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Visual Acuity does not Moderate Effect Sizes of Higher-Level Cognitive Tasks

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Abstract

Background—Declining visual capacities in older adults have been posited as a driving force behind adult age differences in higher-order cognitive functions (e.g., the "common cause" hypothesis of Lindenberger & Baltes, 1994). McGowan, Patterson and Jordan (2013) also found that a surprisingly large number of published cognitive aging studies failed to include adequate measures of visual acuity. However, a recent meta-analysis of three studies (LaFleur & Salthouse, 2014) failed to find evidence that visual acuity moderated or mediated age differences in higher-level cognitive processes. In order to provide a more extensive test of whether visual acuity moderates age differences in higher-level cognitive processes, we conducted a more extensive meta-analysis of topic.

Methods—Using results from 456 studies, we calculated effect sizes for the main effect of age across four cognitive domains (attention, executive function, memory, and perception/language) separately for five levels of visual acuity criteria (no criteria, undisclosed criteria, self-reported acuity, 20/80-20/31, and 20/30 or better).

Results—As expected, age had a significant effect on each cognitive domain. However, these age effects did not further differ as a function of visual acuity criteria.

Conclusion—The current meta-analytic, cross-sectional results suggest that visual acuity is not significantly related to age group differences in higher-level cognitive performance—thereby replicating LaFleur and Salthouse (2014). Further efforts are needed to determine whether other measures of visual functioning (e.g. contrast sensitivity, luminance) affect age differences in cognitive functioning.

Recently, McGowan, Patterson and Jordan (2013) noted concerns regarding the lack of visual acuity assessment in aging studies involving linguistic stimuli. By exploring the

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incidence of specific visual acuity criteria used, these researchers found that the majority of 240 studies using linguistic stimuli published from 2000–2010 in *Experiment Aging Research, Journal of Gerontology: Psychological Sciences*, and *Psychology and Aging* either made no mention of the visual acuity of their participants (59%) or relied on self-report (8.8%). Furthermore, numerous studies documented visual acuity capacities with no mention of a specific assessment (17.9%), and just over 14% of articles had documented participants' visual abilities while also providing the specific assessment that was utilized. Thus, a concern in this paucity of visual acuity screening in studies of cognitive aging is that visual acuity deficits in older adults might be moderating or mediating age-related differences in higher-order cognitive performance (e.g., attention, executive function, memory, and perception/language).

Considering the widespread decline in visual sensory processing that is normative to the aging process (Lindenberger & Baltes, 1994), it is alarming that so many studies have not controlled for acuity in their comparisons between younger and older participants. Moreover, it is also conceivable that the wide array of inclusionary criteria (e.g. Snellen 20/20, Snellen 20/40, self-report) incorporated into studies across several domains of cognitive function may also have an impact on the interpretation of results. For example, numerous reports have provided evidence of a dissociation between subjective and objectively measured visual acuity (Friedman et al., 1999; Ross et al., 1999; Warrian, Altangerel, & Spaeth, (2010). While visual acuity assessment is time consuming and requires trained examiners, there is evidence that that the large stimuli and proper lighting used in earlier studies may not preclude declining abilities from influencing performance (Skeel et al., 2003; Skeel et al., 2006).

However, La Fleur and Salthouse (2014) recently reported a meta-analysis on three of Salthouse's past studies (Salthouse, Hambrick & McGuthry, 1998; Salthouse, 2013, 2014) that examined the relationship between age-related differences in processing speed and memory with visual acuity. Two of these datasets were cross-sectional, and one was longitudinal. They stated: "In conclusion, although we confirmed prior findings of moderate relations between sensory ability and measures of cognitive functioning, our results are not consistent with the hypothesis that age-related declines in sensory ability contribute to age-related declines in cognitive functioning" (p. 1208). La Fleur and Salthouse made this conclusion because their mediation analyses were inconclusive and because their observed relations between visual acuity and processing speed and memory were constant across all adult ages. Consequently, we conducted the present more comprehensive meta-analysis to follow-up on the LaFleur and Salthouse meta-analysis to assess the generality of the earlier finding of no moderation of visual acuity on age-related differences in higher cognitive processes. We believe that it is important to replicate these earlier findings because of the importance of the common cause hypothesis originally proposed by Lindenberger and Baltes (1994) to theories of cognitive aging.

In the present project, we meta-analyzed the data from 456 cognitive aging studies published from 1995 to 2013 using the Pubmed academic database, as well as searching the aforementioned cognitive aging journals. The major issue of interest was whether the effect size of age would vary as a function of visual acuity category and/or higher-level processing domain. If the common cause theory can be applied to visual acuity, we assumed that studies that did not assess visual acuity, or used self-report indices of visual acuity, or studies in which visual acuity ranges were lower (20/80 to 20/31) would have larger disparities between younger and older adults' higher-level cognitive performances than studies in which visual acuity was higher (20/30 or better). That is, if all participants (younger and older) were required to have 20/30 visual acuity, or better, than the average age deficit in higher-level cognitive performance would be smaller than if participants were required to have a minimum of just 20/40 visual acuity, or higher (because the average visual acuity would have tended to be higher in younger adults). Building on this logic, we predicted that if visual acuity modulated age-related differences in higher-cognitive function, then the effect size for age in meta-analyses should be greater for the three groups expected to have poorer visual acuity (e.g., see McGowan et al., 2013).

The Common Cause Theory of Cognitive Aging

Given that there is frequently a lack of consensus in the cross-sectional and longitudinal cognitive aging literature (e.g., is there general, process-specific, or domain-specific slowing?), part of this lack of consensus may be due to the potentially confounding effect of uncontrolled visual acuity differences across age. A critical theory related to this issue is the common cause theory (Lindenberger & Baltes, 1994; Baltes & Lindenberger, 1997) of cognitive aging. For example, Lindenberger and Baltes (1994) examined a sample of 156 older adults from the Berlin Aging Study (mean age = 84.9 years, range = 70–103 years). They found that visual and auditory acuity accounted for 93.1% of the age-related reliable variance in intelligence. This type of empirical evidence has led common cause advocates to hypothesize that underlying age-related differences in visual or auditory sensory function moderate (change the direction or intensity of the age effect) or mediate (cause) age-related differences across a wide number of cognitive domains (Baltes & Lindenberger, 1997; Li & Lindenberger, 2002; Lindenberger & Baltes, 1994; Lindenberger & Ghisletta, 2009). There is evidence for age-related declines in sensory function. Indeed, previous efforts have found significant adult age-related differences in visual acuity, contrast sensitivity, and visual field (e.g., Brabyn et al., 2001; Evans & Rowlands, 2004; Glass, 2007; Greene & Madden, 1987; Klein et al., 2006; Lindenberger & Baltes, 1994; Madden & Greene, 1987;). These differences have been found across multiple settings and even in participants using their current optical correction (Brabyn et al., 2001; Greene & Madden, 1987; Skeel et al., 2003). Other research groups have explored the impact of acuity in processing visually-presented stimuli through the use of occlusion filters in younger adults (e.g., Gilmore, Spinks & Thomas, 2006). However, findings under this framework have reached inconsistent conclusions, perhaps due to these blurring filters impeding the functionality of neural compensatory mechanisms in the visual processing of experimental stimuli (Bertone et al., 2007). Regardless, dependent upon the requirements of the particular cognitive task, age-related deficits in visual information processing have been suggested in both the periphery as well as central processing areas (Berry et al., 2010; Elliott et al., 1990; Owsley, 2011; Zhang et al., 2008).

However, the literature is mixed with regard to whether sensory decrements are correlated with, moderate, or mediate age-related differences in higher cognitive function. For example, Lindenberger and Baltes (1994) and Baltes and Lindenberger (1997), Anstey, Lord, and Williams (1997), Anstey and Smith (1999), Salthouse, Hambrick and McGuthry (1998), and Salthouse, Hancock, Meinz, and Hambrick (1996) all reported evidence of sensory mediation of age-related differences in cognitive processing. However, Allen et al. (2001), Anstey, Luszcz, and Sanchez (2001), Baena, Allen, Kaut, and Hall (2010), Schmiedek and Li (2004), and Verhaeghen (2003, 2011) all found evidence of substantial indirect effects of age on higher-level cognitive variables that were not accounted for (mediated by) common causes such as sensory processes (e.g., visual acuity). Consequently, past results using causal modeling (SEM) methods and meta-analysis have resulted in seemingly inconsistent results with regard to sensory effects accounting for age-related differences in higher-level processes. An important contribution of the present study is that we present a meta-analysis of data from a much larger sample of studies (456) than has been used in the past (e.g., LaFleur & Salthouse, 2014; and past SEM studies). Our goal is to assess whether the effect size of age-related differences in four different cognitive domains for the present substantial set of experimental studies vary as a function of visual acuity in younger and older adults.

The Present Study

There are two reasons for reporting the present meta-analyses in spite of the fact that La Fleur and Salthouse (2014) recently reported a similar study. First, La Fleur and Salthouse reported results from just two cognitive domains (processing speed and memory), and our design includes four domains (attention, executive function, memory, and perception/ language) as well as multiple visual acuity categories (no assessment of visual acuity, undisclosed visual acuity, self-reported assessment of visual acuity, 20/80-20/31, and 20/30 or better). Second, given the importance of the common cause hypothesis (Lindenberger & Baltes, 1994) to the cognitive aging field, it is important to replicate these earlier results with a larger set of studies. Consequently, the present meta-analysis of visual acuity levels and their relationship to age-related differences in higher-level cognitive function uses a sample 456 aging studies across four cognitive domains and four levels of visual acuity.

METHOD

Literature Search

To further the effort of McGowan et al. (2013) and La Fleur and Salthouse (2014), we surveyed the literature from the online PubMed academic database (PubMed.gov) in conjunction with the databases for three journals used by McGowan and colleagues: *Psychology and aging, Experimental Aging Research, and The Journals of Gerontology, Series B: Psychological Sciences & Social Sciences*, as well as many other journals. To be included in the meta-analysis, studies were required to; (1) be cross-sectional in nature (because so few longitudinal studies on this topic have been published), (2) have documented at least one age group comparison as a main effect, (3) have documented raw statistics in the form of Pearson's r, regression coefficient R^2, variance F ratio, Student's t, β, or Spearman's ρ, (4) involve cognitive tasks in which stimuli were presented visually and performance could be objectively measured (i.e. by reaction time, percentage correct, or overall task performance), and (6) for the circumstances in which multiple studies were incorporated into a single publication, contain an orthogonal sample with participants not participating in any other portion of the study. Data collection took place in two stages. Stage one involved collecting studies from the PubMed database and from the three journals dating back to 2002. After examining the characteristics of these studies, we then conducted an additional search in the three journals dating back to 1995, targeting only studies that incorporated objectively measured visual acuity criteria in order to evenly distribute our categorizations and allow for representative comparison across visual acuity criteria for each cognitive domain.

Coding Procedure

In total, 456 studies were incorporated into the statistical analyses. We categorized these studies by visual acuity criteria and four cognitive domains: attention, executive function, memory, and perception. Many studies recorded measures from more than one domain. However, to satisfy independence requirements for the meta-analysis, only measures from one category per study were added into the analysis. For these studies with multiple domains, domains were chosen based upon either the emphasis of the study or, and provided that no emphasis was apparent, we assigned studies by need of the statistical analysis (i.e., to evenly distribute category cell counts). Building upon the visual acuity criteria employed by McGowan et al. (2013), studies were assigned to seven separate visual acuity categories in the current protocol. However, it should be noted that we "over-sampled" in certain categories so that we would have enough cases—so the present results cannot be directly compared to those of McGowan et al. The first and most frequently assigned category (36.4% of cases) included studies in which no visual acuity criterion was required for participation. Separate categories were also established for studies documenting self-reported visual acuity (5.9% of cases) and adequate visual acuity with no documentation of the specific acuity threshold required (23.0% of cases). The final two criteria incorporated studies that provided a specific acuity threshold required to participate. All presented visual acuity thresholds were converted to Snellen ratios and initially assigned to the categories of 20/80-20/41, 20/40-20/31, 20/30-20/21, or 20/20 or better. Due to a limited number of studies utilizing the thresholds of 20/80 and 20/20 or better, the visual acuity categories were reduced to two categories for analysis, 20/80-20/31 and 20/30 or better. The classification of studies to both cognitive domain and visual acuity category is presented in Table 1 below.

As with McGowan et al. (2013), we also examined the prevalence of studies that documented the use of a specific visual acuity screener instrument. For 158 studies in which a specific threshold was required for participation, 53.8% (85) of studies documented the utilized measure of visual acuity. For comparison, 41.9% (44) of studies omitting documentation of an acuity threshold listed a vision assessment tool. However, a Chi-square test of independence between these two likelihoods failed to reach statistical significance, $\chi^2 = 3.58$, $p = .058$, thus providing evidence that researchers using a specific exclusionary criteria were no more likely to document an assessment tool than those not utilizing a specific visual acuity criteria.

Effect Size Calculation

For each study, the raw statistic characterizing the main effect of age group (r, R^2, F, t, β, or ρ) was converted to Fisher's Z (Z_r), weighted by the study sample size (Rosenthal & DiMatteo, 2001). When necessary, the sign of the raw statistics were adjusted such that positive Z_r values indicate better performance (i.e., higher accuracy, faster reaction time) in younger adults relative to older adults. We then averaged the Z_r values across studies, separately for each visual acuity criteria and cognitive domain, and then converted back to r values (see Hedges & Vevea, 1998).

RESULTS

The averaged effect sizes (r) are presented separately for each visual acuity criterion and cognitive domain in Table 2. We also calculated overall values for each visual acuity criterion by collapsing across the cognitive domains and for each cognitive domain by collapsing across visual acuity criteria. These moderate to large effect sizes (Cohen, 1988) indicate that, as expected, older adults performed significantly worse on all cognitive tasks than younger adults. Multiple Z tests of the weighted effect sizes (Z_r) further confirmed that the effect of age on cognitive performance was significant for each cognitive domain at each visual acuity criteria (Z's > 5.43, p's < 0.001).

Additional Z tests of the differences between the weighted effect sizes revealed that the effect of age did not significantly differ across the visual acuity criteria for any cognitive domain (Z's < |1.11|, p's > 0.13). Similar non-significant differences were observed across the visual acuity criteria when using the overall cognitive measure (i.e., collapsed across domains) (Z's < |0.49|, p's > 0.31). See Appendix B for individual study categorizations with their associated weighted effect size values.

DISCUSSION

The main finding of the present meta-analysis of 456 cognitive aging studies across four domains was that there were no significant differences in effect size for age across the five categories of visual acuity in any of the four different cognitive domains. A key assumption was that if the visual acuity data supported the predictions of the common cause hypothesis, then there would be larger relative sensory decrements in the unreported VA, self-reported VA, and 20/80-20/31 visual acuity categories than in the 20/30 or above VA category (because this final category of the highest VA group required that younger and older adults had a minimum of 20/30 visual acuity). In the other groups, one would expect that older adults would have poorer visual acuity than younger adults in causes in which visual acuity was not controlled, and thus, the effect size for age should largest in the groups with relatively larger age-related differences in VA. However, the effect sizes for age did not differ across the five VA groups in any of the four cognitive domains, or overall (i.e., when collapsing into a single cognitive domain). These results therefore suggest that one type of sensory effect, visual acuity, does not moderate age-related differences in higher cognitive processes in seeming violation of the predictions of the common cause hypothesis (Lindenberger & Baltes, 1994; Baltes & Lindenberger, 1997).

With regard to the limitations of the current design, the most apparent consideration is that we drew our results from a single measure of visual functioning—visual acuity. This parameter was selected due to its ubiquity in the published cognitive aging literature. However, this meta-analysis does not rule out a potential moderation or mediation relationship between other measures of visual functioning, such as contrast sensitivity or visual field size (or measures of auditory sensory functioning), and differences in age-group comparisons of cognitive performance. Also, the present study consisted of a healthy aging sample. Thus, it could be that for, say, dementia patients that sensory decrements could moderate or mediate performance in higher-level cognition. Note that this is a particularly important possibility because the sample used in Lindenberger and Baltes (1994) was approximately 85 years of age, and the odds of dementia at this age is likely over over 30% (Herbert, Weuve, Scherr, & Evans, 2013). Nevertheless, we argue that the lack of a sensory-cognition association as measured by the most ubiquitously reported measure of sensory function, visual acuity, provides an important consideration to the discussion of general and specific effects associated with cognitive aging. Namely, based on a meta-analysis of 456 studies, we could not detect significant age-related differences in overall visual acuity, and we found that different categories of visual acuity did not moderate age-related differences in higher-level cognitive function.

The independence of age-related visual sensory and cognitive effects is surprising in light of the common cause hypothesis. One possibility is that older adults compensate for sensory deficits using top-down processes (e.g., Madden, 2007) and/or increased bottom-up chunking skill and normalization (Allen et al., 2002, 2011; see Stine-Morrow, Miller & Hertzog, 2006, for an information-processing model of compensation). At a neural level, compensation is reflected in age-related differences in task-related functional brain activation, and perhaps in brain structure as well (e.g., white matter integrity), linked to age-related differences in behavioral performance (Cabeza et al., 2002; Grady, 2012). The aspects of brain structure and function that define compensation, however, are not yet known entirely and appear to depend on many variables related to task demands and the overall level of task performance (Davis et al., 2008; Daselaar et al., 2013; Logan et al., 2002). Alternatively, it may be the case that, for the types of cognitive measures reviewed here, the variance associated with computational (encoding), decision-related, and response-related aspects of the task is more relevant for age-related differences than the variance associated with visual acuity. Finally, as noted earlier, it could be that sensory moderation or mediation of age-related differences in higher-level cognitive function may not occur into much later (e.g., in the mid 80s—as in Lindenberger & Baltes, 1994). Consequently, other factors in addition to sensory decrements are important for a thorough understanding of age-related differences in cognitive processing. While we in no way suggest that researchers should not screen for visual acuity, our meta-analysis results show that that such a situation would probably not bias estimates of age-related differences in higher cognitive processing, although not screening for visual acuity could exacerbate age-related differences in visual acuity.

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Appendix A

Appendix Table 1

Common tasks representing cognitive domains

Attention	Executive Function	Memory	Perception
Asynchronous Dual-task	Driving	Metaphor Completion	Binocular Rivalry
Attentional Blink	Fluency	Non-partisan lookup	Circle Discrimination
Change Detection	Image Generation	Object Naming	Embedded Figures
Continuous Performance Task	Intelligence	Paired Associates	Emotion Identification
Error Detection	Letter-Number Sequencing	Repetition Priming	Face Discrimination
Flanker	Mental Rotation	Rote Recall	Face Encoding
Go/No Go	N-back	Rote Recognition	Face/Location Matching
Letter Identity	Span	Semantic Priming	Fragmented Picture Naming
Negative Priming	Stroop	Semantic-judgment	Haylings Test

Attention	Executive Function	Memory	Perception
Novelty Oddball	Tower of (Hanoi, London, etc.)	Sentence Completion	Letter Detection
Simultaneous Dual-task	Trailmaking B	Vocabulary	Lexical Decision
Stimulus Suffix	Virtual Maze		National Adult Reading Test
Tap	Wisconsin Card Sorting Test		Object Tracking
Visual Search	Working Memory		Reading
			Texture Discrimination
			Visual Field Sensitivity

Appendix B

Appendix Table 2

Individual study citations with sample sizes and weighted age-related effect sizes

Study	N	Cognitive Domain	Visual Acuity Criteria	Weighted Avg. Fisher's Z
Bartels et al. (2010)	36	Attention	Unreported	8.55
Gamboz, Russo, & Fox (2000)	48	Attention	Unreported	11.77
Greenhut-wertz & Manning (1995)	32	Attention	Unreported	18.41
Malmstrom & LaVoie (2002)	48	Attention	Unreported	40.24
Maylor & Lavie (1998)	30	Attention	Unreported	26.72
Mienaltowski et al. (2011)	31	Attention	Unreported	19.90
Plude & Doussard-Roosevelt (1989)	24	Attention	Unreported	14.30
Salthouse (1992) – 2	100	Attention	Unreported	25.12
Smyth & Shanks (2011) – 1	40	Attention	Unreported	18.39
Sorond et al. (2008)	29	Attention	Unreported	10.22
Vallesi, Hasher, & Stuss (2010)	40	Attention	Unreported	22.63
Verhaeghen, Cerella, & Basak (2006)	62	Attention	Unreported	9.75
Bertsch et al. (2009)	56	Attention	Undisclosed	22.90
Bock (2008) – 1	33	Attention	Undisclosed	13.92
Bock (2008) – 2	32	Attention	Undisclosed	11.49
Brache, Scialfa, & Hudson (2010)	35	Attention	Undisclosed	15.10
Ceponiene et al. (2008)	38	Attention	Undisclosed	16.31
Dywan et al. (2001)	61	Attention	Undisclosed	35.08
Gamboz, Zamarian, & Cavallero (2010)	135	Attention	Undisclosed	58.61
Georgiou-Karistianis et al. (2006)	60	Attention	Undisclosed	−4.12
Guerriero, Adam, & Van Gerven (2012)	55	Attention	Undisclosed	45.45
Hartley & Kieley (1995) – 1	34	Attention	Undisclosed	24.12
Hartley & Kieley (1995) – 2	40	Attention	Undisclosed	29.66
Hartley & Kieley (1995) – 3	34	Attention	Undisclosed	6.98
Hartley & Kieley (1995) – 4	32	Attention	Undisclosed	11.59
Hartley (2001)	44	Attention	Undisclosed	21.81
James & Kooy (2011) – 1	36	Attention	Undisclosed	16.24

Study	N	Cognitive Domain	Visual Acuity Criteria	Weighted Avg. Fisher's Z
James & Kooy (2011) – 2	40	Attention	Undisclosed	18.06
Kennedy & Raz (2009)	52	Attention	Undisclosed	16.56
Maylor, Birak, & Schlaghecken (2011)	47	Attention	Undisclosed	26.03
McDowd & Oseas-Kreger (1991)	40	Attention	Undisclosed	19.18
McLaughlin & Murtha (2010)	50	Attention	Undisclosed	42.00
McLaughlin et al. (2010)	60	Attention	Undisclosed	29.80
Müller-Oehring et al. (2007)	37	Attention	Undisclosed	13.17
Neider & Kramer (2011) – 1	48	Attention	Undisclosed	20.02
Neider & Kramer (2011) – 2	24	Attention	Undisclosed	9.13
Prado, Stoffregen, & Duarte (2007)	24	Attention	Undisclosed	13.42
Roux & Ceccaldi (2001) – 1	34	Attention	Undisclosed	15.95
Roux & Ceccaldi (2001) – 2	37	Attention	Undisclosed	16.63
Sander, Werkle-Bergner, & Lindenberger (2011) - 1	80	Attention	Undisclosed	98.68
Schmitz, Cheng, & De Rosa (2010)	27	Attention	Undisclosed	13.46
Tucker et al. (2009)	43	Attention	Undisclosed	3.78
Van Gerven & Murphy (2010)	96	Attention	Undisclosed	33.08
Allen et al. (1993a) – 1	40	Attention	Self-reported	19.34
Allen et al. (1993a) – 2	40	Attention	Self-reported	20.62
Allen, Weber, & Madden (1994)	40	Attention	Self-reported	17.32
Lien, Gemperle, & Ruthruff (2011) – 1	32	Attention	Self-reported	18.18
Lien, Gemperle, & Ruthruff (2011) – 2	30	Attention	Self-reported	22.44
Maquestiaux et al. (2010)	32	Attention	Self-reported	22.28
Quigley et al. (2010)	19	Attention	Self-reported	7.38
Solbakk et al. (2008)	25	Attention	Self-reported	10.88
Strobach et al. (2012)	19	Attention	Self-reported	10.35
Titz, Behrendt, & Hasselhorn (2010)	80	Attention	Self-reported	32.32
Allen et al. (1998) – 1	40	Attention	20/40	18.85
Allen et al. (1998) – 2	40	Attention	20/40	28.18
Allen et al. (2009)	36	Attention	20/40	21.04
Allen, Weber, & May (1993) – 1	40	Attention	20/40	17.40
Allen, Weber, & May (1993) – 2	40	Attention	20/40	24.28
Atchley & Kramer (2000) – 1	24	Attention	20/40	14.46
Atchley & Kramer (2000) – 2	24	Attention	20/40	14.05
Batsakes & Fisk (2000)	48	Attention	20/40	60.40
Bojko et al. (2004)	31	Attention	20/40	19.65
Bucur et al. (2005)	40	Attention	20/40	31.07
Bucur, Madden, & Allen (2005)	40	Attention	20/40	23.19
Coeckelbergh et al. (2004)	14	Attention	20/40	15.77
Costello et al. (2010a) – 1	48	Attention	20/40	28.85
Costello et al. (2010a) – 2	48	Attention	20/40	31.94
Costello et al. (2010b)	48	Attention	20/40	28.82

Study	N	Cognitive Domain	Visual Acuity Criteria	Weighted Avg. Fisher's Z
Gottlob (2006)	30	Attention	20/40	14.85
Graham & Burke (2011)	112	Attention	20/40	48.14
Greenwood & Parasuraman (2004) – 1	32	Attention	20/40	12.12
Hugenschmidt et al. (2009)	52	Attention	20/40	10.66
Jennings et al. (2011)	98	Attention	20/40	41.23
Kaneko (2004)	14	Attention	20/40	6.47
Kramer et al. (1999) - 1	16	Attention	20/40	11.56
Kramer et al. (1999) - 2	16	Attention	20/40	10.80
Langley et al. (2007) - 1	64	Attention	20/40	30.79
Langley et al. (2007) - 2	56	Attention	20/40	27.26
Langley et al. (2008a) – 1	60	Attention	20/40	45.01
Langley et al. (2008a) – 3	60	Attention	20/40	55.84
Madden & Langley (2003) – 1	48	Attention	20/40	33.93
Madden & Langley (2003) – 2	64	Attention	20/40	24.53
Madden & Langley (2003) – 3	48	Attention	20/40	28.91
Madden (1982) – 1	96	Attention	20/40	29.58
Madden (1982) – 2	72	Attention	20/40	27.94
Madden (1992a) – 1	48	Attention	20/40	43.26
Madden (1992a) – 2	24	Attention	20/40	18.85
Madden et al. (2002)	24	Attention	20/40	13.06
Madden et al. (2005) - 1	48	Attention	20/40	49.16
Madden et al. (2005) - 2	48	Attention	20/40	28.57
Madden et al. (2007)	48	Attention	20/40	37.93
Mani, Bedwell, & Miller (2005)	32	Attention	20/40	10.36
Nielson, Langenecker, & Garavan (2002) – 1	34	Attention	20/40	14.45
Veiel, Storandt, & Abrams (2006) – 1	80	Attention	20/40	41.29
Veiel, Storandt, & Abrams (2006) – 2	60	Attention	20/40	29.87
Whiting et al. (2005) – 1	48	Attention	20/40	35.37
Whiting et al. (2005) – 2	48	Attention	20/40	34.14
Whiting et al. (2005) – 3	48	Attention	20/40	30.05
Whiting, Madden, & Babcock (2007)	48	Attention	20/40	18.68
Colcombe et al. (2005)	60	Attention	20/30	29.54
Fisk & Rogers (1991) – 1	95	Attention	20/30	3.14
Fisk & Rogers (1991) – 2	85	Attention	20/30	39.14
Hogan (2003)	172	Attention	20/30	149.98
Hoyer, Cerella, & Buchler (2011)	36	Attention	20/30	31.26
Humphrey & Kramer (1997)	30	Attention	20/30	21.72
Kotary & Hoyer (1995)	40	Attention	20/30	30.29
Kramer & Atchley (2000) - 1	48	Attention	20/30	45.63
Kramer & Atchley (2000) - 2	24	Attention	20/30	21.21
Kramer & Weber (1999) – 1	36	Attention	20/30	29.37

Study	N	Cognitive Domain	Visual Acuity Criteria	Weighted Avg. Fisher's Z
Kramer & Weber (1999) – 2	32	Attention	20/30	15.84
Kramer et al. (1996) - 1	29	Attention	20/30	22.52
Kramer et al. (1996) - 2	34	Attention	20/30	33.26
Ellis et al. (1996)	24	Attention	20/29	23.73
Burton-Danner, Owsley, & Jackson (2001)	40	Attention	20/25	33.12
Owsley, Burton-Danner, & Jackson (2000)	40	Attention	20/25	20.03
Hahn & Kramer (1995)	20	Attention	20/24	14.51
Georgiou-Karistianis et al. (2007)	50	Attention	20/20	18.15
Norman et al. (2007) – 1	16	Attention	20/20	6.73
Scialfa & Thomas (1994)	40	Attention	20/18.9	33.23
Anderson et al. (2011a)	80	Executive	Unreported	21.50
Andrés & Van der Linden (2000)	95	Executive	Unreported	27.25
Artistico, Cervone, & Pezzuti (2003)	60	Executive	Unreported	30.55
Ashendorf & McCaffrey (2008)	44	Executive	Unreported	27.50
Ashley & Swick (2009)	40	Executive	Unreported	8.01
Baudouin et al. (2009)	100	Executive	Unreported	70.84
Beaunieux et al. (2009)	100	Executive	Unreported	42.72
Bell, Buchner, & Mund (2008) – 3	91	Executive	Unreported	27.77
Bock (2005)	24	Executive	Unreported	14.01
Bopp & Verhaeghen (2009) – 1	96	Executive	Unreported	57.04
Bopp & Verhaeghen (2009) – 2	50	Executive	Unreported	30.08
Bopp & Verhaeghen (2009) – 3	62	Executive	Unreported	38.86
Borella et al. (2011)	79	Executive	Unreported	43.88
Brehmer, Westerberg, & Backman (2012)	55	Executive	Unreported	29.58
Briggs, Raz, & Marks (1999)	85	Executive	Unreported	30.12
Bugg et al. (2006)	196	Executive	Unreported	119.70
Chen, Ma, & Pethtel (2011)	184	Executive	Unreported	37.50
Copeland & Radvansky (2007) – 1	72	Executive	Unreported	39.87
Copeland & Radvansky (2007) – 2	72	Executive	Unreported	41.15
Copeland & Radvansky (2007) – 3	60	Executive	Unreported	27.49
Davis & Klebe (2001)	23	Executive	Unreported	11.80
Denburg, Tranel, & Bechara (2005)	80	Executive	Unreported	29.35
Dorbath, Haselhorn, & Titz (2011)	176	Executive	Unreported	45.58
Doumas, Rapp, & Krampe (2009)	18	Executive	Unreported	12.95
Eckert et al. (2010)	42	Executive	Unreported	23.81
Einstein et al. (1997) – 1	64	Executive	Unreported	29.06
Einstein et al. (1997) – 2	128	Executive	Unreported	41.45
Elwan et al. (1996)	88	Executive	Unreported	57.60
Emery, Hale, & Myerson (2008)	134	Executive	Unreported	49.40
Esposito et al. (1999)	41	Executive	Unreported	−1.37
Fein, McGillivray, & Finn (2007)	164	Executive	Unreported	50.67

Study	N	Cognitive Domain	Visual Acuity Criteria	Weighted Avg. Fisher's Z
Ferraro & Kellas (1992)	48	Executive	Unreported	30.68
Foos & Goolkasian (2010)	45	Executive	Unreported	16.02
Hale et al. (2011)	388	Executive	Unreported	168.02
Hampshire et al. (2008)	32	Executive	Unreported	8.75
Head et al. (2002)	68	Executive	Unreported	14.66
Henninger, Madden, & Huettel (2010)	112	Executive	Unreported	6.09
Kemper et al. (2010)	197	Executive	Unreported	76.18
Krampe et al. (2010)	44	Executive	Unreported	17.65
Kray, Lucenet, & Blaye (2010)	85	Executive	Unreported	53.01
Lamar & Resnick (2004)	43	Executive	Unreported	24.37
Lange & Verhaeghen (2009) – 2	48	Executive	Unreported	34.81
Lesch et al. (2011)	101	Executive	Unreported	38.50
Löckenhoff, O'Donogue, & Dunning (2011)	98	Executive	Unreported	23.41
Maintenant, Blaye, & Paour (2011)	121	Executive	Unreported	49.96
Masunaga & Horn (2001)	263	Executive	Unreported	34.78
Mata, Helversen, & Rieskamp (2010)	100	Executive	Unreported	55.45
Mather & Schoeke (2011)	86	Executive	Unreported	−22.12
Maury, Besse, & Martin (2010) – 2	72	Executive	Unreported	50.05
Mayr (2001) – 1	48	Executive	Unreported	29.87
Mayr (2001) – 2	72	Executive	Unreported	31.43
McAuley et al. (2010)	79	Executive	Unreported	56.46
McDowd & Craik (1988)	32	Executive	Unreported	24.11
Mell et al. (2009)	28	Executive	Unreported	24.98
Miller & West (2010)	95	Executive	Unreported	41.51
Morrow et al. (2001)	182	Executive	Unreported	41.74
Perry et al. (2009)	24	Executive	Unreported	15.60
Phillips, Kliegel, & Martin (2006)	78	Executive	Unreported	36.33
Phillips, Smith, & Gilhooly (2002)	96	Executive	Unreported	34.92
Radvansky et al. (2001) – 1	96	Executive	Unreported	22.30
Radvansky et al. (2001) – 2	144	Executive	Unreported	71.23
Richmond et al. (2011) w/ additional data from Chein & Morrison (2010)	35	Executive	Unreported	15.42
Rypma et al. (2001)	12	Executive	Unreported	4.78
Salthouse (1992) – 1	180	Executive	Unreported	79.52
Scheibe & Blanchard-Fields (2009)	142	Executive	Unreported	92.70
Shafto (2010)	72	Executive	Unreported	28.44
Shan et al. (2008)	475	Executive	Unreported	95.98
Silver et al. (2011)	134	Executive	Unreported	48.82
West (2004)	28	Executive	Unreported	15.37
Wood et al. (2005)	155	Executive	Unreported	27.43
Wood et al. (2011)	121	Executive	Unreported	41.17

Study	N	Cognitive Domain	Visual Acuity Criteria	Weighted Avg. Fisher's Z
Bell, Buchner, & Mund (2008) – 1	104	Executive	Undisclosed	44.84
Bo, Borza, & Seidler (2009)	50	Executive	Undisclosed	30.10
Carp, Gmeindl, & Reuter-Lorenz (2010)	41	Executive	Undisclosed	26.76
Chaparro et al. (2005)	28	Executive	Undisclosed	11.64
Clapp et al. (2011)	37	Executive	Undisclosed	9.80
Gamboz, Borella, & Brandimonte (2009)	80	Executive	Undisclosed	25.69
Guerreiro & Van Gerven (2011)	60	Executive	Undisclosed	33.35
Kemtes & Allen (2008)	60	Executive	Undisclosed	16.16
Kieley & Hartley (1997) – 1	32	Executive	Undisclosed	9.97
Kieley & Hartley (1997) – 2	85	Executive	Undisclosed	19.50
Maury, Besse, & Martin (2010) – 1	50	Executive	Undisclosed	38.57
Morrone et al. (2010)	60	Executive	Undisclosed	19.71
Mund, Bell, & Buchner (2010) – 1	96	Executive	Undisclosed	56.37
Mund, Bell, & Buchner (2010) – 2	157	Executive	Undisclosed	72.21
Nagel et al. (2008)	318	Executive	Undisclosed	234.18
Neider et al. (2011)	36	Executive	Undisclosed	8.67
Ni, Kang, & Andersen (2010)	16	Executive	Undisclosed	7.40
Peltz, Gratton, & Fabiani (2011)	58	Executive	Undisclosed	42.48
Ridderinkhof et al. (2002) – 1	40	Executive	Undisclosed	21.54
Rose et al. (2009)	48	Executive	Undisclosed	36.98
Rose et al. (2010)	106	Executive	Undisclosed	79.11
Sambataro et al. (2010)	57	Executive	Undisclosed	20.02
Zamarian et al. (2008)	85	Executive	Undisclosed	28.53
Hartman, Bolton, & Fehnel (2001) – 1	161	Executive	Self-reported	49.94
Hartman, Bolton, & Fehnel (2001) – 2	96	Executive	Self-reported	33.06
Hartman, Nielsen, & Stratton (2004)	72	Executive	Self-reported	43.45
Karayanidis et al. (2011)	95	Executive	Self-reported	42.61
Saimpont, Pozzo, & Papaxanthis (2009)	39	Executive	Self-reported	34.28
Touron & Hertzog (2009)	124	Executive	20/50	49.31
Allen et al. (1997) – 1	40	Executive	20/40	19.48
Allen et al. (1997) – 2	48	Executive	20/40	11.39
Basak & Verhaeghen (2011)	55	Executive	20/40	27.94
Feld & Sommers (2009)	81	Executive	20/40	41.96
Hertzog et al. (1996)	201	Executive	20/40	128.44
Jamieson & Rogers (2000)	80	Executive	20/40	48.41
Kirasic et al. (1996)	477	Executive	20/40	94.23
Kramer et al. (1994)	62	Executive	20/40	21.96
Langley et al. (2005)	48	Executive	20/40	23.01
Trick, Perl, & Sethi (2005) – 1	38	Executive	20/40	27.71
Trick, Perl, & Sethi (2005) – 2	40	Executive	20/40	23.38
Zanto, Toy, & Gazzaley (2010)	43	Executive	20/40	12.95

Study	N	Cognitive Domain	Visual Acuity Criteria	Weighted Avg. Fisher's Z
Brigman & Cherry (2002)	40	Executive	20/30	19.51
Cherry & Park (1993)	194	Executive	20/30	70.89
Reese & Cherry (2002)	128	Executive	20/30	40.46
Touron, Hoyer, & Cerella (2004)	60	Executive	20/30	55.18
Verhaeghen & Hoyer (2007)	48	Executive	20/30	27.22
Cansino et al. (2011)	50	Executive	20/20	19.11
Risse & Kliegle (2011)	80	Executive	20/20	17.13
Aizpurua, Garcia-Bajos, & Migueles (2009)	68	Memory	Unreported	27.99
Aizpurua, Garcia-Bajos, & Migueles (2011) – 1	65	Memory	Unreported	28.36
Aizpurua, Garcia-Bajos, & Migueles (2011) – 2	67	Memory	Unreported	21.80
Anderson et al. (2011) – 1	60	Memory	Unreported	31.74
Anderson et al. (2011) – 2	63	Memory	Unreported	33.83
Badham & Maylor (2011)	108	Memory	Unreported	67.70
Bayer et al. (2011)	40	Memory	Unreported	4.52
Bell, Buchner, & Mund (2008) – 2	99	Memory	Unreported	50.05
Benjamin (2011)	79	Memory	Unreported	18.22
Bryan & Luszcz (1996)	72	Memory	Unreported	34.46
Buchler et al. (2011)	60	Memory	Unreported	8.95
Cabeza et al. (2004)	40	Memory	Unreported	11.80
Charness et al. (2001) – 1	72	Memory	Unreported	70.78
Charness et al. (2001) – 2	48	Memory	Unreported	20.58
Craik & Schloerscheidt (2011) – 2	32	Memory	Unreported	23.21
Denney & Larsen (1994)	80	Memory	Unreported	29.45
Dew & Giovanello (2010a) – 1	48	Memory	Unreported	23.18
Dew & Giovanello (2010a) – 2	60	Memory	Unreported	44.40
Dew & Giovanello (2010b) – 2	64	Memory	Unreported	36.31
Doose & Feyereisen (2001)	59	Memory	Unreported	39.53
Emery & Hess (2011)	101	Memory	Unreported	16.22
Ford et al. (2001)	26	Memory	Unreported	8.53
Frings, Mader, & Hull (2010)	17	Memory	Unreported	12.14
Gardner, Hill, Was (2011)	92	Memory	Unreported	42.06
Glahn et al. (1997)	181	Memory	Unreported	53.39
Grady et al. (2002)	44	Memory	Unreported	27.39
Halamish, McGillivray, & Castel (2011)	40	Memory	Unreported	15.89
Hamami, Serbun, & Gutchess (2011) – 2	54	Memory	Unreported	21.49
Hanna-Pladdy & Choi (2010)	135	Memory	Unreported	31.66
Henkel & Rajaram (2011)	192	Memory	Unreported	61.81
Hertzog & Touron (2011)	152	Memory	Unreported	121.83
Jager, Mecklinger, & Kliegel (2010)	40	Memory	Unreported	21.76
Joy, Kaplan, & Fein (2004)	950	Memory	Unreported	467.05
Kave, Knafo, & Gilboa (2010)	1145	Memory	Unreported	104.58

Study	N	Cognitive Domain	Visual Acuity Criteria	Weighted Avg. Fisher's Z
Kim & Giovanello (2011) – 2	24	Memory	Unreported	13.63
Kitzan et al. (1999)	88	Memory	Unreported	39.67
Kornell et al. (2010)	112	Memory	Unreported	44.11
Li, Nilsson, & Wu (2004)	98	Memory	Unreported	37.74
Luo, Hendriks & Craik (2007) – 1	64	Memory	Unreported	23.93
Luo, Hendriks & Craik (2007) – 2	52	Memory	Unreported	13.23
Luo, Hendriks & Craik (2007) – 3	36	Memory	Unreported	27.80
Luo, Hendriks & Craik (2007) – 4	64	Memory	Unreported	17.45
Maddox et al. (2011) – 1	60	Memory	Unreported	44.87
Maddox et al. (2011) – 2	78	Memory	Unreported	39.09
McGillivray & Castel (2010)	50	Memory	Unreported	20.63
McGillivray & Castel (2011)	52	Memory	Unreported	27.18
Moffat et al. (2007)	68	Memory	Unreported	39.55
Nashiro & Mather (2011)	48	Memory	Unreported	17.38
Naveh-Benjamin & Craik (1995)	50	Memory	Unreported	9.48
Nemeth & Janacsek (2010)	129	Memory	Unreported	65.66
Ostreicher et al. (2010)	32	Memory	Unreported	12.04
Overman & Becker (2009)	151	Memory	Unreported	−42.60
Rosa & Gutchess (2011)	90	Memory	Unreported	38.81
Simon, Howard Jr., & Howard (2010)	30	Memory	Unreported	16.22
Smith (2011) – 1	256	Memory	Unreported	62.99
Smith (2011) – 2	70	Memory	Unreported	24.44
Stern et al. (2008) – 1	68	Memory	Unreported	25.19
Stern et al. (2008) – 2	45	Memory	Unreported	17.27
Toth, Daniels, & Solinger (2011)	72	Memory	Unreported	19.50
Troyer et al. (2011)	40	Memory	Unreported	23.38
Tse, Balota, & Roediger (2010) – 1	96	Memory	Unreported	27.35
Tse, Balota, & Roediger (2010) – 2	44	Memory	Unreported	12.36
Wang & Dew (2010)	112	Memory	Unreported	51.52
West, Welch, & Thorn (2001)	218	Memory	Unreported	128.68
Wiggs & Martin (1994) – 1	32	Memory	Unreported	12.12
Wiggs & Martin (1994) – 2	64	Memory	Unreported	22.15
Bender, Naveh-Benjamin, & Raz (2010)	278	Memory	Undisclosed	62.13
Bergerbest et al. (2009)	30	Memory	Undisclosed	12.13
Craik & Schloerscheidt (2011) – 1	50	Memory	Undisclosed	26.94
Craik & Schloerscheidt (2011) – 2	64	Memory	Undisclosed	10.98
Fernandes et al. (2008)	95	Memory	Undisclosed	45.01
Gaesser et al. (2011) – 1	32	Memory	Undisclosed	20.32
Gaesser et al. (2011) – 2	30	Memory	Undisclosed	14.16
Glass (2007)	345	Memory	Undisclosed	240.43
Gopie, Craik, & Hasher (2010) – 1	40	Memory	Undisclosed	13.88

Study	**N**	**Cognitive Domain**	**Visual Acuity Criteria**	**Weighted Avg. Fisher's Z**
Gopie, Craik, & Hasher (2010) – 2	40	Memory	Undisclosed	11.69
Hartley et al. (2011) – 1	48	Memory	Undisclosed	20.98
Hartley et al. (2011) – 2	46	Memory	Undisclosed	16.24
Kemps & Newson (2006)	96	Memory	Undisclosed	45.27
Lin et al. (2010)	60	Memory	Undisclosed	8.59
Lövdén et al. (2005)	32	Memory	Undisclosed	36.13
Murray, Muscatell, & Kensinger (2011) – 1	48	Memory	Undisclosed	26.03
Murray, Muscatell, & Kensinger (2011) – 2	78	Memory	Undisclosed	54.06
Murray, Muscatell, & Kensinger (2011) – 3	40	Memory	Undisclosed	11.45
Shih, Meadmore, & Liversedge (2012)	90	Memory	Undisclosed	29.41
Skinner & Fernandes (2009) – 1	30	Memory	Undisclosed	11.73
Skinner & Fernandes (2009) – 2	32	Memory	Undisclosed	7.74
Vakil & Agmon-Askenazi (1997)	50	Memory	Undisclosed	29.13
Viggiano et al. (2010)	30	Memory	Undisclosed	22.49
Aizpurua & Koutstaal (2010)	71	Memory	Self-reported	27.87
Feng et al. (2011)	85	Memory	Self-reported	7.63
Hamami, Serbun, & Gutchess (2011) – 1	64	Memory	Self-reported	22.34
Rémy, Taconnat, & Isingrini (2008)	60	Memory	Self-reported	38.58
Stine-morrow et al. (2006)	73	Memory	Self-reported	14.60
Tun et al. (1992)	50	Memory	Self-reported	25.47
Hertzog et al. (2007) – 1	103	Memory	20/50	33.71
Hertzog et al. (2007) – 2	84	Memory	20/50	30.48
Hertzog et al. (2007) – 3	86	Memory	20/50	4.70
Touron, Hertzog, & Frank (2011) – 1	40	Memory	20/50	14.34
Allen et al. (2002b)	80	Memory	20/40	26.77
Allen et al. (2011) – 1	40	Memory	20/40	28.37
Allen et al. (2011) – 2	120	Memory	20/40	69.53
Bowles (1994)	64	Memory	20/40	53.84
Fisk et al. (1995)	201	Memory	20/40	172.35
Fisk et al. (1997) – 1	174	Memory	20/40	220.04
Fisk et al. (1997) – 2	48	Memory	20/40	41.89
Jenkins et al. (2000)	32	Memory	20/40	25.52
Langley et al. (2008b) – 1	72	Memory	20/40	19.25
Langley et al. (2008b) – 2	68	Memory	20/40	22.16
Langley et al. (2008b) – 3	64	Memory	20/40	17.72
Lawson, Guo, & Jiang (2007)	28	Memory	20/40	15.28
Rogers & Gilbert (1997) - 1	32	Memory	20/40	20.68
Rogers & Gilbert (1997) - 2	32	Memory	20/40	19.80
Rogers & Gilbert (1997) - 3	32	Memory	20/40	20.36
Rogers & Gilbert (1997) - 4	32	Memory	20/40	17.62
Rutledge, Hancock, & Walker (1997)	93	Memory	20/40	32.37

Study	N	Cognitive Domain	Visual Acuity Criteria	Weighted Avg. Fisher's Z
Cerella et al. (2006)	98	Memory	20/30	48.05
Cherry & Jones (1999) – 1	144	Memory	20/30	58.92
Cherry & Jones (1999) – 2	144	Memory	20/30	70.19
Cherry & LeCompte (1999)	96	Memory	20/30	18.63
Cherry & St. Pierre (1998)	64	Memory	20/30	24.86
Cherry et al. (2003) – 1	96	Memory	20/30	75.94
Cherry et al. (2003) – 2	96	Memory	20/30	81.94
Karpel, Hoyer, & Toglia (2001)	122	Memory	20/30	44.99
Park et al. (1990) – 1	84	Memory	20/30	20.92
Park et al. (1990) – 2	128	Memory	20/30	28.05
Smith et al. (1998) - 1	76	Memory	20/30	55.84
Smith et al. (1998) - 2	48	Memory	20/30	26.04
Bowles & Poon (1981)	43	Perception	Unreported	20.78
Cohen & Faulkner (1983)	24	Perception	Unreported	9.29
Elliott et al. (2007)	20	Perception	Unreported	5.97
Grady et al. (1994)	32	Perception	Unreported	21.46
Hildebrandt et al. (2011)	448	Perception	Unreported	26.76
Hunter, Phillips, & MacPherson (2010) – 1	50	Perception	Unreported	19.45
Hunter, Phillips, & MacPherson (2010) – 2	40	Perception	Unreported	13.83
Kalisch et al. (2012)	81	Perception	Unreported	38.28
Krendl & Ambady (2010) – 1	78	Perception	Unreported	48.26
Krendl & Ambady (2010) – 2	80	Perception	Unreported	37.08
Lange & Verhaeghen (2009) – 1	48	Perception	Unreported	45.44
McLellan, Marcos, & Burns (2001)	38	Perception	Unreported	13.45
Mikels et al. (2005)	40	Perception	Unreported	15.62
Mill et al. (2009)	607	Perception	Unreported	245.57
Park et al. (2010)	38	Perception	Unreported	17.19
Stine-Morrow et al. (2001)	243	Perception	Unreported	96.94
Westbury & Titone (2011)	68	Perception	Unreported	23.08
Allen, Madden, & Crozier (1991)	48	Perception	Undisclosed	38.13
Andersen et al. (2010) – 1	18	Perception	Undisclosed	14.37
Andersen et al. (2010) – 3	16	Perception	Undisclosed	0.14
Bannerman, Regener, & Sahraie (2011)	60	Perception	Undisclosed	23.87
Burke, White, & Diaz (1987)	64	Perception	Undisclosed	25.45
Caplan et al. (2011)	200	Perception	Undisclosed	56.57
Chaby, Narme, & George (2011)	66	Perception	Undisclosed	36.33
Deiber et al. (2010)	56	Perception	Undisclosed	25.77
Del Viva & Agostini (2006)	32	Perception	Undisclosed	35.54
Halpern (1984)	40	Perception	Undisclosed	38.81
Kadota & Gomi (2010)	32	Perception	Undisclosed	24.75
Kennedy et al. (2009)	169	Perception	Undisclosed	85.83

Study	N	Cognitive Domain	Visual Acuity Criteria	Weighted Avg. Fisher's Z
Klein et al. (2000)	36	Perception	Undisclosed	23.93
Kolarik, Margrain, & Freeman (2010)	39	Perception	Undisclosed	8.72
Madden (1992b)	108	Perception	Undisclosed	50.38
O'Connor, Margrain, & Freeman (2010) – 1	39	Perception	Undisclosed	10.11
Orgeta (2010)	80	Perception	Undisclosed	25.73
Owsley, Sekuler, & Boldt (1981)	27	Perception	Undisclosed	27.24
Ridderinkhof & Wijnen (2011)	40	Perception	Undisclosed	35.46
Slessor et al. (2010)	59	Perception	Undisclosed	60.72
Spaniol et al. (2011)	53	Perception	Undisclosed	16.66
Speranza, Moraglia, & Schneider (2001) – 1	22	Perception	Undisclosed	6.35
Speranza, Moraglia, & Schneider (2001) – 2	22	Perception	Undisclosed	6.36
Speranza, Moraglia, & Schneider (2001) – 3	22	Perception	Undisclosed	17.97
Speranza, Moraglia, & Schneider (2001) – 4	22	Perception	Undisclosed	1.75
Werheid, Gruno, & Kathman et al. (2010) – 1	40	Perception	Undisclosed	14.89
Werheid, Gruno, & Kathman et al. (2010) – 2	40	Perception	Undisclosed	16.83
Winneke & Phillips (2011)	34	Perception	Undisclosed	6.33
Allen et al. (1993b) – 1	40	Perception	Self-reported	28.14
Allen et al. (1993b) – 2	40	Perception	Self-reported	26.98
Allen et al. (1993b) – 3	40	Perception	Self-reported	16.88
Madden (1988)	48	Perception	Self-reported	36.64
Maguinness et al. (2011)	41	Perception	Self-reported	37.43
Robert & Mathey (2007)	54	Perception	Self-reported	13.45
Allen et al. (2002a) – 1	67	Perception	20/40	30.70
Allen et al. (2002a) – 2	84	Perception	20/40	27.23
Allen et al. (2002a) – 3	40	Perception	20/40	17.88
Allen et al. (2004)	193	Perception	20/40	68.19
Gottlob et al. (2007)	40	Perception	20/40	8.60
Hugenschmidt, Mozolic, & Laurienti (2009)	41	Perception	20/40	28.79
Tye-Murray et al. (2008)	86	Perception	20/40	35.28
Tye-Murray et al. (2010)	106	Perception	20/40	37.61
Scialfa et al. (1999)	36	Perception	20/33	15.88
Clancy-Dollinger (1995)	24	Perception	20/30	18.58
Garnham & Sloper (2006)	60	Perception	20/30	22.40
Johnson, Adams, & Lewis (1989)	62	Perception	20/30	39.22
Klistorner & Graham (2001)	100	Perception	20/30	5.06
Kurylo (2006)	26	Perception	20/30	18.20
McKendrick, Weymouth, & Battista (2010)	43	Perception	20/30	11.53
Nguyen-Tri, Overbury, & Faubert (2003)	102	Perception	20/30	31.84
Redmond et al. (2010)	68	Perception	20/30	7.02
Ross, Clarke, & Bron (1985)	70	Perception	20/30	45.89
Ruffman, Sullivan, & Dittrich (2009) - 1	60	Perception	20/30	26.10

Study	N	Cognitive Domain	Visual Acuity Criteria	Weighted Avg. Fisher's Z
Ruffman, Sullivan, & Dittrich (2009) - 2	79	Perception	20/30	26.08
Ryan, Murray, & Ruffman (2010)	80	Perception	20/30	25.40
Scialfa & Hamaluk (2001)	20	Perception	20/30	12.07
Sullivan, Ruffman, & Hutton (2007) – 1	60	Perception	20/30	19.58
Sullivan, Ruffman, & Hutton (2007) – 2	54	Perception	20/30	22.40
Elliott & Werner (2010)	26	Perception	20/25	13.59
Elliott et al. (2009)	20	Perception	20/25	6.36
Grunwald et al. (1993)	33	Perception	20/25	19.62
Habak, Wilkinson, & Wilson (2009)	36	Perception	20/25	7.45
Karas & McKendrick (2009)	35	Perception	20/25	10.73
McKendrick et al. (2007)	28	Perception	20/25	23.94
Li et al. (2012)	38	Perception	20/24	21.50
Kennedy, Tripathy, & Barrett (2009)	22	Perception	20/20	10.70
Rayner et al. (2006)	32	Perception	20/20	10.16
Rayner et al. (2009) - 1	48	Perception	20/20	11.95
Rayner et al. (2009) - 2	24	Perception	20/20	15.62
Rayner et al. (2011)	32	Perception	20/20	12.97
Thompson, Garcia, & Malloy (2007)	80	Perception	20/20	45.85
Wilson et al. (2011)	30	Perception	20/20	13.11
Malania et al. (2011)	19	Perception	20/15	9.40

Table 1

Categorical Assignment of Articles by Visual Acuity Criteria & Cognitive Domain.

Visual Acuity Criteria	Cognitive Domain				
	Attention	**Executive Function**	**Memory**	**Perception/Language**	***Overall***
Unreported	15	68	65	18	166
Undisclosed	31	23	23	28	105
Self-reported	10	5	6	6	27
20/80 – 20/31	47	13	21	9	90
20/30 or above	20	8	10	30	68
Overall	123	117	125	91	456

Note. For a list of typical cognitive tasks assigned to each domain, please see Appendix A

Table 2

Average effect sizes for each visual acuity criteria and cognitive domain

Visual Acuity Criteria	Cognitive Domain				
	Attention	**Executive Function**	**Memory**	**Perception/ Language**	***Overall***
Unreported	0.49 [0.38, 0.57]	0.41 [0.37, 0.45]	0.42 [0.37, 0.47]	0.43 [0.33, 0.52]	0.44 [0.41, 0.47]
Undisclosed	0.47 [0.39, 0.55]	0.48 [0.41, 0.54]	0.45 [0.37, 0.53]	0.51 [0.43, 0.59]	0.48 [0.44, 0.52]
Self-reported	0.44 [0.40, 0.49]	0.47 [0.31, 0.60]	0.36 [0.20, 0.50]	0.58 [0.42, 0.71]	0.47 [0.43, 0.51]
20/80 – 20/31	0.56 [0.51, 0.61]	0.45 [0.35, 0.54]	0.51 [0.39, 0.62]	0.38 [0.32, 0.44]	0.48 [0.44, 0.51]
20/30 or above	0.63 [0.54, 0.71]	0.43 [0.30, 0.54]	0.49 [0.39, 0.59]	0.43 [0.36, 0.49]	0.50 [0.46, 0.54]
Overall	0.52 [0.50, 0.55]	0.45 [0.42, 0.48]	0.45 [0.41, 0.48]	0.47 [0.44, 0.50]	

Note. Average effect sizes (r) and 95% confidence intervals (in brackets) are presented as a function of the five visual acuity criteria and four cognitive domains. Overall values were calculated for each visual acuity criteria by collapsing across the cognitive domains and vice versa.