UNDERSTANDING AGE-RELATED DIFFERENCES IN NUMERACY:

A PROCESS LEVEL APPROACH

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UNDERSTANDING AGE-RELATED DIFFERENCES IN NUMERACY:

A PROCESS LEVEL APPROACH

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SUMMARY

This study is an investigation into the relationship between numeric cognition and aging. Specifically, older and younger adults engaged in an experimental protocol that allowed observation of number comparison accuracy and response time latencies associated with the SNARC effect, the distance effect, and number format.

The experimental protocol featured a computerized magnitude comparison task wherein the participants were prompted to identify the larger of two numbers. Half of the trials featured whole numbers and half featured fractions. The number stimuli were consistently mapped such that half of all trials were at near distance (i.e., difference of 2) or far distance (i.e., difference of 4) and half of all trials had the larger numerosity on the left side of space and the other half with the larger numerosity on the right side of space.

Older adults were significantly slower and less accurate than young adults. Both age groups were significantly slower and less accurate when comparing fractions as opposed to comparing whole numbers. The SNARC effect impaired accuracy in both age groups but did not significantly impact response times. The distance effect impacted both age cohorts in accuracy but differentially impacted older adult response times more than young adult response times.

The results of this study support the model of numeric cognition as an automatic process when comparing whole numbers at a far distance and this process is not disrupted by the SNARC effect but is when comparing whole numbers at near distance. The results also indicate that fraction comparison is a controlled process even when the fraction stimuli are consistently mapped. Further investigation is necessary to understand the amount of cognitive resources necessitated by fraction processing and if training can improve fraction comparison.

Keywords: Numeracy, The SNARC effect, Distance effect, Number format, Age-related differences

CHAPTER 1

Introduction

Most of America's 40,267,984 older adults are living independently and wish to remain that way (AARP, 2005; U.S. Census, 2010). The desire for independence is driven largely by its impact on quality of life. Also, in times of economic hardship, independence is of the utmost importance because it greatly influences cost of living.

Numeracy is essential for independence. Loosely defined, numeracy is the ability to make meaning of numeric information. In fact, certain levels of numeracy are necessary for successfully carrying out each of the Instrumental Activities of Daily Living IADLs (Lawton & Brody, 1969). The IADLs are a set of eight categories of activities that one must be able to effectively complete to maintain an independent life. For example, to effectively use a recipe to prepare a meal one must usually identify and make meaning of multiple kinds of numeric information. Recipes also often feature information presented as a fraction (e.g., 3/4 of a cup). While effective management of any IADL is reliant on numeracy, this need is exaggerated for self-medication and managing finances (Fausset, 2009; Smith, McArdle, & Willis, 2010). The increased need for sufficient numeracy in these domains may be because older adults are often forced to mediate their health and financial needs through social welfare systems such as Social Security and Medicare, both of which are complex systems that may feature special difficulties for older adults (Besedes, Deck, Sarangi, & Shor, 2010). For instance, the decision to take one medication over another might involve understanding which needs to be taken more often as well as a comparison of the chances for a medicinal interaction or negative side-effect and the financial cost of taking one medicine over another.

Unfortunately, low levels of numeracy are prevalent in older adults (Kirsch, Jungleblut, Jenkins, & Kolstad, 2002). Kirsch and colleagues (2002) defined numeracy as, “the knowledge and skills required to apply arithmetic operations, either alone or sequentially, using numbers embedded in printed materials; for example, balancing a checkbook, figuring out a tip, completing an order form, or determining the amount of interest from a loan.” (p. 3). They surveyed 26,091 people, including 2,214 older adults (i.e., people 65 and over), to assess numeracy levels in America. The study had two discouraging findings. First, only 17% of participants had enough proficiency in numeracy to complete tasks that required, "the reader to perform two or more sequential operations or a single operation in which the quantities are found in different types of displays, or the operation must be inferred from semantic information given or drawn from prior knowledge" (p. 11). Second, the mean participant aged 65 and older operates at a numeracy level that is sufficient for performing, "a single operation using numbers that are either stated in the task or easily located in the material," and, "the operation to be performed may be stated in the question or easily determined from the format of the material" (p. 11).

Kirsch et al. (2002) proposed that cohort differences in years of education between older and younger adults was the cause of these differences in numeracy but their own definition of numeracy can be used to refute this claim via a wealth of research dealing with age-related differences in cognition. For example, age-related differences in sensory functioning could be a major factor driving differences in the ability to perceive numbers embedded in printed materials (Fisk, Rogers, Charness, Czaja, & Sharit, 2009). Also, age-related differences in working memory would most likely impact one's ability to sequentially apply arithmetic operations (Lusczc, 2011). Both of these examples highlight age-related differences in the use of (i.e., way that people use resources) and ability to use (i.e., differing levels of proficiency in resource utilization) cognitive resources (e.g., attention, inhibition, and working memory).

Consider the more descriptive definition of numeracy proposed by Gal (2000):

> an aggregate of skills, knowledge, beliefs, dispositions, habits of mind, communication capabilities, and problem-solving skills that individuals need in order to autonomously engage and effectively manage numeracy situations that involve numbers, quantitative or quantifiable information, or visual or textual information that is based on mathematical ideas or has embedded mathematical elements. (p. 12)

This definition paints a cognitively complex picture of numeracy, elaborating upon the definition of Kirsch et al. (2002). This definition broadens the list of cognitive inputs into numeracy outcomes and, therefore, numeric decision-making becomes increasingly demanding of cognitive resources.

Resource demanding tasks can impair older adult performance (Park, 2000). Verhaeghen and Salthouse (1997) conducted a meta-analysis of studies featuring cognitive differences related to aging. The meta-analysis featured 91 different studies dealing with a wide range of tasks. Importantly, greater age-related differences were found in tasks featuring heavy demands on cognitive resources compared to tasks that were essentially knowledge and perception driven. A key piece of information gleaned from this study is that age-related differences in response times on non-resource demanding tasks show a much different pattern than age-related response time differences on resource demanding tasks. Consequently, as the amount of resources needed to successfully comprehend numeric information increases, older adult performance will likely decrease in the form of extended response times. Moreover, numeracy related phenomena that are more perceptually driven at the process level will likely be more comparable between younger and older adults than numeracy related phenomenon that are more demanding of working memory.

Current knowledge of age-related differences in numeracy is generally derived from survey design experiments. While this is important to understanding the phenomena, it is only the beginning of the process. To truly understand the psychology of numeracy, we must investigate at a more basic level: the cognitive process level. By understanding age-related differences in numeracy at the process level we can begin to understand the causes of these differences. Furthermore, process level investigation will be a sufficient base of understanding to describe the kinds of numeracy processes that will create the most difficulty for older adults and will, therefore, allow researchers and policy makers to identify tasks that need the most attention for improving older adult numeracy outcomes. Also, understanding age-related differences in numeracy at the process level will help provide a base of knowledge for neuroscience researchers to link nervous system functioning to numeracy.

Lipkus and Peters (2009) proposed an information-processing model of numeracy (Figure 1).

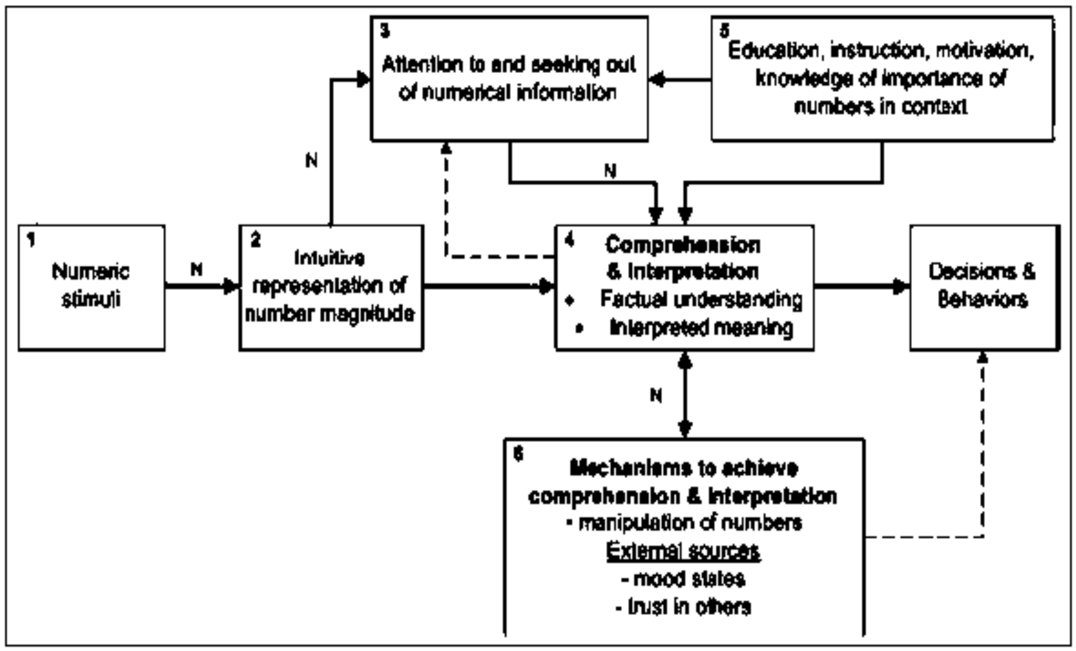


Figure 1. Process Model of Numeracy. Taken from Lipkus & Peters, 2009 (p. 1073).

There are three phenomena that can be manipulated to understand process level determinants of numeracy and describe age-related differences at the process level to help explain age-related differences in numeracy: The Spatial-Numerical Association of Response Codes (SNARC), the distance effect, and presentation format. Furthermore, cognitive resource demands associated with each phenomenon can provide insights into how resource demands influence older adult performance. These demands can be viewed in relation to Figure 1 and I will elucidate further on the meaningfulness. First, the SNARC effect is highly associated with a process loop composed of nodes 1, 2, 3, and 4. Second, the distance effect and presentation format are both associated with the full model but with the effects of nodes 5 and 6 being more influential for presentation format than for the distance effect. The proposed study features a modified magnitude comparison task to capture response times associated with location of presentation, magnitude differences, and number format (i.e., the SNARC effect, the distance effect, and presentation format, respectively).

The Mental Number Line

The concept of a mental number line has been prominent in studies of numeric cognition. The essential idea is that people, at least people in Western societies, cognitively represent numbers in a spatial fashion as an automatic/intuitive process with smaller values on the left side of space and larger values on the right side of space (Figure 2). In addition, the mental number line is comprehensive and logarithmically scaled. When a given node of the number line is activated through number perception, a Gaussian distribution of activation occurs around the node with constant width and maximal levels of activation at the center of the node (Izard & Dehaene, 2007). A visualization of the activation of nodes on the mental number line can be seen in Figure 2.

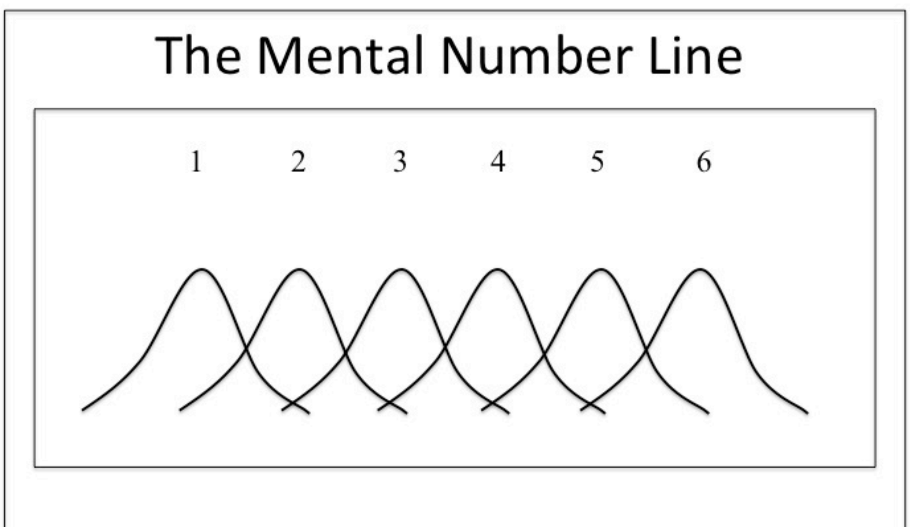


Figure 2. The Mental Number Line

The Spatial-Numerical Association of Response Codes (SNARC)

Evidence for the mental number line is firmly grounded in the studies of the SNARC effect. Using a series of studies, Dehaene, Bossini, and Giraux (1993) observed that young adults engaged in a numeric judgment task respond significantly faster when the larger numbers were presented on the right side of space. This trend was observed when verbal numbers were substituted for Arabic numerals. Also, the trend was observed in samples of left-handed people and right handed people while crossing hands to respond (i.e., left hand responded for right side of space and visa versa). Importantly, this effect was seen on a parity judgment task (i.e., participants were judging whether the number stimulus was an odd or even number), therefore the participants did not explicitly analyze number magnitude; this suggests that the mental number line is activated automatically.

Differences in response time due to the SNARC effect can be related to cognitive resources. Specifically, response times are quicker when numeric stimuli align with the perceptual representation thereof (i.e., the mental number line). That is, because large numbers are represented on the right side of the mental number line, large numbers are responded to more quickly when presented on the right side of space than on the left side of space. Successfully responding to numeric stimuli that are spatially mismatched with the orientation of the mental number line requires more cognitive resources than when the stimuli matches the mental number line. That is, when the stimuli do not match well to the alignment of the mental number line, some form of translation must take place before sense can be made of the stimulus.

The Distance Effect

The distance effect is another phenomenon that relates to numeric processing. The distance effect is observed as latency in response times associated with the magnitude differences between numeric stimuli. Moyer and Landauer (1967) investigated young adult response times on a whole number comparison task. The authors observed greater latency in response times for judgments of magnitude between two numbers if the numbers were close in value (5 and 6: distance of 1: mean RT 620 ms) and smaller latency in response times if the numbers had greater distance in value (2 and 6: distance of 4: mean RT 560 ms).

When viewed at the process level, the distance effect can be seen as difficulties encountered at the interpretation stage due to interference from competing, perceptual representations. Evidence for this is based on fuzzy-trace theory (Reyna & Brainerd, 2008). According to fuzzy-trace theory, there are two kinds of memory representations: verbatim and gist representations. Verbatim representations are recollective in nature and include great amounts of detail. Gist level representations only feature the semantic features of a stimulus, with much less detail for surface features. Reyna and Brainerd (2008) examined how well fuzzy-trace theory fits with extant numeracy related literature. Their results fit well with the fuzzy-trace theory proposition that people generally activate gist based representations of memory for numeric decision making, only moving on to algorithmic based processing when gist based processing proves insufficient. As distance between numbers decreases, the less sufficient gist based processing becomes, and algorithmic processing is required. Utilization of algorithmic processing is more demanding of cognitive resources than gist based processing (Holyoak, 1995).

Furthermore, the need to utilize algorithmic processing involves the integration of signal detection theory and the mental number line (Izard & Dehaene, 2007). As discussed earlier, when a node on the mental number line is activated there is a normally distributed pattern of activation around that node. When two nodes are activated, the closer the nodes are on the number line, the more overlapping activation they will share thus making it difficult to distinguish between the two. In this case, one must use more stringent criterion to distinguish between two nodes when the activation patterns around those nodes begin to overlap. The need for more stringent criterion to distinguish between node activations on the mental number line directly impacts one's ability to use gist processing for number comparisons.

I hypothesize that gist level memory of node activation has greater width of activation and therefore two gist representations of number node activation will have more overlap than algorithmic/verbatim representation and therefore one must utilize the latter form to distinguish between two numerosities when they are in close proximity on the number line. See Figures 3 and 4 for visualizations of the idea that gist level processing of near distance comparisons, in a signal detection paradigm, have more overlapping activation and are therefore more difficult to distinguish than both gist level processing at far distance and algorithmic processing of near distance comparisons. In Figure 3, you can see the overlapping activation distributions associated with gist level processing. Note the larger overlap in the near condition, this leads to greater interference in a signal-detection framework and necessitates moving to algorithmic processing. In Figure 4, you can see the overlapping activation distributions associated with algorithmic processing. Note the differences in the overlapping distribution patterns in the far condition between Figure 3 and Figure 4; in this case, it is unnecessary to use extra resources to distinguish between far numerosities via algorithmic processing because gist processing is sufficient.

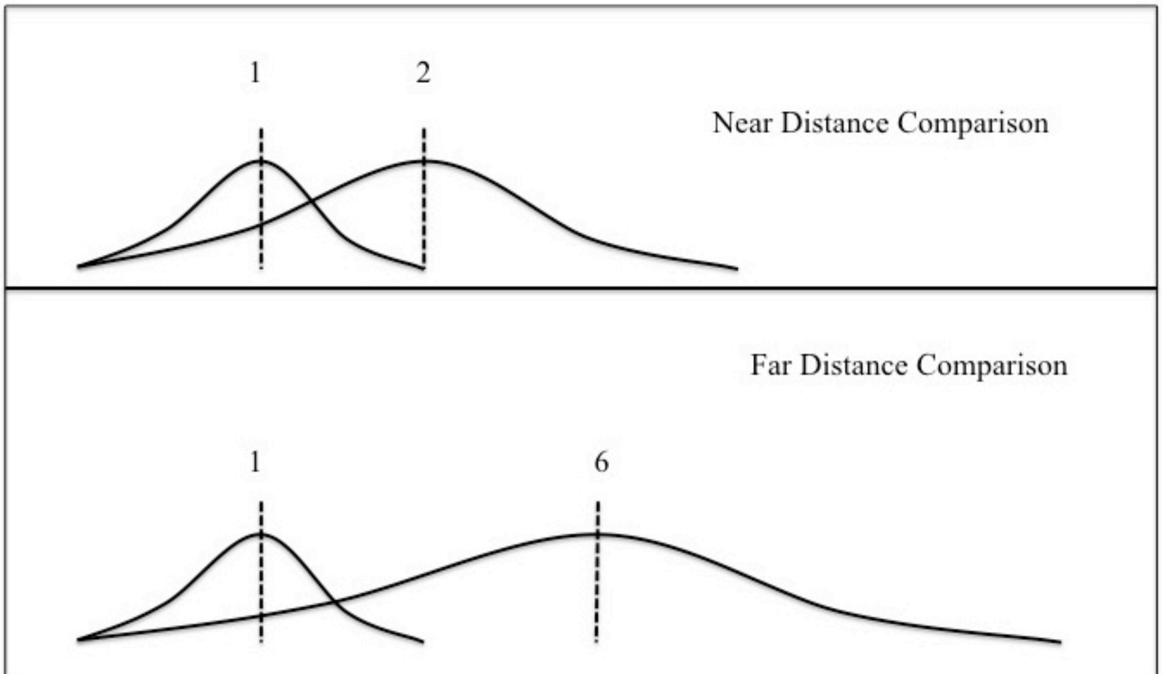


Figure 3. Gist Processing of Whole Number Distances

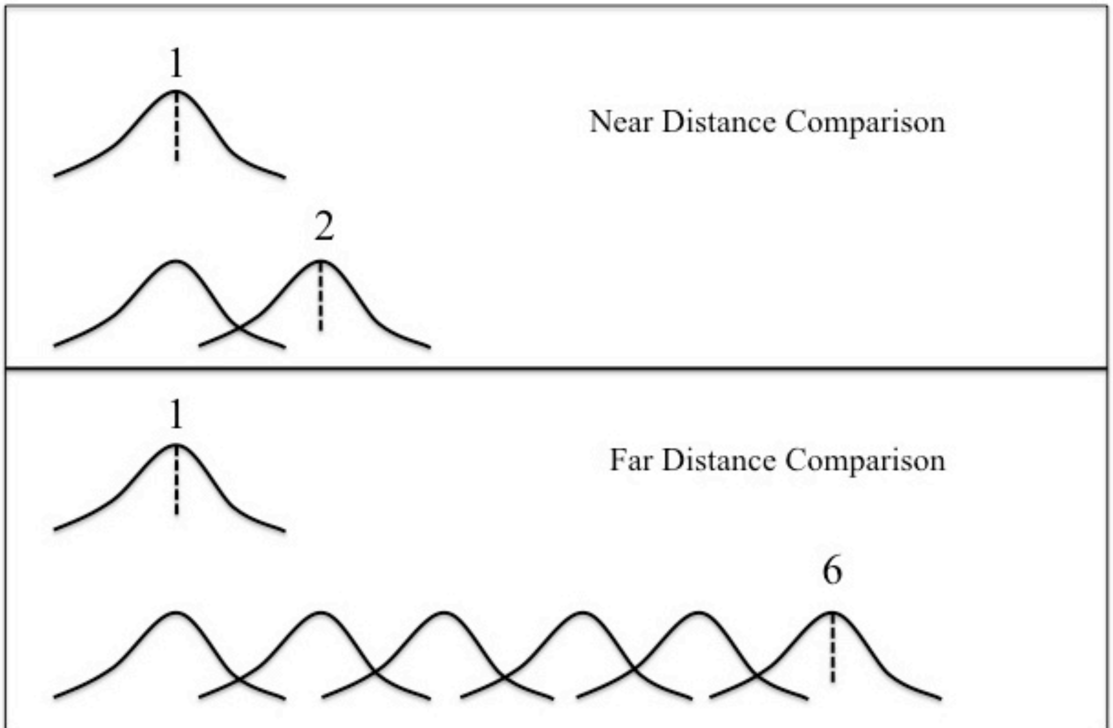


Figure 4. Visualization of algorithmic processing

Number Format

The distance effect and SNARC effect are well established phenomena and research about them has helped us understand numeric cognition for whole numbers, but do these phenomena relate to other kinds of number processing (i.e., how do they relate to rational number processing)? Debate remains about the cause of difficulties associated with interpretation of rational numbers (Bonato, Fabbri, Umilta, & Zorzi, 2007; DeWolf & Vosniadou, 2011; Ni & Zhou, 2005; Peters, Slovic, Västfjäll, & Mertz, 2008; Reyna & Brainerd, 2008; Schneider & Siegler, 2010; Stafylidou & Vosniadou, 2004; Yamagishi, 1997). However, there is agreement that this difficulty is associated with the need to process rational numbers differently than whole numbers to interpret them appropriately. If latencies in response times are used as a metric of task demand for cognitive resources, then interpretation of rational numbers is more demanding of cognitive resources than either the distance effect or the SNARC effect. Given that rational numbers are a common way to communicate risk information, the need to understand the perception of these numbers is of great and increasing importance (Fausset, 2009). Also, current knowledge of age-related differences in cognition, neuroanatomy, and central nervous system functioning can help elucidate the structure and development of rational number cognition.

Extant research examining rational number processing is generally aimed at investigating the relationship of rational numbers to the mental number line and the distance effect. Bonato, Fabbri, Umilta, and Zorzi (2007) conducted a series of experiments to investigate the relationship between the mental number line and rational numbers. They found that the true value of the fraction was not represented on a mental number line; they interpreted the results to indicate that people only represent fraction components on the mental number line and that there is a disconnect between the componential processing and true value processing. That is, people analyze the fraction components and then use them to make sense of the fraction's true value, with the fraction components driving perception more than the true value. Although not investigating response times, Yamagishi (1997) demonstrated that the components of a frequency were more important to the meaning making and decision making processes than the true value of the frequency.

These results might not be generalizable to all forms of fraction comparison, it could be that the stimuli in Bonato et al. (2007) predisposed participants to a specific kind of fraction comparison process that did not necessitate accessing the true values of the fractions. If this is true then the results that fraction components were more associated with processing in their experiments might only apply to componential processing. Schneider and Siegler (2010) varied their fraction stimuli such that comparisons could not be made without accessing the true value of the fractions before comparison (i.e., componential processing would not lead to high accuracy in magnitude comparisons). In this study, the authors found that as the true value of the fractions became closer in value, the more extended the response times became. Dewolf and Vosniadou (2011) investigated fraction comparison with two kinds of fraction stimuli, consistent fraction comparisons and inconsistent fraction comparisons (the differences between these kinds of stimuli will be discussed at length further in this paper). The results indicated higher accuracy and quicker response times for consistent fraction comparison compared to inconsistent fraction comparison.

The studies of rational number processing call into question the nature of rational number cognition. What kind of fraction processing is most utilized in everyday life: componential processing or true value processing? Are age-effects present in rational number processing and are age-effects different depending on whether componential or true value processing is utilized? I proposed a study to determine: if true value processing is the preferred form of fraction processing, if true value processing is the preferred form of fraction comparison for older adults, and if there are age-related differences in both whole number processing and rational number processing (i.e., in relation to the SNARC effect and the distance effect). This was accomplished by observing accuracy and response times on a computerized magnitude comparison task. Patterns in accuracy and response times were used to increase understanding of these phenomena.

The method and stimuli in this study were specifically chosen to capture response times for the distance effect and the SNARC effect embedded within whole number and fraction contexts. The method for this magnitude comparison task is a computerized version of the whole number comparison task used in Moyer and Landauer (1967), with two numbers being presented simultaneously and participants responding with either the right or left hand in correspondence with the side of space containing the larger of the two numbers. This was chosen in part because of concerns that practice effects may greatly influence response times if all comparisons are made sequentially in relation to a fixed number, a very common method for magnitude comparison tasks (Bonato, Fabbri, Umilta`, & Zorzi, 2007; Dehaene, Bossini, & Giraux, 1993; Peters, Slovic, Västfjäll, & Mertz, 2008; Schneider & Siegler, 2010).

The stimuli in this study were chosen to avoid very specific confounds and allow a novel form of comparison. All stimuli were created out of Arabic numerals ranging from 1 to 11. This was done to minimize the influence of cognitive resource demand intrinsic to processing large numbers, especially fractions with large numerators and denominators (Schneider & Siegler, 2010). Each whole number comparison (WNC) stimulus featured comparisons with either a distance of 1 (i.e., near distance condition) or distance of 4 (i.e., far distance condition). To investigate the SNARC effect, each stimulus had an opposite order counterpart.

The fraction stimuli were inspired by those used by Bonato et al. (2007), Dewolf and Vosniadou (2011), and Schneider and Seigler (2010). Bonato et al. (2007) utilized fraction stimuli with changing denominators and a fixed numerator of 1 (i.e., $\frac{1}{x}$). When fraction comparisons are made with this format, people can respond correctly by using the heuristic that the fraction with the smaller denominator is always the larger value. If people use the aforementioned heuristic, they will not need to fully interpret the fractions and therefore response times for this form of comparison are not generalizable to fraction comparison in everyday life.

Practice effects could contribute to mean response times if this form of comparison is the only one used. Changing numerators and changing denominators were used in this study. All fraction stimuli are non-reducible; this made it possible for participants to reduce the number of steps necessary for interpretation. A possible confound was including fractions with real values greater than 1 in fraction comparison tasks (Bonato et al., 2007; Dewolf & Vosniadou, 2011). There is the possibility that these kinds of fractions could be compared to other fractions using a heuristic whereby any fraction with a numerator larger than the denominator is automatically judged as being greater than fractions with the opposite composition. Once again, this kind of comparison might be unique and not generalizable to other kinds of fraction comparisons.

The distinction of Consistent Fraction Comparison and Inconsistent Fraction Comparison has had a major impact on the stimuli used in this study (Dewolf & Vosniadou, 2011; Schneider & Siegler, 2010). Consistent Fraction Comparison occurs when fraction comparisons can be accurately made solely by comparing fraction components (i.e., comparing numerator to numerator or denominator to denominator) and, importantly, it is not necessary to access the real value of the fraction. That is, a fraction comparison is consistent when the numbers composing the fraction with the larger true value are larger than the numbers composing the fraction with the smaller value. An example of Consistent Fraction Comparison is comparing $\frac{2}{3}$ and $\frac{3}{4}$. This is consistent fraction comparison because $\frac{3}{4}$ is equal to .75 and $\frac{2}{3}$ is equal to .66 (giving $\frac{3}{4}$ the larger true value), and the components of $\frac{3}{4}$ are larger than $\frac{2}{3}$ (denominator of 4 is greater than 3 and numerator of 3 is greater than 2, respectively). However, if the components of the fraction with the higher real value are smaller than the components of the fraction with the smaller real value, this leads to inaccurate comparisons without accessing real fraction values. This kind of comparison is called Inconsistent Fraction Comparison. An example of Inconsistent Fraction Comparison is comparing $\frac{3}{5}$ and $\frac{4}{9}$. This is Inconsistent Fraction Comparison because $\frac{3}{5}$ is equal to .60 and $\frac{4}{9}$ is equal to .44 (i.e., $\frac{3}{5}$ is greater than $\frac{4}{9}$) even through both the numerator and denominator of $\frac{4}{9}$ is greater than $\frac{3}{5}$. For images detailing the differences between Consistent Fraction Comparison and Inconsistent Fraction Comparison see Figure 5.

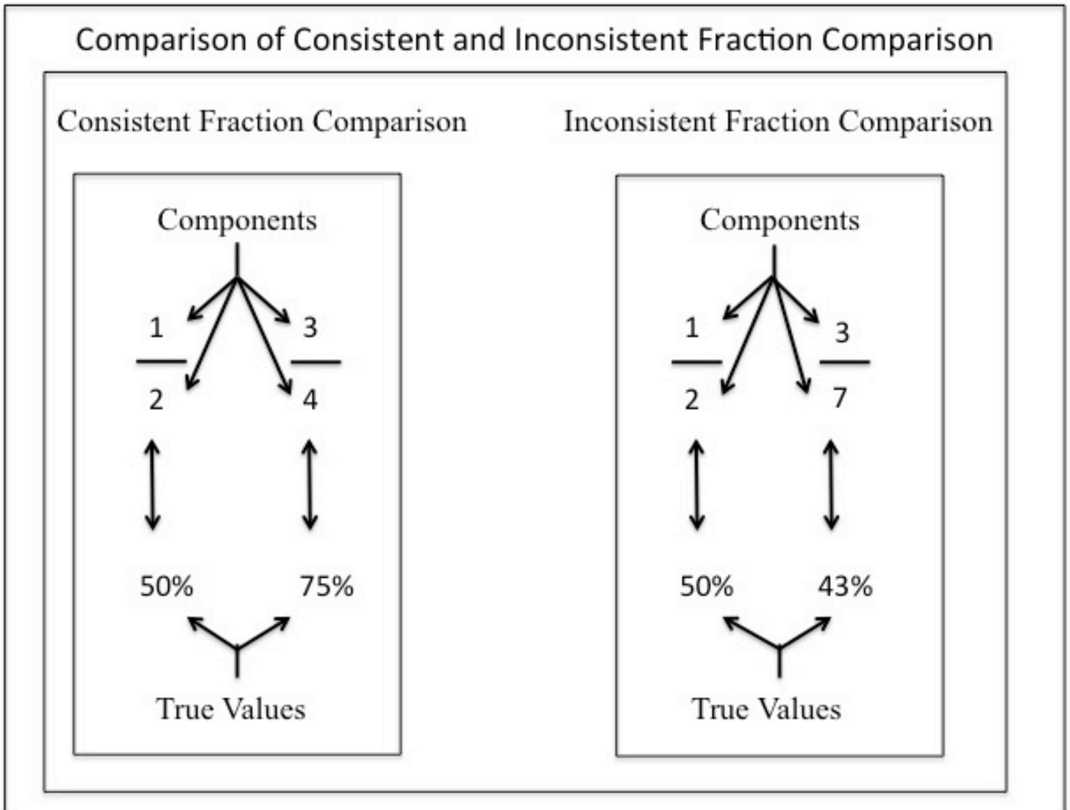


Figure 5. Illustration of differences between consistent fraction comparison and inconsistent fraction comparison

This study only utilized Consistent Fraction Comparison stimuli. This decision was driven largely by the desire to replicate the manipulation of the distance effect used for Whole Number Comparison. That is, the distance between numerators were identical to the distance between denominators and these were identical to distances used in the near and far conditions for Whole Number Comparison stimuli. Figure 6 clarifies the near and far distance conditions for Consistent Fraction Comparison.

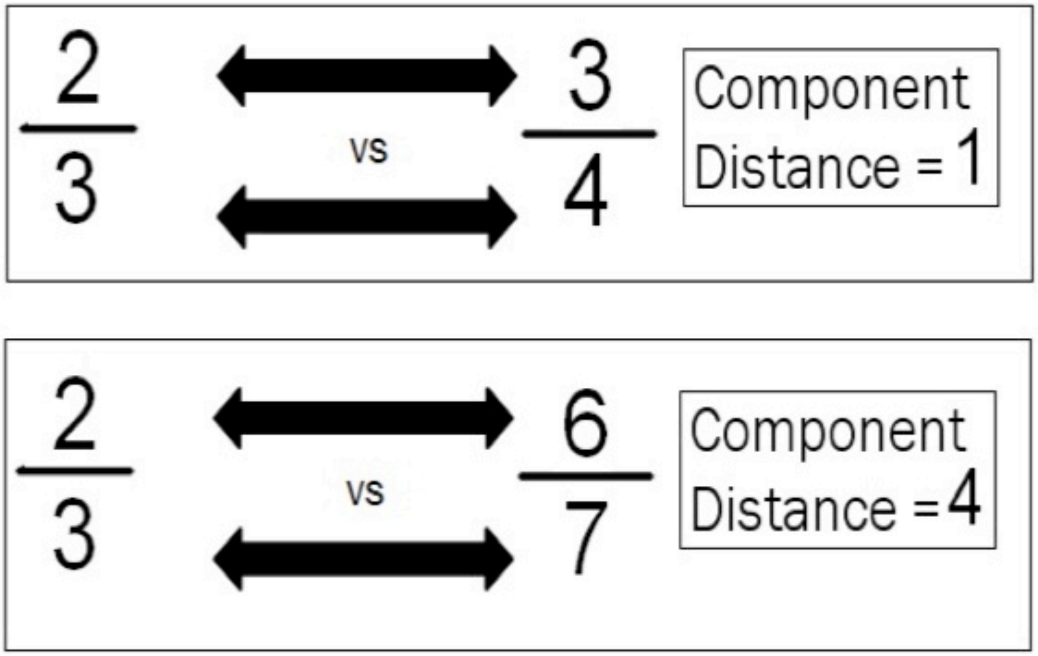


Figure 6. Examples of near and far distance conditions in fraction context. The top figure represents the near condition and the bottom figure represents the far condition.

An important point of investigation for this study was to observe whether people processed the Consistent Fraction Comparison stimuli as if it were Inconsistent Fraction Comparison. The stimuli were designed in such a manner to address this question. If people use a numerosity heuristic (i.e., that the fraction with the larger components represents the largest value) to decide which fraction has the greater value, we would observe very specific patterns in response times. Specifically, people using the numerosity heuristic for Consistent Fraction Comparison would have mean response times for the near and far distance conditions that are commensurate to the mean response times for near and far distance conditions in Whole Number Comparison. However, if the participants used deeper processing to interpret the stimuli on Consistent Fraction

Comparison they would have mean response times for the distance effect that do not resemble response times for the distance condition in Whole Number Comparison. This is due to the fact that, while the distance between fraction components were held identical to the Whole Number Comparison condition, the distance between the true values of the Consistent Fraction Comparison stimuli were variable. For example, in the Consistent Fraction Comparison near distance condition, all stimuli featured differences of one for all fraction components but differences between real values of these stimuli include .15, .09, .05, .03, .027, .018, and .011.

Knowing how people process Consistent Fraction Comparison is important because it will help inform on the way people interpret fractions in everyday life. If people do not favor algorithmic processing of fractions even when it is not necessary, it is safe to assume that this is not typically the way people interpret fractions when encountered in the environment. Also, if there are age-related differences in utilization of the numerosity heuristic, then this could reflect age-related differences in the interpretation process.

In summation, survey results indicate large age-related differences in numeracy (Kirsch et al., 2002). Current explanations of these differences neglect to include age-related cognitive differences as a main factor related to numeracy. This study will investigate age-related differences in numeracy at the process level to better understand how cognitive resource demands associated with numeracy affect performance in older and younger adults. Specifically, accuracy and response time latencies will be used as an indicator of the cognitive resource demands associated with the SNARC effect, the distance effect, and number format effects. I predicted significant effects of all three phenomena on response time latencies, with significant interactions for Age x Distance, Age x Format, Distance x Format, and SNARC x Format. I predicted significantly longer response times for older adults on all measures, with SNARC effect showing smallest effect size, distance effect showing a larger effect size than SNARC, and format showing a larger effect size than distance. Knowledge of the cause for these phenomena-associated, cognitive demands will elucidate age-related differences in numeracy at the process level.

CHAPTER 2

METHOD

Participants

To minimize the role of education and current experience, the following inclusion/exclusion criteria were followed. First, all participants had to have attended elementary school in the United States. To minimize cross-cultural differences associated with orientation of the mental number line. Young adults majoring in engineering were excluded from this study to reduce the impact of everyday math usage on the comparability of the young and older adult samples. Finally, older adults without a bachelor's degree were excluded so young and older adult samples were comparable on education level.

Thirty young adults (50% female), between the ages of 18-23 (M_{age} = 20, SD_{age} = 1.43), and thirty-two older adults (50% female) between the ages of 65-75 (M_{age} = 71, SD_{age} = 3.41) participated in this study. All participants were either in college or self-reported having attended college. All participants were native English speakers. All participants lived independently. All participants self-reported fair health or better. Few participants reported health often interfering with daily activities. No young adults reported having diabetes or hypertension. A few older adults reported currently having diabetes (n=3) and roughly half of the older adults reported experiencing hypertension (n=11). Only 12 young adults reported having prescribed medications but none regularly took four or more. Most of the older adults regularly took prescribed medications, five took less than four medications and 21 took four or more medications. See Appendix F for charts representing these demographic and health data. See Appendix G for correlation matrices of ability test data.

The young adult sample consisted of undergraduate students taking a psychology class at the Georgia Institute of Technology who received course credit for their participation. The older adult sample was recruited for the study from the Human Factors and Aging Laboratory's participant database. Older adults received financial compensation for participation. Two older adults were excluded from analysis as outliers in accuracy on the computerized number comparison task.

Design

This study was a 2x2x2x2 split-plot design. It featured a quasi-experimental design, with age (Young Adult and Older Adult) as a grouping factor and three within participants factors: location of presentation (larger value on either the left or right side of space), distance (near or far distance), and number format (whole numbers or fractions). That is, there were four independent variables: age, location of presentation, distance, and number format. Both distance and location of presentation were nested within number format. Accuracy and response time were the dependent variables.

Stimuli

The number stimuli in this study consisted of 14 whole number comparisons and 14 fraction comparisons. Each comparison consisted of two values, one of which was larger than the other. See Appendix A for a list of all number comparison stimuli. All fraction stimuli were crafted with numbers used in the Whole Number Comparison stimuli set. In the whole number condition, stimuli were 8mm wide and 12mm vertical with an approximate distance of 600mm. In the fraction condition, stimuli were 10mm wide and 32mm vertical with an approximate distance of 600mm. Differences in visual angle were the result of utilizing the same font size in both conditions and the differences in presentation format.

For location of presentation, all fraction comparisons were crafted in a way that allowed accurate magnitude comparisons by componential processing alone (i.e., consistent fraction comparison). Comparisons were created so that the distance between the whole numbers and fraction components were either a difference of one or four (near vs. far distance, respectively). There were fourteen Whole Number Comparison stimuli and fourteen Consistent Fraction Comparison stimuli. Half of the Whole Number Comparison were at near distance and half were at far distance, this is also true for the Consistent Fraction Comparison stimuli. For each comparison, there was another with the exact same stimuli but transposed location of presentation (to assess SNARC). For a full list of the comparisons used see Appendix A.

Choice of fraction stimuli used in these comparisons was influenced by several factors. First, Schneider and Seigler (2010) observed that response times to comparisons with the fraction $\frac{1}{2}$ show anomalously quick response times, this may be due to the capacity to quickly ascertain the true value of $\frac{1}{2}$ and make quick judgments of other fractions relative to that value (i.e., 50%). For this reason, comparisons using $\frac{1}{2}$ were only used during practice trials. Second, all fractions used in comparisons were non-reducible to minimize the chance that multiple steps could be used by participants to make comparisons. Third, fractions were chosen such that no two fractions had identical true values. Finally, four of the comparisons in each fraction comparison condition featured distances of one between numerator and denominator and three comparisons per condition featured larger distances between numerator and denominator.

Measures

Ability tests. Participants' vision was assessed using a revised Snellen chart for near vision (Snellen, 1868). All participants had at least 20/40 vision. A math ability test (Ekstrom, French, Harman, & Derman, 1976), the reverse digit span test (Wechsler, 1997), the vocabulary measure from the Shipley Institute of Living Scale (Shipley, 1986), and the Digit-Symbol substitution test (Wechsler, 1997) were administered to describe the samples and identify outliers.

Surveys. All participants completed a demographic and health survey (Czaja et al., 2006). The Subjective Numeracy Scale, an eight-item survey with .68 correlation to math performance, was used to assess participant numeracy levels (Zikmund-Fisher, Smith, Ubel, & Fagerlin, 2007). An internally developed survey titled, "Number Comparison Task Questionnaire" was also used to determine strategy utilization and self-reported difficulty for Whole Number Comparison and Consistent Fraction Comparison.

Table 1.

Ability test data; mean scores, standard deviations, and t-test results.

	Young Adults		Older Adults			
	Mean	SD	Mean	SD	t statistic	p value
Subjective Numeracy Scale	4.67	0.76	4.06	0.93	2.73	< .05
Subtraction and Multiplication Test	23.64	9.71	25.03	9.63	-0.54	> .05
Reverse Digit Span Test	9.07	2.24	7.66	2.76	2.12	< .05
Digit Symbol Substitution Test	72	11.65	46.41	10.94	8.55	< .05
Vocabulary Test	31.07	3.2	35.79	2.14	-6.57	< .05

Computer Tasks. Dell P190S with a resolution of 1280x1024 pixels and a 19" screen were used as for stimulus display. E-prime 2.0 (E-Prime 2.0, 2003) was used to both present stimuli as well as capture response times and accuracy on all trials. The program had two phases: a Choice Response Time Task and a Number Comparison Task. The Choice Response Time Task was used to familiarize participants with the response key mapping used in the Number Comparison Task.

Participants responded using the M and V keys on the keyboard. Using stickers, the keys were labeled "L" and "R" (for Left and Right, respectively). Prompts encouraging speed and accuracy were included in the program. In the Choice Response Time task, participants pressed either the "L" or "R" key to signify that a black box appeared on either the Left or Right side of a fixation cross.

Each trial of the Choice Response Task consisted of a fixation cross presented in the middle of the screen for 250ms followed by a blank screen for 100ms and then followed by presentation of the black box. The fixation cross was presented at a visual angle of .6°. The black box was presented for either 10s or until the participant responded to the stimulus, after one of these conditions were met the next trial began. There were 80 trials in the Choice Response Task. Stimuli in this task were 33mm in height and 40mm in width at a distance of approximately 60cm representing visual angles of 3.15° and 3.81°. Stimuli in this task were presented off center by a visual angle of 1.7°.

The same key response mapping was used in the Number Comparison Task. That is, the "L" key signified "Left Side" and the "R" key signified the "Right Side". The main differences between the Choice Response Task and the Number Comparison Task were the type and number of stimuli. In the Choice Response Task there was only one stimulus presented on either the Right or Left side of the screen per trial and the stimulus was a black box. In the Number Comparison Task there were two stimuli presented per trial, one stimulus on either side of the screen, and the stimuli presented were either two whole numbers or two fractions.

Each block in the number comparison task consisted of 28 trials. Each block featured either whole number or fraction stimuli. There were a total of 16 blocks, making a total of 448 trials; therefore there were 224 trials of fractions and 224 trials of whole numbers. Participants received two blocks of a given condition at a time, with a 15 second break between blocks; therefore each participant received a block of whole number trials followed by a 15 second break then another block of whole number trials.

After two blocks of one number format, the process was repeated with two blocks of the other number format; therefore participants received two blocks of whole numbers followed by two blocks of fractions or visa versa. This task was divided in half, with each half consisting of 8 blocks. There were two versions of the Number Comparison task for counterbalancing: one in which whole number trials preceded fractions and one where fractions preceded whole numbers. See Appendix B for a visualization of the Computerized Number Comparison Task design.

Procedure

Informed consent was obtained prior to any data collection. The participants began the study by completing the demographic and health survey followed by the Subjective Numeracy Scale and the Math ability task. Participants then received a five-minute break followed by the computerized potion of the study.

The computerized portion began with the Choice Response Task followed by the Number Comparison Task. After completing half of the Number Comparison Task, participants received another five-minute break and then completed the Shipley Institute of Living Scale Vocabulary Test (Shipley, 1986), the Digit-Symbol Substitution Task (Wechsler, 1997), the Reverse Digit Span task (Wechsler, 1997), and the Snellen Eye Chart (Snellen, 1868) in that order. Participants then completed the second half of the Number Comparison Task, followed by the Number Comparison Task Questionnaire, debriefing, and compensation. The whole procedure took approximately 2.5 hours for older adults and approximately 1.5 hours for young adults. A visual representation of the experimental procedure is found in Appendix C.

CHAPTER 3

Results Analysis

Overview of Analysis

Split-plot MANOVAs were used to analyze all accuracies and response time latencies with an alpha level of .05. Analyses of response time data were only conducted for accurate trials. To best understand the meaningfulness of these results they are arranged such that young adult data is presented before older adult data, followed by analysis of the combined age-groups. Also, analyses are arranged such that response time data is presented before accuracy data. Finally, independent group t-tests with an alpha level of .05 were used to analyze data collected in the Number Comparison Task Questionnaire.

The SNARC effect

The SNARC effect impacted the performance of young adult whole number comparison accuracy. They were significantly more accurate when the larger number appeared on the right side of the screen (M_{right}= .775, SD_{right} = .023) than when the larger number appeared on the left side of the screen (M_{left} = .970, SD_{left} = .026) in the young adult sample, $F(1,29) = 663$, $p < .05$. This trend is evident in Figure 7.

We observed no replication of the SNARC effect in whole number comparison as described in Dehaene, Bossini, & Giraux (1993). There were no significant differences in average RTs between comparisons when the larger number appeared on the left side of the screen (M_{left} = 488, SD_{left} = 54) and when the larger number appeared on the right side of the screen (M_{right} = 492, SD_{right} = 62) in the young adult sample, $F(1,29) = .01$, $p > .05$. This trend can be observed in Figure 8.

There was no significant main effect of number format on comparison accuracy in the young adult sample but there was a significant interaction between location of presentation and number format in the young adult sample, $F(1,29) = 68.43$, $p < .05$. That is, in the young adult sample, there were smaller differences in accuracy levels in the fraction comparison condition related to location of presentation than in the whole number comparison condition. This trend can be viewed in Figure 7.

There was a significant main effect of number format on young adult comparison times, $F(1,29) = 112.77$, $p < .05$. That is, young adults were significantly slower when comparing fractions than when comparing whole numbers. This fact is qualified by a significant interaction between number format and location of presentation in average young adult response time latencies, $F(1,29) = 23.42$, $p < .05$. Analyses of these data replicated the results observed in Schneider & Seigler (2010). For fraction comparisons, no significant differences were observed in average RTs between comparisons when the larger number appeared on the left side of the screen screen ($M_{left} = 1532$, $SD_{left} = 520$) and when the larger number appeared on the right side of the screen ($M_{right} = 1524$, $SD_{right} = 516$) in the young adult sample, $F(1,29) = .139$, $p > .05$. To explain further, the SNARC effect was only evident on young adult response times in the whole number condition. This trend can be viewed in Figure 8.

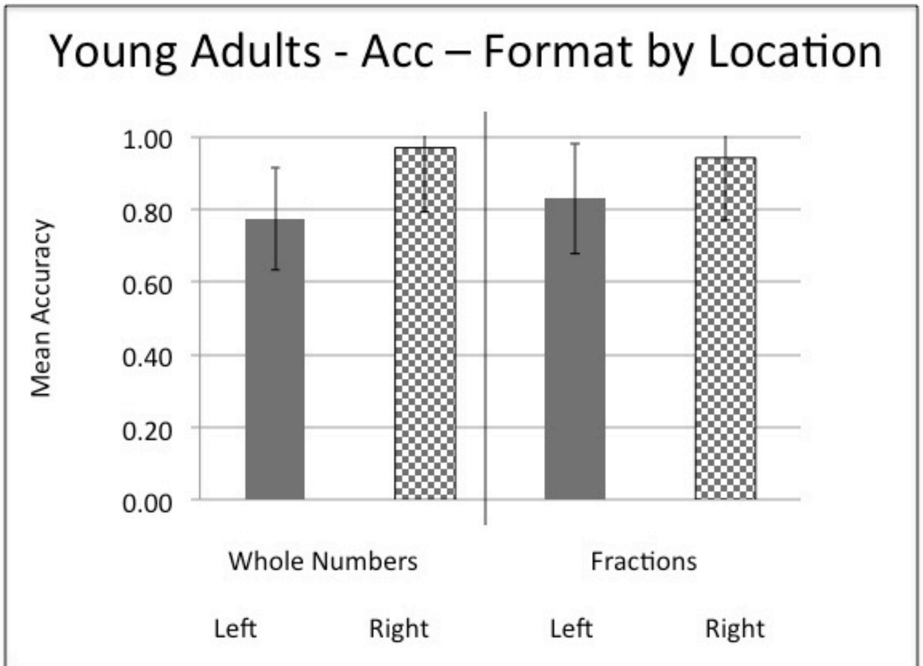


Figure 7. Bar Chart of accuracy levels as a function of number format and spatial presentation of location for the young adult sample.

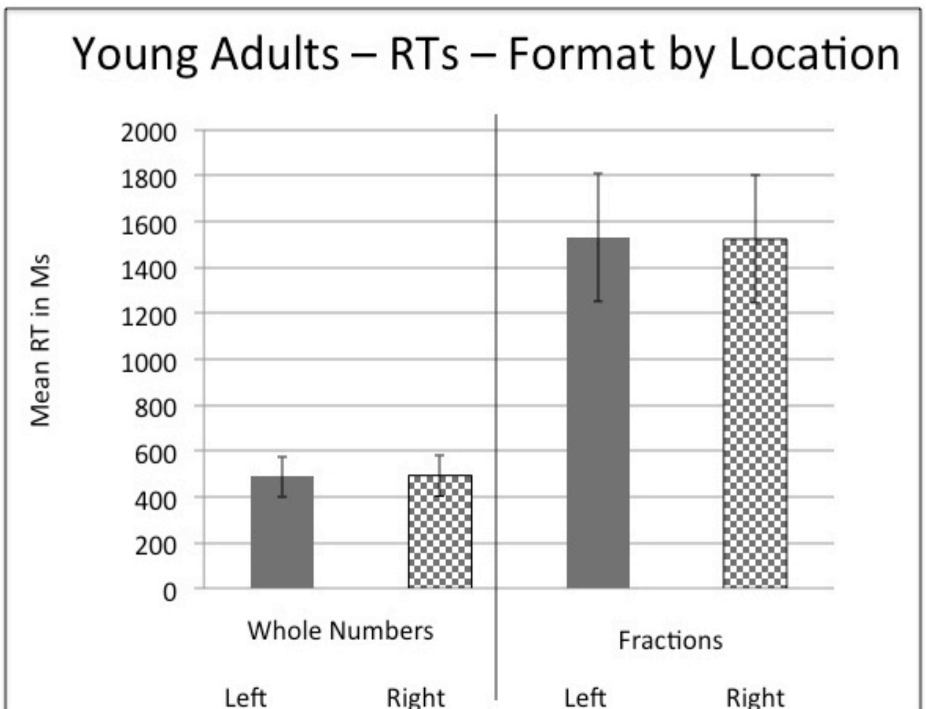


Figure 8. Bar chart of response time latencies as a function of number format and spatial presentation of location for the young adult sample.

Older Adults and the SNARC Effect

Similar patterns related to the SNARC effect were observed in comparison accuracy for older adults and young adults. For average accuracy levels in older adults, there was a significant interaction between number format and location, $F(1,29) = 93.00$, $p < .05$. There was a significant main effect of number format, $F(1,29) = 25.98$, $p < .05$, there was also a significant main effect of location, $F(1,29) = 509.87$, $p < .05$. That is, older adults were significantly more accurate when the larger number was presented on the right side of the screen. They were also significantly less accurate during fracture comparison. Finally average accuracy differences due to location of presentation were attenuated during fration comparison. These trends are presented in Figure 9.

A similar pattern of results was observed in the older adult response time latencies. First, there was a different effect of location on average older adult response times observed as a statistically significant interaction of format by location, $F(1,29) = 5.37$, $p < .05$. There was a significant main effect of format, $F(1,29) = 208.32$, $p < .05$, but no significant main effect of location.

That is, older adults were significantly faster when comparing whole numbers relative to fractions but there was no significant difference in average comparison RTs when the larger number was presented on the right side of space relative to average comparison RTs when to number was presented on the left side of spaces. These trends can be viewed in Figure 10.

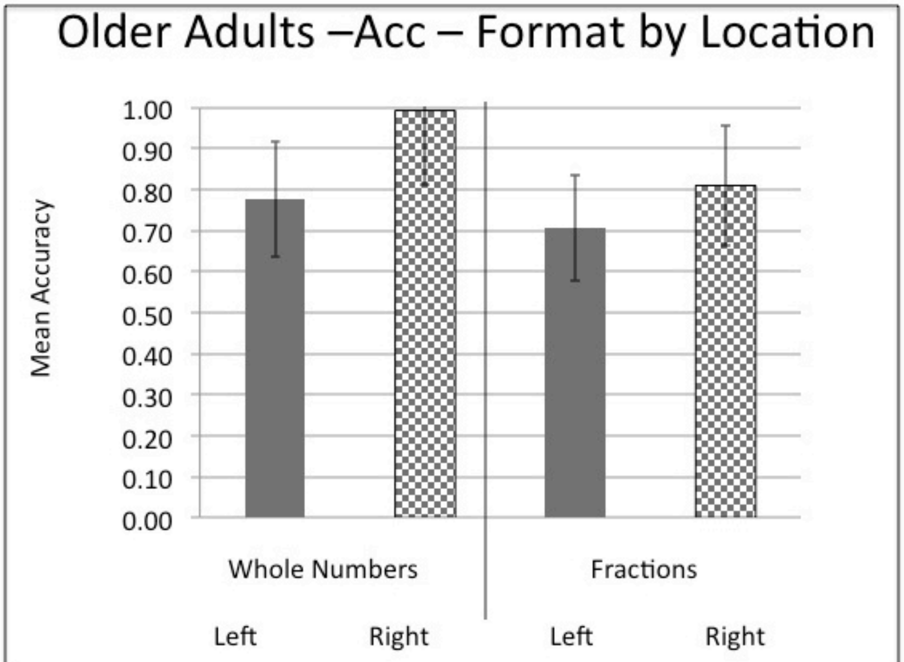


Figure 9. Bar Chart of accuracy levels as a function of number format and spatial presentation of location for the older adult sample.

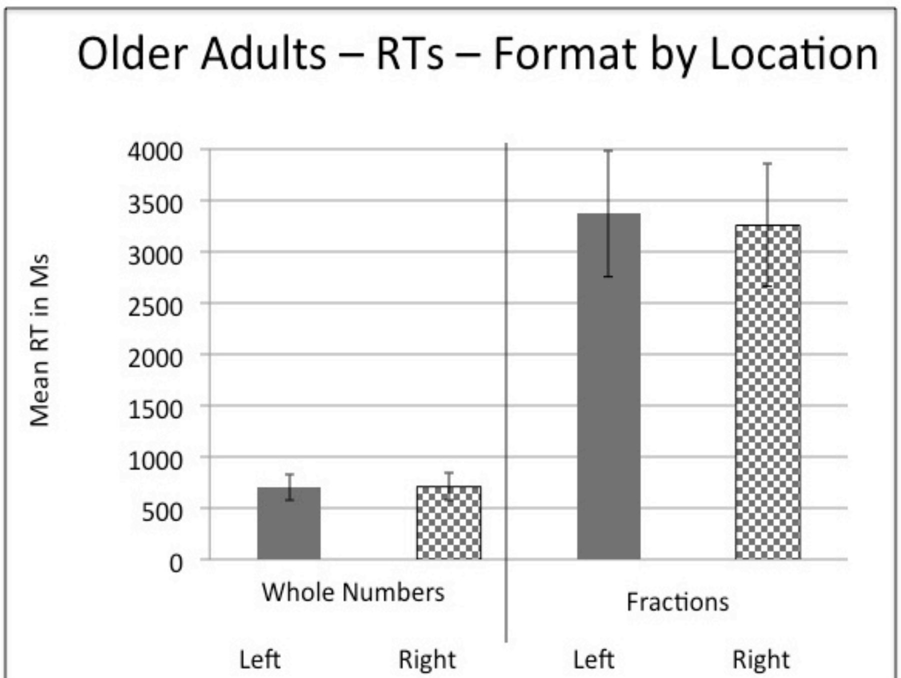


Figure 10. Bar chart of response time latencies as a function of number format and spatial presentation of location for the older adult sample.

Age-related Differences in the SNARC Effect

A MANOVA was conducted to investigate the relationship between age and comparison accuracy relative to location of presentation. We observed two significant interactions; a significant interaction of age and number format, $F(1,58) = 23.09$, $p < .05$, and a significant interaction of number format and location of presentation, $F(1,58) = 153.39$, $p < .05$. These interactions were qualified by a significant main effect of age, $F(1,58) = 15.28$, $p < .05$, a significant main effect of number format, $F(1,58) = 18.29$, $p < .05$, and a significant main effect of location of presentation, $F(1,58) = 978.23$, $p < .05$. There was no significant interaction of age by format by location and there was no significant interaction of age by location of presentation.

That is, there was no significant difference in average comparison accuracy between age groups during whole number comparison but average older adult comparison accuracy was significantly lower than average young adult comparison accuracy during fraction comparison. With respect to the significant interaction of number format and location of presentation, average accuracy differences were attenuated in the fraction comparison condition relative to the whole number comparison condition in both age groups. Older adults were significantly less accurate than young adults and both age groups were significantly more accurate when the larger value was presented on the right side of space. These trends can be viewed in figure 11.

A MANOVA of average age-related response times was in relation to location of presentation. There were significant interactions between age and number format, $F(1,58) = 59.73$, $p < .05$, as well as number format and location, $F(1,58) = 5.10$, p

< .05. These results are qualified both by a significant main effect of age, $F(1, 58) = 88.77$, $p < .05$, and a main effect of format, $F(1,58) = 336.41$, $p < .05$. All other main effects and interactions in this comparison were non-significant. That is, no main effect of location, no age by location interaction, and no age by format by location interaction.

That is, there was no significant difference in average comparison RTs between age groups during whole number comparison but average older adult comparison RTs were significantly slower than average young adult comparison RTs during fraction comparison. With respect to the significant interaction of number format and location of presentation, average RT differences were attenuated in the fraction comparison condition relative to the whole number comparison condition in both age groups. Older adults were significantly slower than young adults and both age groups were significantly faster when the larger value was presented on the right side of space. These trends can be viewed in Figure 12.

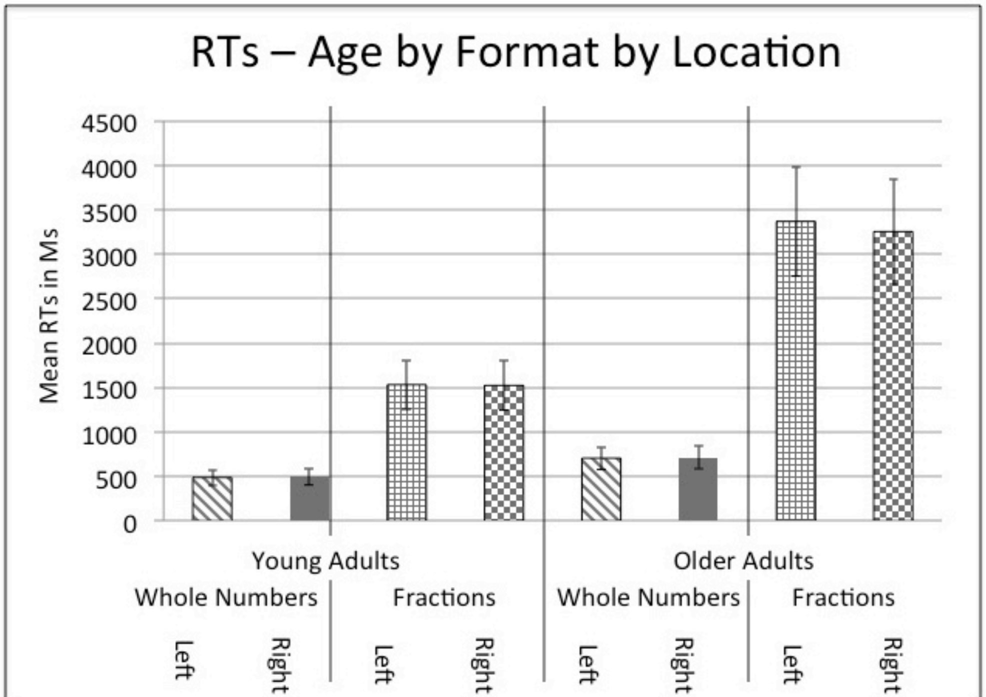


Figure 12. Bar chart of response time latencies as a function of age cohort, number format, and spatial presentation of location.

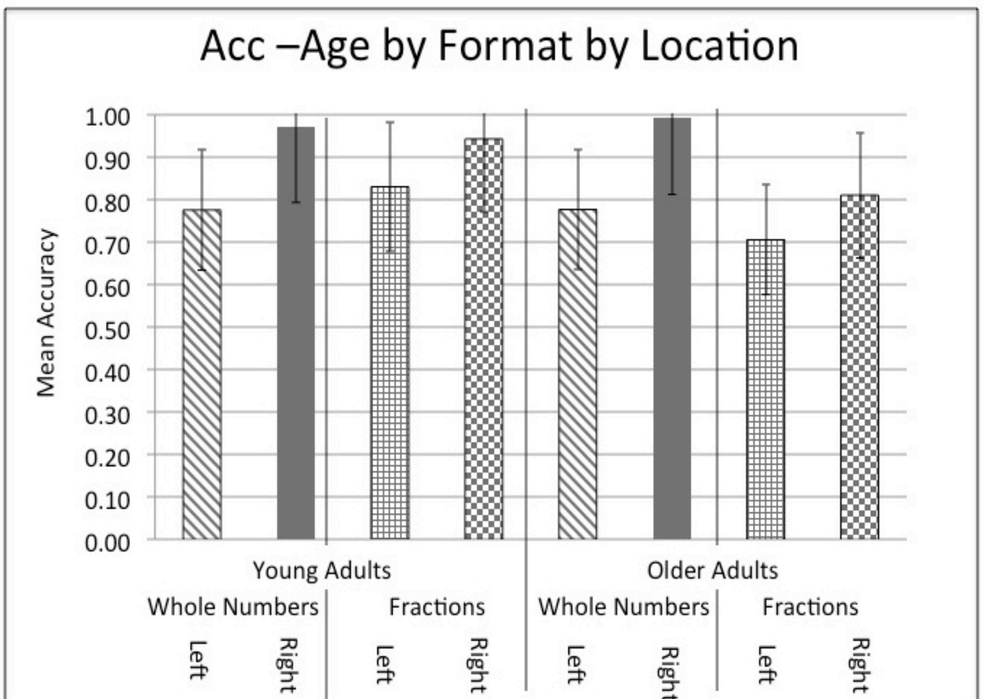


Figure 11. Bar chart of accuracy levels as a function of age cohort, number format, and spatial presentation of location.

The distance effect

The distance effect impacted both the average accuracy and average response times for young adult number comparison. Young adults were significantly more accurate when there was a large difference between numerosities (M_{far} = .98, SD_{far} = .024) than when there was a small difference between numerosities (M_{near} = .763, SD_{near} = .037), $F(1,29) = 621.82$, $p < .05$. There was also a replication of the results obtained by Moyer & Landauer (1967). During whole number comparison, young adults responded significantly faster when there was a large difference between number values (M_{far} = 474, SD_{far} = 50) than when there was a small difference between number values (M_{near} = 511, SD_{near} = 71), $F(1,29) = 12.74$, $p < .05$. These trends can be viewed in Figure 13 for whole number comparison accuracy and Figure 14 for whole number comparison response times.

While there was no significant main effect of number format on accuracy, there was a significant interaction between format and distance, $F(1,29) = 23.42$, $p < .05$. That is, accuracy differences related to both location and distance were attenuated in the fraction condition relative to the whole number condition. This trend can be viewed in Figure 13. There was a significant difference between RTs in fraction comparisons depending on the magnitude differences; that is, young adults responded significantly faster when there was a large difference between fractions (M_{far} = 1455, SD_{far} = 594) than when there was a small difference between fractions (M_{near} = 1600, SD_{near} = 482), $F(1,29) = 4.83$, $p < .05$. This trend can be viewed in Figure 14.

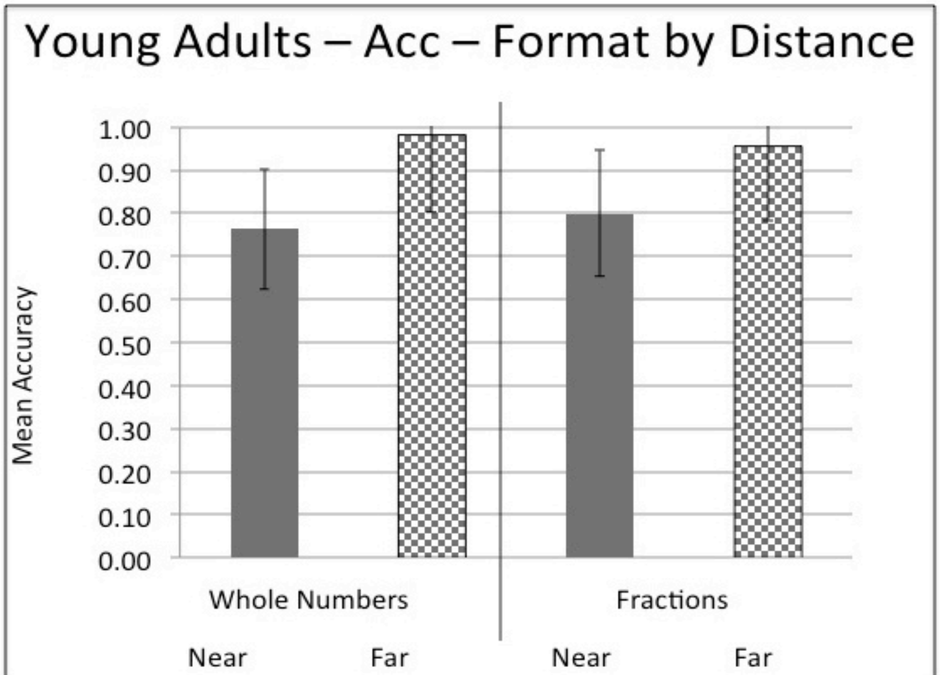


Figure 13. Bar Chart of accuracy levels as a function of number format and numeric magnitude differences for the young adult sample.

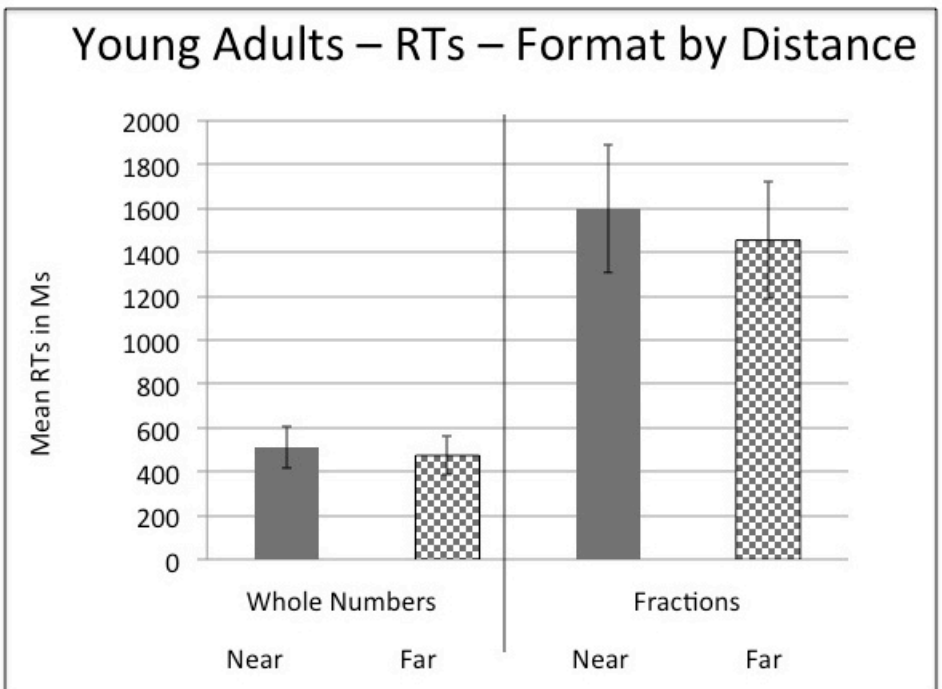


Figure 14. Bar chart of response time latencies as a function of number format and number magnitude differences for the young adult sample.

Older Adults and the Distance Effect

The accuracy trends for distance in older adults were similar to those obtained for location. The trends for the distance effect in older adults featured a significant interaction of format by distance, $F(1,29) = 5.27$, $p < .05$. There was also a significant main effect of number format, $F(1,29) = 28.98$, $p < .05$, as well as a significant main effect of distance, $F(1,29) = 170.56$, $p < .05$. These results suggest that the older adult sample experienced more cognitive burden due to stimulus manipulation via location of presentation, number magnitude difference, and number format than the young adult sample.

That is, older adult average accuracy differences were attenuated in the fraction comparison condition relative to the whole number comparsion condition. Also, older adults were significantly less accurate during fraction comparison compared to whole number comparison and significantly more accurate in the far distance condition relative to the near disatance condition. These trends can ber viewed in figure 15.

The differences in response times associated with the distance effect for older adults were robust. There was a significant interaction between number format and distance, $F(1,29) = 17.31$, $p < .05$. There was a significant main effect of format, $F(1,29) = 214.56$, $p < .05$, as well as a significant main effect of distance, $F(1,29) = 29.30$, $p < .05$.

Older adults were significantly slower to respond during fraction comparison than during whole number comparison. Older adults were also significantly slower to respond when comparing fractions with small magnitude differences compared to fractions with large magnitude differences. However, relative to the distance by format by accuracy interaction, the average response time differences associated with the distance effect were accentuated during fraction comparison relative to whole number comparison. These trends can be viewed in figure 16.

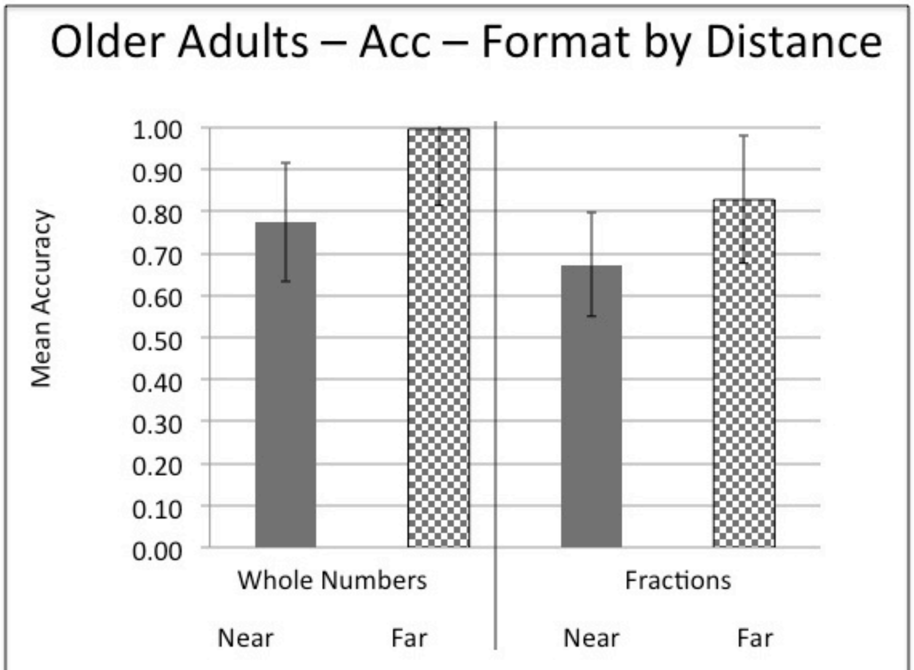


Figure 15. Bar Chart of accuracy levels as a function of number format and numeric magnitude differences for the older adult sample.

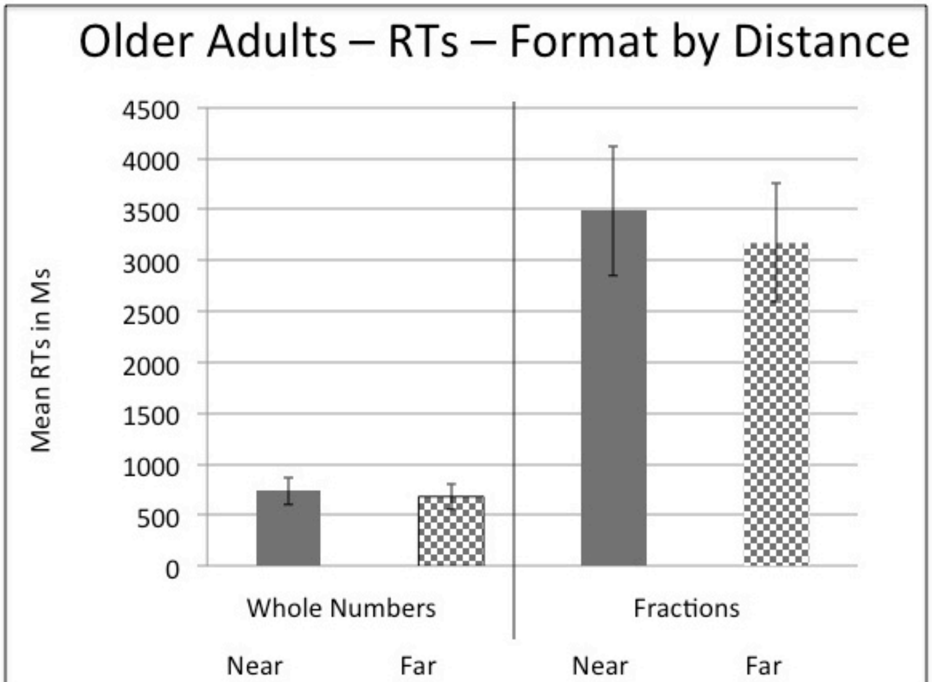


Figure 16. Bar chart of response time latencies as a function of number format and number magnitude difference for the older adult sample.

Age Differences in the Distance Effect

An additional MANOVA was used to investigate the relationship between age and comparison accuracy associated with the distance effect. There were two significant interactions. There was a significant interaction between age and number format, $F(1,58) = 22.84$, $p < .05$. There was also a significant interaction of number format and distance, $F(1,58) = 15.73$, $p < .05$. Three statistically significant main effects qualify these interactions. There was a main effect of age, $F(1,58) = 15.19$, $p < .05$. There was a significant main effect of number format, $F(1,58) = 23.73$, $p < .05$. There was also a significant main effect of comparison distance, $F(1,58) = 488.51$, $p < .05$. There was no significant interaction between age and comparison distance and there was no significant interaction between age and number format and comparison distance. These results support the findings reported when the analyses were conducted for the two age-cohorts by separately.

That is, older adults were significantly less accurate than young adults, both age groups were less accurate when comparing fractions relative to comparing whole numbers, and both age groups were significantly less accurate when comparing numerosities in the near distance condition relative to the far distance condition. To qualify the age by format interaction, older adult comparison accuracy was significantly more effected by number format than young adults. To qualify the format by distance interaction, average accuracy differences were attenuated in the fraction comparison condition relative to the whole number comparison condition. These trends can be viewed in figure 17.

The next MANOVA was used to investigate the relationship between age and response time latencies associated with the distance effect. There was a significant age by format interaction, $F(1,58) = 59.24$, $p < .05$, a significant age by distance interaction, $F(1,58) = 4.32$, $p < .05$, and a significant format by distance interaction, $F(1,58) = 23.92$, $p < .05$. This was qualified by a main effect of age, $F(1,58) = 88.53$, $p < .05$, a main effect of number format, $F(1,58) = 353.08$, $p < .05$, and a main effect of distance, $F(1, 58) = 49.82$, $p < .05$. There was a non-significant age by format by distance interaction.

More specifically, older adults were significantly slower to respond than young adults. Also, both age groups were slower to respond when the stimuli were near in numeric magnitude than when they were far in numeric magnitude. The age by format interaction was observed as accentuated response time latencies in the older adult fraction comparison condition relative to either the young adult fraction comparison condition or either age group's whole number comparison conditions. The age by distance interaction was observed as differences in significant differences in response latency and variability in the older adult sample compared to the yound adult sample. Finally, the format by distance interaction was observed as significantly larger response time latencies and greater response time variability in the fraction condition relative to the whole number comparison condition and there differences were accentuated in the fraction condition relative to the whole number condition. These trends can be viewed in Figure 18.

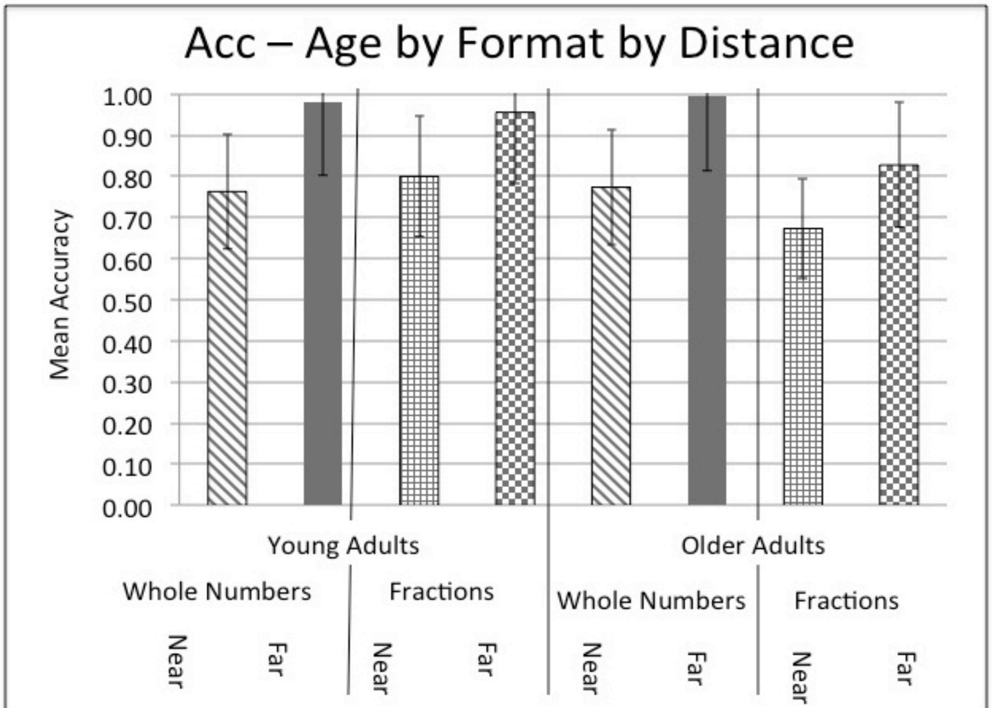


Figure 17. Bar chart of accuracy levels as a function of age cohort, number format, and number magnitude differences.

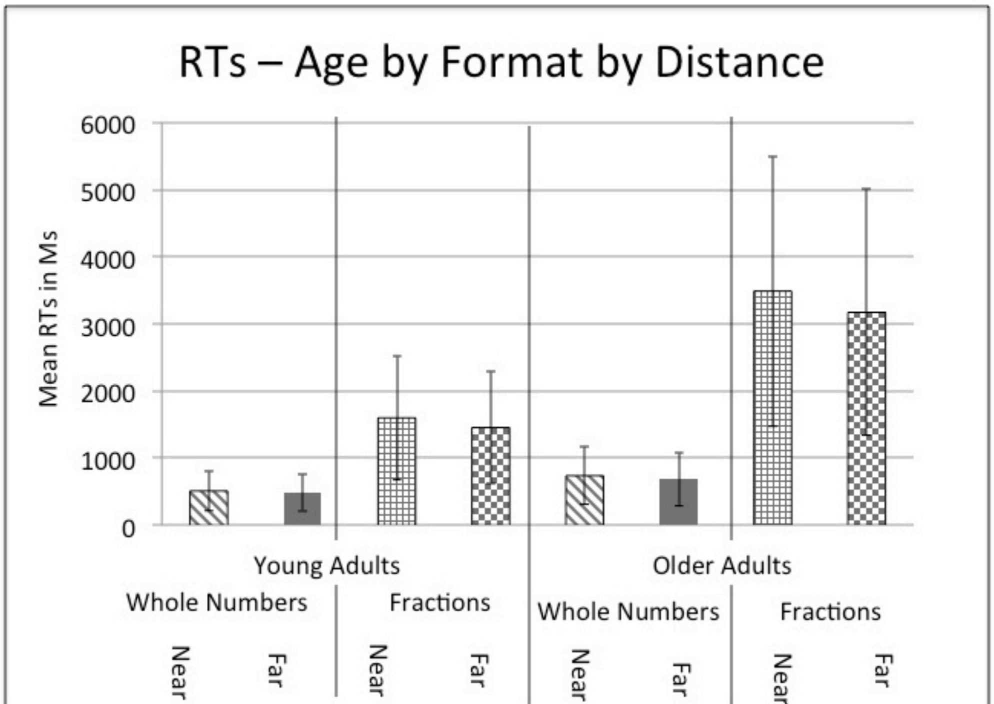


Figure 18. Bar chart of response time latencies as a function of age cohort, number format, and number magnitude differences.

Number Comparison Task Questionnaire

Independent Samples T-tests were conducted on self-report data for ease of processing for the young and older adults samples as collected in the Number Comparison Task Questionnaire. There was no significant difference is self-reported ease of processing for whole number stimuli between the two age-cohorts. Processing fractions stimuli was significantly harder for the older adult sample ($M_{\text{difficulty}} = 4.21$, $SD_{\text{difficulty}} = 1.11$) than the young adult sample ($M_{\text{difficulty}} = 3.29$, $SD_{\text{difficulty}} = 1.30$); ($t = -3.06$, $p < .05$).

To gain a better understanding of the kinds of processing favored by young and older adults, Independent Samples T-tests for average processing style for the young adults and older adults were conducted on the self-report data about number processing collected in the Number Comparison Task Questionnaire. There were no significant differences between the two age cohorts in likeliness to process fraction stimuli by comparing denominators, imagining a visualization of the fraction stimuli, or using the method of least common multiples. However, young adults were significantly more likely than older adults to report processing fraction stimuli via comparing numerators ($t = 2.36$, $p < .05$); and older adults were significantly more likely than young adults to report comparing fractions via guessing ($t = -2.58$, $p <.05$) and converting fraction stimuli to percentages ($t = -2.87$, $p < .05$).

Table 2.

Average ease of processing and kind of processing according to age-cohort as self-reported in the Number ComparisonTask Questionnaire.

	Young Adults		Older Adults			
	Mean	SD	Mean	SD	t statistic	p value
Ease of processing (Whole Numbers)	1.32	0.702	1.12	0.415	1.386	p > .05
Ease of processing (Fractions)	3.29	1.296	4.21	1.111	-3.061	p < .05
Processing by comparing numerators	4.48	1.503	4.03	1.311	1.289	p > .05
Processing by comparing denominators	3.94	1.75	3	1.414	2.359	p < .05
Processing by guessing	2.29	1.419	3.33	1.78	-2.582	p < .05
Processing by visualization	3.16	1.772	3.45	1.438	-0.729	p > .05
Processing by method of least common multiples	2.68	1.777	2.12	1.341	1.419	p > .05
Processing by converting to percentages	1.77	1.087	2.73	1.547	-2.866	p < .05

Note. Ease of processing was self-reported on a 6 point scale where 1 meant Very Easy and 6 meant Very Difficult. Processing method was self-reported on a 6 point scale where 1 meant Never and 6 meant Always.

CHAPTER 4

Discussion

The SNARC Effect

One of the main goals of this study was to investigate to relationship of the SNARC effect as observed in previous studies to both fraction comparison and aging. First, the results of this study did not replicate those observed in Dehaene, Bossini and Giraux (1993). However, this may be due to differences in study methodology. In Dehaene, Bossini, and Giraux the participants compared a single stimulus number to a single, fixed value; whereas, in this study, participants compared two stimulus numbers that changed from trial to trial. It is possible that the results of Dehaene, Bossini, &

Giraux (1993) were partially due to practice effects relative to comparison stimuli to a fixed value and that the results of this study were due to lack of practice effects. Therefore, the results of this study inform our understanding of the SNARC effect in a different context. Importantly, the SNARC effect was still observed in whole number comparison but these effects are clearly more evident in comparison accuracy relatively to comparison response time latencies. This is evidence that supports the notion that whole number comparison is an automatic process. Specifically, once whole number processing is initiated, it goes unconsciously till completion. In this study, this was observed in that the amount of time it takes for whole number processing is stable in relation to manipulation of the spatial location of numeric stimuli presentation and deficits in processing are not observable in response time latencies but in accuracy deficits of which participants are unaware.

This study also investigated the relationship between the SNARC effect and aging. Again, the results of this study support the conception of whole number processing as an automatic process (Izard & Dehaene, 2007). Specifically, in relation to age-related differences, older adults did not show a significant impact of spatial location of presentation of numeric stimuli (i.e. the SNARC effect) on number comparison response times but did show a main effect of SNARC on number comparison accuracy within the age group. Importantly, older adult number comparison response times were significantly slower than young adult response time and these differences fit the pattern of age-related differences in response time for an automatic process; that is, average older adult response times are equal to average young adult response times multiplied by a constant value (i.e., in this case average young adult response time multiplied by 1.5). Also, older adult response times for whole number comparisons were stable regardless of location of spatial of numeric stimuli but accuracy in number comparison was unconsciously impaired just as in the young adult sample.

The Distance Effect

Another goal of this study was to investigate the relationship of the distance effect as observed in previous studies to both fraction comparison and to aging. First, the distance effect taxes cognitive resources more than the SNARC effect. I make this claim because distance impacted both response times as well as accuracy in whole number comparison in both age cohorts. However, the biggest effect of distance was found in accuracy as opposed to response times in whole number comparison. This does not support the findings of Moyer and Landauer (1967). This fits with the model of numeric cognition as laid out in the introduction section of this paper.

As discussed earlier, the structure and utilization of the mental number line as the default method of numeric cognition when framed by the context of signal detection theory and gist level processing as the default method of processing led me to hypothesize that manipulation of numeric magnitude would both demand more cognition resources than the SNARC effect manipulation and that older adults would be impacted more by distance effect manipulation than young adults. The results of this study support this hypothesis. Therefore, it is possible that utilization of the mental number line in conjunction with gist level processing is an automatic process but manipulation of numeric magnitude differences forces one to move from gist level processing to a deeper level of processing which causes numeric cognition of come under more cognitive control (Izard & Dehaene, 2007; Reyna & Brainerd, 2008). Therefore observed differences in response time latencies between older and younger age cohorts resembled age-related differences in response time latencies associated with a controlled process (Verhaeghen & Salthouse, 1997).

Number Format

Fraction comparison, which is generally a variably mapped task and therefore cannot become automatized, is a controlled process even when the fraction stimuli are made to be a consistently mapped task. The results of this study suggest that individuals are unaware that my fraction stimuli represented a consistently mapped task and therefore engaged in controlled processing of the fraction stimuli throughout the duration of the experiment.

Older adults were more likely to utilize guessing, as opposed to an algorithmic version of fraction processing such as those taught during grade school, during fraction comparison relative to young adults. This may be due to lack of far transfer in the time context (Barnett & Ceci, 2002). That is, older adults are further removed in time of original training to our observation than young adults. I also theorize that lack of far transfer is likely due to under utilization of previously learned fraction comparison methods in everyday life after leaving school in the older adult cohort. Thusly, the reason the young adult cohort used previously learned fraction comparison methods is due to either consistent utilization of these methods in everyday life, likely because of constant exposure to the academic environment, or there being less time between test and original acquisition of these methods or, most likely, a combination of these two factors.

Young adults are more likely to utilize verbatim representations of the fraction stimuli than the older adults (Reyna & Brainerd, 2008). These results indicate either kind of representation for whole number processing in either age group but, if anything, it supports the idea of a gist level representation of whole numbers because of the ease with which both age-groups can represent this kind of stimuli. These results also indicate that deeper processing of whole number stimuli is necessitated by manipulation of both distance and location of presentation with an interaction of these variables because, when the whole number stimuli become more difficult to distinguish (due to incongruity with the SNARC perceptual schema or difficulty in signal detection due as assessed in the near distance condition) people must move from gist level representations to deeper levels of processing which can be observed in my results as latencies in response times and lower accuracy levels when the larger whole number is presented on the left side of space and when the whole numbers are in the near distance condition. However this does not apply to the fraction stimuli because the algorithmic processing overrides the gist level interference caused by SNARC incongruity or magnitude distance manipulations. That is, algorithmic processing forces the utilization of more cognitive resources than is forced by either the magnitude difference manipulation or the spatial location of presentation manipulation.

The results of this study support those found in Schneider and Seigler (2010). That is, accuracy discrepancies and response time latencies indicate that the true value of the fractions influences stimulus representation more than the fraction components. These results contradict the results of Devolf and Vosniadou (2011) because this study featured a consistently mapped discrimination tasks but participants responded as if it was a varied mapped task (e.g., inconsistent fraction comparison). I theorize that this represents a beneficent environmental adaptation because, in order to correctly represent inconsistent fractions, one must utilize algorithmic processing. This pattern of behavior is also consistent with the training programs utilized during early childhood education (e.g., the method of least common multiples and/or conversion to percentages).

Age-related Patterns in Accuracy and Response Times

One of the main contributions of this study is the observation of age-related patterns in accuracy levels and time response latencies associated with the SNARC effect, the distance effect, and number format. First, it was clear that the largest age differences in both accuracy and response time latencies were related to number format. That is, older adults took much longer to compare fractions than young adults. Older adults were also less accurate than young adults when comparing fractions. Importantly, age-related differences in whole number comparison and fraction comparison fit patterns for non-resource intensive and resource intensive processes, respectively (Verhaeghen & Salthouse, 1997).

However, the SNARC effect and the distance effect did not impair older adult performance relative to young adult performance as originally hypothesized. It is intriguing that there were no age differences in the response times associated with the SNARC effect. In fact, the SNARC effect was only observed in accuracy levels. This supports the proposition that utilization of the mental number line is an automatic process (Izard & Dehaene, 1997). Next, the distance effect showed similar, age-related patterns of accuracy to the SNARC effect but different, age-related patterns in response times compared to the SNARC effect. This suggests that processing fractions at near distance increases the amount of resources necessary for processing in older adults but not in young adults.

Future Directions

While these data suggest that true value processing is the default mode of fraction processing, these data are inconclusive because it is possible that these response times could be indicative of serial, componential processing (i.e., comparing denominators then comparing numerators, or visa versa, then response selection). Further exploration of these phenomena is essential for disentangling this enigma. It is important to understand both whether people utilize serial, componential processing as well as the directionality of this mode of processing (i.e., whether they process numerator or denominator first) and whether these possibilities interact with age-cohort.

Validation of serial, componential processing could be possible via assessing the directionality of the processing. If directionality is present, then serial processing is present. The converse possibility, that directionality is not present, would not invalidate serial, componential processing necessarily however because this could be a matter of individual differences that might be randomly distributed throughout the population and therefore could not be directly observed via experimentation.

Importantly, serial componential processing still necessitates a deeper level of processing than whole number processing. Further experimentation is necessary to identify the level of processing associated with different kinds of processing associated with whole number comparison and fraction comparison. It would also be necessary to identify the level of processing necessitated by the kind of processing within a domain. Hypothetically, one could correlate levels of processing to the kind of processing being utilized by assessing memory traces for the stimuli. That is, the deeper the level of processing associated with the kind of processing utilized should necessitate a stronger memory trace for the stimuli that is being processed.

Another follow-up experiment that could help disentangle the kinds of processing most favored in everyday life, as well as the levels of processing associated with different forms of processing, would be to use my exact method but manipulating the stimuli such that one of the components of one of the two fraction stimuli be missing and assessing how this affects accuracy levels, response times, and memory traces. Specifically, if a person is using gist level, componential processing of these stimuli, even with one component missing, they should still be highly accurate in their comparisons and their response times should be smaller than people using algorithmic based processing. However, the group utilizing algorithmic based processing should have stronger memory traces for the stimuli.

To determine the effects of training on processing consistently mapped fractions, it will be necessary to conduct follow up experiments in which participants are informed that the stimuli are consistently mapped. This is essential because it could inform as to what kind of training would be necessary for optimal decision making and if there is an interaction between training, consistently mapped fraction stimuli, and age. It is possible that there is an interaction between consistently mapped fraction stimuli and training such that, when individuals are given insight into the nature of the task (reference the dart in water experiment), there will be a corresponding change in behavior that will be observed as higher levels of accuracy in the task. Also, a brief training period and consistently mapped fractional risk information could improve decision-making in the medical context, improving decision-making this way could save both time and financial resources as opposed to other methods (e.g., training in least common multiples), and these benefits could be greatest for older adults.

Application of study findings

Spatial augmentation of fraction stimuli does not produce the differences in decision-making accuracy as observed in the whole number condition. Therefore, the location of fractional risk information should not be of concern when relaying risk information to individuals regardless of age. However, magnitude differences do impact one's ability to accurately interpret fractions such that people have difficulty distinguishing between fractions when the fractions being displayed have similar numerosities. Therefore, it is particularly important to assess understanding when conveying fractional risk information when the fractions have similar numerosities. The importance of assessing the impact of different number format's impact on older adult's understanding of risk information is of exaggerated importance in the health context (Fausset, Morgan, & Rogers, 2012). The teach-back method is an evidence-based way to assess understanding (Fausset, Rogers, & Fisk, 2014). It is of exaggerated importance for assessment of understanding of similar fraction risk information in older adults because they were significantly more likely to guess during decision-making.

Conclusion

The results of this study indicate that people use different forms of numeric processing for whole number comparison and fraction comparison. These data also support a model of whole number processing founded on the automatic utilization of the mental number line in conjunction with gist level processing for whole numbers at far distance and deeper processing for whole numbers at near distance. Different patterns of average response time latencies for the two age cohorts support this assertion because the older adult sample was impacted more by the near distance stimuli than the young adult sample; and, while the average response time latencies associated with the SNARC effect support the assertion that whole number processing is an automatic process, different patterns of average response time latencies and accuracies between the stimulus conditions associated with the distance effect and SNARC effect support differences in levels of processing associated with these phenomena.

Finally, more investigation will be necessary to understand the relationship between age-related differences in fraction comparison and both the SNARC effect and the distance effect, these data indicate that the participants used a different form of numeric cognition for fraction comparison than for whole number comparison. Also, these data suggest that the processing utilized during fraction comparison is more demanding of cognitive resources than whole number comparison (i.e., fraction comparison is a controlled process). Finally, these data indicate that the study participants did not recognize that the fraction stimuli used in this study were consistently mapped and could have been accurately judged using the same process associated with whole number processing. Therefore, it is possible that people would not recognize consistently mapped fraction stimuli in every day life. Further investigation will be necessary to determine if practice or training effects could improve the recognition of consistently mapped fractions

APPENDIX A

TABLE OF STIMULI

Table 3

List of all fraction and whole number presentations.

Fractions Near Distance	Fractions Far Distance	Whole Number Near Distance	Whole Number Far Distance
$\frac{2}{3}$ vs. $\frac{3}{4}$	$\frac{2}{3}$ vs. $\frac{6}{7}$	2 vs. 3	1 vs. 5
$\frac{4}{5}$ vs. $\frac{5}{6}$	$\frac{3}{4}$ vs. $\frac{7}{8}$	3 vs. 4	2 vs. 6
$\frac{6}{7}$ vs. $\frac{7}{8}$	$\frac{4}{5}$ vs. $\frac{8}{9}$	4 vs. 5	3 vs. 7
$\frac{8}{9}$ vs. $\frac{9}{10}$	$\frac{5}{6}$ vs. $\frac{9}{10}$	5 vs. 6	4 vs. 8
$\frac{4}{7}$ vs. $\frac{5}{8}$	$\frac{1}{4}$ vs. $\frac{5}{8}$	7 vs. 8	5 vs. 9
$\frac{1}{4}$ vs. $\frac{2}{5}$	$\frac{3}{5}$ vs. $\frac{7}{9}$	9 vs. 10	6 vs. 10
$\frac{7}{10}$ vs. $\frac{8}{11}$	$\frac{4}{7}$ vs. $\frac{8}{11}$	10 vs. 11	7 vs. 11

APPENDIX B

EXPERIMENTAL METHODOLOGY

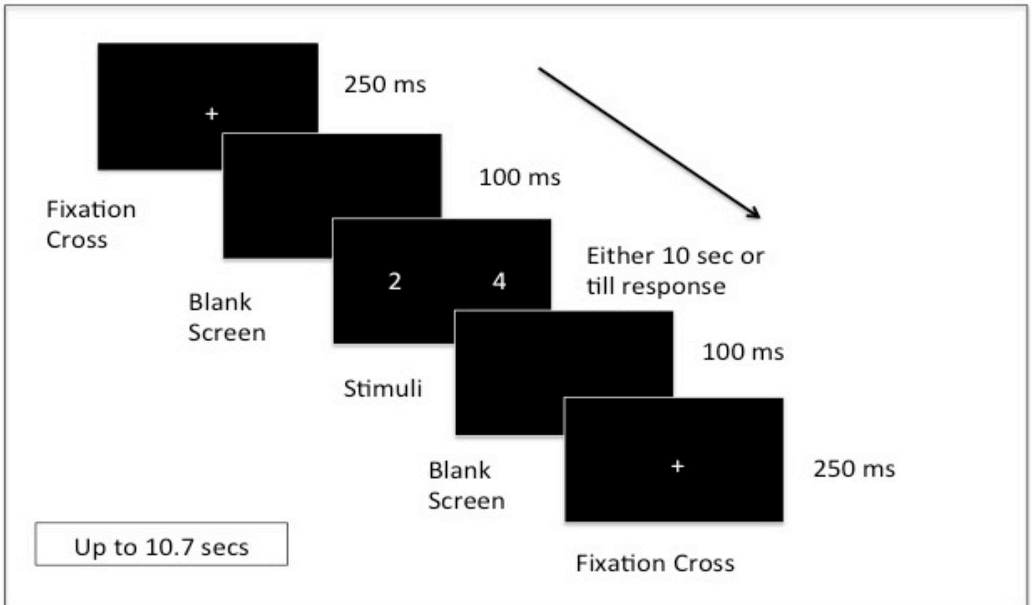


Figure 19. Visualization of computerized number comparison task featuring whole numbers

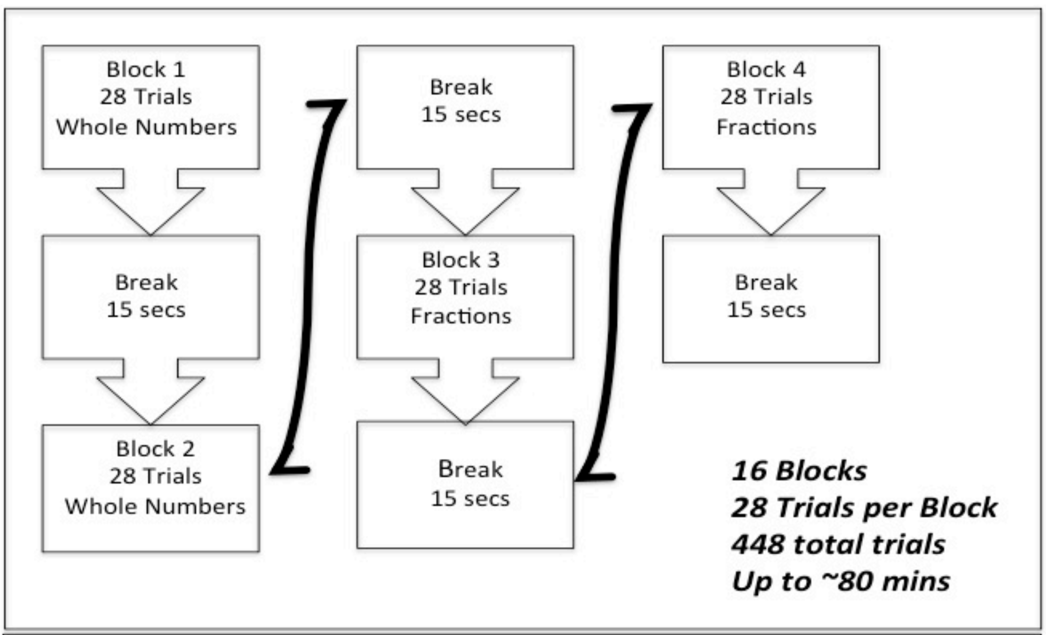


Figure 20. Visualization of block procedure of the computerized number comparison task.

APPENDIX C

EXPERIMENTAL PROTOCOL OUTLINE

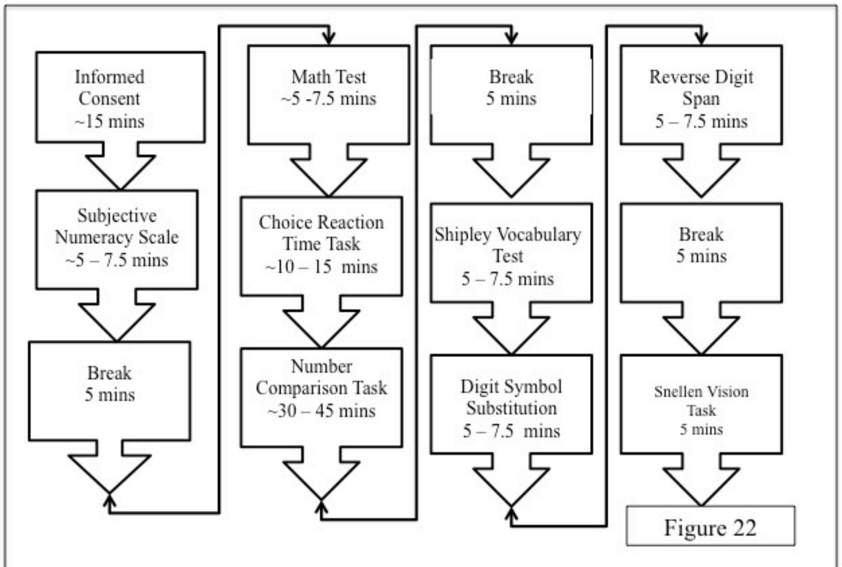


Figure 21. Flow chart of experimental protocol

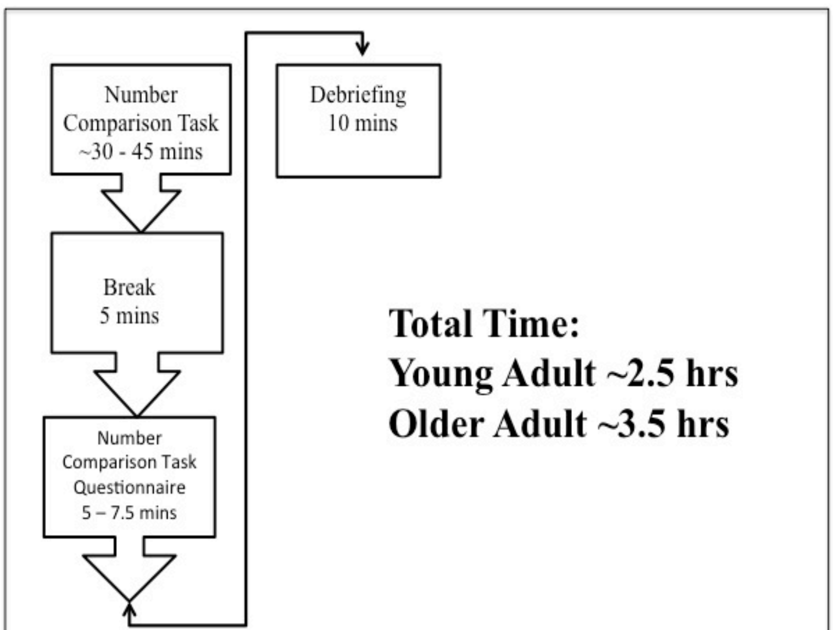


Figure 22. Flow Chart of experimental protocol, continued

APPENDIX D

NUMBER COMPARISON TASK QUESTIONNAIRE

(Draft) Subject Number: ____

Number Comparison Task Questionnaire

Now that you have completed our experiment, we would like you to answer a few questions to help us better understand how you make numeric comparisons.
(circle one number)

(1) How easy/difficult was the number comparison task using **whole numbers**?

1	2	3	4	5	6
Very Easy	*Easy*	*Somewhat Easy*	*Somewhat Difficult*	*Difficult*	*Very Difficult*

(2) How easy/difficult was the number comparison task using **fractions**?

1	2	3	4	5	6
Very Easy	*Easy*	*Somewhat Easy*	*Somewhat Difficult*	*Difficult*	*Very Difficult*

(3) During the **Fraction Comparison Task**, what method did you use to make the comparison :

Compare Denominators

1	2	3	4	5	6
Never		*Some of the time*			*Every Time*

Compare Numerators

1	2	3	4	5	6
Never		*Some of the time*			*Every Time*

(Draft) Subject Number: ____

Convert to Percentages

1	2	3	4	5	6
Never		*Some of the time*			*Every Time*

Estimate/Guess Percentages

1	2	3	4	5	6
Never		*Some of the time*			*Every Time*

Least Common Multiples

1	2	3	4	5	6
Never		*Some of the time*			*Every Time*

Visualization

1	2	3	4	5	6
Never		*Some of the time*			*Every Time*

(4) Did you ever change your method of making comparisons? If so, why?

(5) Did you ever use more than one method of comparison on any single comparison? If so, why?

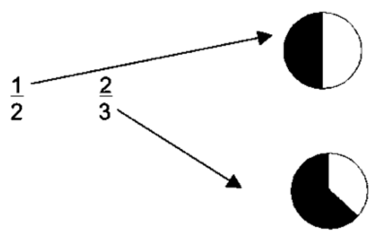
(Draft) Subject Number: ____

An Example of Least Common Multiples Comparison:

$\frac{1}{2}$ $\frac{2}{3}$ → $\frac{1}{2} \times \frac{3}{3} = \frac{3}{6}$ → $\frac{3}{6}$ $\frac{4}{6}$

$\frac{2}{3} \times \frac{2}{2} = \frac{4}{6}$

An Example of Visualization:



An example of Converting to Percentages:

$\frac{1}{2}$ $\frac{2}{3}$ → $1 \div 2 = .5$ → $.5 \times 100 = 50\%$

$2 \div 3 = .66$ → $.66 \times 100 = 66\%$

An Example of Comparing Numerators:

$\frac{1}{2}$ $\frac{2}{3}$ → 1 2

An Example of Comparing Denominators:

$\frac{1}{2}$ $\frac{2}{3}$ → 2 3

APPENDIX E

SUBJECTIVE NUMERACY SCALE

For each of the following questions, please check the box that best reflects **how good you are at doing the following things**:

1. How good are you at working with fractions?

❑1	❑2	❑3	❑4	❑5	❑6
Not at all good					**Extremely good**

2. How good are you at working with percentages?

❑1	❑2	❑3	❑4	❑5	❑6
Not at all good					**Extremely good**

3. How good are you at calculating a 15% tip?

❑1	❑2	❑3	❑4	❑5	❑6
Not at all good					**Extremely good**

4. How good are you at figuring out how much a shirt will cost if it is 25% off?

❑1	❑2	❑3	❑4	❑5	❑6
Not at all good					**Extremely good**

For each of the following questions, please check the box that **best reflects your answer**:

5. When reading the newspaper, how **helpful** do you find tables and graphs that are parts of a story?

❑1	❑2	❑3	❑4	❑5	❑6
Not at all helpful					**Extremely helpful**

6. When people tell you the chance of something happening, do you prefer that they use **words** ("it rarely happens") or **numbers** ("there's a 1% chance")?

❑1	❑2	❑3	❑4	❑5	❑6
Always Prefer Words					**Always Prefer Numbers**

7. When you hear a weather forecast, do you prefer predictions using **percentages** (e.g., “there will be a 20% chance of rain today”) or predictions using only **words** (e.g., “there is a small chance of rain today”)?

❑1	❑2	❑3	❑4	❑5	❑6
Always Prefer Percentages					**Always Prefer Words**

8. How **often** do you find numerical information to be useful?

❑1	❑2	❑3	❑4	❑5	❑6
Never					**Very Often**

APPENDIX F

PIE CHARTS OF DEMOGRAPHICS AND HEALTH DATA

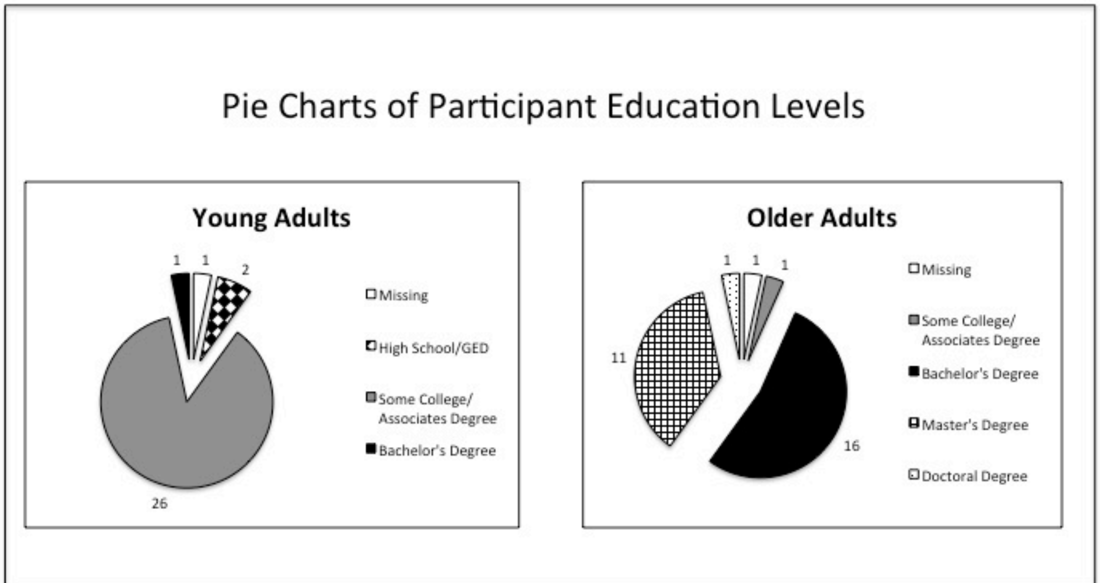


Figure 23. Pie charts of participant education levels

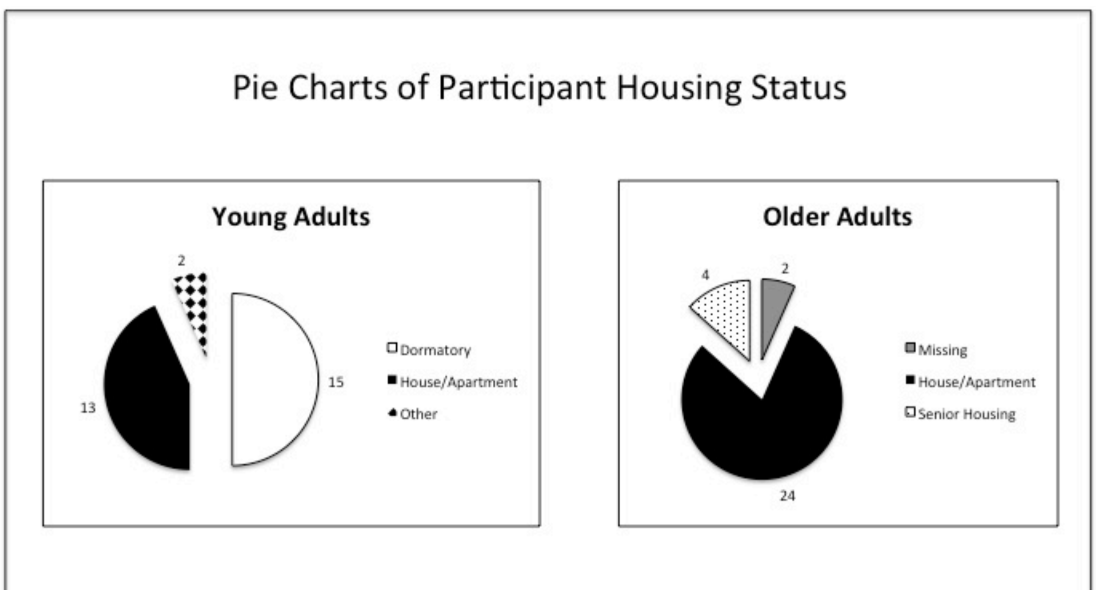


Figure 24. Pie charts of participant housing status

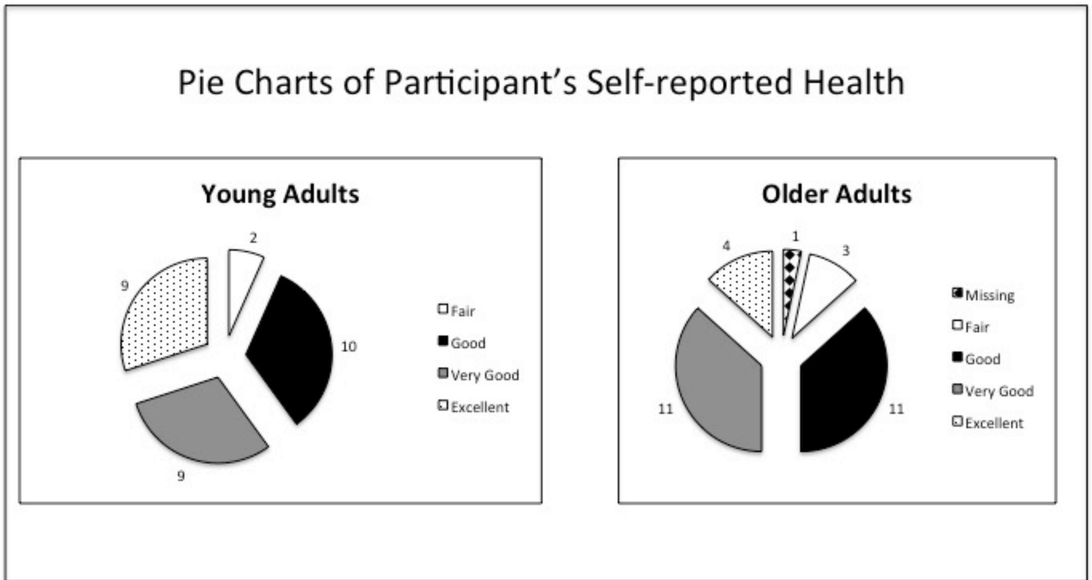


Figure 25. Pie charts of participant's self-reported health

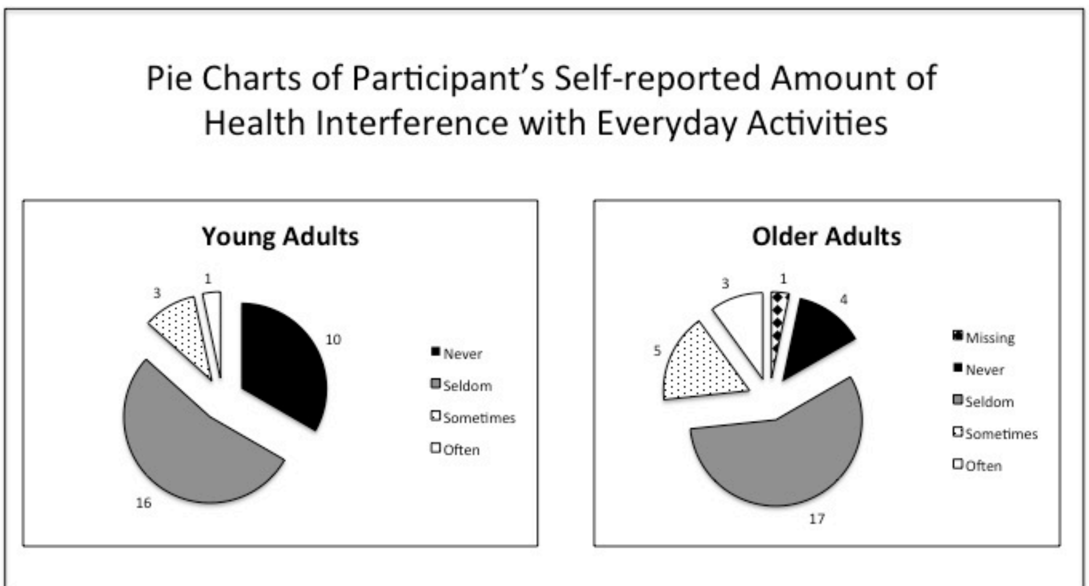


Figure 26. Pie charts of participant's self-reported amount of health interference with everyday activities

Figure 27. Pie charts of participant's self-reported prevalence of diabetes

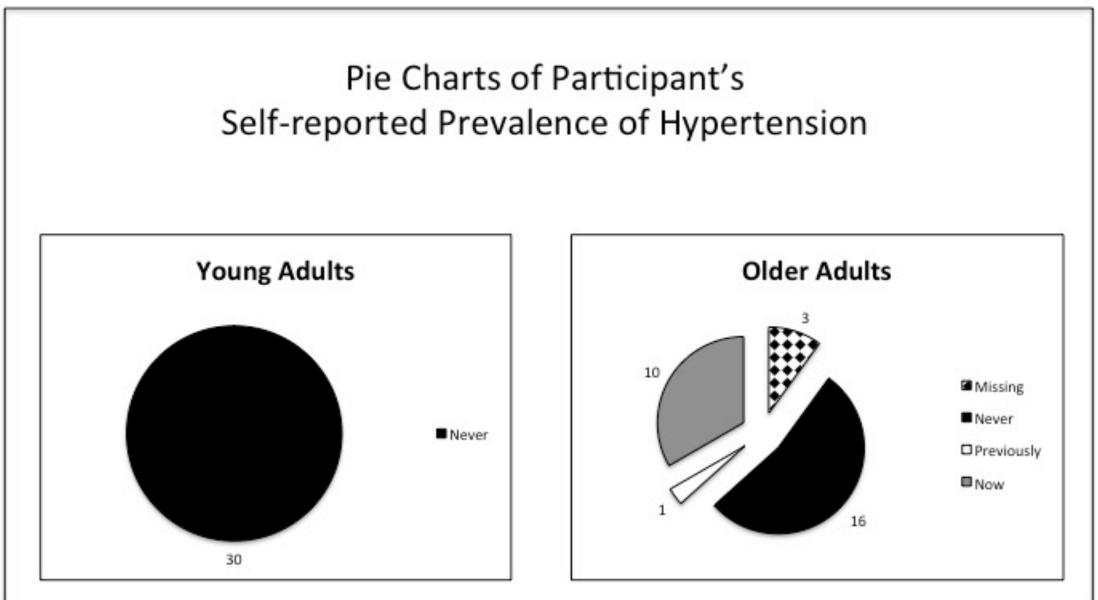


Figure 28. Pie charts of participant's self-reported prevalence of hypertension

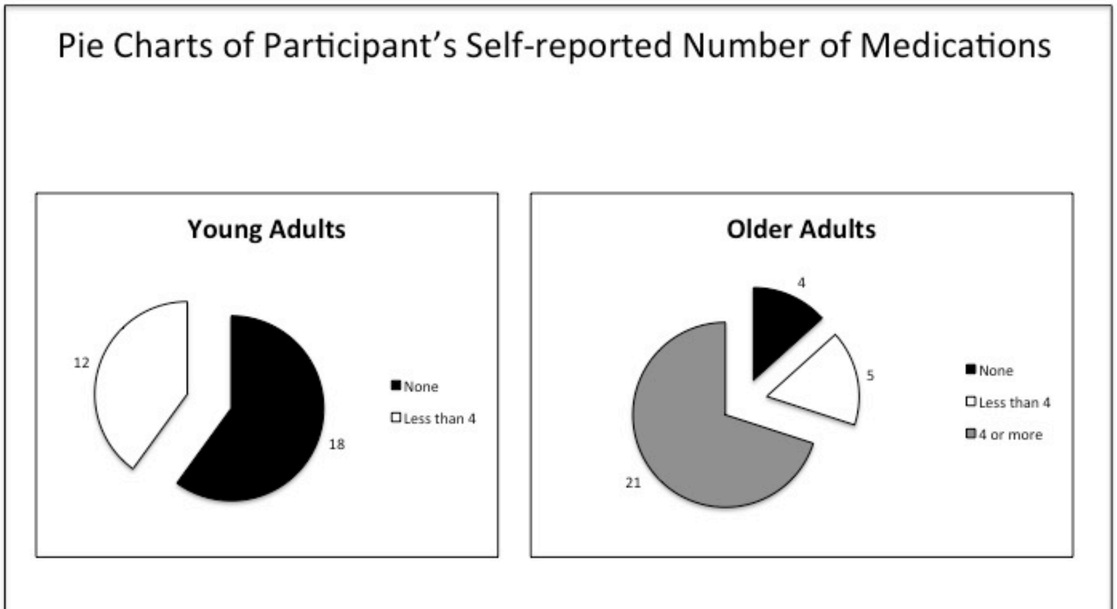


Figure 29. Pie charts of participant's self-reported number of medications

APPENDIX G

ABILITY TEST CORRELATION MATRICES

Table 4. Correlation matrix of ability test data and number comparison accuracy data for young adults.

Correlations

			Whole Numbers	Fractions	Sub Numeracy Scale	Multiplication and Subtraction test	Reverse Digit Span	Digit Symbol Substitution	Shipley Vocabulary test
Young Adults	Whole Numbers	Pearson Correlation	1	.182	.107	-.166	-.026	.004	-.282
		Sig. (2-tailed)		.336	.574	.380	.890	.982	.131
		N	30	30	30	30	30	30	30
	Fractions	Pearson Correlation	.182	1	.169	-.063	.401	.047	-.155
		Sig. (2-tailed)	.336		.371	.741	.028	.805	.413
		N	30	30	30	30	30	30	30
	Subjective Numeracy Scale	Pearson Correlation	.107	.169	1	.189	.203	.044	.008
		Sig. (2-tailed)	.574	.371		.318	.283	.816	.968
		N	30	30	30	30	30	30	30
	Multiplication and Subtraction test	Pearson Correlation	-.166	-.063	.189	1	.011	.290	-.198
		Sig. (2-tailed)	.380	.741	.318		.953	.120	.294
		N	30	30	30	30	30	30	30
	Reverse Digit Span	Pearson Correlation	-.026	.401	.203	.011	1	-.187	.284
		Sig. (2-tailed)	.890	.028	.283	.953		.322	.129
		N	30	30	30	30	30	30	30
	Digit Symbol Substitution	Pearson Correlation	.004	.047	.044	.290	-.187	1	-.229
		Sig. (2-tailed)	.982	.805	.816	.120	.322		.224
		N	30	30	30	30	30	30	30
	Shipley Vocabulary Test	Pearson Correlation	-.282	-.155	.008	-.198	.284	-.229	1
		Sig. (2-tailed)	.131	.413	.968	.294	.129	.224	
		N	30	30	30	30	30	30	30

Table 5. Correlation matrix of ability test data and number comparison accuracy data for older adults.

Correlations

			Whole Numbers	Fractions	Sub Numeracy Scale	Multiplication and Subtraction test	Reverse Digit Span	Digit Symbol Substitution	Shipley Vocabulary test
Older Adults	Whole Numbers	Pearson Correlation	1	.164	.618	.184	.329	-.137	-.202
		Sig. (2-tailed)		.386	.000	.331	.075	.472	.284
		N	30	30	30	30	30	30	30
	Fractions	Pearson Correlation	.164	1	.240	.180	.279	.049	.149
		Sig. (2-tailed)	.386		.202	.342	.135	.797	.433
		N	30	30	30	30	30	30	30
	Subjective Numeracy Scale	Pearson Correlation	.618	.240	1	.476	.483	.095	.083
		Sig. (2-tailed)	.000	.202		.008	.007	.619	.663
		N	30	30	30	30	30	30	30
	Multiplication and Subtraction test	Pearson Correlation	.184	.180	.476	1	.160	.008	.115
		Sig. (2-tailed)	.331	.342	.008		.398	.965	.546
		N	30	30	30	30	30	30	30
	Reverse Digit Span	Pearson Correlation	.329	.279	.483	.160	1	.163	.353
		Sig. (2-tailed)	.075	.135	.007	.398		.388	.056
		N	30	30	30	30	30	30	30
	Digit Symbol Substitution	Pearson Correlation	-.137	.049	.095	.008	.163	1	.017
		Sig. (2-tailed)	.472	.797	.619	.965	.388		.930
		N	30	30	30	30	30	30	30
	Shipley Vocabulary Test	Pearson Correlation	-.202	.149	.083	.115	.353	.017	1
		Sig. (2-tailed)	.284	.433	.663	.546	.056	.930	
		N	30	30	30	30	30	30	30

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