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Aging and Weight-Ratio Estimation

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AGING AND WEIGHT-RATIO ESTIMATION

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AGING AND WEIGHT-RATIO ESTIMATION

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Directed by: J. Farley Norman, Ph.D., Andrew Mienaltowski, Ph.D., and W. Pitt Derryberry, Ph.D.

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Many researchers have explored the way younger people perceive weight ratios using a variety of methodologies; however, very few researchers have used a more direct ratio estimation procedure, in which participants estimate an actual ratio between two or more weights. Of the few researchers who have used a direct method, the participants who were recruited were invariably younger adults. To date, there has been no research performed to examine how older adults perceive weight-ratios, using direct estimation or any other technique. Past research has provided evidence that older adults have more difficulty than younger adults in perceiving small differences in weight (i.e., the difference threshold for older adults is higher than that of younger adults). Given this result, one might expect that older adults would demonstrate similar impairments in weight ratio estimation compared to younger adults. The current experiment compared the abilities of 17 younger and 17 older adults to estimate weight ratios, using a direct ratio estimation procedure. On any given trial, participants were presented with two weights, and were asked to provide a direct estimate of the ratio, with the heavier in relation to the lighter. The results showed that the participants' perceived weight ratios increased as a linear function of the actual weight ratios and that compared to younger adults, the older adults overestimated the weight ratios. The age-related overestimation was especially pronounced at higher weight ratios.

Chapter 1

Introduction

We live in a world in which the population of older adults is growing rapidly. The United States Census Bureau (2011) found that the number of adults 62 years of age or older grew 21.1 percent from 2000 to 2010. This increase in population size was the largest among all the age groups assessed by the Census Bureau. With an aging population that is expanding at such a fast pace, it is becoming more important to understand the course of normal (i.e., non-demented) aging.

Some areas of sensory decline are relatively well studied in aging research. Age-related changes in many aspects of vision are very well documented: in addition to global decreases in visual acuity (Elliott, Yang, & Whitaker, 1995; Scheiber, 2006), numerous studies report declines in other areas of visual perception, including reduced low edge-contrast sensitivity and low-contrast visual acuity (Choy, Brauer, & Nitz, 2008); reduced color discrimination (Scheiber); and reduced sensitivity to form-from-motion cues (Norman, Payton, Long, & Hawkes, 2004). In addition to visual deficits, age-related declines have also been reported for the modalities of audition (Chou, Dana, Bougatsos, Fleming, & Bell, 2011), olfaction/gustation (Karpa et al., 2010), somatosensory functioning (Choy et al., 2008), and touch (Norman et al., 2011). Older adults also show an impairment compared to younger adults in the ability to integrate multiple sensory inputs (Nusbaum, 1999).

Though there have been several studies exploring the visual, auditory, olfactory/gustatory, and tactile functioning of older adults, one area of aging and sensory function that has not been well studied is weight perception. Weight perception may be studied using a variety of tasks, including weight discrimination and weight estimation (see Stevens & Galanter, 1957). The ability of younger adults to accurately discriminate weights has been studied for over 175 years (Weber, 1834/1996); however, very little weight discrimination research had been performed with older adults until Norman, Norman, Swindle, Jennings, and Bartholomew (2009) employed a weight-discrimination task to determine difference thresholds in younger and older adults. Their younger adults (18 to 30 years of age) needed only a 6.6 percent difference between two weights to be able to reliably discriminate which was heavier, whereas older adults (60 years of age and older) needed a 10.4 percent difference. Weight-ratio estimation, another method used to study weight perception, also has a relatively long history in psychophysics (see, e.g., Stevens & Galanter); however, to date there have been no studies that explore weight-ratio estimation in older adults. A full understanding of weight perception in older adults is an important area of sensory functioning that has long been ignored. Before explaining the significance of weight perception and what it may tell us about the sensory functioning of older adults, it is valuable to review the weight-ratio estimation literature concerning perception in younger adults.

Weight-Ratio Estimation

There are many methods used to study the perception of weight, which may be functionally split into two classes: those that involve category scales, which employ measurement at the ordinal level, and those involving ratio scales, which employ measurement at the ratio level (Nakatani, 1967; Stevens & Galanter, 1957). Category-related methodologies require a participant to effectively rate given weights; when presented with two weights, a participant may simply have to judge which of the two is heavier (e.g., Norman et al., 2009; Woodrow, 1933), or, when presented with three or more weights, a participant may have to rank them in order of heaviness (Curtis & Fox, 1969; Rule, Curtis, & Mullin, 1981; Stevens & Galanter). Ratio methodologies, on the other hand, are designed to require a participant to estimate the ratio between two or more weights (Stevens & Galanter). These methods include magnitude estimation, constant sum, fractionation, and multiplication (Nakatani).

Of the many ratio methods, the most commonly used is magnitude estimation. This method requires a participant to assign point values to weights based on the perceived magnitude, or heaviness, of each, usually—but not always—in relation to the perceived heaviness of a standard (often given the arbitrary point value of 100 by the experimenter). Nakatani (1967) used the method of magnitude estimation in one experiment in which participants were asked to assign point values to weights based on the apparent proportion of variable stimuli compared to a standard, which was assigned a point value of 100. The weights ranged from 40 to 200 grams, spaced in 20-gram increments, with a 100-gram weight as the standard. Using this methodology, Nakatani found that the relationship between physical weight and perceived weight was not linear, but could be well described by a power law (see Stevens, 1975, p. 13), where the exponent was 1.466. Some researchers employ a variation of magnitude estimation, in which no standard is provided and participants are required to estimate the magnitude of the given weights and assign points proportionate to the weight's heaviness (Stevens & Galanter, 1957). While no direct ratio is given in the method of magnitude estimation, the point values are meant to imply a ratio.

The constant sum method, originally proposed by Metfessel (1947), requires a participant to divide a given number of points between two weights. A study by Guilford and Dingman (1954) provides a good example of the use of this method. In one experiment, the authors asked their participants to lift two weights successively and divide 100 points between the weights (the number of given points, 100, is arbitrary); accordingly, if one weight felt four times as heavy as the other, the participant would assign 80 points to the heavier weight and 20 points to the lighter. In a second experiment, the authors provided five weights for the participants with the same instructions. As with the method of magnitude estimation, participants do not directly estimate a ratio, such as 1:4, but the division of points implies a ratio. Like Nakatani (1967), Guilford and Dingman found the relationship between physical and perceived weight to obey a power law.

Fractionation is another ratio method, along with its less-used counterpart, multiplication. With the method of fractionation, a participant is supplied a set of weights along with a standard. After lifting the standard, the participant must choose the weights that satisfy given ratios—for example, a participant may be asked to find a weight that seems half the weight of the standard. The method of multiplication is fundamentally the opposite of fractionation. Once again, a participant is provided with a standard and a set of weights, and must choose weights that seem to satisfy a given ratio; however, the standard is always the lightest weight, and the participant must find weights that seem twice as heavy, three times as heavy, etc. (Guilford & Dingman, 1954). Stevens and Galanter (1957) advise that multiplication should always be used with fractionation, to serve as a check of the fractionation results. Like the methods described above (magnitude estimation, constant sum), fractionation and multiplication do not require that a participant estimate a ratio directly; rather, the results are used to infer ratios.

Direct ratio estimation, though the least used, is the most straightforward of weight-ratio estimation methods. This method requires that the participant lift two weights and provide a direct estimate of the ratio between them (the heavier in relation to the lighter, a test in relation to a standard, etc.). Baker and Dudek (1955) were the first to study weight-ratio perception using the direct method. In their experiment two, the authors studied the accuracy of direct ratio judgments. Rather than having participants grasp the weights and lift them directly, the researchers constructed a box that had holes drilled in the top, through which metal chains were hung. At the top of the chains were loops for the participants to hold, and weights were hung on the other end of the chains. The participants lifted the weights by pulling upwards on the chains. There were nine stimuli whose weights ranged from 108.5 to 919.8 grams (chain weight included); each possible pair of the nine stimuli was presented to each participant. The participants were required to directly estimate the objects' weight ratio (i.e., the ratio of the heavier object compared to the lighter object). The authors found that there was a linear relationship between the physical weight ratios and the perceived weight ratios (see their Table 6). However, the slope of the linear function relating physical and perceived ratios was not 1.0, but 1.56, meaning that as actual ratio increased, the perceived ratio was consistently overestimated.

Rule and colleagues (1981) sought to further evaluate the accuracy of ratio estimations. The researchers used eight weights ranging from 20 to 290 grams, spaced equally following a cube-root transformation, and they employed a lifting method similar to Baker and Dudek (1955). In this study, each of the 80 participants made estimates using a single weight as the standard; varying the standard weight was a between-subjects manipulation. For example, in one condition the 20-gram weight would serve as the standard, and each of the other seven (i.e., test) weights would be paired with it in a random order, with a participant making ratio estimations for each pair. Using this method, the authors were able to produce eight different psychophysical functions describing the perceived weight ratios as a function of the various test weights (one function for each of the standard weight conditions). The authors found that, like the results of Baker and Dudek's study, as actual weight ratio increased, participants had a tendency to overestimate the ratios.

DeCarlo (2006) studied ratio estimation in a slightly different way; instead of presenting two weights on each trial, the author used a "successive" method, in which a participant would lift one weight and compare it to the weight presented on the previous trial. The weights ranged from 50 to 900 grams. DeCarlo found that there was a linear relationship between physical weight ratios and perceived weight ratios—the results indicated that there was a remarkably accurate one-to-one relationship between actual weight-ratios and perceived weight-ratios. This result contrasts with the results obtained by Baker and Dudek (1955) and Rule et al. (1981), and may be due to differences in methodology: DeCarlo's successive lifting method was quite different from the method employed by both Baker and Dudek and Rule and colleagues, in which two weights were presented within each trial.

Although there are differences in methods used to study weight ratio estimation (i.e., magnitude estimation, constant sum, fractionation and multiplication, and direct estimation), a review by Stevens and Galanter (1957) found that each method produces comparable results: as the actual ratio between object weights increases, so does the perceived ratio, and as the actual ratio becomes larger (i.e., as two weights become more dissimilar), participants tend to overestimate weight ratios.

Given the long history of weight-ratio estimation studies in psychology, it is surprising that no studies have performed this task with older adults as participants. The results from two previous studies using direct-ratio estimation with two weights presented on each trial (Baker & Dudek, 1955; Rule et al., 1981) show that, for younger adults, as actual weight ratio increases, perceived weight ratio also increases, and that the ratios tend to be overestimated. Would the same be true for older adults, or would their results differ? The purpose of this study was to investigate older adults' perception of weight ratios.

Chapter 2

Method

Participants

Seventeen older adults (age range was 64 to 78 years, mean age was 68.9 years, *SD* = 4.6) and 17 younger adults (range was 18 to 31 years, mean age was 23.9, *SD* = 3.6) participated in the experiment. Two potential participants (one older and one younger) were excluded because they did not understand the task. The participants were students at Western Kentucky University or were recruited from the local community. Participants were offered monetary compensation for their participation in the experiment.

Apparatus

The order of presentation of the experimental stimuli was randomly determined for each participant by an Apple iMac computer. Each presentation order was printed out, and the participants' weight-ratio estimates were manually recorded.

Stimuli

The stimuli were similar in size and shape to those used by Norman et al. (2009). The stimuli were small cylindrical bottles (all of identical size), which were filled with lead shot. The six test weights were 30, 55.9, 93.7, 145.5, 213.7, and 300 grams, the spacing of which was based on a cube-root transformation (see Rule et al., 1981). Two stimuli for each weight were created, so that each weight could be paired with itself and every other weight.

Procedure

There were 36 conditions (a result of each stimulus being paired with every other stimulus and with itself) and three repetitions for each condition, creating a total of 108 trials. Every participant made 108 judgments. The participants were visually separated from the stimuli and experimenter by an occluding barrier, through which participants placed their preferred arm. The stimuli were placed in front of the participants so they could be easily reached and lifted. On any given trial, two stimuli were set side-by-side in front of the participant, with the standard always on the participant's left. The participant's task was to lift the stimuli one at a time, always starting with the stimulus on the right (the test stimulus). The participants were instructed to lift each stimulus once and set it back down before lifting the next one. The participants had up to 30 seconds to lift the test and standard stimuli. The participants were required to keep their elbows on the table at all times and lift with their forearms, and were instructed to use their thumb and first two fingers to grasp the experimental stimuli. By keeping the grasping and lifting methods constant, any error that may have resulted from individual differences in grip was reduced (Flanagan & Bandomir, 2000).

After lifting each weight as many times as was necessary (within the 30-second time limit) to make a conscientious judgment, participants estimated the ratio of the heavier weight in relation to the lighter (i.e., how much heavier the heavier weight felt compared to the lighter). The participants had the option of saying the weights were equal if the two stimuli felt that they weighed the same amount. At the end of the experimental session, the participants were asked to report how many unique stimuli they thought had been presented. The participants' responses were manually recorded during the experiment.

Chapter 3

Results

For every participant, the perceived weight ratios for each of the 108 stimulus pairs were plotted against the actual weight ratios. The relationship between perceived and actual weight ratio was found to be linear, and the Pearson *r*, along with the y-intercept and slope of the best-fitting regression line, were calculated. Figures 1 and 2 show results for representative younger and older participants, respectively.

A Wilcoxon rank-sum test (Wilcoxon, 1945) was used to test for differences between the younger and older groups. As can be seen in Figure 3, the mean slope of the older group was significantly higher than that of the younger group ($W_s = 235$, $p = 0.031$). The older adults' unique weight estimates ($M = 12.00$, $SD = 4.86$) were also higher than those of the younger adults' ($M = 11.24$, $SD = 12.39$; $W_s = 234.5$, $p = 0.029$). As shown in Figure 4, the mean Pearson *r*'s for each group were not significantly different ($W_s = 283.5$, $p = 0.63$). Likewise, the difference in y-intercepts for the younger group ($M = -0.03$, $SD = 1.4$) and older group ($M = -3.35$, $SD = 10.6$) was not significant ($W_s = 257.5$, $p = 0.17$).

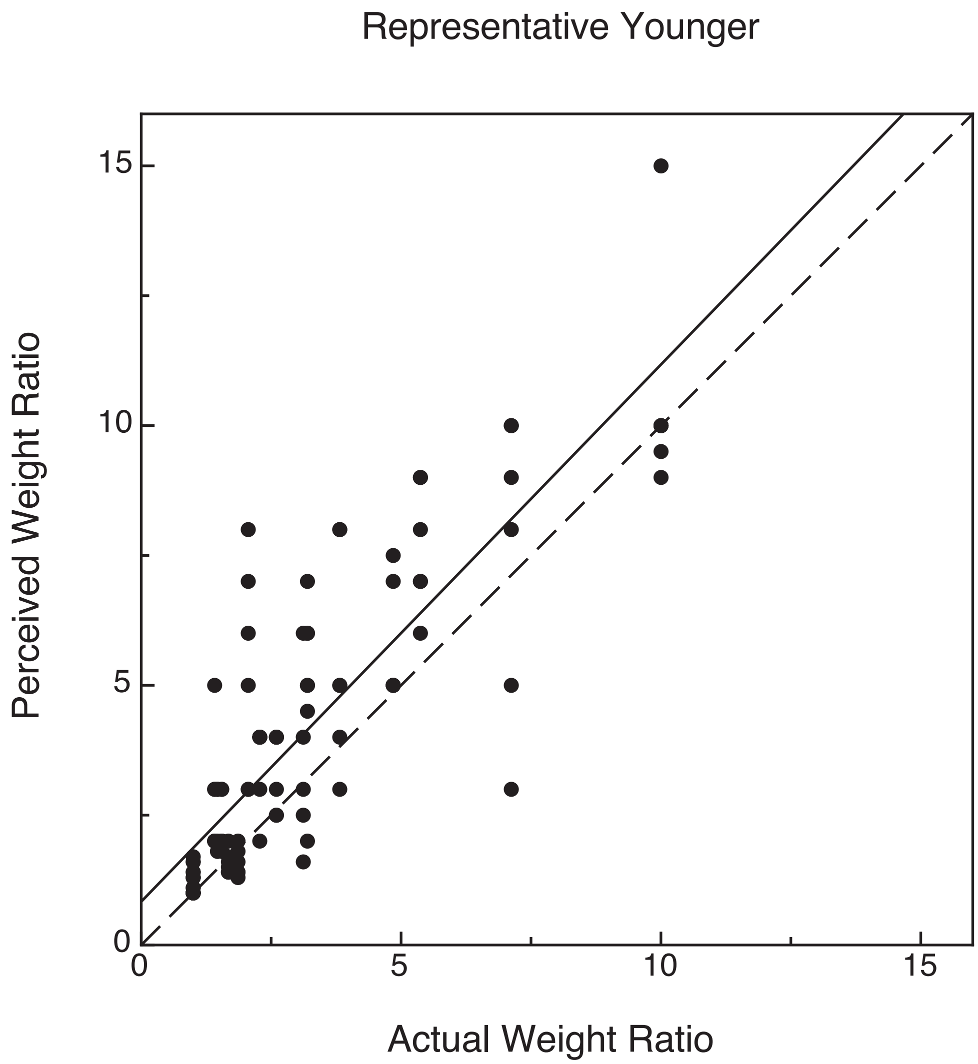

Figure 1. Individual results for a representative younger participant. The participant's perceived weight ratios are plotted against the actual weight ratios. The slope of the best-fitting regression line (solid line) for this participant is 1.03. The dashed line represents perfect perceptual performance.

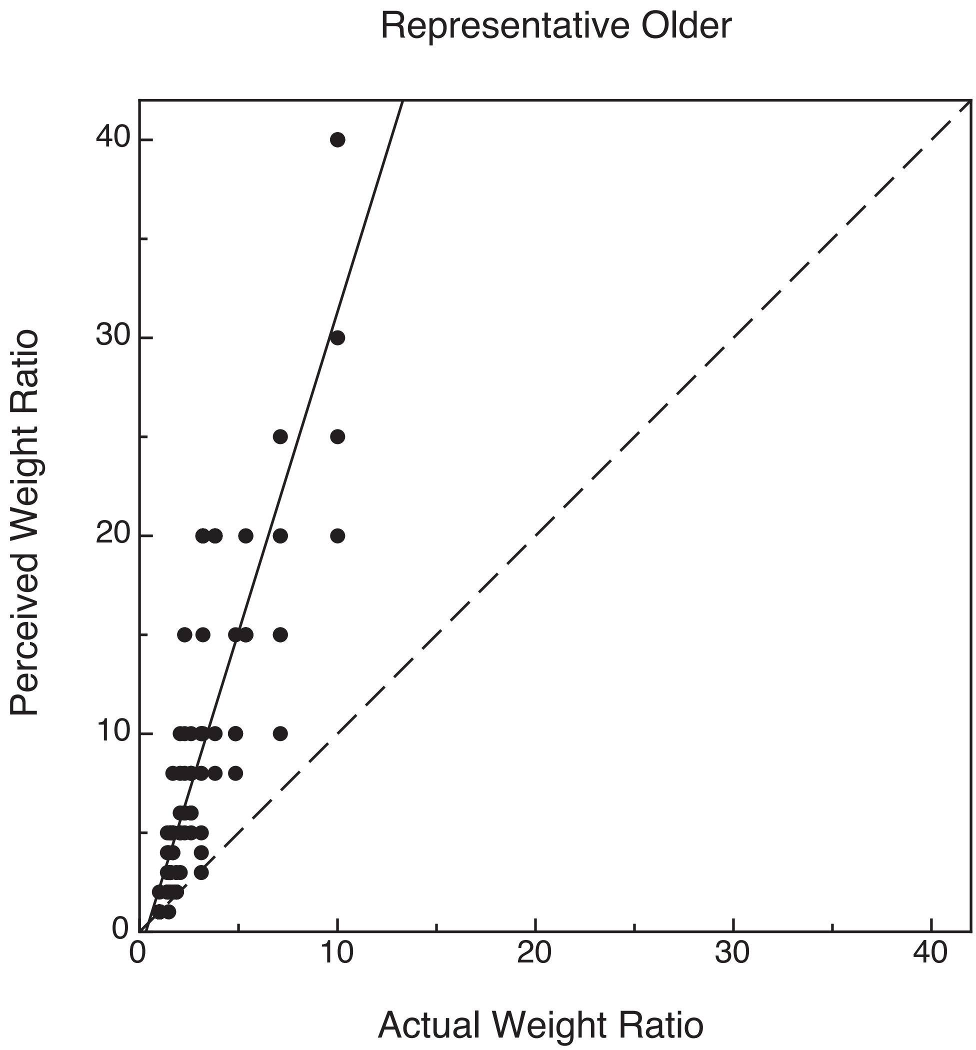

Figure 2. Individual results for a representative older participant. The participant's perceived weight ratios are plotted against the actual weight ratios. The slope of the best-fitting regression line (solid line) for this participant is 3.92. The dashed line represents perfect perceptual performance.

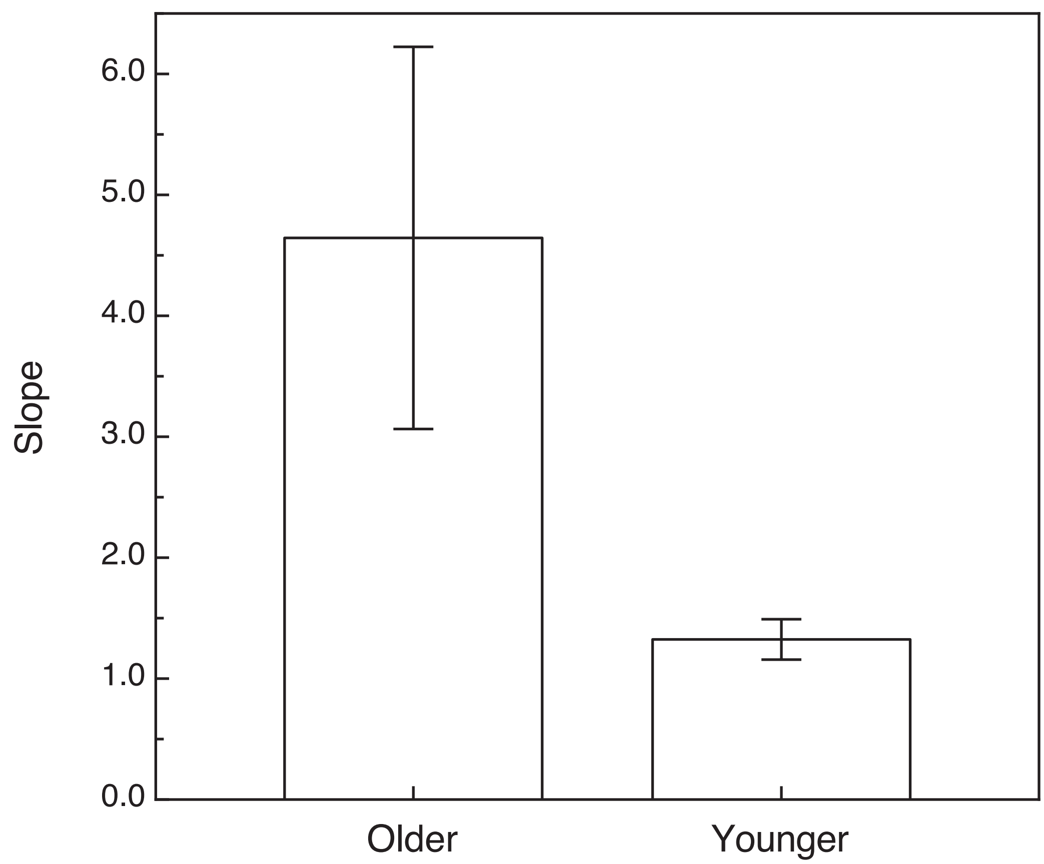

Figure 3. The mean slopes (of the best-fitting regression lines) for the younger and older groups of participants are plotted separately. The error bars indicate +/- one SE.

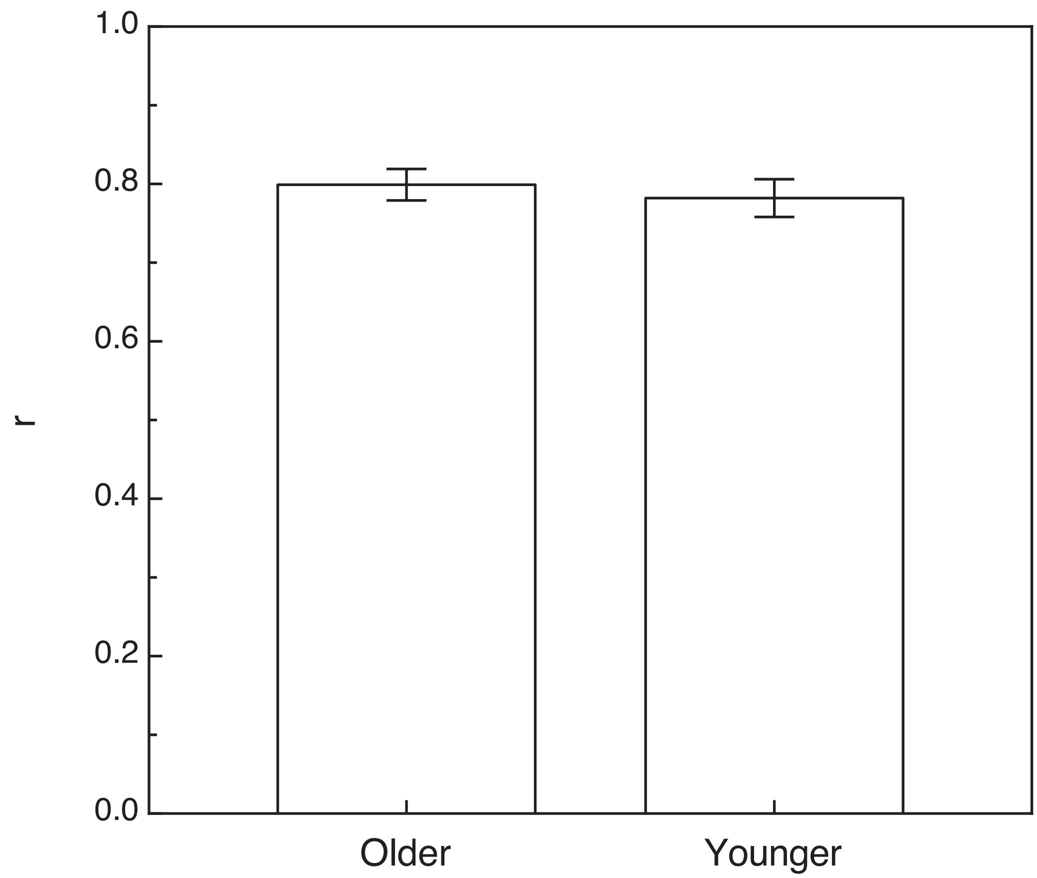

Figure 4. The mean Pearson r for the older and younger groups of participants are plotted separately. The error bars indicate +/- one SE.

Chapter 4

Discussion

The results of the current study show that there is no difference between younger and older adults in the magnitude of the correlation between perceived weight ratio and actual ratio, or in the y-intercept of the best fitting regression line. However, differences between age groups did emerge in the comparison of slopes and unique weight estimates. In terms of the differences in slope, the older adults greatly overestimated the weight ratios; for example, when the actual weight ratio was 10, many older adults perceived the ratio to be 30 or 40. The unique weight ratio estimate for older adults was also larger than that for younger adults; however, it is important to keep in mind that the estimates of both groups were very inaccurate (12.00 and 11.24 for the older and younger participants, respectively). It therefore appears that the difference in unique weight estimates cannot explain why the younger participants' weight ratio estimates were fairly accurate, while those of the older participants were highly inaccurate. The difference in slopes between the groups is probably caused by perceptual, not cognitive, differences between younger and older adults.

The results for the younger group are similar to those found by Baker and Dudek (1955) and Rule et al. (1981)—there was a linear relationship between the perceived and actual weight ratios (i.e., as the actual ratio increased, so did the perceived ratios). Baker and Dudek and Rule et al. found that younger adults moderately overestimate weight ratios as actual ratio increases, and the results of the current study replicate these findings. Baker and Dudek's mean slope for younger adults was 1.56, while the mean slope for the younger adults in the current study was 1.32.

In contrast, the results of this experiment differ from those of DeCarlo's (2006) study, which found a one-to-one relationship between perceived and actual weight ratios—the younger participants in his study were almost perfect in their perception of weight ratios. This difference in results may be due to the fact that DeCarlo used a successive lifting method, in which a single weight was presented on each trial and was compared to the weight that had been presented on the preceding trial. Even taking this methodological difference into account, his results are very surprising, and it would be worthwhile to attempt to replicate his study using both older and younger adults as participants.

Younger adults overestimated the current weight ratios, and this overestimation was greatly increased for older adults. Aging has been shown to have detrimental effects on weight discrimination tasks (Norman et al., 2009). Why do older adults possess these weight perception deficits? For the task employed in the current study, we can rule out a difference between the groups in their ability to use numbers effectively: the mean Pearson r was essentially identical for younger (r = 0.78) and older participants (r = 0.80). In this case, a high magnitude of r indicates that the participants understood the task, and were effectively providing smaller numbers for smaller ratios and larger numbers for larger ratios (i.e., the younger and older adults were equally precise in their weight ratio estimates).

To help explain the age differences that were obtained in this weight-ratio estimation task, it is important to understand the brain mechanisms underlying weight perception. Weight perception is, counter-intuitively, not primarily a product of afferent signals coming from muscle receptors in the arm and hand, but is due to physiological mechanisms entirely contained within the cerebral cortex. According to Clark and Horch (1986), a “command center” in the brain sends a directive to the motor system, which sends a signal to skeletal muscles, causing a person to make voluntary movements to grasp and lift an object. Simultaneously, a copy of that original motor signal, called a corollary discharge, is sent to the cortical center responsible for weight perception. It is mainly the strength of this motor signal that produces one’s perception of heaviness, not peripheral sensory information coming from muscle receptors, as was long believed (Bell, 1826; Bell, 1833).

There is evidence from patient case studies (Chatterjee & Thompson, 1998) as well as from functional magnetic resonance imaging (fMRI) experiments (Jenmalm, Schmitz, Forssberg, & Ehrsson, 2006; Schmitz, Jenmalm, Ehrsson, & Forssberg, 2005) that the perceptual center for heaviness in the cerebral cortex is located in the parietal lobe, specifically, the right hemisphere’s supramarginal gyrus and left hemisphere’s parietal operculum. DC, a woman whose case was reported by Chatterjee and Thompson, presented with damage to the right parietal lobe, including the supramarginal gyrus. DC had a severe deficit in weight perception. In a series of experiments, the authors found that DC consistently judged weights lifted by her left arm and hand (the side contralateral to the area of brain damage) as being lighter than weights lifted by her right arm and hand. These errors occurred even if the weight on the left side was much heavier (e.g., 800 grams more) than the weight on the right side. This result was consistent across changes in method (i.e., whether the weights were lifted simultaneously or successively, or whether they were lifted actively or felt passively).

Schmitz et al. (2005) and Jenmalm et al. (2006), in a series of fMRI experiments, sought to further delineate the areas of the parietal lobe responsible for weight perception. Schmitz et al. had participants lift objects that had either constant weight, changed weight from trial to trial in a regular pattern, or changed weight unexpectedly. In the conditions in which weight was changed regularly and irregularly, activation was stronger in the left parietal operculum and the right supramarginal gyrus, compared to constant weight conditions. Specifically, the authors posited that activation of the left parietal operculum reflected an updating about changes in object weight.

In a similar study, Jenmalm and colleagues (2006) had participants lift objects that changed in weight unpredictably (i.e., the stimulus lifted on any given trial might be 500 grams heavier or lighter than, or the same weight as, the stimulus lifted on the preceding trial). The authors found that, regardless of whether the weight of the stimulus was lighter or heavier than expected (based on the weight of the immediately preceding stimulus), the right supramarginal gyrus was active. The authors suggested that this region is involved in signaling a mismatch between expected and presented object weight.

Animal studies have indicated that the posterior parietal cortex (PPC) is involved in the planning of reaching for and grasping objects (Andersen & Buneo, 2002; Snyder, Batista, & Andersen, 1997) and in hand-object manipulation (Sakata, Taira, Murata, & Mine, 1995; Taira, Mine, Georgopoulos, Murata, & Sakata, 1990). Lesion studies of humans also show that PPC damage often results in severe impairments of reaching and grasping (Fattori, Breveglieri, Amoroso, & Galletti, 2004). The PPC lies adjacent to the supramarginal gyrus and parietal operculum; it is not surprising that cortical areas responsible for weight perception are close to areas responsible for the planning and execution of reaching for, grasping, and manipulating objects (actions that are necessary for one to to form accurate weight perceptions of those same objects).

How does this information help explain the impairment of older adults in the current weight-ratio estimation task? Consider studies of cortical atrophy and aging. Resnick, Pham, Kraut, Zonderman, and Davatzikos (2003) found in their study that the parietal lobe of the cerebral cortex loses volume more rapidly than any other lobe, even for a group of “very healthy” older adults (p. 3295). Considering that the parietal lobe is the area of the cerebral cortex responsible for weight perception, its atrophy could logically lead to poorer weight discrimination, such as Norman et al. (2009) found, and this atrophy could help explain the results of the current study as well.

The current study has filled a void in the relevant scientific literature by examining the effects of aging on weight-ratio estimation. Very little research has explored the abilities of older adults to accurately perceive and discriminate weight, although the visual (see Scheiber, 2006) and auditory abilities (see Chou et al., 2011) of older adults have been very thoroughly studied. Understanding the sensory functioning of older adults is important because sensory abilities are robust indicators of cognitive functioning (i.e., low sensory functioning suggests low cognitive functioning in older adults; Park, 1999). With the American population aging rapidly (United States Census Bureau, 2011), any means by which we may be able to identify and treat the sensory and cognitive deficits of aging is important for both caregivers and the affected older adults. Future research should attempt to confirm the importance of the parietal operculum and supramarginal gyrus in weight perception using imaging or electrophysiological techniques. Psychophysical tasks, like the one employed in the current study, may be useful clinically in diagnosing cerebral atrophy in aging populations.

Appendix

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In future correspondence, please refer to HS11-222, March 18, 2011

Jessica S. Holmin
c/o Dr. Norman
Psychology
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Jessica S. Holmin:

Your research project, *Aging and Weight-ratio Estimation*, was reviewed by the IRB and it has been determined that risks to subjects are: (1) minimized and reasonable; and that (2) research procedures are consistent with a sound research design and do not expose the subjects to unnecessary risk. Reviewers determined that: (1) benefits to subjects are considered along with the importance of the topic and that outcomes are reasonable; (2) selection of subjects is equitable; and (3) the purposes of the research and the research setting is amenable to subjects' welfare and producing desired outcomes; that indications of coercion or prejudice are absent, and that participation is clearly voluntary.

1. In addition, the IRB found that you need to orient participants as follows: (1) signed informed consent is required; (2) Provision is made for collecting, using and storing data in a manner that protects the safety and privacy of the subjects and the confidentiality of the data. (3) Appropriate safeguards are included to protect the rights and welfare of the subjects.

This project is therefore approved at the Expedited Review Level until March 18, 2012.

2. Please note that the institution is not responsible for any actions regarding this protocol before approval. If you expand the project at a later date to use other instruments please re-apply. Copies of your request for human subjects review, your application, and this approval, are maintained in the Office of Sponsored Programs at the above address. Please report any changes to this approved protocol to this office. A Continuing Review protocol will be sent to you in the future to determine the status of the project. Also, please use the stamped approval forms to assure participants of compliance with The Office of Human Research Protections regulations.

Sincerely,

Paul J. Mooney, M.S.T.M.
Compliance Manager
Office of Research
Western Kentucky University

cc: HS file number Holmin HS11-222

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