjects were marginally more likely to use the side rig, meaning they grasp the bottom of the jar, if the jar size was larger, see Tables 11, 21 and 23.
2. Hand breadth (Marginal P = 0.0588), as hand breadth increases, the probability of using a side rig increases; meaning that a subject is more likely to grip the jar from its bottom, see Table 21.

The examination of laterality did not uncover great insight as to why subjects grasp or opening jars in the way they do. However, this study did agree with the findings of Mohr et. al. (2003, 2006) in that the subjects in this study had a nearly equal distribution across the four laterality codes [8, 9].

Chapter 6

RECOMMENDATION AND FUTURE STUDIES

- Yoxall et. al. (2007) examined the role that grip styles play in opening jars of varying sizes [14]. According to their research, for the jar sizes used in this study, subjects should have demonstrated several grip styles including spherical, box, lateral and cylindrical. It is recommended to explore the role that grip style has on the opening motion used by the closure and jar hands.
- Compared to the data from the NTIS study [13] subjects in this report had on average relatively large hands. It is recommended to investigate a population of subjects with relatively small hands for a comparison, and to investigate whether or not subjects of smaller size hands would show the same biomechanical approaches to opening.
- The current study recruited subjects who did not have a history of injury to the hands, wrists, arms or shoulders. This was done to simplify refinement of the methodological approach. It is recommended that the study be repeated using a more varied population.
- With only one left handed subject dexterity could not be used as a factor in the statistical analysis. Inclusion of a larger sample size of left handed subjects is recommended in order to have a balance between left and right handed subjects.

- The population was recruited as a convenience sample from the MSU campus, and was comprised of college students. This is obviously, not representative of the population at large. It is recommended that a more representative population be recruited for future studies. Of particular interest is the aging population, who are known to have difficulty with these types of packages [1 – 4].
- As indicated, in this study, all subjects were screened to insure they did not have a history of injury to the hands, wrists, arms or shoulders. Subjects were also found to have very similar measurements related to strength in each hand. It is recommended to investigate how opening motion and style change in relation to loss of strength in the hands, wrists, arms or shoulders due to injury.
- Several studies in the literature review examined the forces involved in opening jars [1 – 5]. In order to investigate motion in greater detail forces were not included in this study. Incorporation of the forces involved in opening a jar coupled with motion is recommended.
- This study investigated the motion associated with opening two jars. These jars were similar in all dimensions other than jar diameter. It is recommended that this study be used to look at other variations in jar dimensions such as differences in height, closure diameter, contents and weight be explored by future researchers.
- Due to the lack of observations for the combination of the side rig (rig type 3) and the left hand on closure (closure hand 2) simultaneous

fitting of the two (rig type and closure hand) as explanatory variables in a given model was not possible. Therefore, the closure hand as an explanatory variable could not be used in the analysis. Collection of data to fill this gap and allow for analysis of the closure hand is recommended.

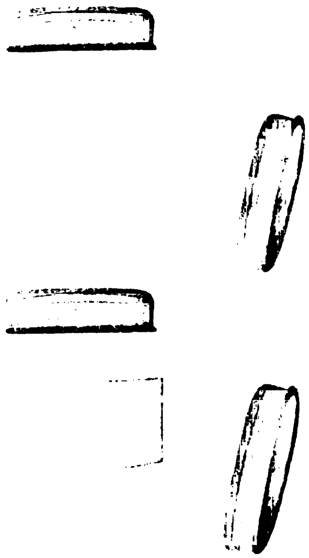
APPENDICES

Appendix A – Recruitment Flyer

Opportunity for people 18 and older that have NO history of injury to the hands, wrists or shoulders to participate in a research project regarding the opening of jars in exchange for a $25 Meijer Gift Certificate

This research project is a joint study between the MSU School of Packaging and the Department of Mechanical Engineering. The study will examine the biomechanical features of opening a series of filled glass jars. All testing will take place at:

- 4133 Engineering Building



Please come to testing wearing a comfortable, short sleeved tee shirt. Testing will take no longer than 2 hours; during testing the researchers will measure and size of your hands, you will be asked to participate in several tests of hand strength, clasp your hands, your arms and open several different glass jars. Testing will be videotaped.

In exchange for your participation, you will be provided with a $25 Meijer gift certificate. If at any time you are uncomfortable with the testing or wish to discontinue the data collection process, you may discontinue participation without penalty.

If you are interested in learning more about this study, please contact Joe Fair at fairjose@msu.edu or phone 517-410-2960 to make an appointment. If you have questions or comments regarding this study, please contact Dr. Laura Bix, at the School of Packaging at (517) 355-4556 or bixlaura@msu.edu or Dr. Tamara Reid-Bush from the Department of Mechanical Engineering at reidtama@msu.edu. If you have questions or concerns about your rights as a study participant contact the SIRB at (517) 355-2180.

Appendix B – Data Collection Form

Subject # ________________________________

Female Male

Age __________

Preferred Dexterity (circle)

Right hand

Left hand

History of allergic reaction or irritation to rubbing alcohol or surgical tape? __________

History of Injury to hands, shoulders, arms or wrists? __________________________

Digital Photo of Right hand, palm down (file number) __________________________

Digital Photo of Right hand, palm up (file number) _____________________________

Digital Photo of Left hand, palm down (file number) ____________________________

Digital Photo of Left hand, palm up (file number) ______________________________

Digital Photo of Right Thumb ____

Digital Photo of Left Thumb ____

Right Grip Strength Measurement
1. ____________________
2. ____________________
3. ____________________

Left Hand Strength Measurement
1. ____________________
2. ____________________
3. ____________________

Right Wrist Strength Measurement
1. ____________________
2. ____________________
3. ____________________

Left Wrist Strength Measurement
1. ____________________
2. ____________________
3. ____________________

Palm to Palm Squeeze
1. ____________________
2. ____________________
3. ____________________

Digital Photo Hand Clasp ______________________________

Digital Photo Arm Folding ______________________________

Package testing Jar 1 Position				
Fixturing				
Trial	Opened in Time? Yes/No	Right or Left Hand on Top?	Jar Hand Position (T,M,B)	Comments Heard?

Jar 2 Position				
Fixturing				
Trial	Opened in Time? Yes/No	Right or Left Hand on Top?	Jar Hand Position (T,M,B)	Comments Heard?

Jar 1 Position				
Fixturing				
Trial	Opened in Time? Yes/No	Right or Left Hand on Top?	Jar Hand Position (T,M,B)	Comments Heard?

Jar 2 Position				
Fixturing				
Trial	Opened in Time? Yes/No	Right or Left Hand on Top?	Jar Hand Position (T,M,B)	Comments Heard?

Thank the subject.

Have them print and sign that they have received the Meijer gift card.

Appendix C – Torque Requirements

In order to determine the rotation in degrees that was required to open the jars a series of ten jars, for both the large diameter and small diameter jar, had a torque force of 35 in – lbs applied using a Secure Pak, Inc. electronic torque tester, see Figure 35.

Figure 35 – Secure Pak, Inc. electronic torque tester

From the series an average and standard deviation for the rotation in degrees was calculated for both the large diameter and small diameter jars. The results were used during the data processing. Results from the torque testing are shown in Table 26. To obtain the values in Table 26 one large diameter jar and one small diameter were used. For each trial a new closure that had never been used before was applied to the jar. Each closure had a circumference of 235 mm, this value was determined by tracing the closure on paper and then using string to obtain the distance. The circumference was not be obtained using the equation $2\pi r$ since the closure diameter used to identify the closure in packaging terms, 70 mm, is the jar diameter at the closure not the exterior diameter of the closure itself. In Table 26 the column Distance (mm) refers to the distance of rotation measured after the lugs in the closure were no longer engaged with the jar.

Table of closure removal trials used for average opening angles (o)		
Jar B (10.95502 cm)		
Trial	Distance (mm)	Angle (o)
1	16	24.5
2	18	27.6
3	16	24.5
4	17	26.0
5	21	32.2
6	11	16.8
7	16	24.5
8	17	26.0
9	15	23.0
10	13	19.9
Average		24.5
Standard Deviation		4.16
Jar A (8.73252 cm)		
Trial	Distance (mm)	Angle (o)
1	17	26.0
2	20	30.6
3	27	41.4
4	19	29.1
5	16	24.5
6	19	29.1
7	23	35.2
8	19	29.1
9	14	21.4
10	24	36.8
Average		30.3
Standard Deviation		6.01

Table 26 – Trials used to calculate average opening angles (o) for both the large and small jar

The Distance (mm) value was found by drawing a vertical line to the closure and jar after applying the torque of 35 in – lbs. The closure was then rotated to the point where the lugs disengaged the jar. At this point another vertical line was drawn on the closure, see Figure 36.

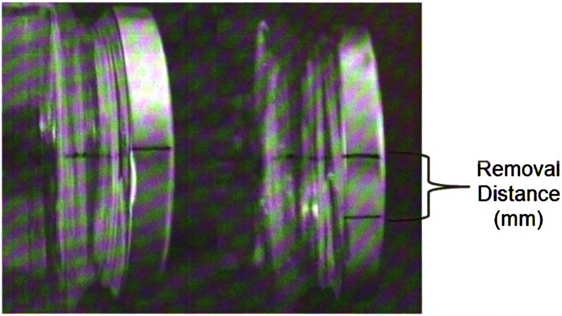


Figure 36 – Lines drawn on closure to determine removal distance

This closure was then removed and the distance between the two lines was measured to obtain the value shown in Table 26. The distance was then divided by the diameter; this value was then multiplied by 360 degrees to obtain the opening angle.

Appendix D – Motion Capture Calibration

Prior to testing the Qualisys software had to be calibrated. The five cameras were positioned around the table set at its height of 36 inches or 91.44 centimeters. The Qualisys software was opened and a calibration file was setup. The calibration capture lasted 10 seconds and was collected at a rate of 60 Hz. One member of the research team ran the computer software while a second member used a specially created L bracket and wand that was ordered from the same company as the Qualisys software, see Figure 37, that had reflective targets on them.

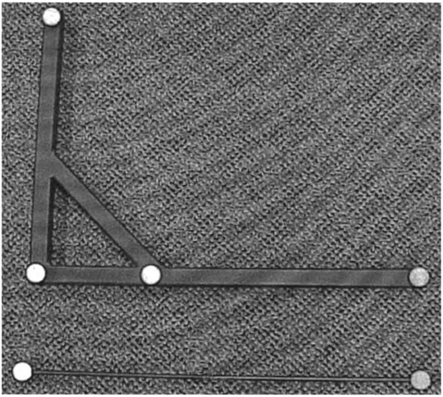


Figure 37 – Calibration bracket and wand

The L bracket was place on the table with the long edge parallel to the back edge (where the subject would stand) of the table. The wand had two targets on it measuring 525 mm between them. The bracket had four targets. The distance on the short arm was 350 mm, the long arm was 500 mm and the mid point on the long arm was 150mm. These values were entered into the setup of the calibration file. Entering the incorrect values would create calibration values that were not desirable and void all data collected.

During the ten second calibration the team member at the table would wave the wand around the table above the L bracket in a random fashion. The software would then process the data from each camera and determine a calibration level for each. The team attempted to make sure that each camera had a calibration level below 1. If one or two of the cameras were over but close to one the system would be considered ready for capture. If more than two of the cameras were over 1 the system was re – calibrated until the issue was solved. Solving the issue of cameras not being calibrated to a desired level included several different trial and error steps. These included but were not limited to re – booting the computer, check the wires from the camera to the computer, adjusting the camera angle, adjusting the camera height and moving the location of the camera.

Appendix E – Opening Rotation Sequence

Subject	Jar Series 1	Jar Series 2	Jar Series 3	Jar Series 4
001	Not Used	Not Used	Not Used	Not Used
002	Jar A Table	Jar B Table	Jar A Free	Jar B Free
003	Jar A Table	Jar B Table	Jar B Free	Jar A Free
004	Not Used	Not Used	Not Used	Not Used
005	Not Used	Not Used	Not Used	Not Used
006	Jar A Table	Jar A Free	Jar B Table	Jar B Free
007	Jar A Table	Jar B Free	Jar B Table	Jar A Free
008	Jar A Table	Jar A Free	Jar B Free	Jar B Table
009	Jar A Table	Jar B Free	Jar A Free	Jar B Table
010	Jar B Table	Jar A Table	Jar A Free	Jar B Free
011	Jar B Table	Jar A Table	Jar B Free	Jar A Free
012	Jar B Table	Jar A Free	Jar A Table	Jar B Free
013	Jar B Table	Jar B Free	Jar A Table	Jar A Free
014	Jar B Table	Jar A Free	Jar B Free	Jar A Table
015	Jar B Table	Jar B Free	Jar A Free	Jar A Table
016	Jar A Free	Jar B Free	Jar A Table	Jar B Table
017	Jar A Free	Jar B Free	Jar B Table	Jar A Table
018	Jar A Free	Jar A Table	Jar B Table	Jar B Free
019	Jar A Free	Jar A Table	Jar B Free	Jar B Table
020	Jar A Free	Jar B Table	Jar A Table	Jar B Free
021	Jar A Free	Jar B Table	Jar B Free	Jar A Table
022	Jar B Free	Jar A Free	Jar A Table	Jar B Table
023	Jar B Free	Jar A Free	Jar B Table	Jar A Table
024	Jar B Free	Jar A Table	Jar B Table	Jar A Free
025	Jar B Free	Jar A Table	Jar A Free	Jar B Table

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