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Size-Weight Scaling in Healthy Young and Old Adults

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SIZE-WEIGHT SCALING IN HEALTHY YOUNG AND OLD ADULTS

by

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of the requirements for the
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Graduate College
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Iowa City, Iowa

CERTIFICATE OF APPROVAL

MASTER'S THESIS

This is to certify that the Master's thesis of

Alyssa Lynn Capper

has been approved by the Examining Committee for the thesis requirement for the Master of Science degree in Health and Human Physiology at the August 2013 graduation.

Thesis Committee: ____________________________________
Kelly J. Cole, Thesis Supervisor

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Clayton R. Peterson

To my parents: Ron and Jenny Capper, for believing in me
To Blake: for being there every step of the way

ABSTRACT

Visual analysis of an object’s size can be used to determine the lifting forces we program to lift the object so that the resulting movements achieve the goals of the lift. These forces are scaled or specified prior to the object moving, that is, before sensory feedback information about the object’s weight is available. Sensorimotor memories are relied on to provide relevant information about an object’s density and weight if the object was previously manipulated. It is well established that young adults accurately scale their forces based on visual size cues. The purpose of this study was to determine if old adults scale their forces to the size of the object or if they rely on sensorimotor memory of the previous object’s weight. There are reports of impaired visuomotor programing for grasp and lift in old adults.

In the present study old and young subjects were required to lift four different sized bottles of constant density from a force plate and then place the object on a shelf. Two experiments were performed. Experiment one featured blocks of lifts for three bottles in the following order: large, small and medium. Experiment two took place fifteen minutes after experiment one and featured a bottle slightly larger than the medium bottle used at the end of the experiment one. The second experiment addressed whether imperceptible changes in size cause changes in predictive force scaling. Peak load force rate in the first force pulse (prior to lift-off) was measured for each lift of the objects with the focus being on the initial and last lift of each bottle.

Both experiments presented a significant effect for bottle size on lift force rates. This result was found regardless of age. It provides additional support that young adults accurately scale their lift force rate based on the visual size cues of the object. Old adults also demonstrated scaling of their lift force rates based on bottle size which failed to support the hypothesis that old adults would merely reproduce their lift force rates from the previous lift with a different object. While both young and old scale lift forces to object size, the old demonstrated a trend for utilizing high lift force rates throughout the experiment as well as greater differences in lift force rate between the initial lift with an object and the final lift with the same object.

Most subjects utilized a target strategy in which they produced a single peak lift force rate pulse. This is indicative of a neural representation of the weight of the object being utilized to program the lift force rate. The remaining subjects exhibited a probing strategy that features several step-wise increases in lift force rate until the object is lifted off. This represents a more cautious approach to lifting novel objects.

Our results indicate that old adults, much like young adults, are able to scale their forces based on visual size cues.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER I

INTRODUCTION

Overview

To successfully interact with objects we must use accurate lifting forces to properly manipulate the object. Weight information about the object is not available until after the object has begun to move in a vertical direction. A consequence of this is that we must rely on past experience and visual analysis to correctly scale our forces (10). Past experience with an object creates a sensorimotor memory, an internal model of the weight of the object and the necessary forces to handle it properly (16). Visual analysis of an object to be manipulated provides information about the relative size of the object as well as friction information. A common density is assumed for object manipulation and ties in with visual analysis and sensorimotor memory to program accurate lifting forces (11). This system of accurately programming lifting forces serves as a feedforward system that enables us to act quickly and not work within the limits of a sensory feedback (13). Additionally by programming accurate forces we are not faced with fatigue issues from consistently programming excessive forces then scaling to lower forces.

It is well documented the elderly have increased slowing and decreased dexterity. Cole has conducted several experiments that have demonstrated the elderly use increased grip force when interacting with a novel object, regardless of the object surface coverings. The grip force showed large variability across all trials. This increase in grip force creates a larger safety margin to prevent object slips. Part of the increase grip force can be explained by the decrease in water content of the skin in the elderly, resulting in increased slipperiness. Additionally deficits in tactile sensation in the fingers of the elderly contribute to increased grip force; however the increase in grip force is beyond that needed to overcome the friction concerns (3, 5).

Diermayr and colleagues conducted a mini-review of the aging literature as it relates to grip force and provided further evidence that supports Cole’s findings. His search revealed more studies showing old adults using increased grip force and presenting with increased slipperiness of the fingers. The use of increased grip force may contribute to impaired dexterity, especially in tasks requiring low force levels. The increase muscle activation would result in variable force presentation and lead to premature fatigue (8).

Gordon has provided the most thorough research on the way healthy young adults accurately program lifting forces for a given object prior to ever actually lifting the object. His series of experiments focused on a precision grip lifting a novel object or a common object off of a platform and featured adults ages 19 to 51 (11). His paper focusing on visual size cues featured boxes of different volumes but the same weight, resulting in varied densities. Boxes were presented randomly after an initial practice period with one box. Gordon and colleagues found subjects were strongly affected by the size-weight illusion, a perception in which the smallest object is perceived as the heaviest despite being the same weight as the other objects. Lift force rate production was highest for the largest box, indicating a strong visual analysis of the object and assumption of a higher weight for the larger object. Additionally subjects scaled smaller lift force rates for the smallest object despite their proclamation of the smallest box being the heaviest. The visual effects of the box size on lifting forces were consistent throughout the duration of the study (12). This study provided evidence of the great impact of visual analysis of object properties on the accurate programming of lifting forces. It demonstrated well established scaling taking place on the first lift. This work established the basis for us using the young adults as a control group as they are accurately scaling to visual size cues.

Gordon and colleagues followed up the visual analysis experiment with a study focusing on haptically acquired size information using blindfolded subjects (11). Subjects lifted boxes after haptically exploring the dimensions of the box. As in the previous study the objects were different sizes but the same weight, again resulting in different densities. Most subjects programmed a single pulse force rate, indicating a target strategy for the lift. A few subjects resorted to a probing strategy in which several pulses of force rate were used to lift the object. Subjects produced higher lift and grip force rates for the large box. The size-weight illusion was demonstrated in nine of the twelve subjects in the third group. Gordon concluded the actual weight information gained from lifting the object had a greater effect on forming a sensorimotor memory of the object than the size information gained from the haptic exploration (11). His work in this study provided evidence of the great impact of information gained from previous experience with an object in forming sensorimotor memories.

The next experiment of Gordon featured objects that varied in both size and weight to evaluate the impact of size cues on the programming of lifting forces. The study featured four boxes, two of each size, with one small and one large weighing 300 grams while the other small and large boxes weighed 1200 grams. The experiment featured different transitions in weight and box size. Visual size cues were used to program larger grip and lift force rates for the larger boxes. This larger programmed force rate was observed when the large 300 g box was lifted, resulting in an increased acceleration of the box. A probing strategy was observed when the small box at 1200 g was encountered due to the expectation of the box being at 300 g. Gordon concluded the high accuracy of using visual size information for programming lifting forces when a constant density is maintained between the objects to be lifted (10). This study furthered the understanding the power visual analysis of object size has on accurately programming lifting forces.

The final Gordon paper to consider focused on sensorimotor memories of weight of common objects as well as the acquisition of weight memories for novel objects with extreme densities. The experiment featured two groups of subjects that lifted either common objects or novel objects. The novel object was constant in appearance but had its weight varied from 300 g to 1200 g, resulting in an extreme density difference. Subjects lifted one of the two weights on day one and day two, and lifted the other weight on the third day. The common object experiment demonstrated consistent lift force rates across the ten lifts for each object, indicating an accurate programming of lift force rate on the initial lift. Loading phase duration was increased for a more fragile object despite it being of lesser weight than many objects, suggesting caution was used by all sixteen subjects. Larger lift force rates were observed for the heavier items consistent with Gordon's previous work.

In the novel object task subjects faced with the 1200 g object first displayed small lift force rates, indicating an assumption of the object weight being less than it was. Higher lift force rates were observed over the first three trials and steadied around the fourth lift with changes continuing through the tenth trial. The second day subjects demonstrated lifting forces consisted with the latter trials of day one, indicative of sensorimotor memory formation. On the third day subjects lifted the 300 g object and presented lifting forces consisted with their previous lifts with 1200 g. By the second lift with the lighter object lifting forces had stabilized. Subjects who first lifted the 300 g object over the first two days accurately scaled their forces on the first lift of day one.

Gordon’s work with the common objects demonstrates that lifting forces were accurately programmed prior to the initial lift with the object. With the novel object subjects assumed a common density and were able to accurately scale their lifting forces after the first trial with the 300 g object. It took several trials for subjects to program their forces to the object of an unusually high density (1200 g object). These subjects also initially featured a probing strategy while a target strategy was employed by those starting with the 300 g object. This experiment demonstrated the strong correlation between visual recognition of an object and sensorimotor memory for weight and density of the object (13). This experiment served as the culmination of Gordon’s previous work in establishing the power of visual analysis in using size cues for extrapolating weight information as well as the strength of sensorimotor memories for weight in accurately scaling lifting forces.

Forssberg expanded on Gordon’s work by examining the development of the precision grip in children in a series of experiments. One study focused on the effect of the previous lift on the load forces for the next lift. His subjects ranged in age from 1 to 15 years old and lifted an object that did not change in appearance when the weight was changed. Subjects lifted the object using a precision grip. The study utilized an object at 200 and 400g for the 2 years and under group and 200 g and 800 g for 3 years and above.

In the 1-2 year old group it was observed that lift force and grip force rates were higher for the heavier of the two objects. Additionally this age division displayed a probing strategy for lifting the object. The 2-3 age division and older groups demonstrated strong weight influences on the grip and lift force rates from the previous lift. This was evident in the presentation of larger forces when lifting the 200 g object after lifting the 800 g object and the opposite being true when lifting the 800 g object after lifting the 200 g object. Forssberg was able to conclude that anticipatory programming of forces emerges around age 2. It takes until the age of 10 for the force program to mature to a near adult level (9). His work provides the foundation for the development of force programming in the young and complements the work of Gordon in the same area in adults.

An experiment conducted by Cole targeted the sharp ability of visual analysis to program forces despite the subject being unaware of any size changes. He presented subjects with a single bottle to be lifted several times followed by a break period. Upon return subjects in the control group encountered the same bottle with a slightly lower weight. They produced lifting forces consistent with the weight of the object in the first part of the experiment. The experimental group returned to a slightly smaller bottle that featured the same lower weight. Despite subjects reporting it was the same bottle their forces were scaled accurately to the smaller size. This study provided strong support for sensorimotor memories when encountering an object a second time and also demonstrates the power of visual analysis of size cues to accurately program lifting forces when the size change is imperceptible (2).

Baugh provided a more thorough look at sensorimotor memories as they relate to object density. His study included four blocks with either a wood or brass veneer covering that were filled with either the matching material or the conflicting material. A final series of lifts took place with a larger brass-filled block that featured the covering of the subject’s previous object. The results demonstrated subjects were able to accurately scale their forces for the small object regardless of its covering. The first lift with the large object was grossly affected by the covering as well as the core material of the previous object. Baugh was able to conclude that sensorimotor memories can be formed for density and contribute to predictions of weight (1). His work contributes to the understanding of accurately programming lifting forces when lifting novel objects as it pertains to density.

Arbitrary visual cues that are unrelated to object properties can be relevant to grip and lift force rate programming. This is seen in our daily lives when we interact with objects that vary only in characteristics, such as shape and color, which contribute to the sensorimotor memory of the object only after it has been manipulated. Nowak conducted an experiment that demonstrated young adults are capable of programming accurate lifting forces based solely on the arbitrary visual cue of color and its relation to object weight. This phenomenon persisted 24 hours after the initial manipulations of the objects. His work also supported the formation of sensorimotor memories for object properties based on arbitrary cues (18).

Cole and Rotella investigated the effects of color as an arbitrary visual cue as it pertains to friction and how the elderly (mean age 74.6 years) can learn these cues. The first experiment indicated the grip surface material via color, sandpaper or acetate. The second portion of the first experiment featured both coverings in the same color, removing the visual cue. Subjects lifted the test object using a precision grip. A second experiment the object weight changed between 2 and 4 N and was marked with a colored tape to indicate the weight of the object for the visual cue part. No colored tape was used for the second half of the experiment (4).

Young subjects used the visual cue of surface friction to produce lower grip forces with acetate covering as compared to the condition in which no cue was given and a larger grip force was employed. This was not observed in the elderly. In the second experiment young subjects lowered their peak grip force rates for the visual cue of weight. Again this was not seen in the elderly. Cole was able to conclude that the young adults were able to use the visual cues of friction and weight to quickly program accurate forces while elderly subjects failed to use the same visual cues. This experiment demonstrated the ability to learn arbitrary visual cues of an object’s characteristic are hindered in the elderly. Additionally larger grip forces were observed in the elderly, believed to be an attempt to prevent slips (4). This work provides a look at possible impairments in object manipulation as we age, in this case deficits in learning arbitrary visual cues.

Cole has demonstrated the elderly struggle with arbitrary visual cues as well as excessive grip force in object manipulation. Cole’s findings provoke additional questions about object lifting issues the elderly may possess. These questions focus on if they have issues with programming forces based on size cues. Errors in the programming of forces would contribute to slowing due to increase variability with each lift. Larger lift force rates would cause accelerated object motion and manipulation issues to use the object. Fatigue would be an issue as well due to the use of excessive grip forces.

The neural substrate most likely involved with accurate force programming includes the anterior intraparietal sulcus (AIP), ventral premotor cortex (PMv), and the primary motor cortex (M1) (7). It appears that the posterior parietal cortex has access to the ventral visual stream involved in object identification necessary to retrieve sensorimotor memories and would contribute to anticipatory scaling as well (6). AIP is shown to be concerned with object size while PMv is concerned with object density and weight. M1 stores sensorimotor memories of object weight after interacting with the object and uses these memories to alter the excitability of necessary muscles to manipulate the object. Davare and his team have used transcranial magnetic stimulation (TMS) and theta-burst TMS (cTBS) to study the interactions of the cortical segments in grasp control. AIP virtual lesions during grasp preparation significantly decreased the PMv-M1 interaction for programming specific muscles. This result suggests AIP provides PMv and M1 with specific object properties to assist in the accurate programming of motor commands (7). This circuit may play a large part in arbitrary visual cues as well and may be a factor in aging.

Purpose of the study

The purpose of this study is to investigate whether all healthy older adults have impairments in scaling lifting force rates on the initial lift of a novel object based on size-weight cues. A second experiment will investigate if older adults accurately scale lift force rates for subtle changes in bottle size that are not visually salient when the previous lift was several minutes prior.

Specific aim and hypothesis

The aim of experiment one is to observe if older adults can accurately program lift force rate on the initial lift with an object. We hypothesize that 1: older adults will fail to produce lift force rates consistent with changes in object size, and 2: older adults will demonstrate lift force rates similar to their previous lift when first lifting an object of a different size. A minor aim of the study is to confirm previous evidence of accurate size-weight scaling in young adults. The aim of experiment two is to determine if old adults are able to accurately scale lift force rates for an imperceptible change in object size (and weight). We hypothesize older adults will produce a lift force rate consistent with the previously lifted object while young subjects will produce a lift force rate scaled to the weight of the new object.

Significance

The results of the experiment may contribute to the understanding of age-related slowing of dexterous manipulation such as multiple force pulses when the first pulse is too small to lift the object. Decreased dexterity may be explained in the elderly if it is found that there are issues in lift force rate programming in the elderly, such as inappropriately high acceleration if the first pulse is too high in relation to object weight.

CHAPTER II

METHODS

Subjects

Eight healthy old adults (70-79 years; 74 ± 3 years [mean ± SD]; three females) and eight healthy young adults (20-25 years; 23 ±2 years [mean ± SD]; four females) were recruited for this study. All participants self-reported which was their preferred hand and claimed to be free of the following: (a) injury or disease affecting the arms or hands, (b) injury or disease of the brain, (c) diabetes, (d) hand or wrist pain that requires daily prescription medication, (e) hypertension requiring medication, (f) sensory disturbances of the dominant arm or hand, and (g) corrected vision worse than 20/20. Approval from the University of Iowa Human Subject Internal Review Board (IRB) was obtained for the experimental procedures. All subjects gave written informed consent according to the Declaration of Helsinki.

Equipment

Four brown opaque plastic bottles that differed in size, but were otherwise identical were used in this study. Each bottle was fitted with a white cap. Each bottle was filled to the brim with the same fine mortar powder. Once filled the weights of the bottles were as follows: 220 grams, 390 grams, 480 grams, and 605 grams (see Table 2-1). Subjects were not informed of the number of bottles nor did they view more than one bottle at a time. Velcro was placed on each cap to allow for the attachment of an accelerometer (SenSym SXL010G; Sunnyvale, CA) to measure vertical acceleration.

Subjects were seated in a chair facing a table situated at a comfortable height. The bottle in use was placed on the top of a force plate (River Lake Weighing Systems, Model RL 1010, 3 KG scale). A towel was placed under the force plate to damp building vibrations in the lift force rate signal. A board 4.5 centimeters in height covered in white paper was placed beside the force plate on the table. The board was moved to the right or the left of the force plate based on the hand the subject used for the experiment. A black poster board was placed behind the force plate and bottle set up to focus the subject's attention exclusively on the bottle.

Subject screening

All subjects were screened on their capacity to consent and sign the consent form to rule out undiagnosed dementia. The Animal Fluency Test was used to assess their current cognitive level (20). Additionally all subjects were screened for undiagnosed neuropathy in the dominant hand using the Rydel Seiffer graduated tuning fork (17).The tuning fork is used to detect any nervous ailment defined as polyneuropathies. These ailments manifest in the form of decreased sensitivity to vibrations. The tuning fork features triangles on the dampers with a scale from 0 to 8. The tynes are set in motion by squeezing the tynes together between the thumb and index finger and released in a snapping motion. This creates an illusion of two triangles on each damper. As vibrations diminish the intersection of the two triangles moves up the scale. The base of the fork was placed on the dorsum of the index finger distal phalange joint on the dominant hand. The subject was instructed to indicate when they no longer sensed the vibrations and the reviewer noted which number the intersection of the vibrating triangles was out to award the subject their score. The acceptable values for the upper extremity were: less than or equal to 40 years was a score of 6.5 or higher and for ages 41 to 85 a score of 6.0 or higher (17). The old subjects had an average score of 6.8 and the young had an average of 7.2.

Experimental one protocol

Figure 2-1 shows the experimental setup the subjects encountered. All subjects participated in a single session using their self-reported preferred hand. In the first experiment subjects were seated in a chair with the first bottle placed on the force plate on a table at a comfortable height in front of them. A large black posterboard was placed on the table behind the force plate and bottle to ensure subjects were looking only at the bottle. Subjects were instructed to grasp the bottle with their full hand, lift it off the force plate at a self-selected pace, and place it on the board. Subjects performed each lift under the direction of the investigator. After placing the bottle subjects looked away to the wall to allow the investigator to place the bottle back on the force plate. The order of bottles was the same for all subjects: the 605 gram bottled was lifted first, the second bottle presented was the 220 gram and the third bottled lifted was the 390 gram. The first bottle was lifted twenty times and the next two were lifted fifteen times each for a total of fifty lifts. The investigator changed the bottles behind the black poster board while the subject was looking away to the far wall. After completing the fifty lifts the subject was asked to be seated in the laboratory lobby for fifteen minutes.

Experiment two protocol

Upon their return to the laboratory they began experiment two in which they lifted the fourth bottle, weight 480 grams, fifteen times, again looking away after each lift to allow the investigator to place the bottle back on the force plate. The fourth bottle was located on the force plate when the subject entered the lab.

Data analysis

Lift force data was sampled at 1000 samples per second, using a 16 bit A/D convertor (Datapac 2K2 version 3.10 RUN Technologies, Mission Viejo, California). The first derivative of the force plate signal was taken to get the load force rate. Load force onset was determined to be the force level that remained above the floor noise of the signal for at least 100 msec, this assured it was the first programmed pulse. The first peak that did not exceed 100 msec from the onset was chosen as the peak of the programmed lift force rate. The onset and offset were also selected based on the force signal; ensuring the onset was after the weight of the bottle was being released from the force plate but the offset was located prior to actual liftoff of the bottle from the force plate. The onset and offset markers can be seen in figures 2-2 and 2-3.

Criteria were established to address different lifting strategies that may be used by subjects when presented with the bottles. Subjects who demonstrated a single lift force rate were said to be using a predictive strategy, a target strategy. A second group that featured several small pulses of lift force rate that built up to eventual liftoff of the object were said to be using a probing strategy. Probing was defined as the presence of more than two pulses in within100 msec that continued to increase in lift force rate. The target strategy was defined as a single lift force rate peak that may be followed by smaller pulses or no pulses at all. Figure 2-2 demonstrates a probing strategy and figure 2-3 demonstrates a target strategy.

Statistical analysis

First and last lift data were entered into repeated-measures ANOVA to determine the effects of Group (old, young) as a between-subject factor, and Size (large, small, medium) and Time (first lift, last lift) for experiment one as within-subject factors. This was done using the load force rate for the initial lift and the last lift with each of the three bottles in the first experiment. Observations were made to confirm no Group X Size interaction in the young and to discover if one exists in the old.

Group, Time and Size effects were tested with the medium bottle of experiment one and the bottle in experiment two. This was conducted to observe a significant main effect of the subtle size change between the medium bottle in the first experiment and the slightly larger bottle in the second experiment. Group (old, young) and Time (first lift, last lift) effects were tested in experiment two using repeated-measures ANOVA with the first and last lift data.

Dependent T-test were done in addition to the ANOVA tests to determine any significant main effect of age and the forces produced with the medium bottle of the first experiment. All statistical analyses were performed using the Statistica program (version 7.1, StatSoft Inc., Tulsa OK). All values in the figures and text represent group means ± 1 standard error.

Experiment One			
BOTTLE	WEIGHT (g)	HEIGHT (cm)	CIRCUMFERENCE (cm)
Large	605	13.5	23.0
Small	220	8.7	16.2
Medium	390	10.9	19.2
Experiment Two			
Medium-Large	480	12.7	20.6

Table 2-1. Weight, height, and circumference measurements for all bottles used in experiment on and in experiment two. Weight is measure in grams and the height and circumference are measured in centimeters.

Figure 2-1.Experiment setup with the bottle located on the force plate with the posterboard behind. The board is moved to the right or left of the force plate based on the dominant hand of the subject.

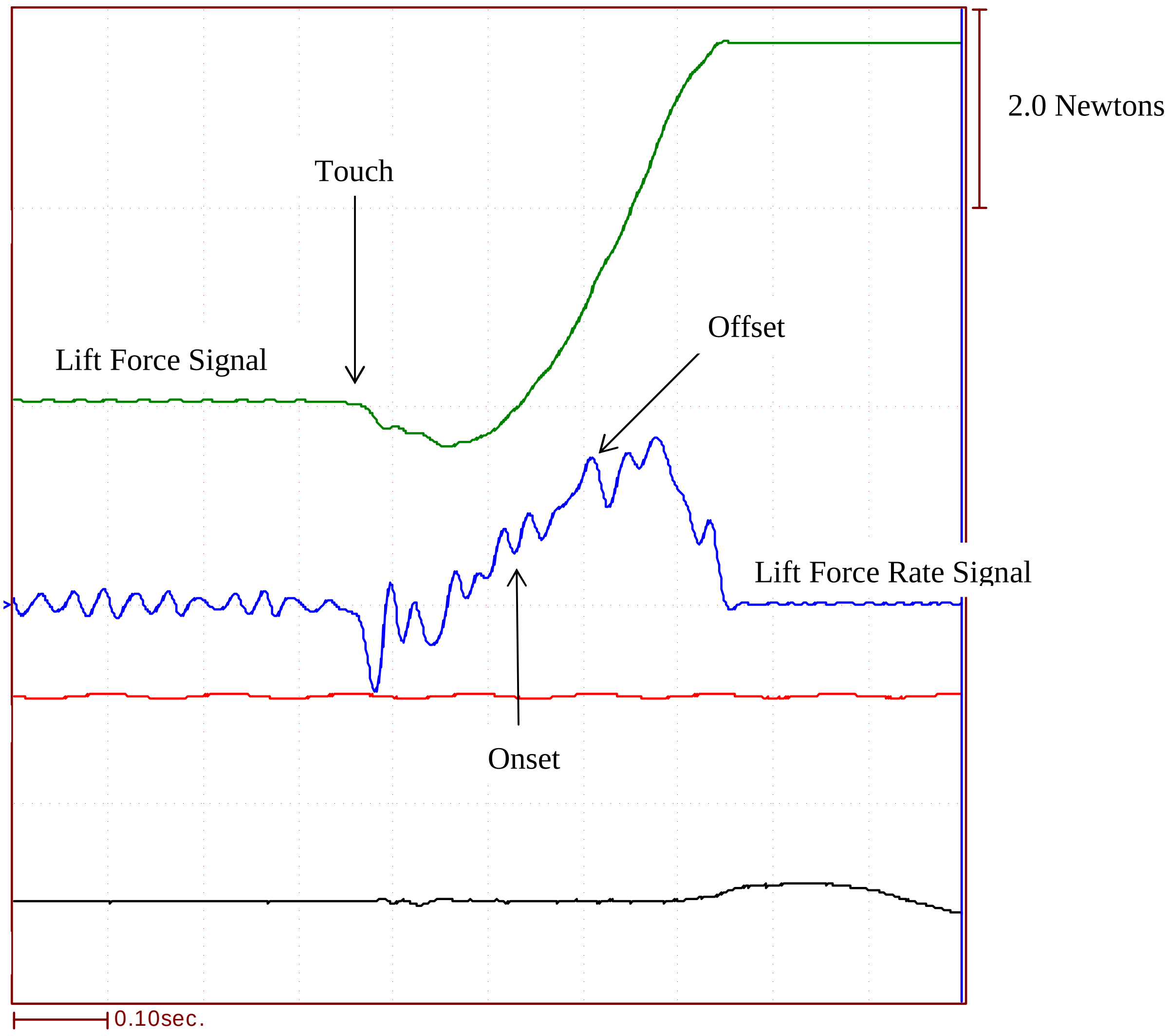

Figure 2-2.Probing strategy in the lift force rate in an elderly subject. The lift force signal is also displayed to verify when the bottle was being unloaded from the force plate as well as when it was completely removed from the plate. Arrows indicate the points used as onset and offset markers.

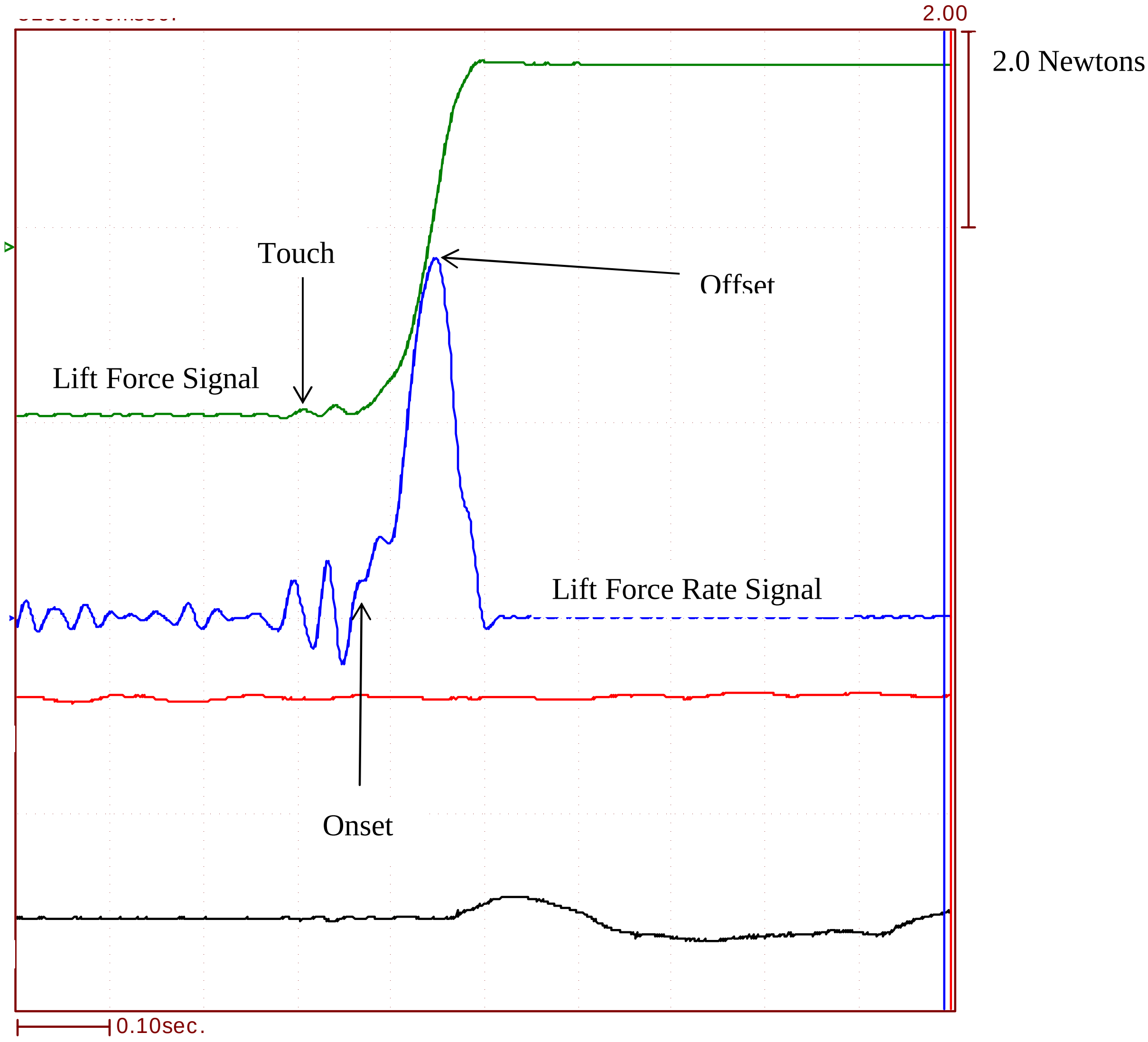

Figure 2-3.Single peak example of lift force rate in a young subject. The lift force data is also displayed to verify the moment the bottle was being unloaded from the force plate as well as when the bottle was fully removed. Arrows demonstrate the points used to determined onset and offset values.

CHAPTER III

RESULTS

Lifting strategy

Consistent with Gordon’s work subjects utilized two different lifting strategies when faced with the novel object (11). Three elderly and three young subjects were found to utilize a ‘probing’ strategy throughout this experiment. A probing strategy is a buildup of several small load force rate pulses until the object is lifted from the force plate, figure 2-2 demonstrates a probing strategy in an elderly subject. This strategy does not demonstrate predictive force scaling; it is a reactive strategy in which the subject builds force up until the object moves. Examination of consecutive lifts of these subjects revealed they maintained the probing strategy throughout the duration of both experiments. As a consequence of two strategies being used results were analyzed with and without the probing subjects’ respective data for all tests. This strategy does not indicate any impairment. It merely indicates a differential approach to lifting novel objects. The remainder of subjects used predictive scaling, a target strategy, featuring a single peak load force rate (11). Figure 2-3 demonstrates a single peak lift force rate in a young subject.

Experiment one

Lift force rates were the primary focus of the data analysis with emphasis on the first and last lifts of each bottle. Figures 3-1 and 3-2 depict the lift force rates in the first experiment with those utilizing a probing strategy excluded from figure 3-1. Age effect for experiment one trended towards being significant with a p value of .137 ($p=.137$).

Both old and young subjects appeared to scale their peak lift force rate based on the visual appearance of the bottle. The repeated-measures ANOVA for the lift force rate data (see Methods) revealed a significant main effect for object size in experiment one for both young and old adults. This effects were significant for data both with (p=.00009) and without (p=.014) the probing subjects' data included. There was no significant (Group x Size) interaction effect. The first lift with the large bottle was the first lift overall and provided information on the density of the bottles to the subjects. Figures 3-3 and 3-4 demonstrate the same results but organized based on bottle size, again focusing on the first and last lifts. It is clear that both young and old subjects were scaling their forces to the size of the bottle. This is evident by the appropriate lift force rates in the initial lift aligning with the size of the bottle.

Transitions in bottle size demonstrate the accuracy of scaling by all subjects. Figures 3-5 and 3-6 show accurate lift force rate adjustments from the large bottle to the small bottle by both old and young. The size effect was significant for this transition (p=.003 with probers, p=.026 without probers). This is indicative of the programming of new lift force rates rather than a reproduction of the lift force rate used in the previous lift. This phenomenon is demonstrated again in the transition from the small bottle to the medium bottle, depicted in Figures 3-7 and 3-8. The size effect again reached significance for this transition (p=.003 with probers, p=.039 without probers).

While it was demonstrated that the old do scale their lifting forces to bottle size they may not be doing so as accurately as young subjects. In Figures 3-9 and 3-10 it is clear that young subjects accurately scale their forces on the initial lift of the medium bottle in the first experiment and maintain that force by the last lift. Old subjects presented a similar lift force rate on the first lift and by the last lift have increased to a level not quite statistically significant but which may signal a trend that bears further consideration (dependent t-test, p=.21).

Experiment two

A reverse in scaling takes place in the transition from experiment one to experiment two; see figures 3-11 and 3-12. In experiment two subjects encounter a bottle slightly larger than the last bottle in experiment one. The difference is visually undetected by healthy young in previous experiments (2). The old and young approached the bottle differently; see Figure 3-13 and 3-14. The old presented a lift force rate less than that of the young at the initial lift in experiment two. The young increased their lift force rates from the previous lift in experiment one on the initial lift in experiment two. The Size x Age effect trended towards significance (p=.118 with probers, p=.081 without probers) when the last lift of the medium bottle and the first lift of experiment two were compared.

Experiment two did not display this main effect of size. The aim of experiment two was to observe if old adults are able to scale for subtle changes in size with the previous lift being several minutes before. The young scaled their forces high on the initial lift and decreased by the final lift. The elderly subjects presented just the opposite by implanting a small lift force rate on the initial lift and increasing it by the final lift (Time x Age effect, p=.224 with probers and p=.376 without probers). The young would go on to decrease their lift force rate by the final lift in experiment two, see figures 3-15 and 3-16, while the old would increase their lift force rate by the final lift. Subjects that utilized a probing strategy in experiment continued to do so in experiment two.

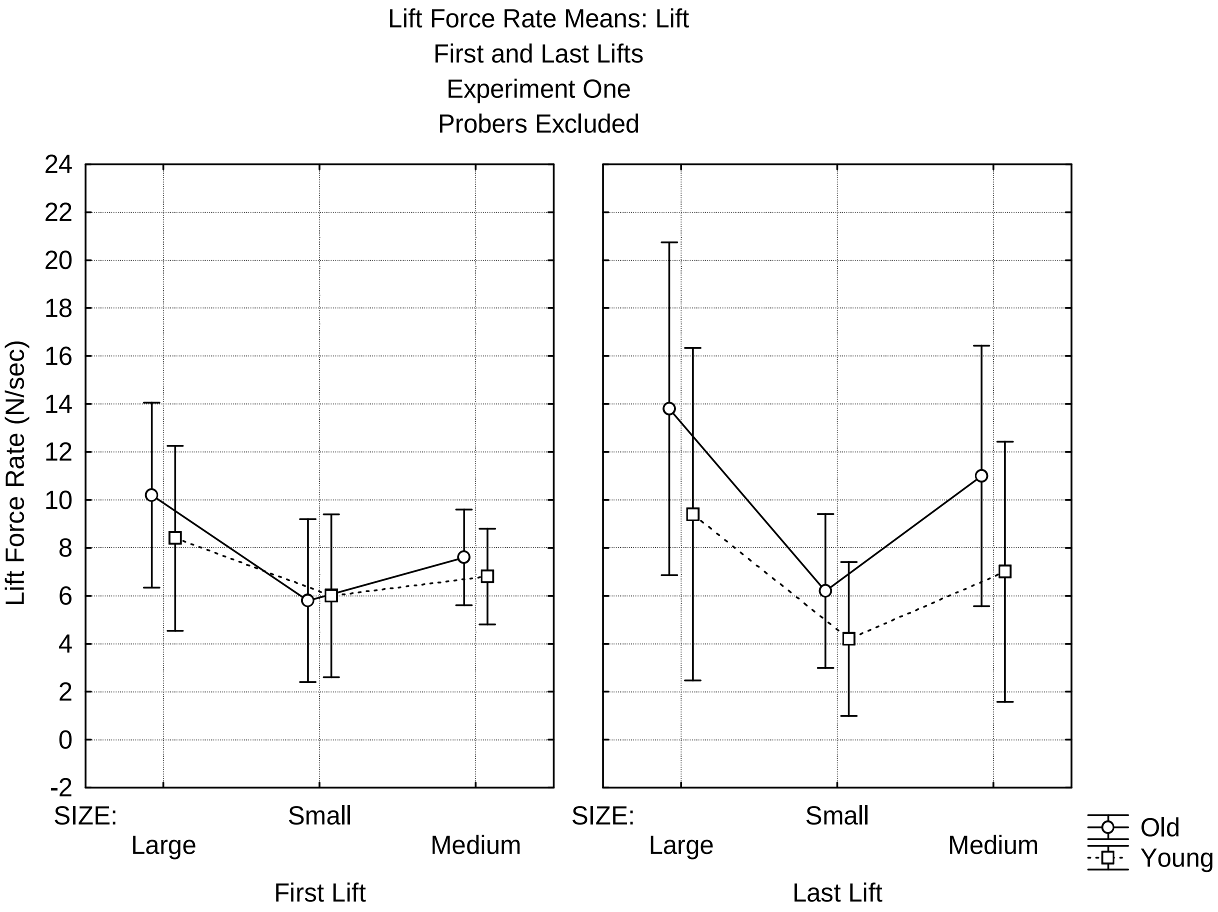

Figure 3-1.Graphical depictions of the lift force rate for experiment one. The data does not include subjects that displayed a probing strategy.

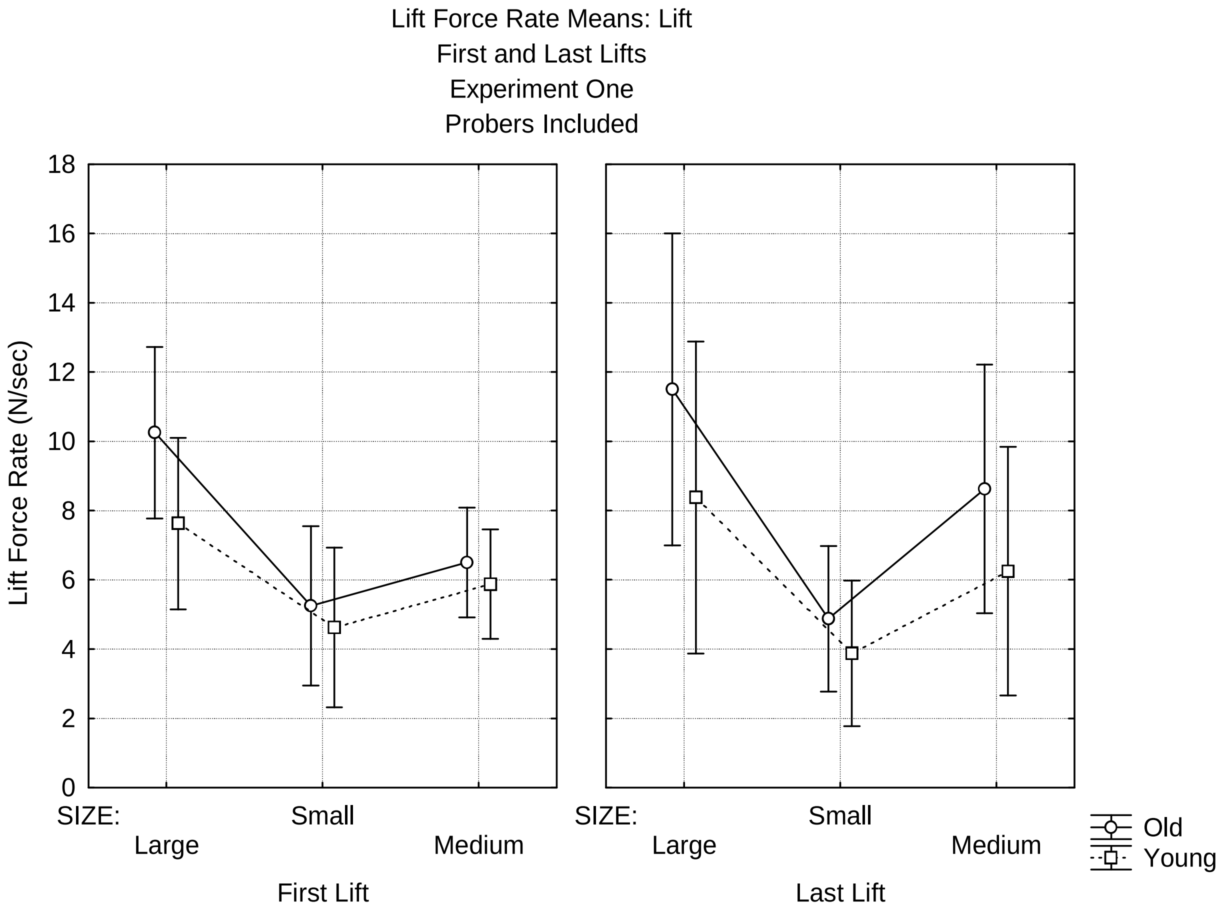

Figure 3-2. Graphical depictions of the lift force rate for experiment one. The data does include subjects that displayed a probing strategy.

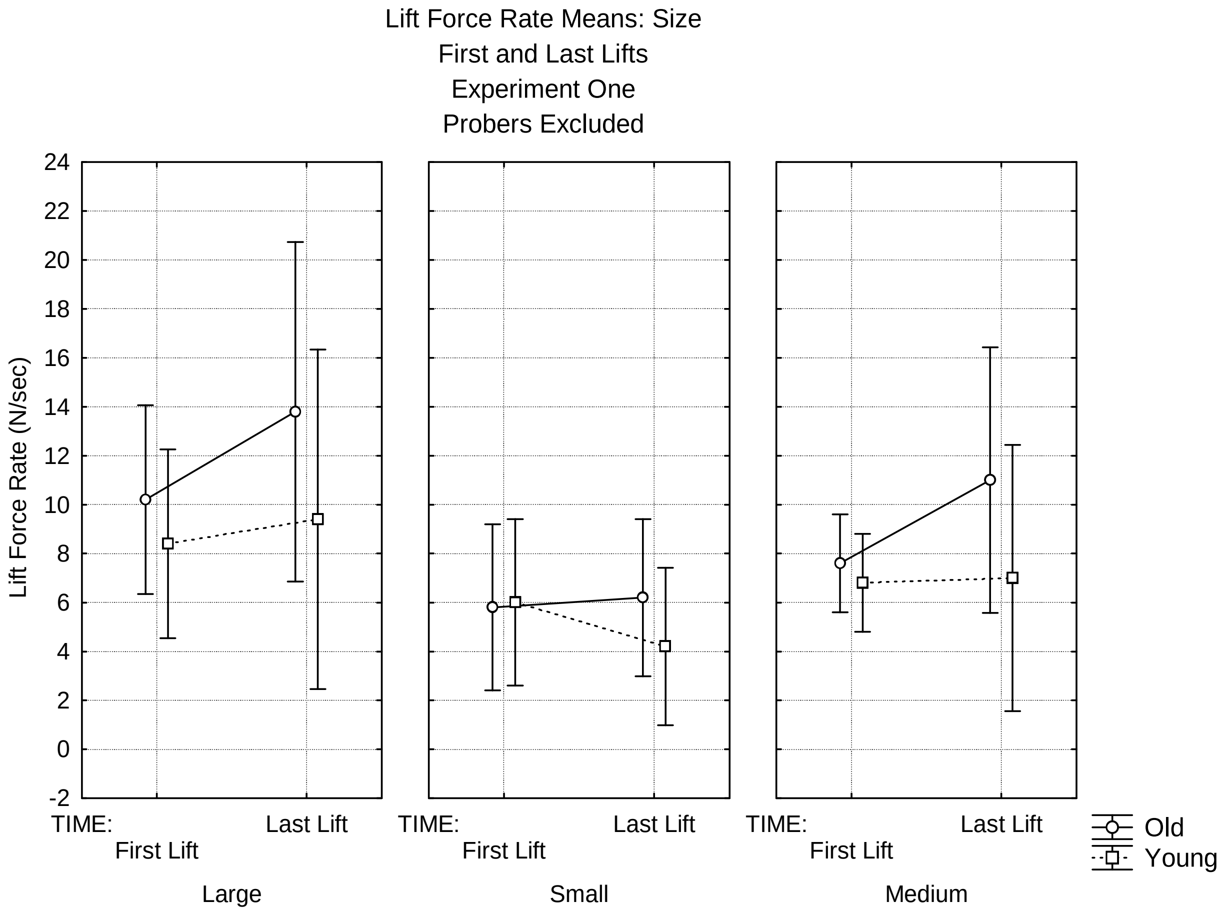

Figure 3-3.Graphical depictions of the lift force rate for experiment one based on the bottle size. The data does not include subjects that displayed a probing strategy.

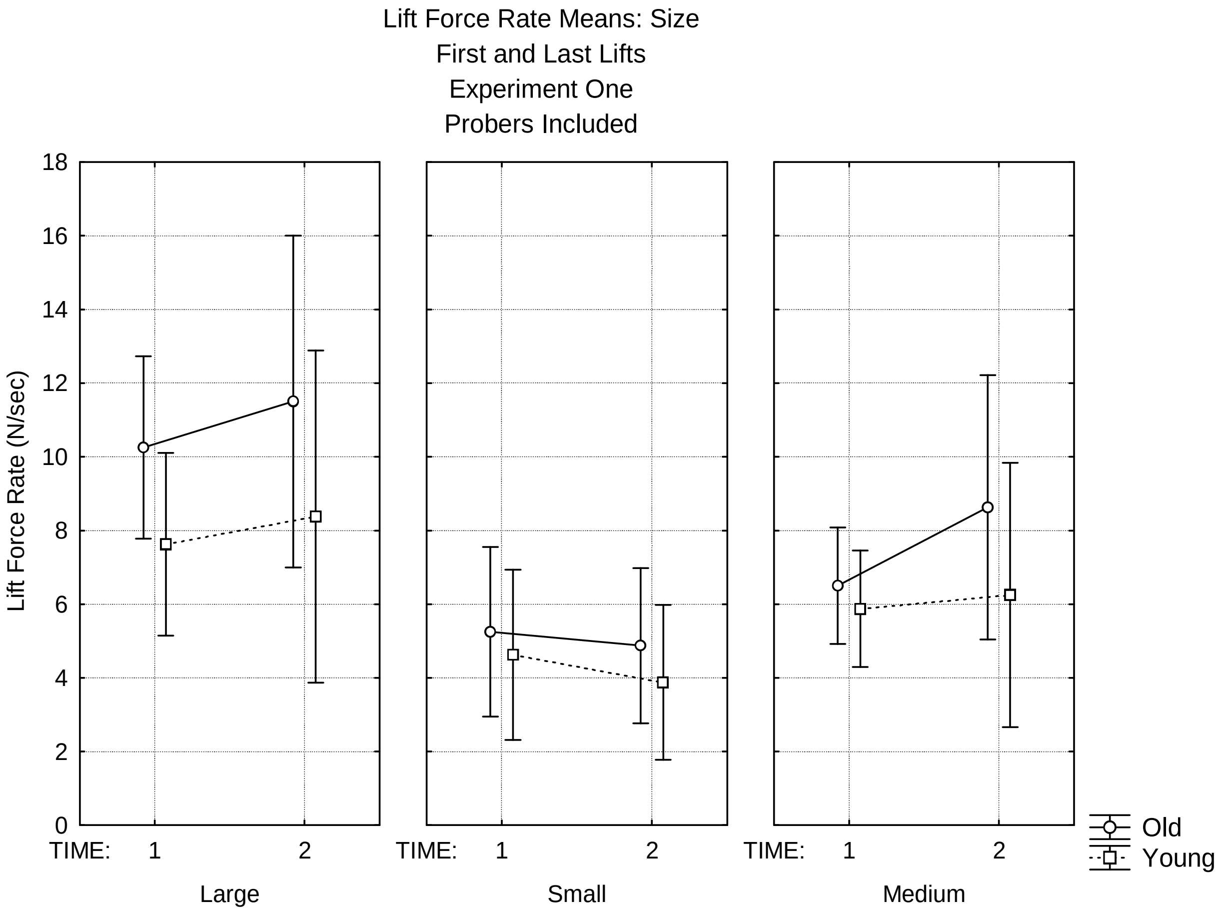

Figure 3-4. Graphical depictions of the lift force rate for experiment one based on the bottle size. The data does include subjects that displayed a probing strategy.

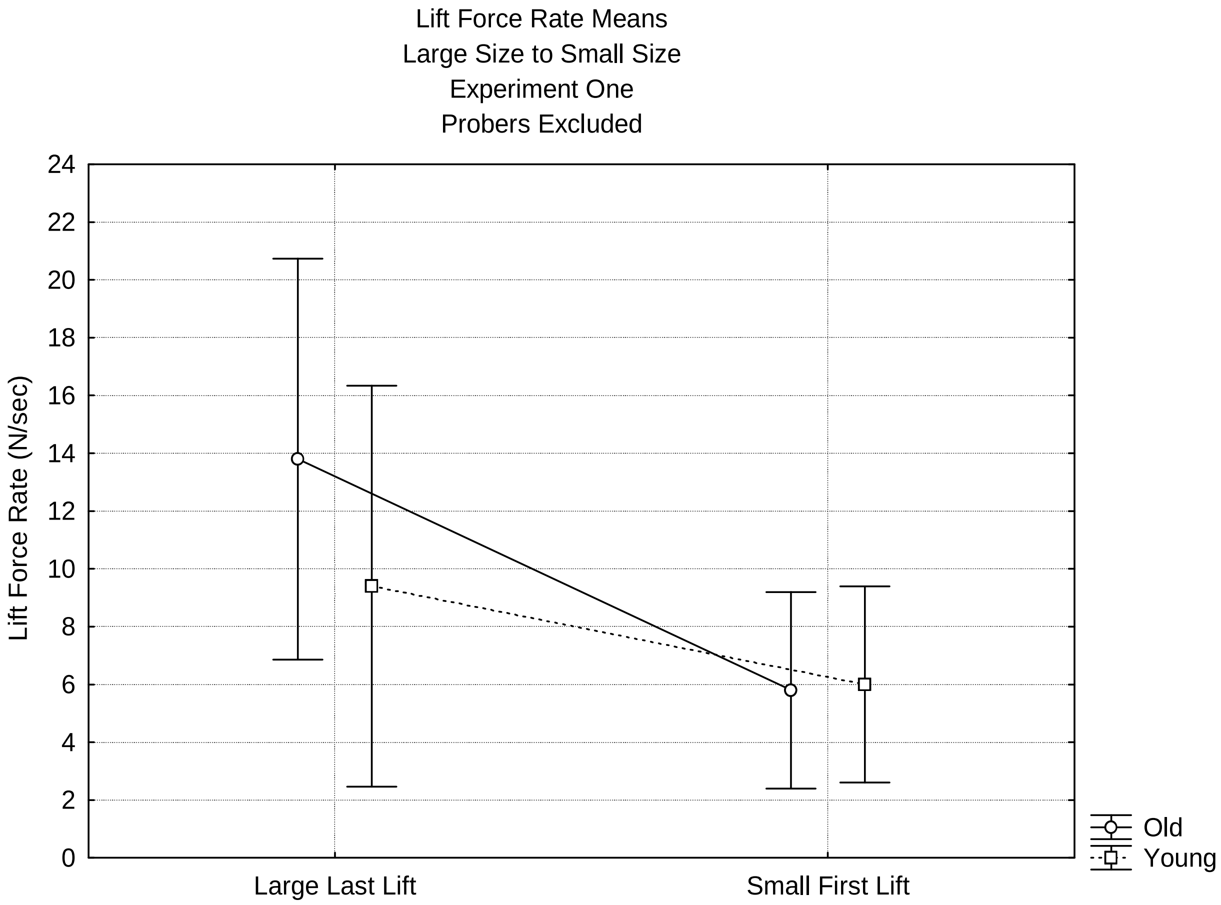

Figure 3-5.Graphical depictions of the lift force rate for experiment one from the last lift of the large bottle to the first lift of the small bottle. The data does not include subjects that displayed a probing strategy.

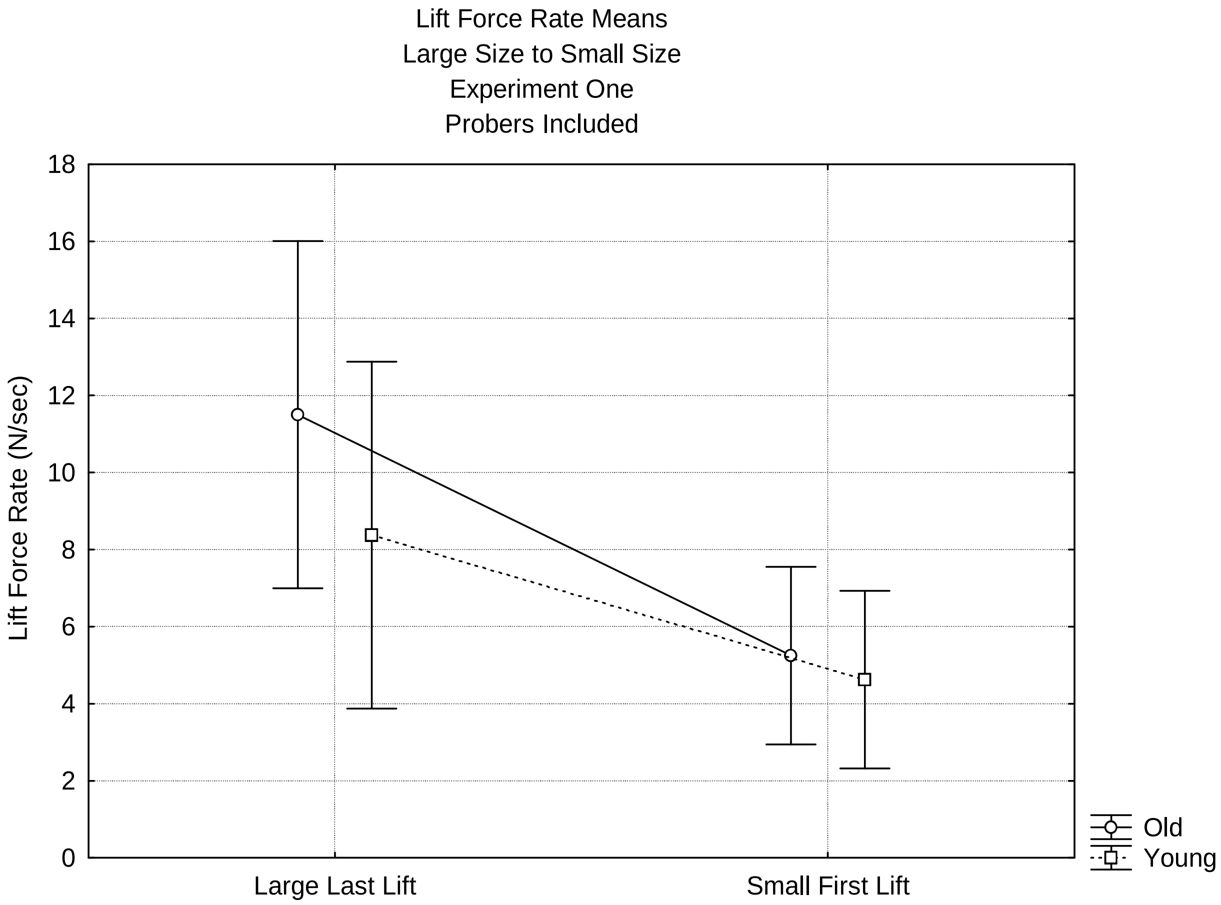

Figure 3-6.Graphical depictions of the lift force rate for experiment one featuring the last lift of the large bottle and the first lift of the small bottle. The data does include subjects that displayed a probing strategy.

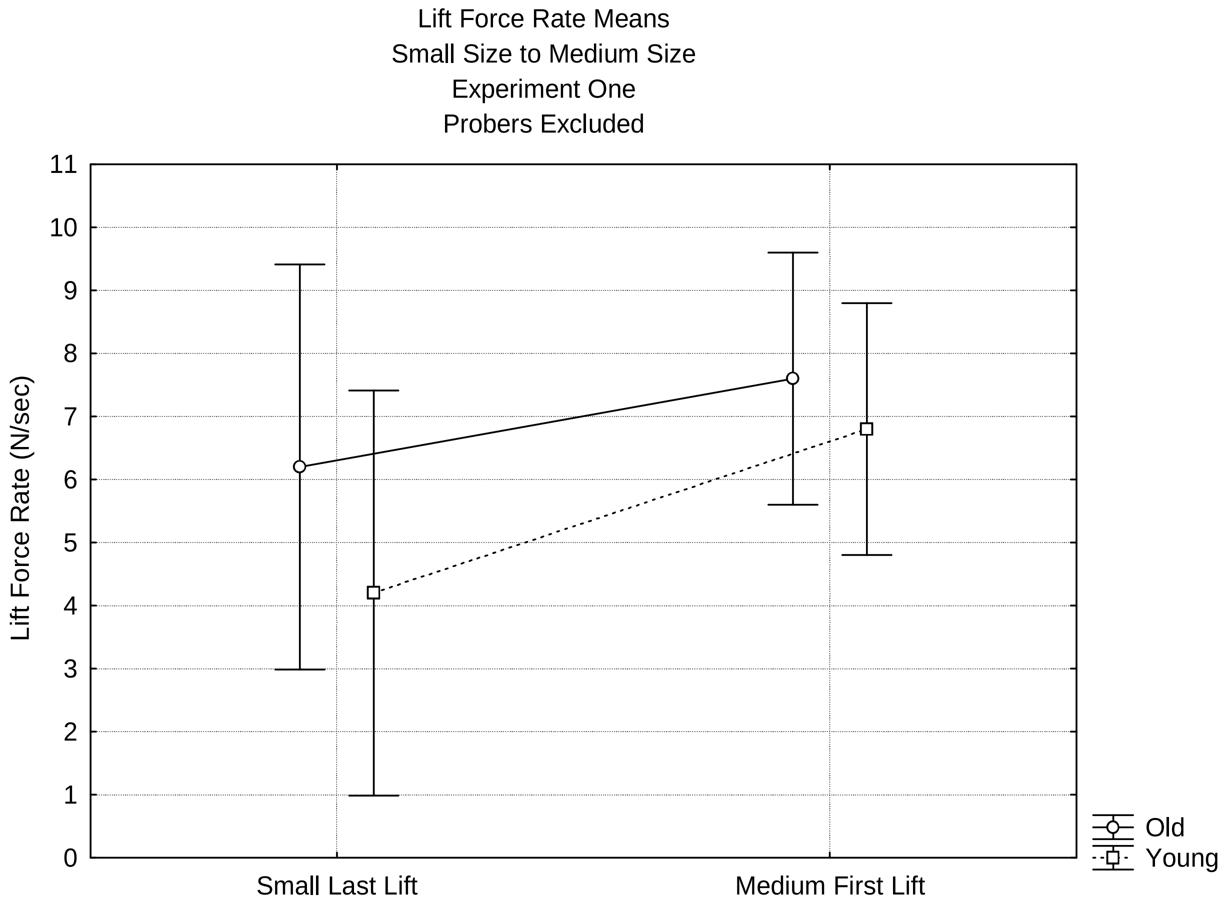

Figure 3-7.Graphical depictions of the lift force rate for experiment one featuring the last lift of the small bottle and the first lift of the medium bottle. The data does not include subjects that displayed a probing strategy.

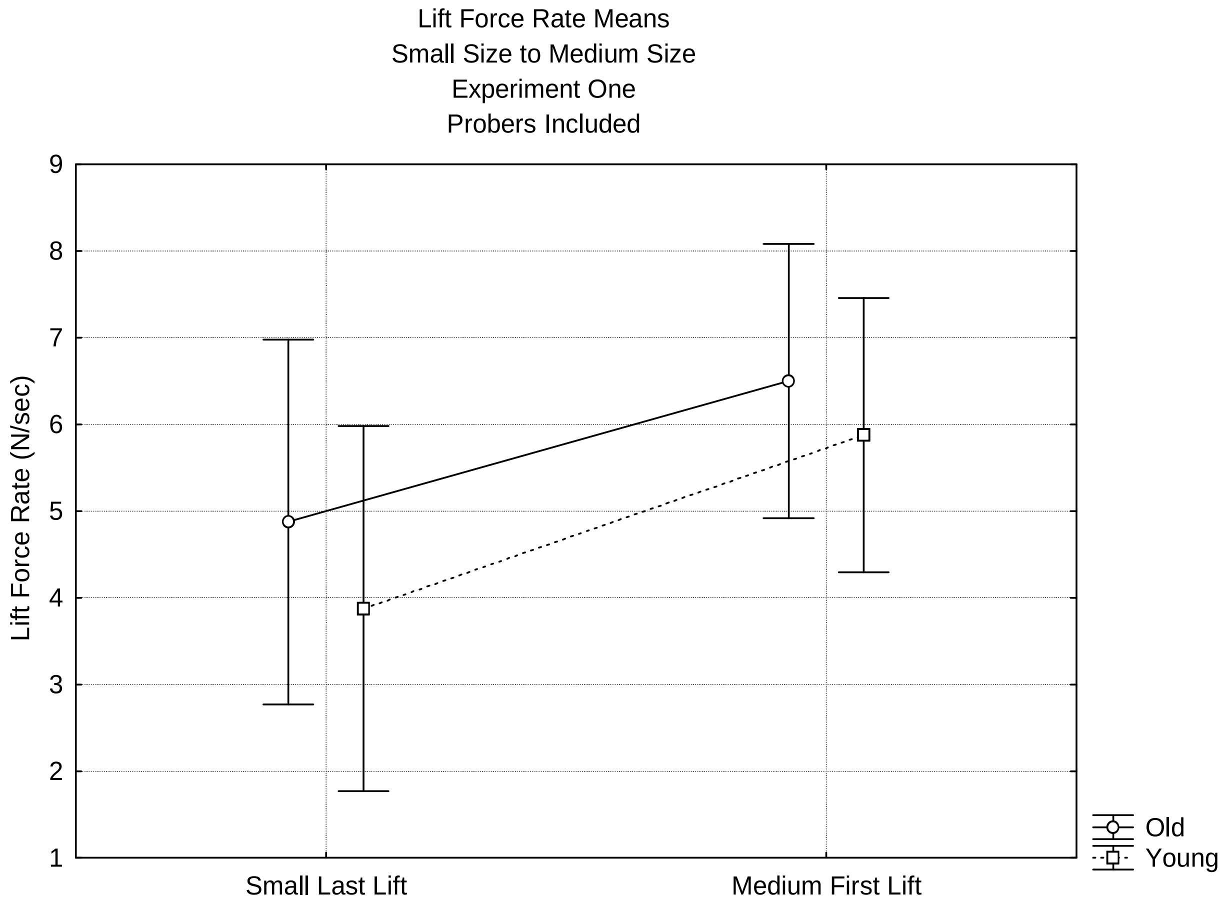

Figure 3-8.Graphical depictions of the lift force rate for experiment one featuring the last lift of the small bottle and the first lift of the medium bottle. The data does include subjects that displayed a probing strategy.

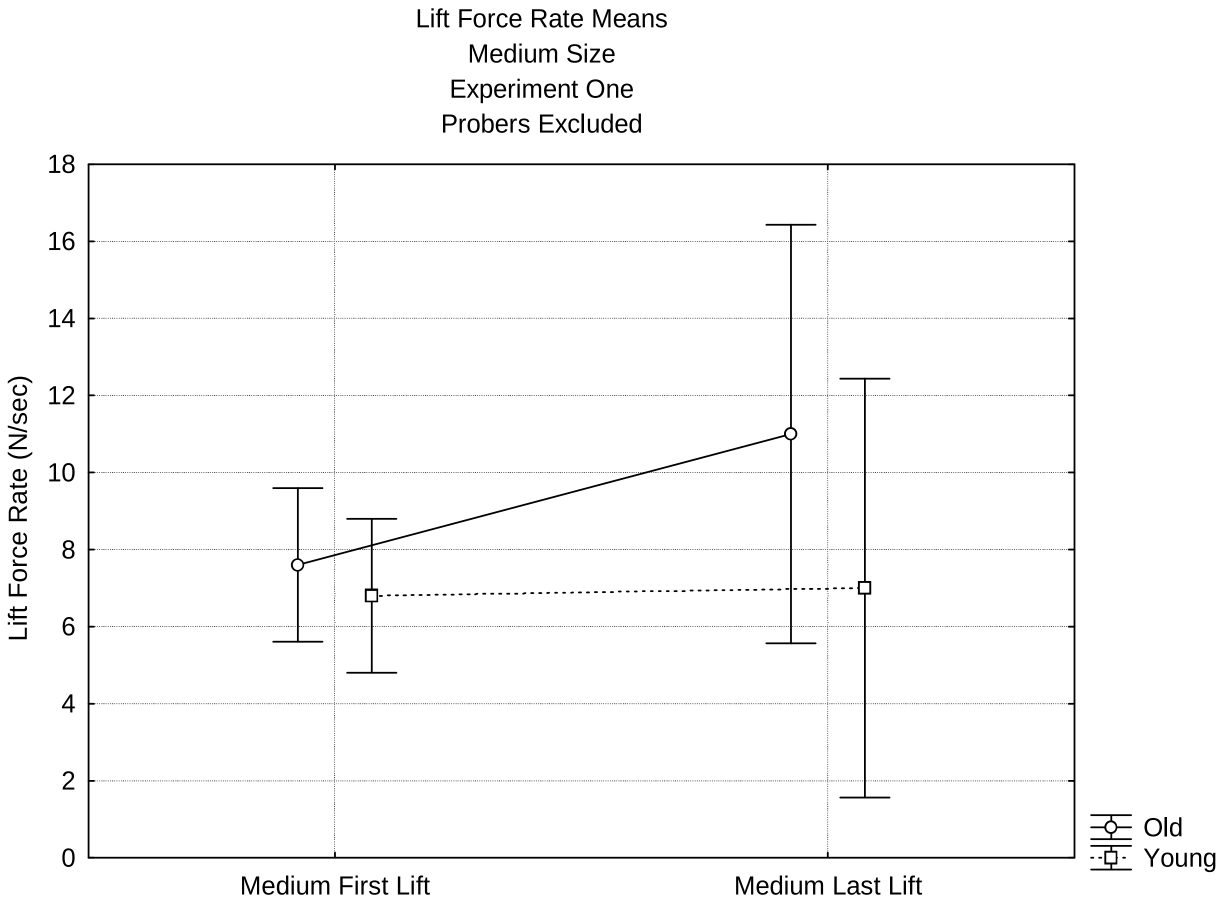

Figure 3-9.Graphical depictions of the lift force rate for experiment one for the medium bottle first and last lift. The data does not include subjects that displayed a probing strategy.

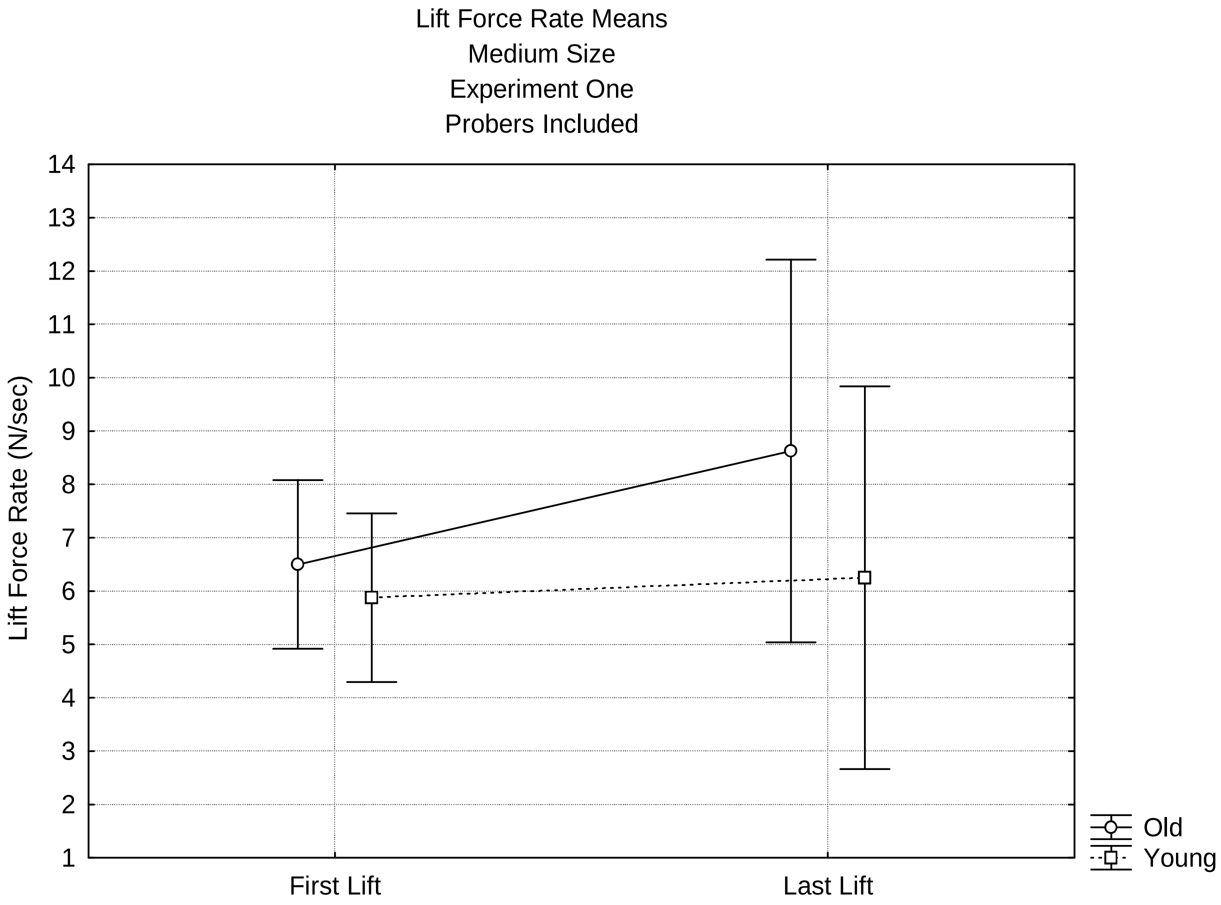

Figure 3-10.Graphical depictions of the lift force rate for experiment one for the medium bottle first and last lift. The data does include subjects that displayed a probing strategy.

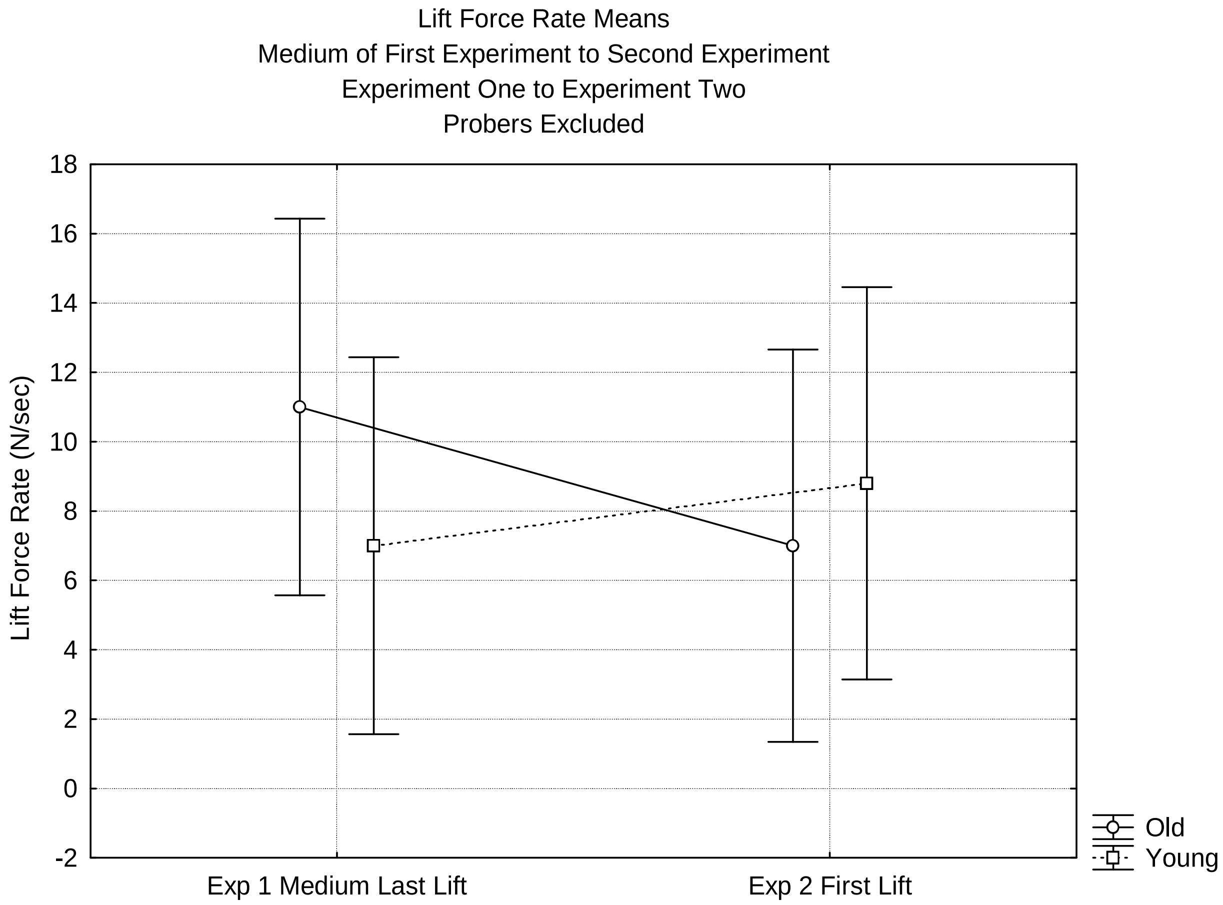

Figure 3-11.Graphical depictions of the lift force rate for experiment one to experiment two. The graph features the last lift of the medium bottle in the first experiment and the first lift of the slightly larger bottle in the second experiment. The data does not include subjects that displayed a probing strategy.

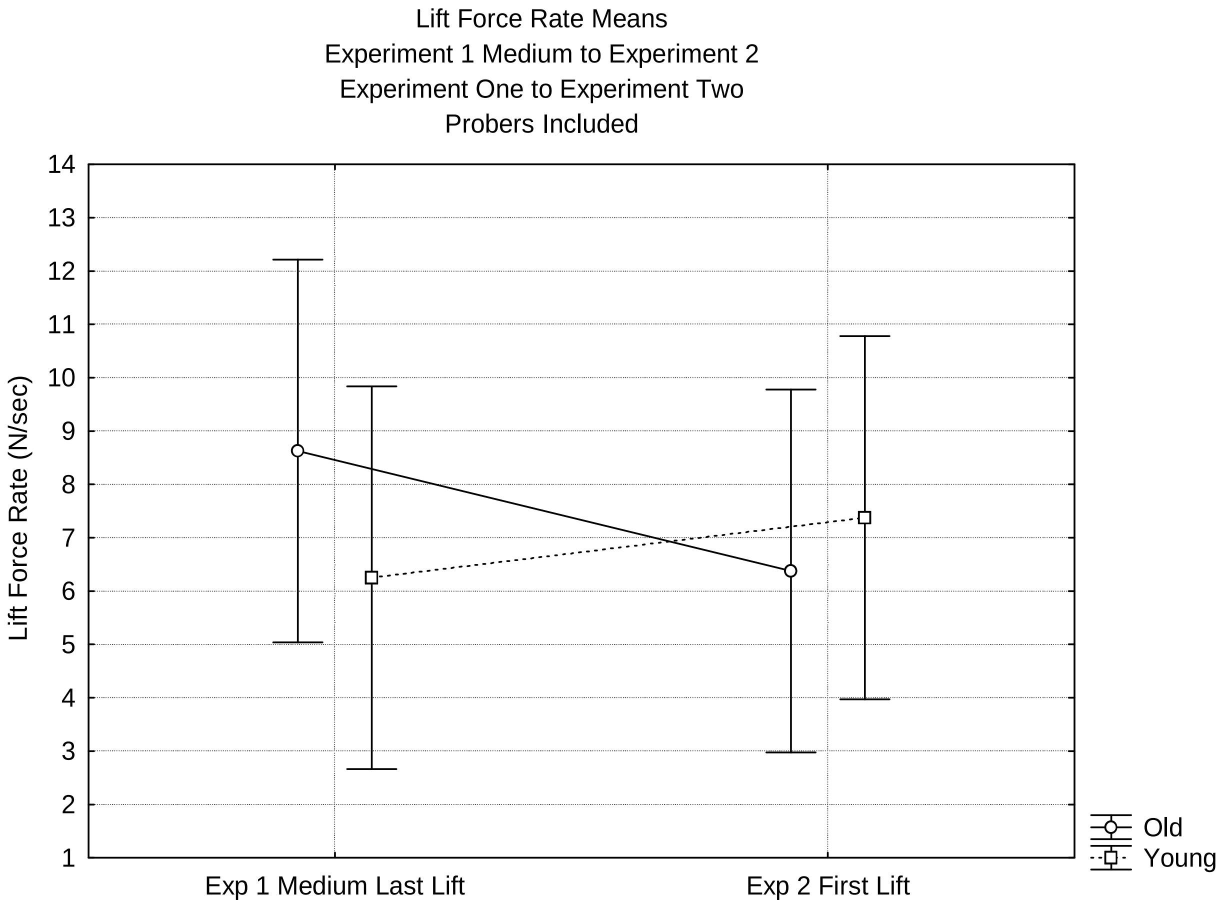

Figure 3-12.Graphical depictions of the lift force rate for experiment one to experiment two. The graph features the last lift of the medium bottle in the first experiment and the first lift of the slightly larger bottle in the second experiment. The data does include subjects that displayed a probing strategy.

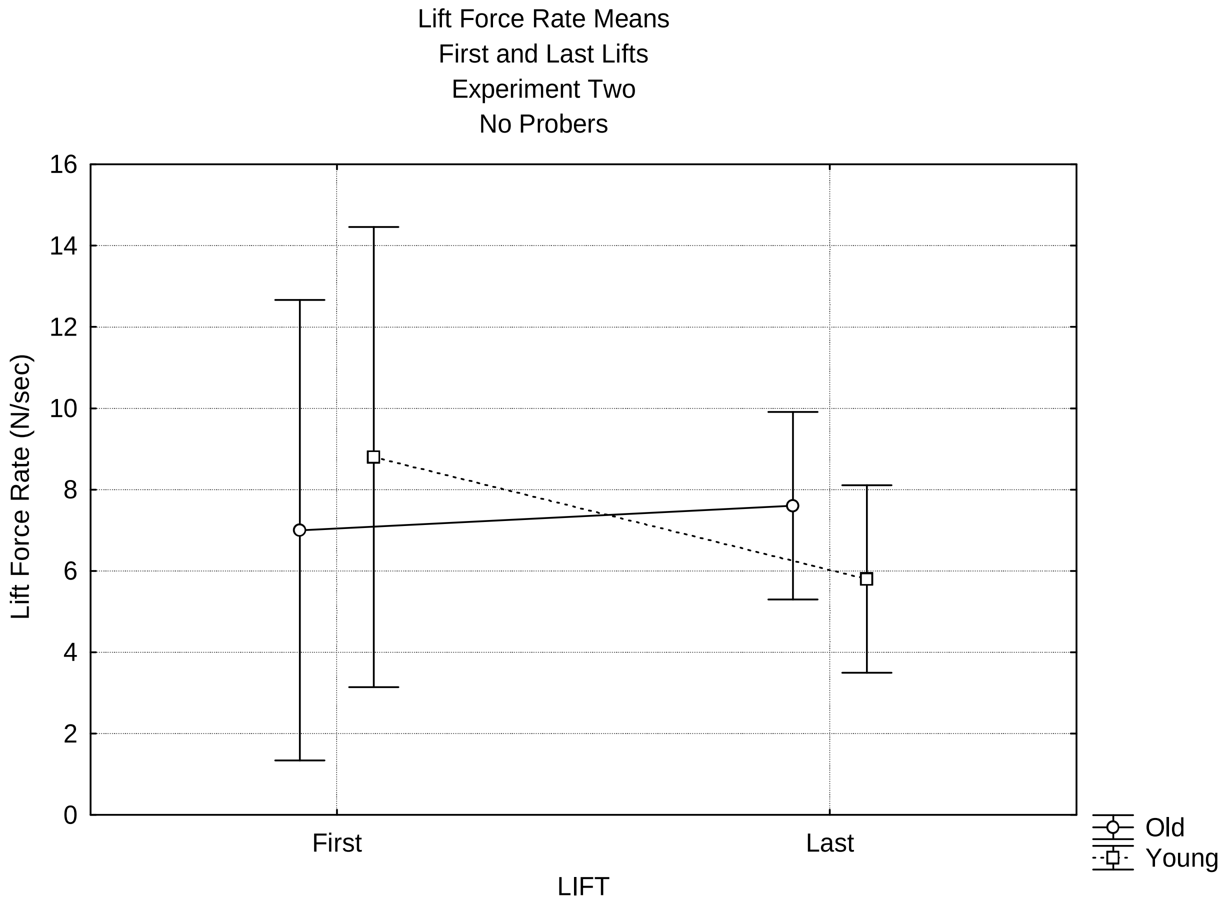

Figure 3-13.Graphical depictions of the lift force rate for experiment two. The graph features the first and last lift. The data does not include subjects that displayed a probing strategy.

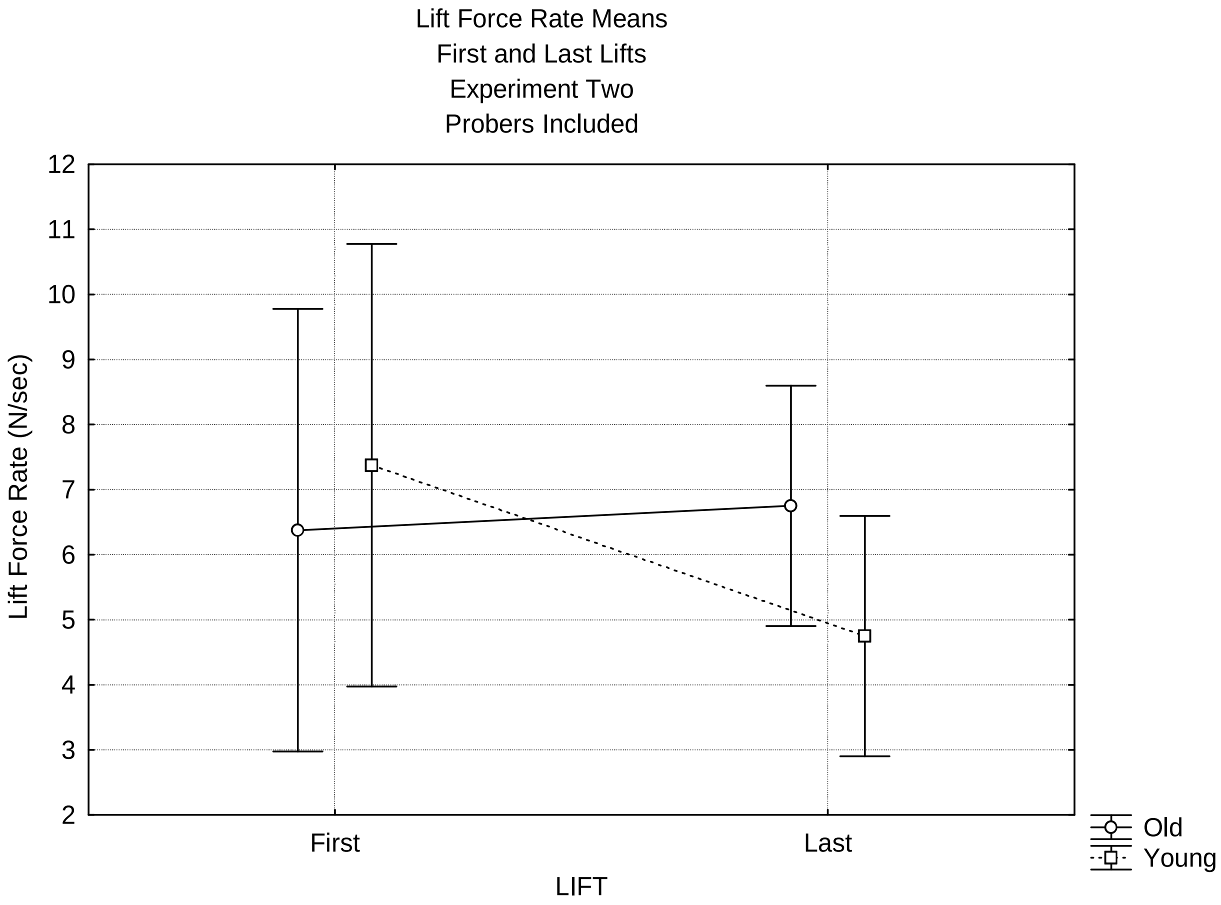

Figure 3-14.Graphical depictions of the lift force rate for experiment two. The graph features the first and last lift. The data does include subjects that displayed a probing strategy.

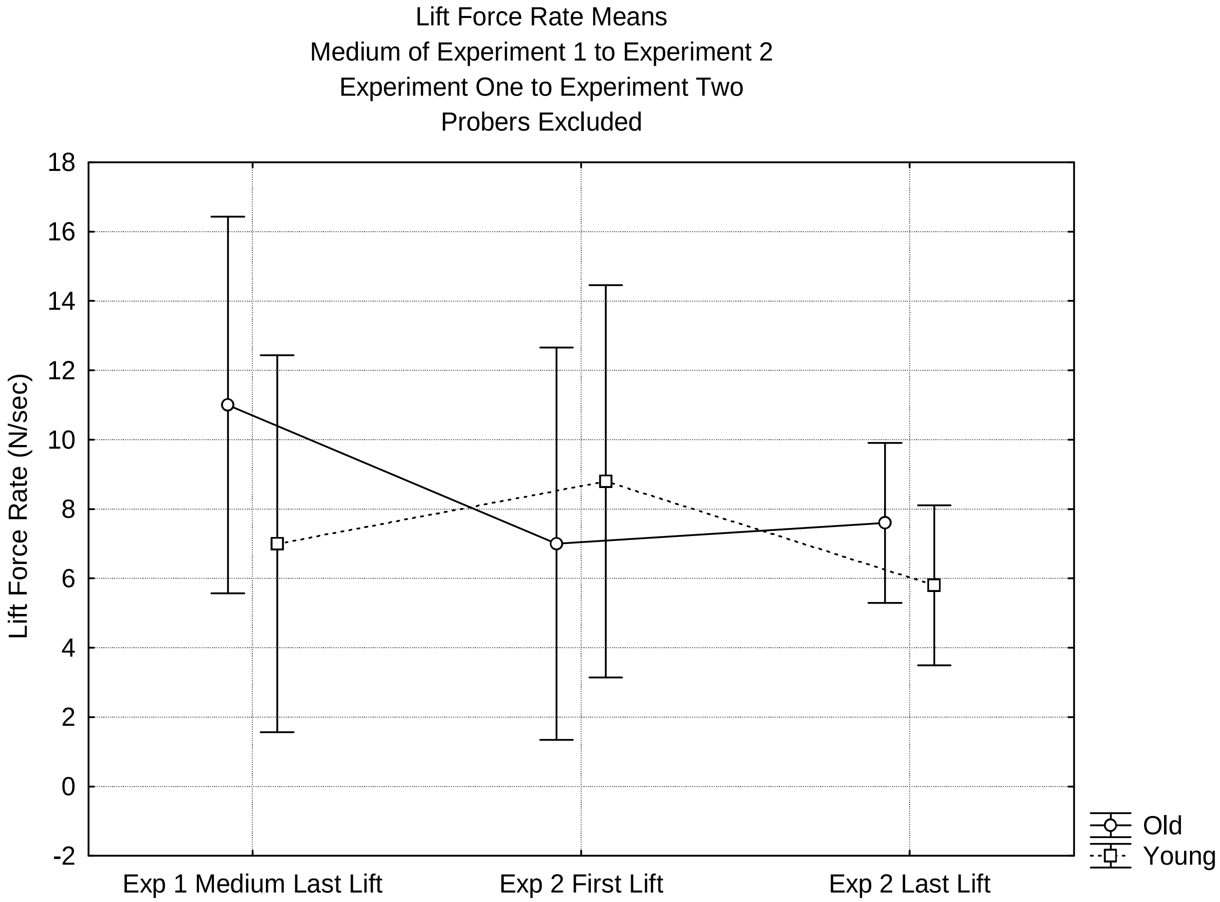

Figure 3-15.Graphical depictions of the lift force rate for experiment one to experiment two. The graph features the last lift of the medium bottle in the first experiment and the first and last lift of the slightly larger bottle in the second experiment. The data does not include subjects that displayed a probing strategy.

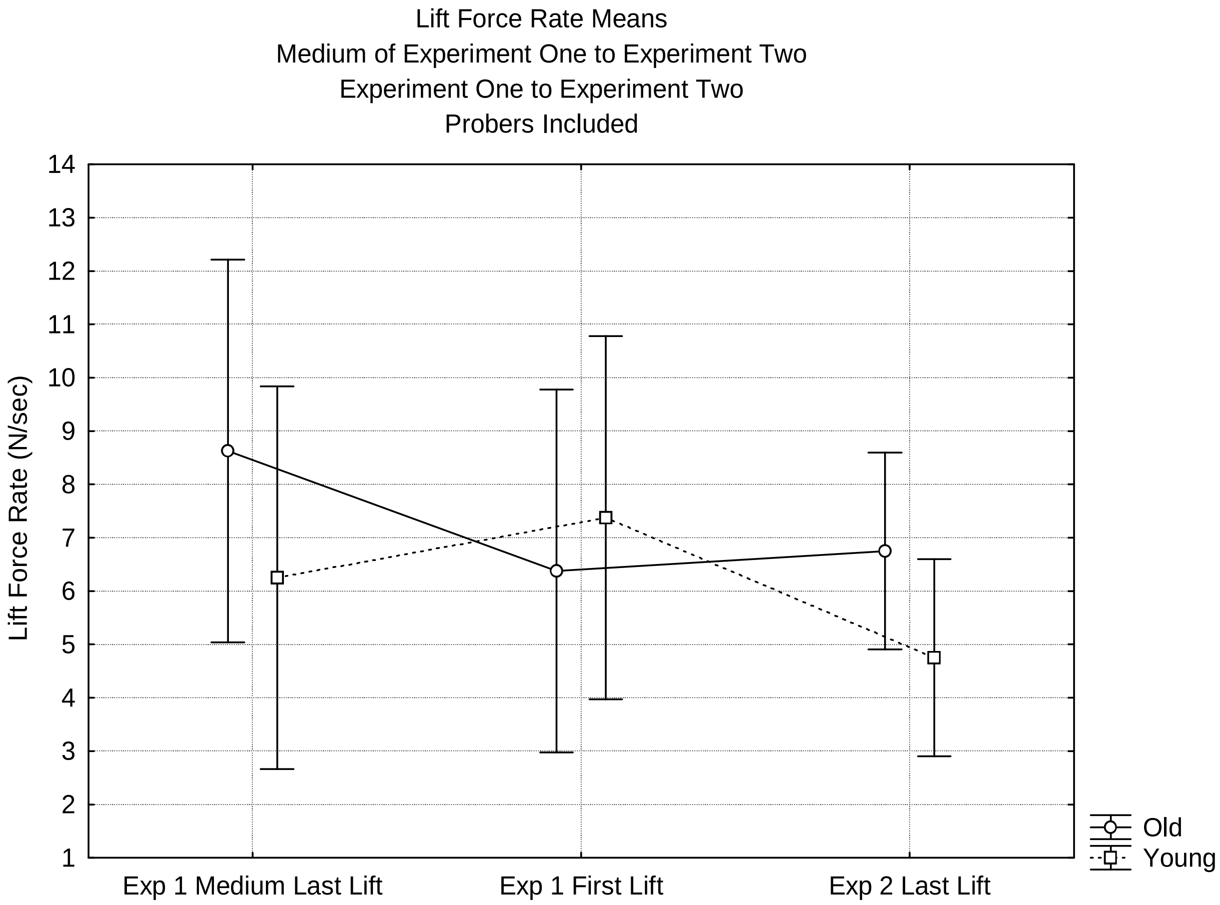

Figure 3-16.Graphical depictions of the lift force rate for experiment one to experiment two. The graph features the last lift of the medium bottle in the first experiment and the first and last lift of the slightly larger bottle in the second experiment. The data does include subjects that displayed a probing strategy.

CHAPTER IV

DISCUSSION

Overview

The purpose of this study was to investigate the accuracy of older adults in programming their lift force rates based on size cues on the initial lift with a novel object. The study included both young and old subjects undergoing the same experimental protocol. An additional purpose of the study was to duplicate previous findings that demonstrate the accuracy of young adults in programming their lift force rates.

Main results found in the study were:

- Consistent with previous findings, subjects utilized both target and probing strategies.
- A significant effect of size was observed in the young and old.
- Gordon’s work was replicated in that young adults accurately scale their lift force rates for changes in visual size cues.
- Old subjects scaled their lift force rates based on the size of the object but not to the accuracy of young adults.

Lifting strategies

This study replicated the findings of Gordon in demonstrating two lifting strategies. Both strategies were observed in the young and in the old subjects. The probing strategy (see Figure 2-2) presented with small lift force rate peaks building up to the liftoff of the bottle from the force plate. A similar step-wise increase in lift force rate was programmed by these subjects for all novel objects. An examination of consecutive lifts in both experiment one and experiment two revealed these subjects maintained use of the probing strategy. This strategy is a more cautious approach to lifting a novel object, relying on feedback from the bottle being lifted off the force plate as a signal to stop increasing lift force rate. Because probing relies on feedback it is not a predictive strategy for lifting; rather it is a strategy of reacting to the object's vertical motion. It prevents the subject from creating larger than necessary lift force rates that result in a high acceleration of the object (11). The remaining subjects presented the predictive, target strategy for lifting the novel object. These subjects presented a single peak (see Figure 2-3) lift force rate for lifting the object. This strategy demonstrates a direct neural representation of the object properties of weight and density due to the scaling of accurate lift force rates. The programmed forces are just enough to move the object against gravity. These anticipatory forces are programmed prior to the initial lift of the object which would provide sensory feedback of the object properties of weight and density.

Size effect

A size effect was observed for all subjects, regardless of age. The effect was pronounced and significant for those using a target strategy alone and for those utilizing a probing strategy. This result demonstrates that both young and old are scaling their initial lift force rate based on the visual size cues of the object in front of them. Visual size cues appear to dominate over sensorimotor memories in the programming of lifting forces when transitioning between objects of constant density but different volume. The first lift of the large bottle was the first encounter of the objects for this subject. This lift created a sensorimotor memory for density that the subjects would use for all lifts in both experiments. The second hypothesis stating older adults will produce lift force rates based on their previous lift was not supported due to the significant effect of size in experiment one. No Group x Size effect was found which provides additional support that both groups exhibited scaling.

The size effect was pronounced for large size transitions, such as from the large bottle to the small bottle (figures 3-5 and 3-6). Old adults were able to correctly scale down their lift force rate to the small bottle after previously lifting the large bottle. The decrease in lift force rate in this transition was greater for the old adult than it was for the young adults. This exemplifies an overshoot of the decrease in lift force rate. By the final lift of the small bottle the old subjects increased their lift force rates while the young decreased their lift force rates from the initial lift.

This effect was maintained in the transition from the small bottle to the medium bottle (figures 3-7 and 3-8). Again old adults demonstrated an accurate increase in lift force rates to lift the medium bottle. However, the old adults increased their lift force rates by the final lift of the medium bottle by nearly three Newtons per second while the young adults demonstrated a near constant lift force rate. The old may have increased their lift force rates over the course of lifts with the medium due to losing focus during the trials or in an effort to prevent slips by presenting an increased lift force rate. The young appear to have adapted better to the subtle size increase of the medium bottle than the old did.

Young adults

In accordance with the work of Cole and Gordon this study provided further evidence that young adults accurately scale their lifting forces prior to the initial lift with a novel object. On each initial lift with a new bottle in the experiment young subjects presented a unique lift force rate specified by the object size in front of them. They did not merely reproduce the lift force rate from the previous lift. Lift force rates were programmed according to the visual size cues of the object, larger lift force rates for the larger object and smaller lift force rates for the small object. This supports the strong association of visual size cues and programmed lifting forces. A stronger association would be observed if the bottles were varied more often which would create more size transitions. Sensorimotor memories were maintained for density between the objects but visual size cues enabled the young to accurately scale their lift force rates on the initial lift with each object (2, 10-12).

These results of accurate scaling were found with young subjects utilizing a full hand grasp to lift the object from the force plate. Previous literature focused on the lift force rates produced when subjects utilized a precision grip (9-13). Cole instructed subjects to grasp and lift only the cap rather than the whole bottle because of the size cues associated with circumference (2). Allowing subjects to feel the circumference of the medium bottle in experiment one may have added to the unique lift force rate produced in experiment two, that is the haptic information supported the visual analysis that the bottle was smaller than the previous bottle. The young adults were able to accurately scale up their lift force rates to the weight of the new bottle in experiment two despite the size difference not being visually salient between the medium bottle in experiment one and the bottle in experiment two.

Old adults

Old adults are in fact scaling their lift force rates based on visual size cues. This result was demonstrated by the lack of a significant effect for age in all parts of the study, however the effect of age was trending towards significant for the first experiment (p=.137). Old adults presented similar lift force rates as young adults as they transitioned from one bottle size to the next. They did not revert to the sensorimotor memory of the previous object weight to program forces for the initial lift of the new object. These results did not support the statement made in the second hypothesis of this study. They did rely on sensorimotor memory for object density across all objects in the study.

Despite scaling for object size old adults did present larger lift force rates for all bottles by the final lift as compared to young adults. The initial lift of the small bottle in experiment one without probers and the initial lift in experiment two were the only times the old adults programmed lift force rates below the young adults. In both cases the final lift of the bottle featured higher lift force rates by the old than by the young. It was expected a higher lift force rate would be used on the initial lift by the old so as to avoid slips. The higher lift force rate on the last lift may be indicative of a loss of focus in the experiment and a higher lift force rate being utilized to compensate for the attention loss. A higher lift force rate is correlated with a higher grip force, the force perpendicular object motion. A higher grip force rate would be necessary to steady the object if it is accelerated at a greater rate due to a higher lift force rate. This finding aligns with finding of Cole in which elderly subjects employ higher grasp forces to prevent object slips (3).

The young subjects were able to utilize information gained about bottle size from the initial grasp of the bottle prior to lifting it. Specifically they were able to deduce the size difference in experiment two from the medium bottle in experiment one and add that information to that already acquired from the visual size analysis and increased their programmed lift force rate for the increased circumference. Old adults did not demonstrate this effect. Old adults scaled their lift force rates for a smaller bottle than the medium bottle. These programmed forces are in opposition of the visual size cues and haptic information obtained from grasping the larger circumference. This result is the only time in the study that the old adults displayed lifting forces errors related to sensorimotor memories of the previous object and visual size cues of the current object. Hypothesis one discussing the production of lift force rates inconsistent with object size in the old is supported by the results of experiment two but is not supported by the results in experiment one. This suggests the lift force rate production based on size cues is subject to the magnitude of the size change.

This error observed in the old subjects with the slight size change may correlate with the work conducted by Cole and Rotella (2002) in which old adults were unable to scale their forces based on the arbitrary cue of color. In that experiment old subjects were able to state the color and were aware of the change in weight and friction but did not use that information to scale their forces properly (4). In this study by visually analyzing the bottle and grasping it in experiment two subjects were aware of the larger size of the bottle, thus providing haptic information of the size of the bottle to tie in with the visual size cues. Despite this information old subjects produced a lift force rate less than the previous smaller bottle. This suggests a decrease in visual sensitivity in the elderly. This result may represent a breakdown in visual analysis or a breakdown in the motor command after the visual information is processed or a combination of both. The motor command would be the accurate visual analysis sending commands to the muscles to be used to produce the necessary forces to lift the object. This experiment does not allow for that conclusion to be made as to which is responsible. In either case this inability to detect a small size changes or inability to program the proper lift force rate for a subtle size change may contribute to the slowing associated with aging. Slowing would result from large force variability and fatigue from utilizing larger lift force rates. The use of large lift force rates may cause decreased dexterity.

Limitations

The small sample size in this study does not allow for all significant effects to be observed that may be present in a larger study. The trends we observed may reach significant levels in experiments that feature more subjects. Additionally a larger sample size may show different effects than those observed in this study.

The block trial approach limits our analysis of the initial lift after a size change to one lift for each bottle. A pseudorandom presentation of bottles would allow for more transitions and more lifts to be analyzed.

Future work

This study opens the door for future studies in which a pseudorandom presentation of bottles is used to observe the effect of size transitions in the accuracy of lift force rate programming in old adults. This is similar to the presentation used by Gordon in his study of young adults (11). Additional objects would allow for more transitions to be analyzed and provide more insight into how well old adults can scale to subtle changes in size. The use of common objects would allow for a possible comparison to be made with novel objects. Time lags between lifts would dive further into the results we observed in experiment two.

Further work needs to explore arbitrary visual associations as they relate to different aspects of programming lift force rates in the old. This can include work with changing densities, the size-weight illusion, or a changing center of mass.

Conclusion

Old and young adults are able to accurately scale their lift force rate based on visual size cues of a novel object. This result supports previous literature of the accuracy of scaling in young adults and provides new insight into lift force rate scaling by old adults. Despite scaling for the visual size cues in obvious size transitions old adults display error in subtle size changes despite the visual and haptic information received prior to lifting the object. A loss of using visual and haptic information in the old to produce accurate lift force rates for subtle size changes may imply a decrease in the use of visual size cues and haptic size information for object manipulation. It appears old adults have decreased visual sensitivity to size changes that are not visually salient.

REFERENCES

1. Baugh, L., Kao, M., Johansson, R., & Flanagan, J. (2012). Material evidence: interaction of well-learned priors and sensorimotor memory when lifting objects. Journal of Neurophysiology, 108, 1262-1269.

2. Cole, K. (2008). Lifting a familiar object: visual size analysis, not memory for object weight, scales lift force. Experimental Brain Research, 188, 551-557.

3. Cole, K. (1991). Grasp force control in older adults. Journal of Motor Behavior, 23, 251-258.

4. Cole, K. & Rotella, D. (2002). Old age impairs the use of arbitrary visual cues for predictive control of fingertip forces during grasp. Experimental Brain Research, 143, 35-41.

5. Cole, K., Rotella, D., & Harper, J. (1999). Mechanisms for age-related changes of fingertip forces during precision gripping and lifting in adults. The Journal of Neuroscience, 19, 3238-3247.

6. Davare, M., Andres, M., Cosnard, G., Thonnared, J.L. & Olivier, E. (2006). Dissociating the role of ventral and dorsal premotor cortex in precision grasping. Journal of Neuroscience, 26, 2260-2268.

7. Davare, M., Rothwell, J., & Lemon, R. (2010). Causal connectivity between the human anterior intraparietal area and premotor cortex during grasp. Current Biology, 20, 176-181.

8. Diermayr, G., McLsaac, T., & Gordon, A. (2010). Finger force coordination underlying object manipulation in the elderly – a mini-review. Gerontology, 57, 217-227.

9. Forssberg, H., Kinoshita, H., Eliasson, A.C., Johansson, R.S., Westling, G. & Gordon, A.M. (1992). Development of human precision grip: II. Anticipatory control of isometric forces targeted for object’s weight. Experimental Brain Research, 90, 393-398.

10. Gordon, A., Forssberg, H., Johansson, R. & Westling, G. (1991). Integration of sensory information during the programming of precision grip: comments of the contribution of size cues. Experimental Brain Research, 85, 226-229.

11. Gordon, A., Forssberg, H., Johansson, R. & Westling, G. (1991). The integration of haptically acquired size information in the programming of precision grip. Experimental Brain Research, 83, 483-488.

12. Gordon, A., Forssberg, H., Johansson, R. & Westling, G. (1991). Visual size cues in the programming of manipulative forces during precision grip. Experimental Brain Research, 83, 477-482.

13. Gordon, A., Westling, G., Cole, K., & Johansson, R. (1993). Memory representations underlying motor commands used during manipulation of common and novel object. Journal of Neurophysiology, 69, 1789-1796.

14. Johansson, R. (1996). Sensory control of dexterous manipulation in humans. In: Wing, A., Haggard, P., Flanagan, J. (eds). Hand and Brain. Academic, San Diego, 381-414.

15. Johansson, R. & Cole, K. (1994). Grasp stability during manipulative actions. Canadian Journal of Physiology and Pharmacology, 72, 511-524.

16. Johansson, R. & Westling, G. (1988). Coordinated isometric muscle commands adequately and erroneously programmed for weight during lifting task with precision grip. Experimental Brain Research, 71, 59-71.

17. Martina IS et al. (1998). Measuring vibration threshold with a graduated tuning fork in normal aging and in patients with polyneuropathy. European Inflammatory Cause and Treat (INCAT) group. Journal of Neurology, Neurosurgery & Psychiatry, 65, 743-747.

18. Nowak, D., Koupan, C., & Hermsdörfer, J. (2007). Formation and decay of sensorimotor and associative memory in object lifting. European Journal of Applied Physiology, 100, 719-726.

19. Parikh, P. & Cole, K. (2012). Handling objects in old age: forces and moments acting on the object. Journal of Applied Physiology, 112, 1095-1104.

20. Sebalt, R. & et. Al. (2009). Detection of cognitive impairment and dementia using the animal fluency test: the DECIDE study. Canadian Journal of Neurological Sciences, 36, 559-604.