A Kinetikk Study: Understanding Hand and Finger Motion Whilst Squeezing Bottles

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Abstract

The aim of this study is to examine the distribution of hand grip force and the movement of the hand and fingers during squeezing a bottle for older groups. In this experiment, the author used the different liquids; mayonnaise, tomato sauce, shampoo and skin cream. The maximum hand force, hand grip style and location, human perception and hand pain experience will be collected through the Tekscan Software result and interviews the responses after undertaken this activity. The results from this study found that the age and human capability is one of the factors why the distribution area on force at the hand and finger for all participants shows a significant difference. The hand and finger movement is related with the higher grip force. The type of the liquid and the design of bottle which is include bottle material, shape and nozzle matching shows a different force when do the comparison data. The hand and finger movement for all participants was seen to be different depending on the age, hand grip style, human capability and the movement of the finger. The result found the age is one of the likely factors why the distribution areas on force at the hand and fingers for all participants show a significant. The motion of the hand and finger for the female (smaller hand size) are more frequent than the male (bigger hand size). The continuous maximum force action in difficult areas and bottle material and design cause pain and discomfort on the hand. Therefore, it is primarily to redesign a more flexible and elastic bottle in order to reduce the pain suffered. The hand and finger movement is related with the higher grip force. The female shows a lower force when compared with the male. The hand and finger movement for all participants was seen to be different depending on the grip style and the movement of the finger
This paper outlines these results and proposes further work with the ultimate aim of providing suitable insight for the redesign of packaging product to reduce instances of discomfort and illness.

Keywords
Design, packaging product, squeezability bottles, hand size and hand and finger motion.

Introduction

The term “Warp Rage” was used to describe consumers frustration [1] with difficult to open packaging. Several surveys have shown significant dissatisfaction with accessing packaging [2,3]. Packaging has to provide a range of functions including protecting and providing access to the contents. Getting the balance between these competing demands is a complex task, where the balance is wrong, the user must employ relatively high forces to break a seal, twist open a food container or squeeze a bottle. With the significant demographic changes [4] this may give problems to the elderly and disabled people who have weaker muscles and joints, especially in the hand and fingers.

Decrease in hand function is defined as a reduction of the human ability to use the hands for Activities of Daily Living (ADL's). It is a limitation for those with common conditions such as arthritis, an upper extremity fracture, hemi-paresis, or who are older than 60 years [5]. The ability to perform many ADL's are dependent on hand function [7,8], and improving hand function is often a common focus of treatment for the aforementioned patient populations.

Recently, many studies have been undertaken to analyze the “action range of motion” (AROM) related to hand function with a decrease of AROM associated with the decrease of hand function [9] whilst other research has shown how upper extremity segments affect hand function [10-14]. Examples include the development and evaluation of an optimization-base model for power-grip posture predication [15]; quantitative analysis of finger motion coordination in hand manipulation and gestic acts [16]; understanding the centre mechanisms of finger interaction during force production ([17] and [18]; and analysis of synergistic finger movement classification of hand manipulation [19] , [20] and [21].

There has been interest in the accessibility of packaging and hand strength/functionality by a number of researchers across various disciplines, from the study by Rholes [22] The Department of Trade and Industry [23], Voorbij et al [24], Yoxall [25], Su et al [26] and Kuo et al [27]. However, the use of the use of motion capture and thin-film force sensors for understanding grip and comfort for packaging uses is limited with a study by Bix et al [28] and a bio-mechanical study by Carse [29].

Further, the majority of this work on packaging accessibility has concentrated on access to wide mouth closures and vacuum lug jars used primarily for packaging jams, pickles and sauces. Given the large variation in packaging formats it is obviously essential that understanding the hand pack interaction is important across a range of products. Yoxall, in his study of squeezable bottles showed that as people aged their ability to squeeze products out of the flexible bottles such as those shown in Figure 1 becomes more difficult [30]. In a previous study Yoxall also identified the best and worst factors in the design of squeezable bottles. He found that there are three main factors important in improving bottle design: bottle style and material; nozzle design; and specific fluid content [31].

This paper presents a further study using motion capture and thin-film force sensors to examine hand forces and finger movement when squeezing bottles of the type described previously with the aim of providing further information to aid in the design of flexible bottles to make them easier to access for all ages and strengths.

Method

Thirty volunteers with ages ranging between 60 and 78 years were chosen to take part in this experiment. The experiment took about 20 minutes to finish. All volunteers were to squeeze the bottles of liquid from half full until empty. All volunteers squeezed the bottles an average of once or twice and it depend on the volunteers capability. The quantity of the liquid sauce from each squeeze was measured using a digital weighing machine. Figure 1b and 1c shows the two participated selected to analysis more detail on the hand grip force, distribution areas and the hand and finger motion while doing the squeezing task.

Instrumentation and apparatus

Grip Measurement

In order to measure the grip, the Tekscan grip pressure measurement system was used in this study as had been used in previous work by the authors [30]. Thin film force and pressure sensors were used to map the force and pressure distribution across the hand-grip interface. Figure 2 shows the location of the handle force sensor on the bottle. In this experiment four types of liquid in bottles of different design were used to look for the distribution of hand grip force while squeezing (see Figure 3). These sensors are non-intrusive and are used in a wide range of force sensing applications [33]. The sensors were calibrated using a known weight before each test.

The MAC Hawk System

Motion-capture systems are most often used in the entertainment industry [34],[35] and have more recently been used for analysing a range of . The system used in this study is shown in Figure 4. The setup used involved a Hawk Digital RealTime System that consisted of seven Hawk Digital Cameras connected to a computer running Eva Real-Time software. The Hawk Cameras are specifically programmed to record only infrared light and are mounted with an array of infrared Light-Emitting Diodes (LEDs); whose intensity can be controlled. The cameras are all connected to a computer, running EvaRT 5.0.4, which allows the computer to store and process all the captured data to give a precise and accurate positioning of the object of focus and even allows the user to view the object from any angle (point of view).

As the cameras only register infrared light, reflective markers are used to capture the motion of the participants' hands. Individual markers were placed at 12 points on the fingers as in Figure 5. The workstation area was 170cm wide and 240cm long. Seven CCD cameras were placed around the subject, with five cameras placed on the floor at different heights.

Results

As described earlier, age is one of the factors correlated with hand grip force. The result on Table 1 shows different liquids and bottle designs influenced hand grip force. The data show that the shampoo shows the highest value of hand grip force, followed by mayonnaise, cream, and lastly tomato ketchup. The highest force was 62.35N by the male participant aged 76. The maximum force generated decreases as age increases, with the maximum force generated by 60 – 74 years old being 20.38N for female. Consequently the hand grip force deceases as age increase. Pressure in the fingers while squeezing a bottle depends on hand size, hand grip style and design of the bottle. Hand size is also a possible factor why the distribution area on force at the hand and finger for both genders is significantly different. The average male volunteer hand size is bigger 0.019m than the female is 0.017m. Table 2 show the overall contact areas and higher pressure force (pressure > 15kPa) from

both genders with the same hand grip style. The distribution of hand grip force for males is bigger compare than female volunteer. The overall contact areas form male are larger than for females; the male has an overall contact area of 0.0029m^2 under pressure and with 0.00140m^2 > 15kPa when squeezing the shampoo bottle. On the other hand, for female volunteer the highest overall contact area are 0.00258m^2 and 0.000864m^2 >15kPa when performing the same action.

The distribution of hand grip force for each liquid is different, depending on the bottle material, bottle shape, viscosity of the liquid and hand size. Table 3 shows the distribution of hand grip force of both genders responses squeezing the bottle. From figure 3d, shampoo shows the highest force which the red color showing the force is > 15 kPa.

Motion Capture System

In this study we try to compare the hand finger motion between elderly male and female volunteer. The elderly male have a hand problem which is he have a carpal tunnel syndrome while the female participant is healthy. Based on our previous Tekscan Software experiment, the highest hand grip distribution force was recorded whilst squeezing the shampoo bottle compare with other liquids or sauce. Therefore, in this section we would like to explain further the analysis motion capture system while squeezing a mayonnaise and shampoo bottle that shows the higher grip force. Figures 5 shows the high grip force on the hand and fingers (wrist, thumb1, thumb2, index1, index2, middle1, middle2, ring1, ring2, little1 and little2 fingers) of the male with bigger hand (0.0176m-0.0180m) during manipulative hand movements while squeezing the shampoo and mayonnaise bottle.

This participant was suffering from carpal tunnel syndrome, where the thumbs do not function well, he felt it difficult to squeeze the bottle without using his thumb. Nevertheless, he hand is bigger because of the carpal tunnel syndrome he tried to use his 4 fingers (index, middle, ring and little) while squeezing the shampoo and moyannies bottle as shown in the Figure 5 and 6.

Figure 5 shows the hand motion and hand grip force when the male hand squeezed the shampoo bottle. The participant produced a highest grip force of 65N at 3.25 seconds. The graph pattern is consistent; the hand grip force produced is fluctuating but the gap between other grip forces is still small. The motion of the fingers is close to each other except little finger 1 is lower and the pattern of the graph looks different. In this action, it looks like the little finger moved frequently compared to the other fingers. The quality shampoo which come out in this equipment is 0.006 gram.

Figure 6 shows the finger movement of the male hand when doing the same activities but different liquid (mayonnaise). The data was taken from 3 seconds until 5.083 seconds as the fingers tried to squeeze the mayonnaise bottle until it came out. The ring 1 finger movement always showed higher distance, which is 70.23 mm and follow by little1 finger. The centre, middle 1 and little 1 fingers movement is similar and cross each other at second higher movement. The index 2 and middle 2 movements are lower and cross each other. The index 2 shows the lowest distance 29.93 mm compared to the other fingers. The maximum hand grip force was 51.7N at 2.17 seconds while squeezing the mayonnaise out. The hand grip force decreased at 3.834 second. Subsequently, the motion of the hand also decreased. However, it increased again when the hand grip forces increased. At 3.583 seconds, all finger motions changed and decreased in distance to 27mm. The hand grip force also decreased from 30N to 24N. At this moment, the participant released his hand grip pressure on the mayonnaise bottle. The quantity of liquid in the bottle had reduced. In order to squeeze out the remaining liquid, the participant had to use more pressure on the bottle. This action continued until the hand grip force decreased to 9.5N at 5.083 seconds. The quality mayonnaise which comes out in this equipment is 0.002 gram.

Figure 7 shows the hand finger motion for the woman Janet who is 74 years old. The participant produced a highest grip force of 14.5N at 3.417 seconds. The graph pattern is shows the fingers use higher pressure, as much as 0.017grams, on the bottle to make the mayonnaise come out. The hand motion shows similar patterns between each finger. The thumb finger movement was always higher. The distance is 61.5 mm while the middle finger show the lower distance at 58.5mm. The index, ring and little finger are consistent hierarchies' motion. Some action shows the ring, and little finger is crossing each other but it never too far apart.

Figure 8 shows the hand finger motion for the female while squeezing shampoo. The participant produce a higher grip force of 6N at 0.580 seconds. The graph pattern is consistent; the hand grip force produced is fluctuating but the gap between other grip forces is look smaller. It shows the fingers used higher pressure on the bottle to squeeze the liquid out. The thumb movement is always higher at a distance of 59 mm and little finger shows a lower distance at 56.5 mm. The thumb, index, middle, ring and little fingers are consistent hierarchies. Some action shows the ring finger and little finger crossing in some areas but they are never too far apart. The little fingers are lower but the hand motion looks similar.

DICUSSION

The aim of this study is to find the fundamental factor of hand comfort and discomfort while squeezing bottles. The study provides a unique opportunity to explore how hand grip factors can affect not only grip force capability, but also the kinetics of the finger motion. The evaluation of handgrip force and the hand and finger motion on the grip style indicate that participant's perception about discomfort and hand pain experience. The age and human capability is the main factor that shows the how the easiest and difficult participant's undertaken squeezing bottle. From observation it can see that, these are a relation between age, human capability, bottle size, and quantity of liquid flowing from the bottle. The male hand try to grip the bottle using 4 finger because of carpal tunnel syndrome so that the hand and finger do no fully cover the bottle so that makes the participant feel pain and discomfort, and it is difficult for them to control the sauce bottle whilst squeezing.

Conversely, for the female hand can grip the sauce bottle fully, so that it is easy to control the bottle and squeeze the sauce. The participant feels easy and comfort but it feel pain and discomfort while squeezing the shampoo and mayonnaise bottle.

Different types of liquid and bottle designs affect the results on hand grip force. The mayonnaise and shampoo bottle had a different shape: the mayonnaise bottle was straight but the shampoo bottle was curved. Most participants felt squeezing the mayonnaise bottle was easier than the shampoo bottle. Most of them thought that when all the hand covered the bottle the squeezing action was easier and a greater quantity of liquid could be squeezed out.

According to the result of distribution areas, the male hand grip force shows a larger area than the female hand. The result of hand grip force is contradictory where the female hand produces higher grip force. However, the female hand shows lower hand grip force but with a greater quantity of liquid squeezed out. The male hand produces the large distribution pressure areas and the total deflection from large hands deflecting a greater surface area of bottle wall. On the other hand, the female hand produced high grip force with less quantity. The famale hand size produces the small distribution pressure areas and the total deflection a lower surface area of the bottle wall. Based on the above hand and finger motion graphs, we conclude that thumb, index, middle, ring and little fingers are the main finger parts in gripping and squeezing a bottle. The motion of these three fingers is more frequent the thumb and index shows the most movement while squeezing the bottle. The middle, ring and little fingers act as support.

Figure 9 shows the key areas of the hand that were identified by the participants in relation to discomfort. The six areas were:

A- Distal phalanges/distal interphalangeal;
B- Middle phalanges/proximal interphalanges (PIP);
C- Flexor Tendon Sheath – for tendons, Proximal phalanges for bone and metacarpophalangeal (MCP) for join;
D- Carpmetacarpal;
E- Metacarpophalangeal /proximal phalanx; and
F- Interphalangeal /distal phalanx.

Figure 9 shows the finger pain location of all 13 participant's after finish doing the 5 time repeatedly the squeezing experiment. Location C (MCP-metacarphalangeal) show the highest number where 14 participant's (70%) followed by location D (carpmetacarpla); 12 participant's (60%), location E (proximal phalanx); 4 participant's (20%) and location A (distal phalanges/distal interphalanges) with 3 participant's. It mean that 70% for all participant's has felt discomfort or pain at hand at location C.D and E. For this reason, the designer should redesign the bottle and nozzle at this area to improve the hand pain experience. The material and design of the bottle and nozzle should be analyzed and the grip style should be improved.

The pain experience result at shoulder, elbow, wrist and finger can show in Figure 10. Level 2 shows the higher number with 9 participants; level 3, 5 participants; level 1, 4 participants and level 4 with 2 participants. The second highest pain experience is cramp, ache, sharp tender, tingling, throbbing and stabbing.

Conclusion

Age is one of the factors why all participants feel different hand pain and discomfort experience. Functional ability seems to stay unchanged until the age of 65 years, after which it declines gradually. Hand grip strength decreases as age increases because the capability of the hand is dwindling. The distribution areas force for female and male hand is dissimilar; simultaneously give different impact to the painful experience. The motion of the hand and finger for the female hand are more frequently comparing with the male hand. It means the male hand struggle further difficult in controlling the bottle, and it given the higher level of pain. We conclude that continues maximum force action, especially at the difficult area causing pain and discomfort. Therefore, it is primarily to redesign the more flexible and elastic bottle in order to reduce the pain suffers by the users.

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FIGURES AND TABLES

Table 1: Hand grip force for different liquids for both genders.

Item	**Janet ,Female, 74 years old**			**Ken, Male, 76 years old**		
	Quantity (gram)	Max Force (N)	Min Force (N)	Quantity (gram)	Max Force (N)	Min Force (N)
Mayonnaise	0.017	12.98	2.14	0.002	56.3	6.24
Ketchup	0.031	13.48	2.79	0.003	54.8	7.82
Cream	0.003	9.37	1.81	0.019	36.07	8.87
Shampoo	0.008	20.38	4.6	0.006	62.32	8.53

Table 2: Overall contact area for different liquids for both genders.

	Janet, Female, 74 years old		**Ken, Male, 76 years old**	
Item	**Overall Area $(m)^2$**	**> 15KPa $(m)^2$**	**Overall Area $(m)^2$**	**> 15KPa $(m)^2$**
Mayonnaise	0.00258	0.00072	0.00225	0.00144
Ketchup	0.00129	0.00014	0.00225	0.00086
Cream	0.00113	0.00014	0.00161	0.00086
Shampoo	0.00258	0.00086	0.00290	0.00144

Table 3: The distribution of hand grip force for both genders

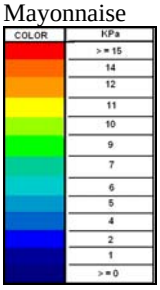
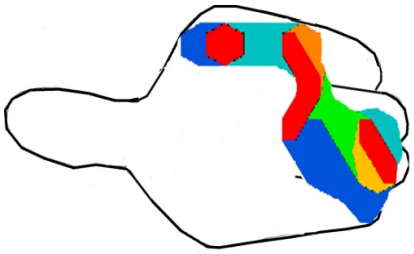
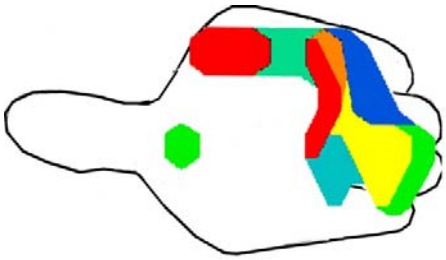
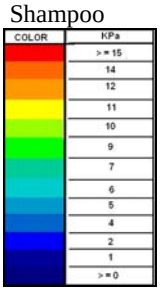
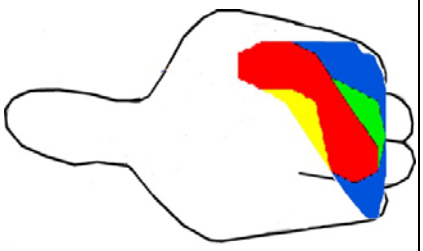
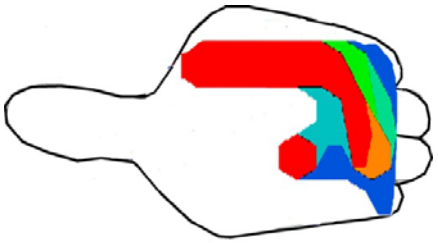
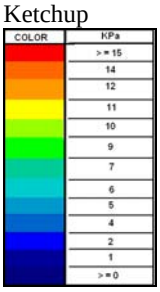
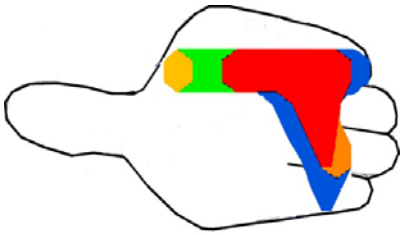
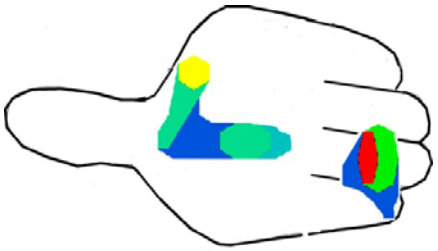
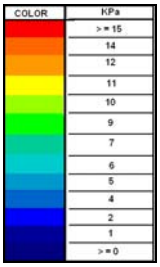
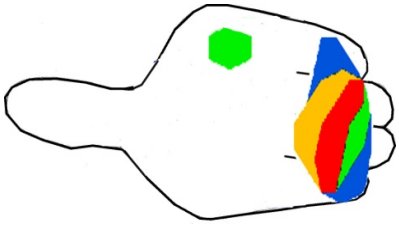
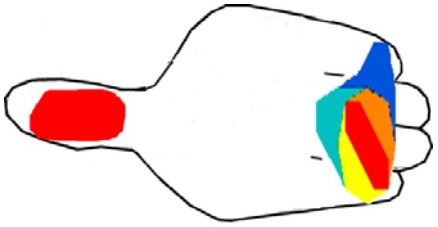
Scale	Janet, Female, 74 year	Ken, Male, 76 year
Mayonnaise 	 Figure a	 Figure b
Shampoo 	 Figure c	 Figure d
Ketchup 	 Figure e	 Figure f
Cream 	 Figure g	 Figure h

Figure 1a: Hand Grip style using one hand while squeezing the bottle.

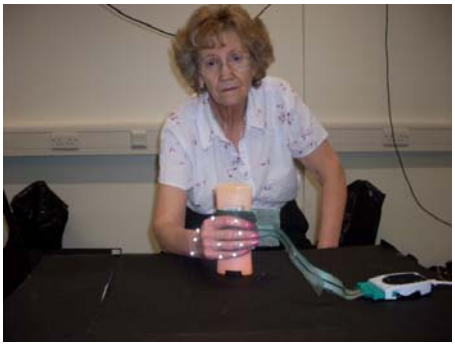


Figure 1b: Janet is an older female volunteer

Figure 1c: Ken is an older male volunteer

Figure 2: The four types of sauce and cream with different bottle shapes.

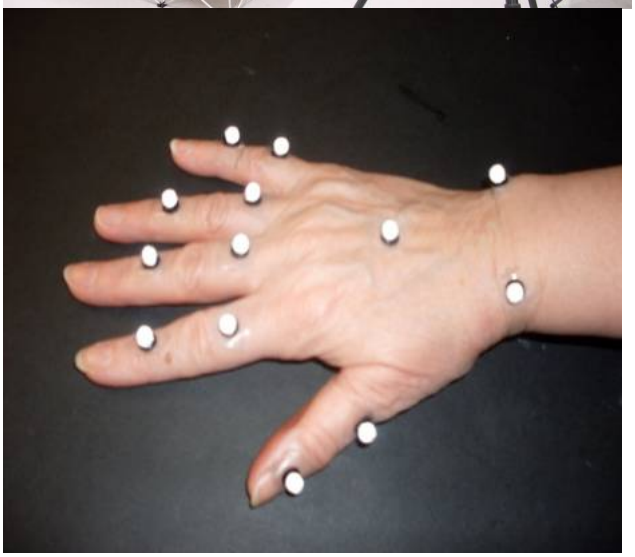


Figure 3: The location of the markers on the fingers

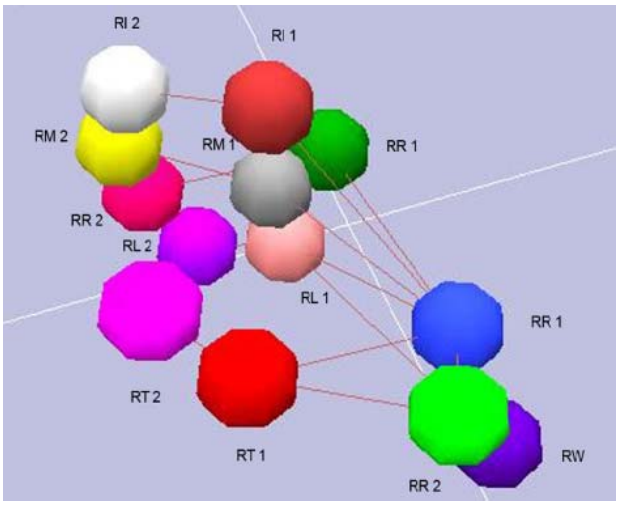


Figure 4: Location of the markers on the hand and fingers on the motion capture software

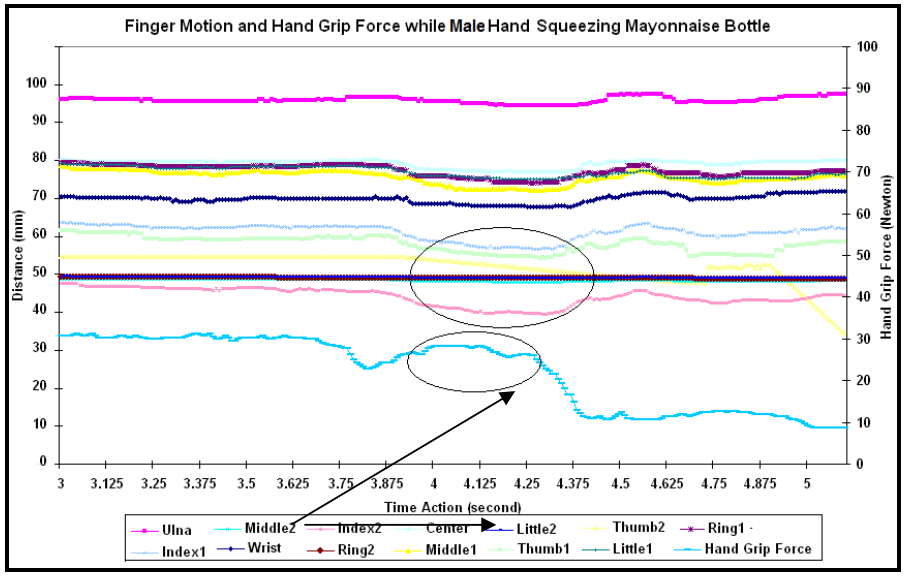


Figure 5: Graph of finger movement and hand grip force for man hand while squeezing mayonnaise.

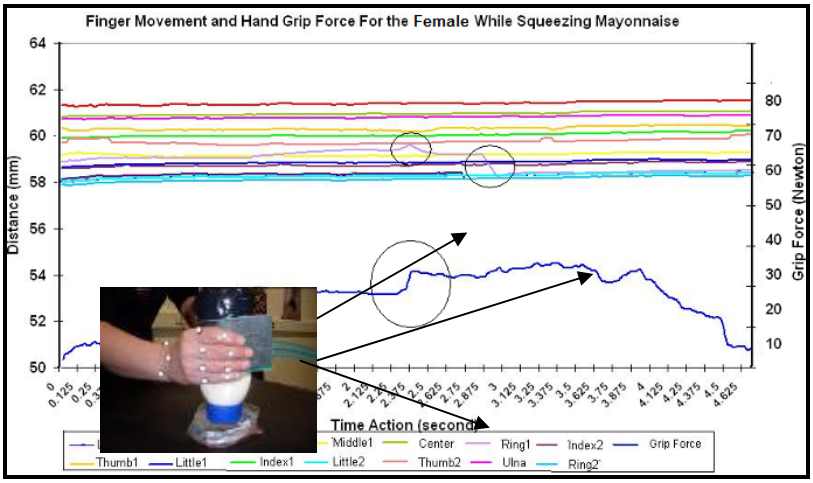


Figure 6: Graph of finger movement and hand grip force for female hand while squeezing mayonnaise.

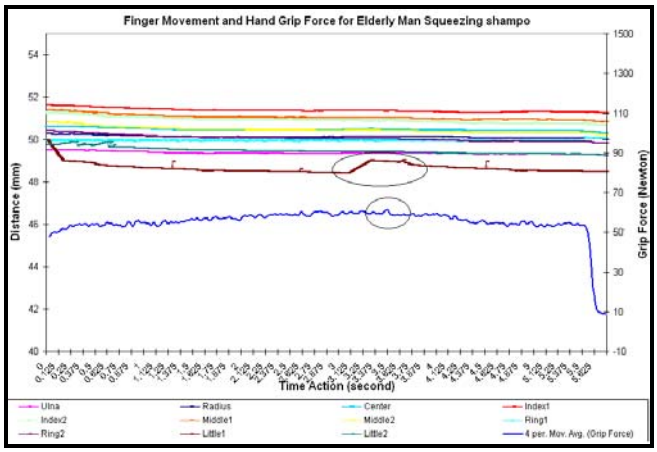


Figure 7: Graph of finger movement and hand grip force for male squeezing shampoo.

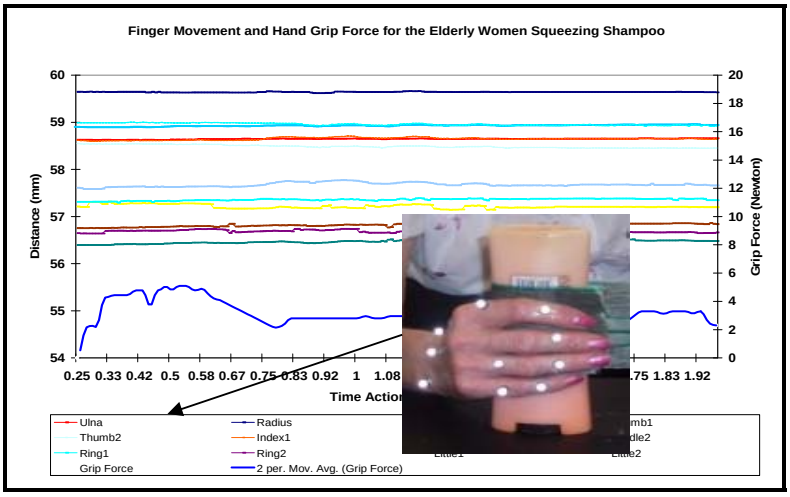


Figure 8: Graph of finger movement and hand grip force for female squeezing shampoo.

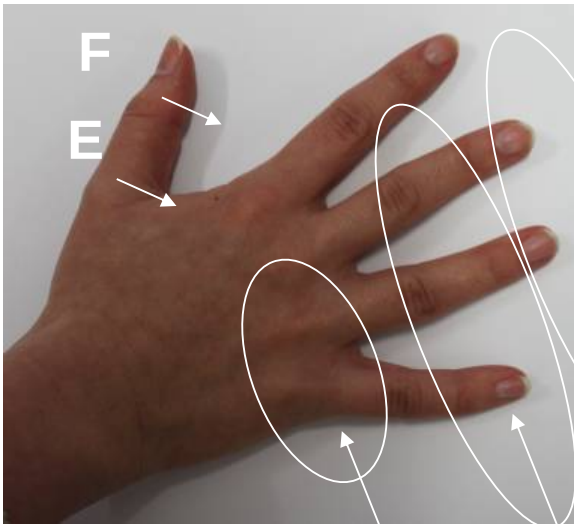


Figure 9: Specific names of the hand

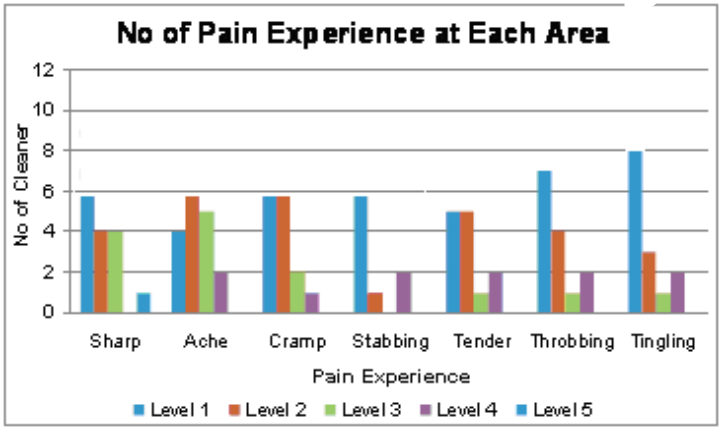


Figure 10: Graph no of pain experience for all participants