A meta-analysis of perceptual and cognitive functions involved in useful-field-of-view test performance

Karlijn Woutersen
Department of Cognitive Neuroscience, Section Biophysics, Donders Institute for Brain, Cognition and Behaviour, Radboud University Medical Center, Nijmegen, the Netherlands

Leslie Guadron
Department of Cognitive Neuroscience, Section Biophysics, Donders Institute for Brain, Cognition and Behaviour, Radboud University Medical Center, Nijmegen, the Netherlands
Department of Biophysics, Radboud University, Nijmegen, the Netherlands

Albert V. van den Berg
Department of Cognitive Neuroscience, Section Biophysics, Donders Institute for Brain, Cognition and Behaviour, Radboud University Medical Center, Nijmegen, the Netherlands

F. Nienke Boonstra
Royal Dutch Visio, National Foundation for the Visually Impaired and Blind, Huizen, the Netherlands
Department of Cognitive Neuroscience, Section Biophysics, Donders Institute for Brain, Cognition and Behaviour, Radboud University Medical Center, Nijmegen, the Netherlands

Thomas Theelen
Department of Ophthalmology, Donders Institute for Brain, Cognition and Behaviour, Radboud University Medical Center, Nijmegen, the Netherlands

Jeroen Goossens
Department of Cognitive Neuroscience, Section Biophysics, Donders Institute for Brain, Cognition and Behaviour, Radboud University Medical Center, Nijmegen, the Netherlands

The useful-field-of-view (UFOV) test measures the amount of information someone can extract from a visual scene in one glance. Its scores show relatively strong relationships with everyday activities. The UFOV test consists of three computer tests, suggested to measure processing speed and central vision, divided attention, and selective attention. However, other functions seem to be involved as well. In order to investigate the contribution of these suggested and other perceptual and cognitive functions, we performed a meta-analysis of 116 Pearson's correlation coefficients between UFOV scores and other test scores reported in 18 peer-reviewed articles. We divided these correlations into nine domains: attention, executive functioning, general cognition, memory, spatial ability, visual closure, contrast sensitivity, visual processing speed, and visual

Citation: Woutersen, K., Guadron, L., van den Berg, A. V., Boonstra, F. N., Theelen, T., & Goossens, J. (2017). A meta-analysis of perceptual and cognitive functions involved in useful-field-of-view test performance. *Journal of Vision*, *17*(14):11, 1–20, doi: 10.1167/17.14.11.

doi: 10.1167/17.14.11 Received February 1, 2017; published December 21, 2017 ISSN 1534-7362 Copyright 2017 The Authors

acuity. A multivariate mixed-effects model analysis revealed that each domain correlated significantly with each of the UFOV subtest scores. These correlations were stronger for Subtests 2 and 3 than for Subtest 1. Furthermore, some domains were more strongly correlated to the UFOV than others across subtests. We did not find interaction effects between subtest and domain, indicating that none of the UFOV subtests is more selectively sensitive to a particular domain than the others. Thus, none of the three UFOV subtests seem to measure one clear construct. Instead, a range of visual and cognitive functions is involved. Perhaps this is the reason for the UFOV's high ecological validity, as it involves many functions at once, making it harder to compensate if one of them fails.

Introduction

Older adults often experience problems in daily activities that require visual processing of peripheral stimuli, such as driving, grocery shopping, and avoiding objects during movement. Although the size of the visual field is known to decrease with age, traditional perimetry methods often fail to explain these difficulties. The useful-field-of-view (UFOV) test was developed to capture such problems and has shown superior performance in doing so (Ball, Owsley, & Beard, 1990).

Currently, the UFOV test consists of three subtests that measure different aspects of cognitive and visual processes by determining the minimal presentation duration that a subject needs to make correct decisions regarding the content of a visual stimulus on 75% of the trials (Figure 1; Aust & Edwards, 2016; Visual Awareness Research Group, 2009). Shorter stimulus presentation durations therefore represent better performance. During the first subtest (UFOV1), central vision and visual processing speed are probed by measuring exposure duration necessary for the subject to correctly identify a centrally presented target. In the second subtest (UFOV2), a peripheral stimulus is presented simultaneously with the central stimulus. In addition to identifying the central stimulus, the subject has to locate the peripheral stimulus. This subtest is therefore suggested to measure divided attention. In the third subtest (UFOV3), the targets are surrounded by distractors that the subject should ignore. This subtest is therefore suggested to measure selective attention. Some researchers have used a fourth UFOV subtest (UFOV4), in which two stimuli appear simultaneously in the center and the subject has to indicate whether they are the same. In addition, subjects have to localize a peripheral stimulus. This subtest is also suggested to measure selective attention. Edwards, Vance, et al. (2005) have reported moderate to high test–retest reliability of the UFOV test depending on the subtest or composite of scores.

Importantly, many reports exist of relations between the UFOV test and various everyday functions. For example, Owsley, Sloane, McGwin, and Ball (2002) showed that older adults who scored worse on UFOV2 also performed worse on the timed instrumental activites of daily living tasks. The latter test measures the speed at which one performs everyday tasks such as finding a telephone number, making change, and reading ingredients on a food can. Furthermore, UFOV test scores have often been related to driving ability (Ball, Owsley, Sloane, Roenker, & Bruni, 1993; Bowers et al., 2013; Hoffman & McDowd, 2010; Rubin et al., 2007; Wood, Chaparro, Lacherez, & Hickson, 2012). Two recent meta-analyses report medium to large effect sizes of the UFOV test's ability to distinguish safe from unsafe drivers based on various measures such as on-road driving, driving-simulator performance, and driving problems (Mathias & Lucas, 2009; Seong-Youl, Jae-Shin, & A-Young, 2014).

Several patient groups show poor performance on the UFOV test, including those with ophthalmological and neurological diseases (Alberti, Horowitz, Bronstad, & Bowers, 2014; Badenes et al., 2014; Classen et al., 2011; Fisk, Novack, Mennemeier, & Roenker, 2002; Rosen et al., 2015). In addition, UFOV performance declines with increasing age (Ball, Beard, Roenker, Miller, & Griggs, 1988; Edwards et al., 2006; Sekuler, Bennett, & Mamelak, 2000). Performance on the UFOV test can be improved with speed-of-processing training. This training simulates the UFOV test, and several clinical trials have been conducted to investigate its effects (Ball et al., 2002; Edwards, Wadley, et al., 2005; Vance et al., 2007). Interestingly, the training effects seem to transfer to other tests, such as the timed instrumental activities of daily living tasks and a driving test, and persist longer than 1 year (Ball et al., 2002; Roenker, Cissell, Ball, Wadley, & Edwards, 2003).

Currently, there is an increasing interest in the mechanisms and functions that underlie UFOV performance. As already mentioned, the UFOV has been suggested to measure central vision and processing speed, divided attention, and selective attention, and it has been so used in various studies (see, e.g., Belchior et al., 2013; Broman et al., 2004; Gray et al., 2014; Rutherford, Richards, Moldes, & Sekuler, 2007). However, apart from processing speed, no study has yet, to our knowledge, confirmed this idea. Instead, a number of studies have shown that other perceptual and cognitive functions are also involved. For example, after relating scores on several perceptual and cognitive tests to UFOV performance, Matas, Nettelbeck, and Burns (2014) concluded that UFOV1 performance is primarily explained by low-level visual functions. Interestingly, they reported that the inspection-time task, which is highly

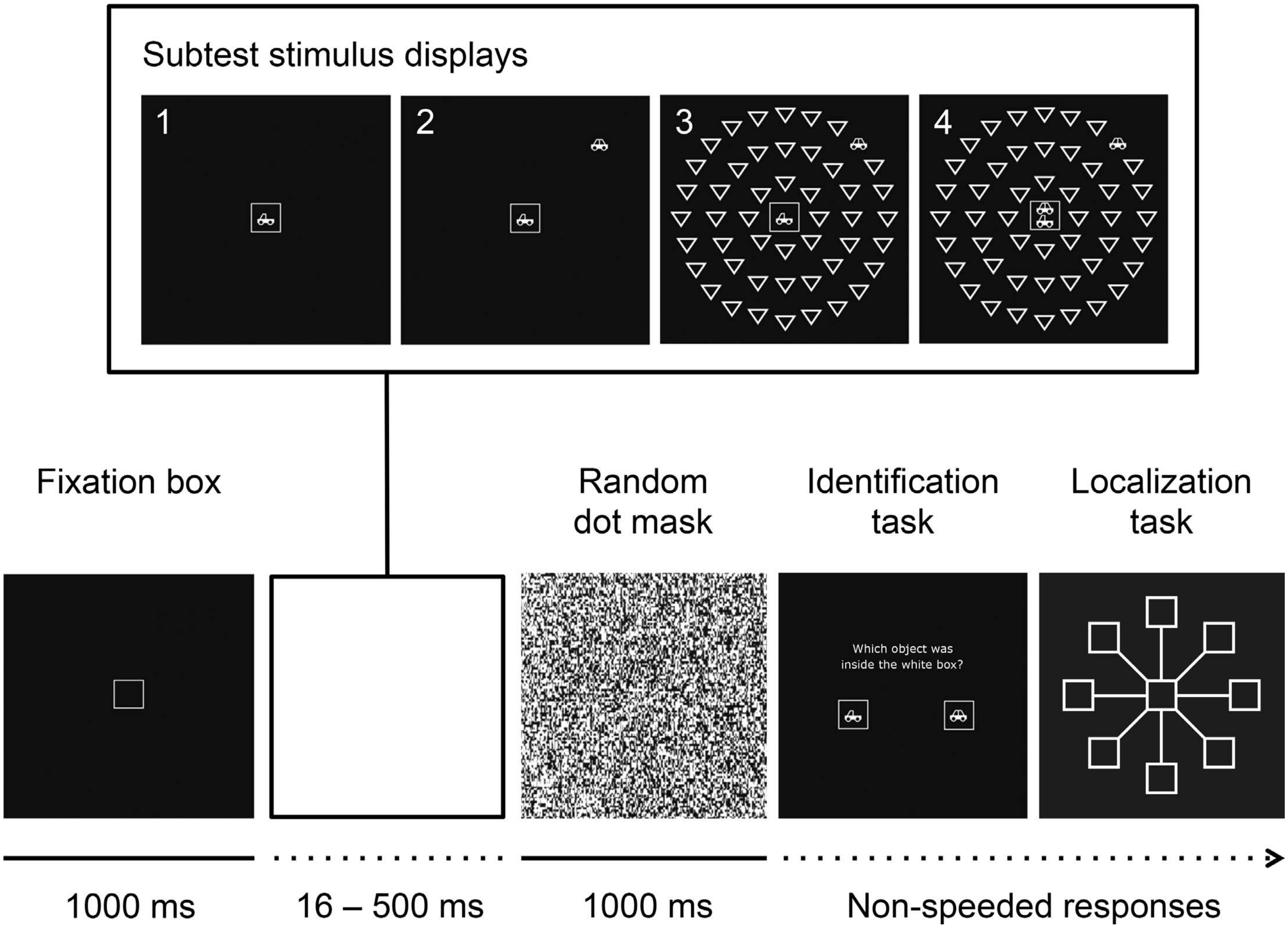

Figure 1. Visual representation of the UFOV test. From "Incremental validity of Useful Field of View subtests for the prediction of instrumental activities of daily living," by F. Aust and J. D. Edwards, 2016, *Journal of Clinical and Experimental Neuropsychology*, *38*(5), pp. 497–515. Copyright 2016 by Taylor & Francis Ltd. Reprinted with permission.

similar to this subtest, did not explain additional variance when they included other low-level functions in their model, including visual acuity, contrast sensitivity, and change detection. They suggested that UFOV2 reflects efficiency of divided attention, while low-level visual and attentional factors, as well as general cognitive ability, were the strongest predictors of UFOV3 performance. Furthermore, O'Brein, Lister, Peronto, and Edwards (2015) have reported correlations between UFOV subtest scores and event-related brain potentials related to low-level visual processes as well as higher processes of attention control and processing speed. These and other studies show that the UFOV tasks may be tapping into other functions in addition to or instead of those that were initially proposed.

Due to the differences between published studies on the subject and the measures they have included, it is difficult to reach a conclusion about the set of functions that may be involved in UFOV performance. In an attempt to clarify previously published results, we systematically analyzed the correlations between UFOV performance and perceptual and cognitive functions that are thus far available in the literature. To our knowledge, no such summary currently exists. This information however, is important for the interpretation of UFOV scores, especially when they are used to represent a person's central vision and processing speed or divided or selective attention. It may also guide future research into the mechanisms underlying UFOV performance.

Methods

Information sources and search

After consulting a librarian, we performed a literature search using the CINAHL, Embase, ERIC, PsycINFO, and PubMed databases on April 22, 2016.

We were interested in Pearson's correlation coefficients between UFOV subtests and other tests measuring a cognitive or perceptual function (see Summary measures and analyses). Because we wanted to include all articles that report this outcome measure of interest, including those that report it as an interim result or secondary outcome measure, we used a very general search phrase: "UFOV OR useful field of view." The search was limited to English-language full-text articles published after 1995, because the current version of the UFOV was not available before that year (Ball, Edwards, & Ross, 2007). We requested copies of unavailable articles via ResearchGate.

Eligibility criteria and study selection

Two independent reviewers (authors KW and LG) selected articles in a two-stage process. First, titles and abstracts were screened. In cases of doubt, abstracts were included. Then the methods and results sections were read carefully for the final selection. In remaining cases of doubt ($n = 8$), a third reviewer was consulted (author JG). Articles were included if they met the following criteria: First, the article describes an experimental or observational study that included at least 15 healthy adults not influenced by any substance or medication. Articles describing patient populations or participants younger than 18 years were included if they reported the outcome of interest separately for a control group that meets the aforementioned criteria. Second, the current version of the UFOV test was used, which measured presentation duration instead of area reduction (Visual Awareness Research Group, 2009). Third, a Pearson's correlation coefficient was reported that quantifies the relationship between UFOV scores and another neuropsychological, psychophysical or ophthalmological test.

Data-collection process and items

The following variables were extracted from each article: publication year, main subject, number of participants, mean age and age range of participants, type of participants (e.g., drivers, community-dwelling older adults) and participant population (for populations that have been described in multiple articles, such as participants from the ACTIVE trial; Ball et al., 2002), male/female ratio, and inclusion criteria. Furthermore, we extracted the correlations between UFOV subtest scores and other neuropsychological, psychophysical or ophthalmological tests, the names of these tests, and the functions they measure. Author LG checked the extracted correlation coefficients.

Once the data were collected, we grouped the coefficients into separate cognitive and perceptual domains systematically. We first sorted coefficients based on the name of the test, and grouped identical tests. Then we sorted coefficients into the perceptual and cognitive functions reported in the articles from which they were extracted. For example, the Early Treatment Diabetic Retinopathy Study and Bailey–Lovie tests were grouped as tests of visual acuity. Last, we categorized these functions into overarching domains using the domains specified in a compendium of neuropsychological tests (Strauss, Sherman, & Spreen, 2006). For example, in accordance with this compendium, we categorized working memory and visual memory as "memory." Because contrast and visual acuity are very different visual functions that may have independent relationships with the UFOV task, and because enough articles reported on these two measures, we split the correlations into different subdomains. Unfortunately, this was not possible for other domains, due to the low number of coefficients available in the literature; only one coefficient would be left per subdomain and UFOV subtest. Since all speed and closure tests turned out to be visual, we termed these domains "vision.speed" and "vision.closure," respectively.

Quality assessment

To assess the quality of the articles included in this study, we modified the QUADAS tool (Whiting, Rutjes, Reitsma, Bossuyt, & Kleijnen, 2003) to fit it to our research purposes (Table 1). Criteria were scored as yes (+), no (–), or unknown (?). We analyzed whether the included studies could be generalized qualitatively based on demographic information extracted from the articles. However, we did not use this assessment in our quantitative analyses.

Summary measures and analyses

We analyzed our data quantitatively using R version 3.1.2 (R Core Team, 2014) with the metafor version 1.9-7 package (Viechtbauer, 2010). The outcome measure of interest was the Pearson's correlation coefficient between a UFOV subtest score and another neuropsychological, psychophysical or ophthalmological test. We chose to include only Pearson's correlation coefficients, because they cannot be combined with nonparametric or regression coefficients in one analysis. Moreover, Pearson's r is easier to interpret because it tests for a linear relationship, as opposed to Spearman's correlation coefficient, and does not depend on the inclusion of other variables,

Original QUADAS (Whiting et al., 2003)	Modified QUADAS
1. Was the spectrum of patients representative of the patients who will receive the test in practice?	Because the spectrum of healthy adults is very broad and influenced by many factors, we investigated the demographic information separately.
2. Were selection criteria clearly described?	This question was unmodified.
3. Is the reference standard likely to correctly classify the target condition?	This question was not applicable.
4. Is the time period between reference standard and index test short enough to be reasonably sure that the target condition did not change between the two tests?	Were the UFOV and the test that is related to it performed in the same month? Since we were interested in the healthy population, we did not expect very fast changes in condition.
5. Did the whole sample or a random selection of the sample receive verification using a reference standard of diagnosis?	This question was not applicable.
6. Did patients receive the same reference standard regardless of the index test result?	Since we included only articles that reported a coefficient for UFOV subtests, the answer to this question was yes for every article. We therefore removed the question.
7. Was the reference standard independent of the index test (i.e., the index test did not form part of the reference standard)?	Some index tests could include the UFOV (for example, the roadwise test), but we did not include those coefficients, so the answer to this question was always yes.
8. Was the execution of the index test described in sufficient detail to permit replication of the test?	Were details provided about the test, such as stimuli, sequence, and so on, or was a name or citation provided to find the original test?
9. Was the execution of the reference standard described in sufficient detail to permit its replication?	Because we included only articles that used the current UFOV version, sufficient details must have been provided in the included articles to determine the version. The answer to this question was therefore always yes.
10. Were the index test results interpreted without knowledge of the results of the reference standard?	Because we were only interested in the actual coefficients, not the authors' interpretations of them, this question was not applicable.
11. Were the reference standard results interpreted without knowledge of the results of the index test?	See criterion 10.
12. Were the same clinical data available when test results were interpreted as would be available when the test is used in practice?	This question was not applicable.
13. Were uninterpretable/intermediate test results reported?	This question was not applicable.
14. Were withdrawals from the study explained?	Were details about missing/removed data or withdrawals provided?

Table 1. QUADAS criteria and modifications used in the current study.

like regression or partial correlation coefficients. We did not analyze combined UFOV scores, because many different combinations have been reported, each with only a few reports. For the same reason, we did not include coefficients of the fourth UFOV subtest.

We first reversed the sign of the correlations, such that all positive correlations indicate that better performance on the index test predicts better performance on the UFOV test. Then we transformed all coefficients to Fisher's Z coefficients. To estimate the true correlations between the UFOV subtests and all domains and their variabilities, we performed a multivariate mixed-effects analysis using the restricted maximum-likelihood estimation method. We included two random-effects variables. The first was to estimate variability caused by the inclusion of multiple participant populations in the model ($T_{pop}{}^2$). By modeling correlations between these estimates of variability, we controlled for dependencies that occur due to the inclusion of several coefficients obtained in the same population. Similarly, we included a random-effects variable of test type ($T_{test}{}^2$). This way we took into account the fact that different index tests can be distinct representatives of the same domain and may therefore show varying correlations with the UFOV test. Test type and population variability were estimated per combination of UFOV subtest and domain.

We included UFOV subtest and domain as fixed-effects variables, as well as their interaction term to obtain estimates of the true correlation between each UFOV subtest and every domain. The structure of the multivariate mixed-effects model was as follows:

$$\text{Estimated correlation} \sim \text{random} \\ (\text{UFOV} - \text{domain combination} \,|\, \text{test type}) + \text{random} \\ (\text{UFOV} - \text{domain combination} \,|\, \text{participant population}) \\ + \text{fixed}(\text{UFOV}) + \text{fixed}(\text{domain}) + \text{fixed} \\ (\text{UFOV} \times \text{domain}).$$

To investigate main and interaction effects of UFOV subtest and domain, we performed a fixed-effects model analysis, where we included the effect sizes and variations that resulted from the previous multivariate model analysis. We used Wald-type tests to determine significance of these effects. Effects were considered significant if their p values did not exceed a type 1 error of 0.05 while controlling for the false discovery rate (FDR).

Results

Data collection

The literature search resulted in 771 records, of which we selected 18 peer-reviewed articles based on our inclusion criteria (Figure 2). These articles contained 208 Pearson's correlation coefficients in total. We systematically categorized the index tests into nine different domains (see Methods): attention, executive functioning, general cognition, memory, spatial ability, vision.acuity, vision.closure, vision.contrast, and vision.speed. Six of the coefficients we could not categorize into any of the domains of the compendium of neuropsychological tests (Strauss et al., 2006), and we therefore excluded them. Twenty-one coefficients were obtained with different versions of the same test in the same population and were therefore combined into six composite coefficients calculated with fixed-effects model analyses. Finally, we analyzed 116 coefficients with the multivariate mixed-effects model. Of these 116 coefficients, only 17 were not significantly different from zero, and none were significantly negative.

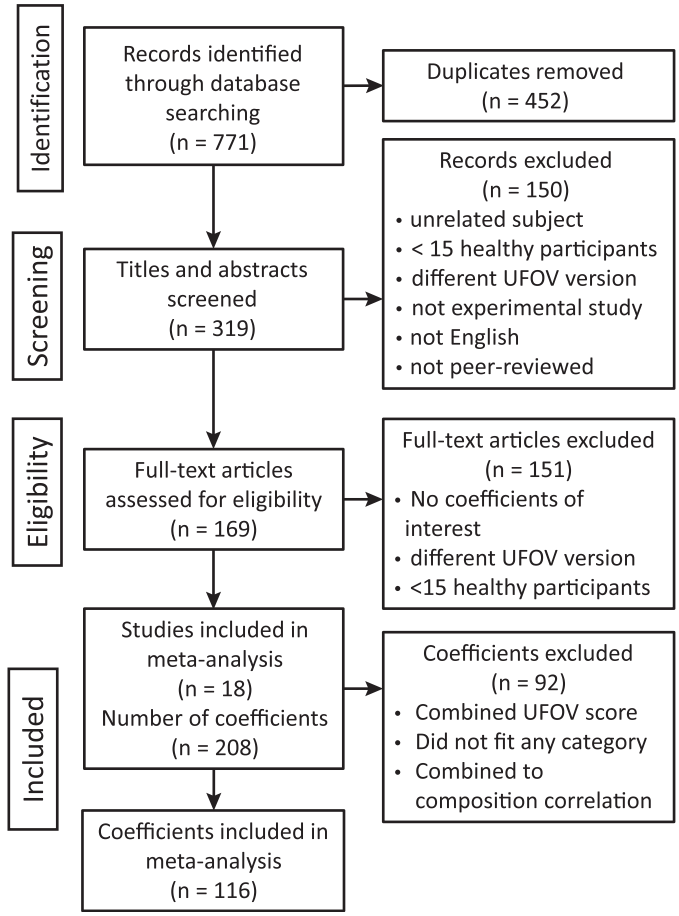

Figure 2. Flowchart of the selection process.

Bias and generalizability

Table 2 lists demographic information reported in the included articles. The number of participants varied greatly between studies, from 19 to 2,759 subjects. A few studies reported data from the same population, for example the ACTIVE and SKILL groups, or combined them into larger data sets (e.g., Ball et al., 2007). Participants were mainly drivers, healthy and/or community-living older adults. Most studies included relatively old participants; only five out of 18 studies included participants younger than 50 years. Although the studies varied considerably in the percentage of included male participants (24.3%–67.3%), overall almost half (46%) of the subjects were male. Ethnicity was reported in eight studies, with the majority of participants in most studies being of Caucasian or White descent (except for Gray et al., 2014, almost half of whose participants were of non-Caucasian descent). African American was the next most common ethnicity. Only two studies reported the inclusion of participants with other ethnicities. Twelve studies reported information about the education their participants had received. Most reported that subjects attained fourth grade to a doctoral degree, with a mean duration of 13–15 years. Eleven studies excluded visual disorders based either on self-report or on a minimal visual acuity of 0.25–0.6. Three studies (Fazeli, Ross, Vance, & Ball, 2013; Hoffman & McDowd, 2010;

Article	Number of participants (population)	Type of participants	Age range (mean age)	Male/female ratio
Anstey et al. (2012)	297	Drivers	65–69 (75.1)	62.2/37.8
Aust & Edwards (2016)	828 (ACTIVE + SKILL)	Healthy older adults	62–69 (73.2)	41.8/58.2
Ball et al. (2007)	2039 (UAB + SKILL + Driving study + ACTIVE + Home-Based training + accelerate)	Community-dwelling older adults	55–95 (73.94)	? (differs per outcome)
Bédard et al. (2010)	50	Drivers	18–83 (?)	42/58
Crisler et al. (2013)	360	Drivers	50–93 (68.7)	49.1/50.9
Dommes et al. (2013)	51	Healthy adults	20–84 (?)	45.1/54.9
Edwards et al. (2005a)	364	Community-dwelling older adults	55–93 (73.19)	38.2/61.8
Edwards et al. (2006)	2,759 (ACTIVE)	Healthy older adults	65–94 (73.54)	24.3/75.7
Fazeli et al. (2013)	634 (SKILL)	Older adults	72.14–75.09 (?)	40.5/59.5
Gray et al. (2014)	52	Healthy adults	18–55 (37.73)	63/37
Henderson et al. (2010)	31	Healthy adults	24–84 (?)	54.8/45.2
Henderson et al. (2013)	49	Healthy drivers	25–82 (?)	67.3/32.7
Hoffman et al. (2005)	155	Community-dwelling drivers	63–87 (75.2)	43.9/56.1
Hoffman & McDowd (2010)	155 (Hoffman et al., 2005)	Community-dwelling drivers	63–87 (75.2)	43.9/56.1
Lunsman et al. (2008)	690 (ACTIVE)	Healthy older adults	65–94 (73.95)	26.2/73.8
Matas et al. (2014)	82	Community-dwelling older adults	62–92 (75)	36.6/63.4
Trick et al. (2010)	19	Older drivers	? (70.8)	57.9/42.1
Vance et al. (2006)	697	Older drivers	55.23–92.34 (71.47)	47.6/52.4

Table 2. Demographics for each included article. *Notes*: —: None. ?: Unknown. VA: Visual acuity. MMSE: Mini-Mental State Examination. SMMSE: Standardized Mini-Mental State Examination.

Ethnicity	Education	Control for visual disorders	Control for cognitive disorders
?	Mean: 14.35 years	—	MMSE ≥24
8.8% African American, 90.5% Caucasian, 0.5% other	93.1% high school, 41.8% college; 6–20 years (mean: 14.1 years)	VA ≥ 20/60	MMSE ≥25 and UFOV scores <500 ms for at least one subtest
?	4th grade–PhD	Varies per study; for 5/6 studies, VA ≥20/80	Varies per study; for 4/6 studies, MMSE ≥23
?	?	—	SMMSE ≥24
?	High school or less through some graduate school	Not legally blind (according to USA regulations)	—
?	?	Binocular VA ≥6/10, good health, no pathological aging	MMSE sufficient (cutoff score not specified), good health, no pathological aging
92.3% Caucasian, 4.9% African American, 0.5% Hispanic American, 0.2% Asian American, 0.2% Native American, 1.6% other	6–20 years (mean: 14 years)	— (but lowest score: 0.36 logMAR)	—
73% Caucasian, 26% African American	4th grade–PhD (mean: 13.52 years)	VA ≥20/70, no sensory deficits	MMSE ≥24 and no self-report of dementia
91% Caucasian	Mean: 13.84 years	VA ≥20/80, contrast sensitivity ≥1.35 log10, adequate vision	MMSE ≥ 23, relatively intact cognition
54% Caucasian	Mean: 14.87 years	No diagnosis, no medication	No diagnosis, no medication
?	?	Self-report	Self-report
?	?	Self-report	Self-report
96% White, 4% African American	17% high school or general educational development degree, 5% associate's degree, 43% bachelor's degree, 25% master's degree, 11% PhD, JD, MD, or ED	— (sample includes visual disorders; lowest score measured: 20/60)	—
96% White, 4% African American	17% high school or general educational development degree, 5% associate's degree, 43% bachelor's degree, 25% master's degree, 11% PhD, JD, MD, or ED	— (sample includes visual disorders; lowest score measured: 20/60)	—
71.9% White, 26.8% African American	6th grade–doctoral degree (mean: 13.38 years)	VA ≥20/50, no functional impairment	MMSE ≥23, no diagnosis of dementia
?	5–25 years (mean: 15.1 years)	— (but minimal score measured: 0.69 logMAR)	MMSE >24
?	?	—	—
91.1% White, 5.7% African American, 3.2% other	?	VA ≥20/40 (and driver's-license renewal in the United States)	— (but driver's-license renewal in the United States)

Table 2. Extended

Article	Were selection criteria clearly described?	Were the UFOV and the test that is related to it performed in the same month?	Were details about missing/removed data or withdrawals provided?	Were details provided about the test, such as stimuli, sequence, and so on, or was a name or citation provided to find the original test?
Anstey et al. (2012)	−	+	+	+
Aust & Edwards (2016)	+	?	+	+
Ball et al. (2007)	+	?	−	+
Bédard et al. (2010)	−	?	+	+
Crisler et al. (2013)	+	+	−	+
Dommes et al. (2013)	+	+	−	+
Edwards et al. (2005a)	−	+	−	+
Edwards et al. (2006)	+	?	−	+
Fazeli et al. (2013)	+	+	−	+
Gray et al. (2014)	+	?	−	+
Henderson et al. (2010)	−	?	+	+
Henderson et al. (2013)	−	?	+	+
Hoffman et al. (2005)	−	+	+	+
Hoffman & McDowd (2010)	+	+	−	+
Lunsman et al. (2008)	+	?	+	+
Matas et al. (2014)	+	+	−	+
Trick et al. (2010)	+	+	+	+
Vance et al. (2006)	+	+	−	+

Table 3. Results of the QUADAS assessment. *Notes*: +: Yes. −: No. ?: Unknown.

Hoffman, McDowd, Atchley, & Dubinsky, 2005) reported the occurrence of various ophthalmological disorders including cataracts, glaucoma, and age-related macular degeneration. We decided to include these studies as well, because some of the other included studies did not report examining or excluding visual disorders at all, even though the mentioned disorders are not uncommon in older adults. Furthermore, 11 studies excluded cognitive disorders, either by self-report or by using a minimal Mini-Mental State Examination (MMSE) score of 23–25. In summary, these results suggest that conclusions can mainly be generalized to healthy, older people of Caucasian descent.

Table 3 shows the QUADAS assessment of bias within studies. Six studies did not describe their inclusion criteria clearly. The time period between the UFOV task administration and the other test was sufficiently small (i.e., less than 1 month) for 11 studies. Although no studies reported a longer interval, the other studies were not clear on this point. Only a few articles clearly reported the number of data points missing or removed from the analyses, such as outliers and withdrawals. Other studies may not have reported any missing or deleted cases because there were none, but they did not mention this explicitly. All studies provided a clear description of the neuropsychological, psychophysical or ophthalmological test that was correlated to the UFOV or reported its official name or a citation.

Meta-analysis

Multivariate mixed-effects model analysis

The results of the multivariate mixed effects model analysis showed significantly positive correlations between UFOV1 and every domain for which correlations have been reported (Figure 3, Table 4). For some domains—attention, executive functioning, and memory—this was not surprising, since only significantly positive correlations have been reported in the literature. For the other domains, the literature has been less consistent; we found at least one nonsignificant correlation reported per domain. In fact, half of the correlations with index tests in the vision.contrast and vision.acuity domains were not significantly different from 0. However, the results of our meta-analysis indicate that significantly positive correlations between UFOV1 and these domains do exist. Moreover, the results of the meta-analysis suggest that most nonsignificant correlations reported in the literature are explained by the large within-study variances. The only exception is the correlation between the road-sign test and UFOV1 reported by Ball et al. (2007), which was not significantly different from zero despite its narrow confidence interval.

Estimated correlations between UFOV2 and all nine domains were also significantly larger than 0 (Figure 4, Table 5). For a number of domains—i.e., attention, executive functioning, spatial ability, vision.closure, and vision.speed—we found good agreement between studies, as they all reported

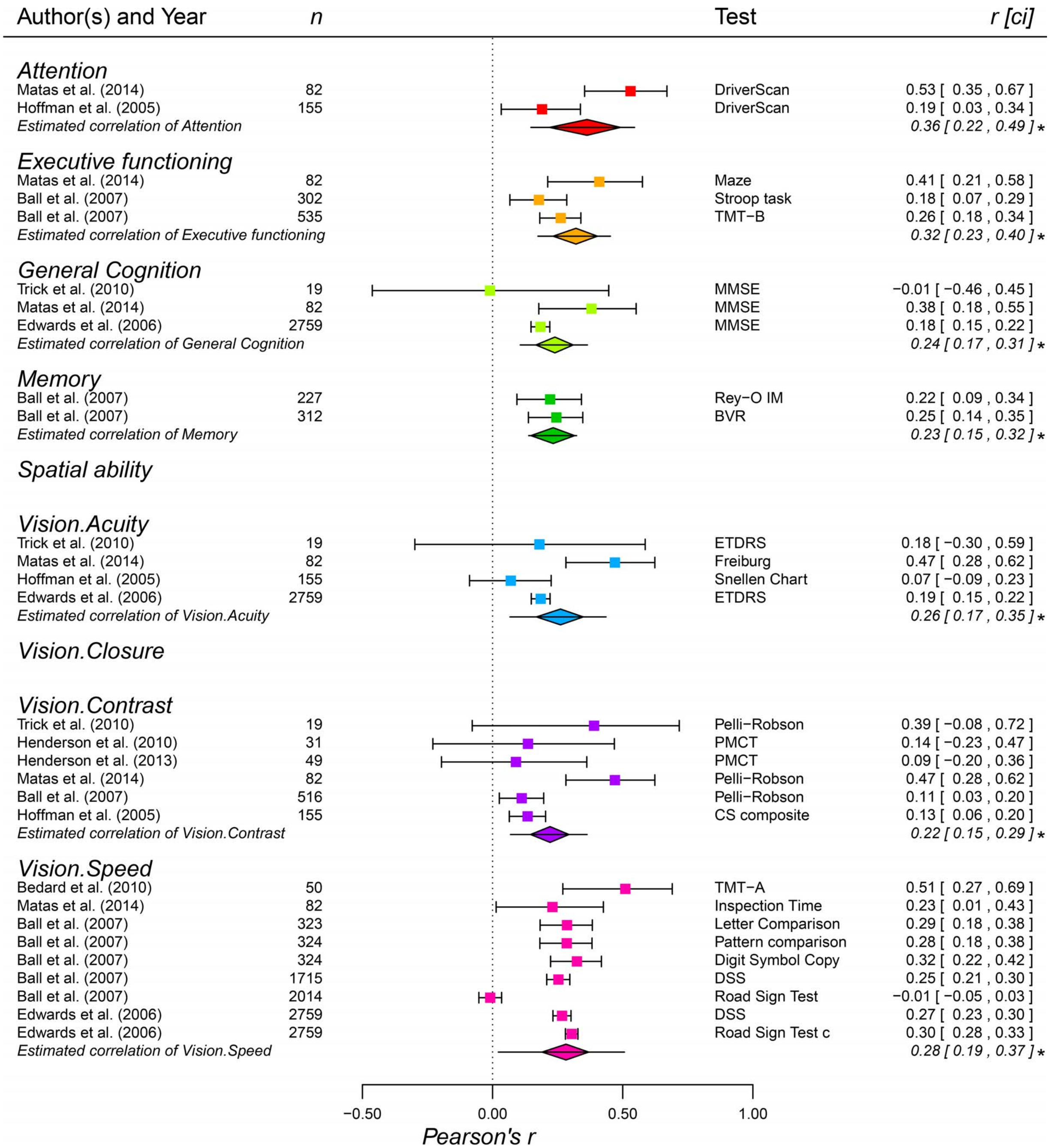

Figure 3. Forest plot of Pearson's correlation coefficients between all tested domains and UFOV1 (processing speed). Every coefficient is shown as a point with its 95% confidence interval. Values are listed in the right-hand column (*r*[*CI*]). Diamonds represent the mean and confidence interval of the random-effect model estimations; the horizontal line shows the prediction interval (i.e., the 95% interval in which the true effect size of a future study will lie; Borenstein et al., 2009). Statistically significant effects ($p_{FDR} < 0.05$) are indicated with an asterisk. The results of spatial ability and vision.closure are missing, because there were no correlations reported in the literature that belong to these domains. BVR: Benton Visual Retention; c: composite; CS: Contrast Sensitivity; DSS: Digit Symbol Substitution; ETDRS: Early Treatment Diabetic Retinopathy Study; MMSE: Mini-Mental State Examination; PMCT: peripheral motion contrast threshold; Rey-O IM: Rey-Osterrieth Immediate Memory; TMT: Trail-Making-Test.

significantly positive correlation coefficients. For the other domains, we again found that at least one of the studies reported nonsignificant correlations with UFOV2. Our meta-analysis suggests, however, that these apparent discrepancies in the literature may be explained by the larger variances that were reported for those studies. Interestingly, although all reported correlations in the vision.speed domain are relatively similar, Bédard, Parkkari, Weaver, Riendeau, and Dahlquist (2010) reported a much higher correlation

Modality	z	$T_{test}^2 \times 10^{-3}$	$T_{pop}^2 \times 10^{-3}$
Attention	4.73*	—	7.54
Executive functioning	6.85*	0.98	3.00
General cognition	6.31*	—	3.42
Memory	5.23*	0.42	—
Spatial ability	—	—	—
Vision.acuity	5.41*	0.98	7.00
Vision.closure	—	—	—
Vision.contrast	5.67*	0.33	4.41
Vision.speed	5.84*	15.89	0.34

Table 4. Results of the multivariate mixed-effects model analysis of correlations between UFOV1 (processing speed) and other tests divided into nine perceptual and cognitive domains. The results for spatial ability and vision.closure are missing, because there were no correlations reported in the literature that belong to these domains. Values of T_{test}^2 and T_{pop}^2 were not estimated for domains where all reported correlations are based on the same test type or subject population, respectively. z = test statistic of the estimated correlation coefficient; T_{test}^2 = estimated amount of heterogeneity due to test; T_{pop}^2 = estimated amount of heterogeneity due to population; $^*p_{FDR} < 0.05$.

between Trail-Making-Test part A and UFOV2 than the others.

Similar to UFOV1, we did not find any studies reporting on correlations between UFOV3 and spatial ability or vision.closure. For all other domains, our meta-analysis shows significantly positive correlations between all domains and UFOV3, even though five of those domains—i.e., executive functioning, general cognition, memory, vision.acuity, and vision.contrast—included studies reporting nonsignificant correlation coefficients (Figure 5, Table 6). Interestingly, memory is the only domain for which the prediction interval included 0, indicating that for this combination of domain and subtest, true effect sizes found in future studies could be zero or even negative. Figure 6 shows all estimated effect sizes together. As for UFOV2, Bédard et al. (2010) reported a comparatively high correlation between Trail-Making-Test part A and UFOV3.

The UFOV subtests were initially suggested to measure central vision and processing speed, divided attention, and selective attention. Although no reports of correlations between the specific subdomains of divided and selective attention are currently available in the literature, the reported correlations of the attention domain are in good agreement. That is, they are all significantly positive, and for UFOV2 and UFOV3 they are reasonably similar to each other. The same is true for vision.speed, although as previously mentioned, one nonsignificant correlation was reported with UFOV1.

For vision.acuity, a central vision test, reported correlations are variable, with some apparent discrepancies between studies. This is also true for reported correlations between vision.contrast and UFOV subtests. Our meta-analysis shows, however, that between studies there is sufficient evidence to conclude that both domains are significantly correlated to each of the three UFOV subtests. This is interesting, because the stimuli used in the UFOV test are quite large and of high contrast, and thereby well above the threshold for healthy subjects. The general cognition and memory domains also showed some variability, and for both domains several nonsignificant correlations have been reported across UFOV subtests. Again, our meta-analysis shows that despite the heterogeneity between studies, there is sufficient evidence to conclude that both domains are significantly correlated to the UFOV subtests.

To explain the heterogeneity in correlations reported in the literature, we investigated how much variance was due to test type and how much was due to subject population. In general, estimated variances due to test type were lower than those due to population (Tables 4–6). For some combinations of UFOV subtest and domain, the reported correlations were based on the same index test. For example, correlations in the attention domain were all based on the DriverScan test. It was therefore not possible or necessary to model the variance due to test type for these combinations. The same is true for the variance due to population in the correlations between memory tests and UFOV1, because they were based on the same subject population. Both variance due to test type and variance due to population influence the prediction interval—i.e., the 95% interval in which the true effect size of a future study will lie (Borenstein, Hedges, Higgins, & Rothstein, 2009). However, the estimated correlations resulting from the meta-analysis and their confidence intervals represent the true underlying effect unaffected by test type or population.

Exploratory analyses

We used a fixed-effects model to investigate main and interaction effects of UFOV subtest and domain on the estimated coefficients that were available for all subtests—i.e., all except spatial ability and vision.closure—resulting from the mixed-effects model analysis. We found significant differences between UFOV subtests, Q_M $(df = 2) = 23.07$, $p < 0.0001$, and between domains, Q_M $(df = 6) = 47.23$, $p < 0.0001$, but no interaction effects between the two variables, Q_M $(df = 12) = 12.93$, $p = 0.37$. This means that the effects of UFOV subtest on the correlation strengths are similar across domains. Likewise, differences in correlations between domains are comparable across UFOV subtests. To visualize these results, Figure 7 shows the estimated correlations between the domains and

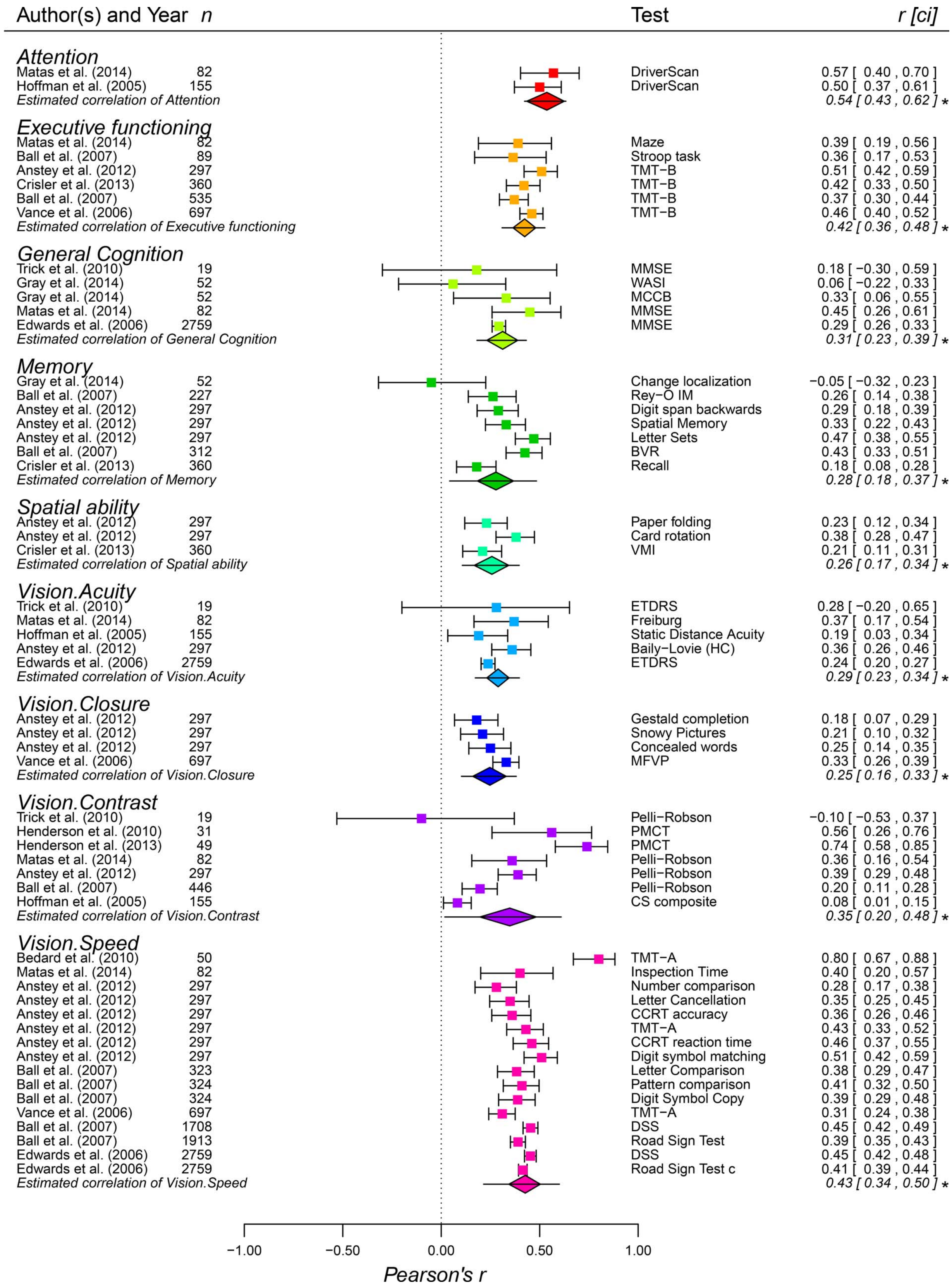

Figure 4. Forest plot of Pearson's correlation coefficients between all tested domains and UFOV2 (divided attention). Same format as Figure 3. BVR: Benton Visual Retention; c: composite; CCRT: Colour Choice Reaction Time; CS: Contrast Sensitivity; DSS: Digit Symbol Substitution; ETDRS: Early Treatment Diabetic Retinopathy Study; HC: High Contrast; MCCB: MATRICS Consensus Cognitive Battery; MFVP: Motor Free Visual Perception; MMSE: Mini-Mental State Examination; PMCT: peripheral motion contrast threshold; Rey-O IM: Rey-Osterrieth Immediate Memory; TMT: Trail-Making-Test; VMI: Visualizing Missing Information; WASI: Wechsler Abbreviated Scale of Intelligence.

Modality	z	$T_{test}^2 \times 10^{-3}$	$T_{pop}^2 \times 10^{-3}$
Attention	8.79*	—	1.02
Executive functioning	12.63*	0.59	2.74
General cognition	7.27*	1.28	1.80
Memory	5.63*	6.94	5.82
Spatial ability	5.50*	2.29	1.72
Vision.acuity	9.47*	0.29	2.64
Vision.closure	5.47*	0.88	2.77
Vision.contrast	4.34*	12.00	11.94
Vision.speed	9.14*	1.55	10.62

Table 5. Results of the multivariate mixed-effects model analysis of correlations between UFOV2 (divided attention) and other tests divided into nine perceptual and cognitive domains. Values of T_{test}^2 are not estimated for domains where all reported correlations are based on the same test type. z = test statistic of the estimated correlation coefficient; T_{test}^2 = estimated amount of heterogeneity due to test; T_{pop}^2 = estimated amount of heterogeneity due to population; $^*p_{FDR} < 0.05$.

subtests in a fixed-effects model where only main effects are estimated, no interaction effects (as opposed to in Figure 6). It also displays the results of the post hoc comparisons.

Post hoc tests of the main effect of UFOV subtest showed significantly higher estimated correlations for the second and third UFOV subtests than for the first (Table 7a). Estimated correlations between domains and the second and third UFOV subtests were not significantly different from each other. Post hoc tests of the main effects of domain showed that estimated correlations between the UFOV subtests and attention were significantly stronger than between UFOV subtests and all other domains (Table 7b)—i.e., vision.speed, executive functioning, vision.contrast, general cognition, vision.acuity, and memory. Furthermore, vision.speed was more strongly correlated with the UFOV subtests than general cognition, memory, vision.acuity, and vision.contrast. Finally, executive functioning showed significantly stronger correlations with the UFOV subtests than memory and vision.acuity.

Discussion

In this review we systematically grouped and analyzed 116 Pearson's correlation coefficients collected from 18 peer-reviewed articles to estimate the relationships between several domains of visual function and cognition and the first three subtests of the UFOV test. Then we compared the estimated correlations to investigate whether UFOV subtests differ in their sensitivities to any of the domains we tested. We were particularly interested in functions the UFOV subtests were initially suggested to measure: central vision and processing speed, divided attention, and selective attention (Edwards, Vance, et al., 2005; Visual Awareness Research Group, 2009).

Our meta-analysis shows that attention, executive functioning, general cognition, memory, vision.acuity, vision.contrast, and vision.speed are domains that are all significantly and positively correlated to each of the three UFOV subtests. For UFOV2, we also found significant positive correlations with spatial ability and vision.closure. Thus, better UFOV performance seems to be associated with better performance on any other task that represents one of these domains. For some domains these results may not be surprising, as we only found reports of significantly positive correlations, for example those between vision.speed and UFOV3 and attention and UFOV3. Other domains, however, have shown less consistency. For example, half of the correlations between UFOV1 and vision.contrast and vision.acuity were not significantly different from zero. Our results show that these domains are significantly and positively correlated with the UFOV subtests as well.

Comparing effect sizes, we found that correlations between UFOV1 and the domains were significantly smaller than those between UFOV2 or UFOV3 and the domains. In addition, some domains showed larger correlations than others. However, we found no interaction effects, indicating that differences between the UFOV subtests are the same for all domains and that differences between domains are similar across UFOV subtests. In other words, none of the UFOV subtests is selectively more sensitive to a particular domain than the others.

UFOV1 is said to measure central vision and processing speed. Indeed, we found significantly positive correlations between UFOV1 and visual processing speed and visual acuity, a central vision test. However, this is also true for the other two UFOV subtests, which show even stronger correlations. Although visual processing speed is indeed more strongly correlated with UFOV1 than some other domains, including visual acuity, the difference is not specific to this subtest. Furthermore, attention—which is purportedly measured by UFOV2 and UFOV3—is more strongly correlated with all subtests, including UFOV1, than visual processing speed and visual acuity. It is important to note, however, that the attention domain was represented by one task only, namely DriverScan, which is a measure of change detection. One should therefore be careful generalizing the results for this test to attention as a general cognitive domain. Although we were particularly interested in the correlations between divided attention and UFOV2, and between selective attention and UFOV3, in our extensive literature search we found no studies that

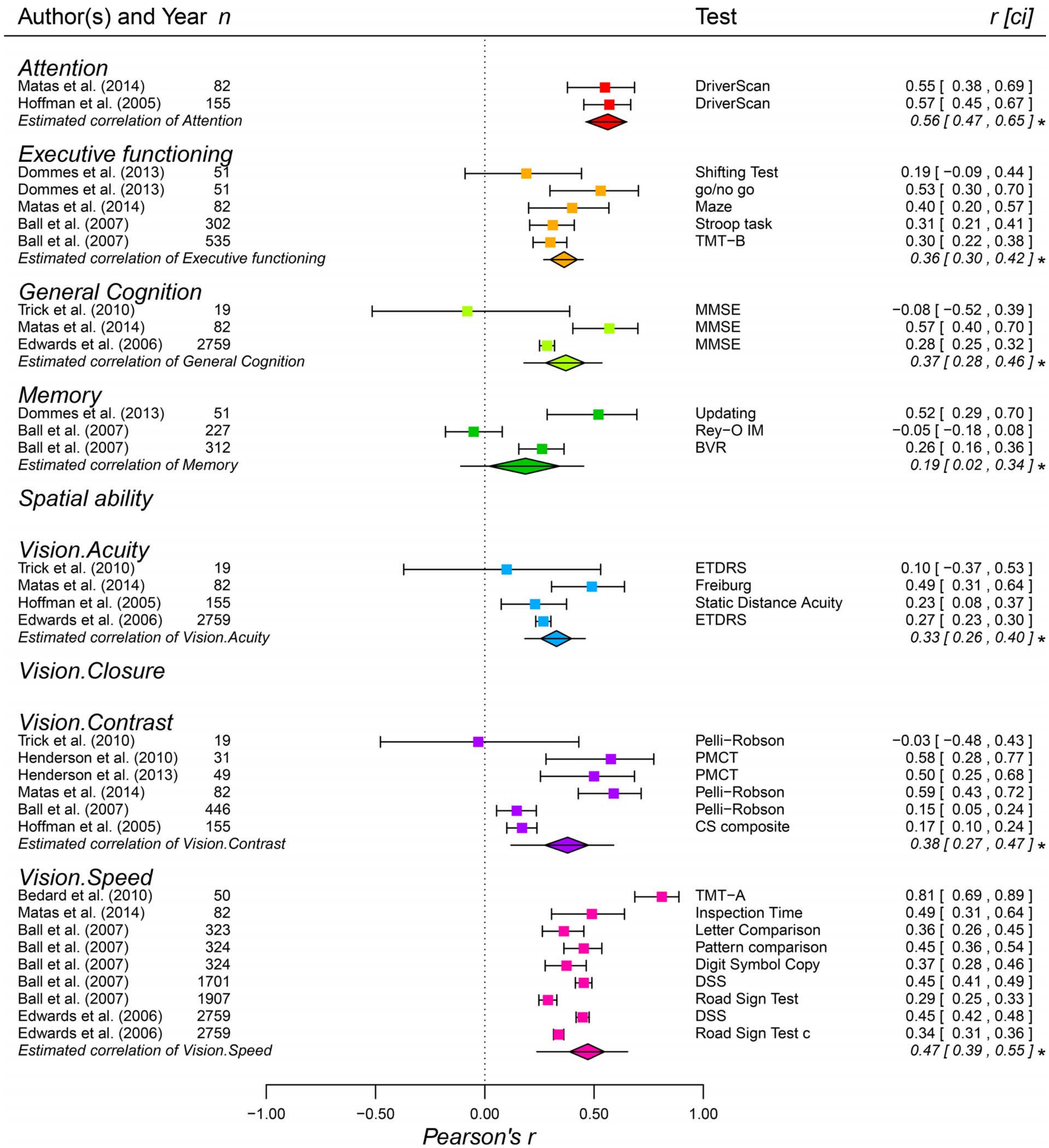

Figure 5. Forest plot of Pearson's correlation coefficients between all tested domains and UFOV3 (selective attention). Same format as Figure 3. The results of spatial ability and vision.closure are missing, because there were no correlations reported in the literature that belong to these domains. BVR: Benton Visual Retention; c: composite; CS: Contrast Sensitivity; DSS: Digit Symbol Substitution; ETDRS: Early Treatment Diabetic Retinopathy Study; MMSE: Mini-Mental State Examination; PMCT: peripheral motion contrast threshold; Rey-O IM: Rey-Osterrieth Immediate Memory; TMT: Trail-Making-Test.

have examined relations between UFOV subtests and these functions with independent tests. We can therefore neither confirm nor disconfirm their involvement in UFOV2 and UFOV3. Our results do show, however, that both subtests are significantly correlated with a series of other lower and higher level functions. This is an important finding, because several studies have taken UFOV2 and UFOV3 as measures of divided and selective attention (e.g., Belchior et al., 2013; Gray et al., 2014). Although attention shows stronger correlations with UFOV2 and UFOV3 than UFOV1, as mentioned before, this is a general effect of UFOV on all domains. This difference in correlation strengths could be due to the floor effect that is often

Modality	z	$T_{test}^2 \times 10^{-3}$	$T_{pop}^{2*} \times 10^{-3}$
Attention	9.47*	—	0.39
Executive functioning	10.33*	0.32	1.14
General cognition	7.37*	—	8.54
Memory	2.20*	12.91	3.05
Spatial ability	—	—	—
Vision.acuity	8.47*	0.69	3.99
Vision.closure	—	—	—
Vision.contrast	6.70*	2.46	14.19
Vision.speed	9.77*	9.08	7.07

Table 6. Results of the multivariate mixed-effects model analysis of correlations between UFOV3 (selective attention) and other tests divided into nine perceptual and cognitive domains. The results for spatial ability and vision.closure are missing because there were no correlations reported in the literature that belong to these domains. Values of T_{test}^2 are not estimated for domains where all reported correlations are based on the same test type. *$p_{FDR} < 0.05$; z = test statistic of the estimated correlation coefficient; T_{test}^2 = estimated amount of heterogeneity due to test; T_{pop}^2 = estimated amount of heterogeneity due to population.

observed in UFOV1 (Aust & Edwards, 2016; Edwards et al., 2006). Because healthy people can easily achieve the best (i.e., lowest) score on UFOV1, there is little variation in the test results, and strong correlations between UFOV1 and other test scores are therefore less likely to be found.

In our meta-analysis, we combined multiple tasks and results from several populations into one analysis. This may account for a considerable amount of heterogeneity among the included correlation coefficients. Therefore, we included these two factors—i.e.,

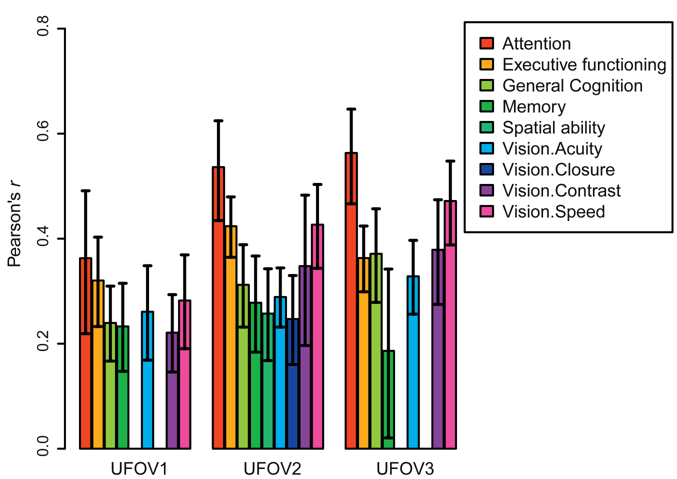

Figure 6. Bar graph of the Pearson's correlation coefficients as estimated with the multivariate mixed-effects model. Every group of bars represents the estimated correlations between one UFOV subtest and the domains, which are indicated by the different colors. Error bars represent 95% confidence intervals.

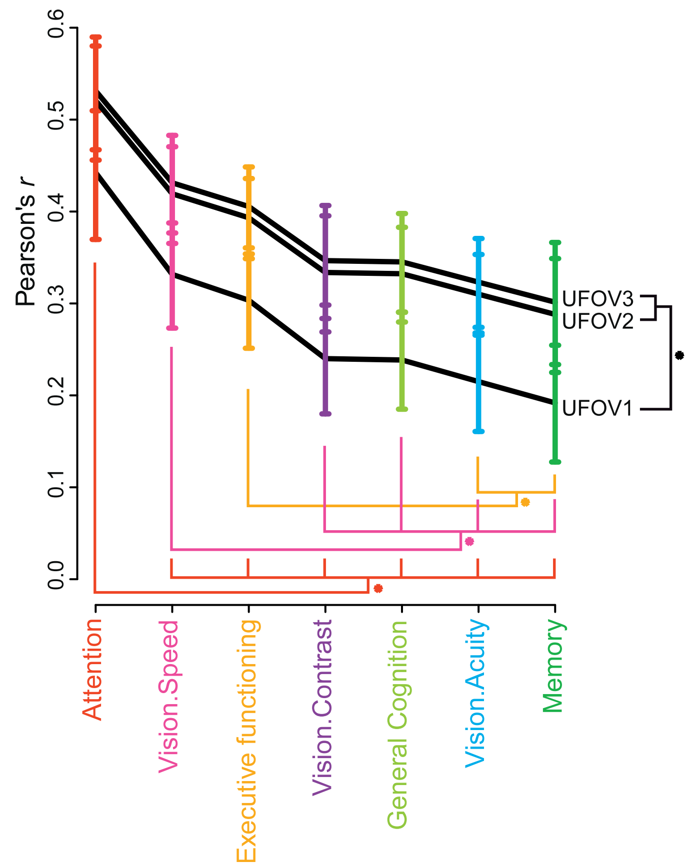

Figure 7. Estimated correlations between UFOV subtests and domains in a fixed-effects model that includes only main effects, no interaction effects. The interaction effects were dropped here because they were not statistically significant. Domains are ordered according to the strengths of their estimated correlations and are represented by different colors. Thinner lines represent the results of post hoc comparisons. Asterisks indicate significant differences.

test type and population—into our model to estimate the amount of variance that can be attributed to each, thereby obtaining more precise estimates of the true correlations and their confidence intervals. In general, estimates of variance due to population were higher than estimates of variance due to test type. This suggests that correlations between UFOV subtests and domains are more sensitive to the group from which researchers collect data than to the specific tasks used to represent these domains. One reason for higher estimates of variance due to population may be the substantial differences of inclusion and exclusion criteria that researchers have used. Some studies screened for cognitive and/or visual disorders with specific measures, some relied on self-report, and some did not control for any disorder but merely reported prevalence in the sample. Although we can therefore not be sure that all populations include only healthy participants, this does make our results more general-

	Contrast	Estimate (standard error)	z
(a)	UFOV1 − UFOV2	−0.102 (0.026)	−4.00*
	UFOV1 − UFOV3	−0.117 (0.027)	−4.34*
	UFOV2 − UFOV3	−0.015 (0.026)	−0.56
(b)	Attention − vision.speed	0.131 (0.050)	2.58*
	Attention − executive functioning	0.162 (0.047)	3.44*
	Attention − vision.contrast	0.230 (0.052)	4.44*
	Attention − general cognition	0.232 (0.048)	4.77*
	Attention − vision.acuity	0.257 (0.047)	5.49*
	Attention − memory	0.281 (0.052)	5.39*
	Vision.speed − executive functioning	0.031 (0.037)	0.84
	Vision.speed − vision.contrast	0.100 (0.043)	2.33*
	Vision.speed − general cognition	0.101 (0.039)	2.61*
	Vision.speed − vision.acuity	0.126 (0.037)	3.43*
	Vision.speed − memory	0.150 (0.043)	3.49*
	Executive functioning − vision.contrast	0.069 (0.039)	1.75
	Executive functioning − general cognition	0.070 (0.035)	2.03†
	Executive functioning − vision.acuity	0.095 (0.032)	2.99*
	Executive functioning − memory	0.119 (0.039)	3.02*
	Vision.contrast − general cognition	0.002 (0.040)	0.04
	Vision.contrast − vision.acuity	0.026 (0.039)	0.67
	Vision.contrast − memory	0.051 (0.044)	1.14
	General cognition − vision.acuity	0.025 (0.034)	0.72
	General cognition − memory	0.049 (0.041)	1.21
	Vision.acuity − memory	0.024 (0.039)	0.62

Table 7. Results of post hoc analysis of the main effects of UFOV and domain. z = test statistic of comparison; $^{*}p_{FDR} < 0.05$; $^{\dagger}p_{unadj} < 0.05$ and $p_{FDR} > 0.05$.

izable to people who are aging typically. Furthermore, our results show that regardless of the population, all tested domains are likely to be positively correlated with the UFOV subtests. In fact, the majority of the individual correlations we found during our extensive literature search were significantly positive—i.e., better performance on another task predicts better performance on the UFOV task. The remainder of the correlations were not significantly different from zero. We found no reports of significantly negative correlations. Our results may therefore suffer from a publication bias: Nonsignificant results are less likely to be published, especially when they are not part of the main analysis. Negative correlations would be difficult to explain—i.e., better performance on the UFOV task predicts worse performance on another visual or cognitive task and may therefore also be harder to publish. It is possible, therefore, that the estimated correlations that we obtained with our multivariate mixed-model analysis may overestimate the true effect sizes.

We have limited our study to coefficients reported for healthy adults older than 18 years. However, when investigating the demographic data reported in the selected articles, we found that most studies only included individuals older than 50 years. Although it would be interesting to know whether the same conclusions can be drawn for younger people, the aforementioned floor effect is especially evident in these subjects. It arises from the limited refresh rate of computer screens, usually 60 Hz, which limits the shortest presentation duration to 16.6 ms. Several authors have tried to work around this problem by designing their own version of the UFOV test (Burge et al., 2013; Rutherford et al., 2007). We did not include those studies, because they used very different stimuli or had another outcome measure. Their results can therefore not be readily compared or included in the same meta-analysis. For the same reason, we did not include Spearman's rho or regression coefficients either. However, we did examine these results qualitatively and found a similar pattern. That is, coefficients were either positive or not significant (Agathos et al., 2015; Bowers et al., 2013). In addition, we found only positive correlations and regression coefficients, both significant and nonsignificant, between combined UFOV scores and perceptual and cognitive index tests (Edwards, Wadley, et al., 2005; Fazeli et al., 2013; Lunsman et al., 2008).

Because we analyzed only correlation coefficients, we cannot draw any causal conclusions based on our results. To further investigate which functions are required for UFOV performance in healthy humans, it is necessary to manipulate these functions. Visual acuity could, for example, be easily reduced with blurred glasses. It would, however, be hard to manipulate some functions, such as processing speed or attention. Neurobiological approaches such as functional MRI and electroencephalography might be useful in this regard. Some researchers have already used this approach to study the neural mechanisms underlying UFOV performance. For example, O'Brien et al. (2015) have shown that UFOV performance was related to two event-related potentials associated with early perceptual stimulus selection, top-down attentional control, and cognitive processing speed. Furthermore, Scalf et al. (2007) have reported training-related increases of brain activity in regions related to shifting and reorienting visual attention in a task similar to the UFOV test. Those authors suggested, therefore, that training increases the ability to direct attention, which is very important in daily life.

Conclusions

We found that a broad range of perceptual and cognitive functions are related to UFOV performance. These include not only visual functions but also other cognitive functions such as executive functioning and memory. Interpreting results of individual UFOV subtests should therefore be done carefully. However, this may also be the reason for the UFOV test's high ecological validity, as it requires many functions to work properly at the same time, similar to daily life activities, making it harder to compensate if any one of them fails.

Keywords: perception, cognition, useful-field-of-view test, healthy adults, meta-analysis

Acknowledgments

This research was supported by the Radboud University Medical Centre (KW, AVvdB, TT, JG) and the European Union Program FP7-PEOPLE-2013-ITN HealthPAC, Grant 604063 - IDP (LG, AVvdB, JG).

Commercial relationships: none.
Corresponding author: Karlijn Woutersen.
Email: k.woutersen@donders.ru.nl.
Address: Department of Cognitive Neuroscience, Section Biophysics, Donders Institute for Brain, Cognition and Behaviour, Radboud University Medical Center, Nijmegen, the Netherlands.

References

Agathos, C. P., Bernardin, D., Huchet, D., Scherlen, A.-C., Assaiante, C., & Isableu, B. (2015). Sensorimotor and cognitive factors associated with the age-related increase of visual field dependence: A cross-sectional study. *Age*, *37*(4), 67, doi:10.1007/s11357-015-9805-x.

Alberti, C. F., Horowitz, T., Bronstad, P. M., & Bowers, A. R. (2014). Visual attention measures predict pedestrian detection in central field loss: A pilot study. *PLoS One*, *9*(2), e89381, doi:10.1371/journal.pone.0089381.

Anstey, K. J., Horswill, M. S., Wood, J. M., & Hatherly, C. (2012). The role of cognitive and visual abilities as predictors in the Multifactorial Model of Driving Safety. *Accident Analysis and Prevention*, *45*, 766–774, doi:10.1016/j.aap.2011.10.006.

Aust, F., & Edwards, J. D. (2016). Incremental validity of Useful Field of View subtests for the prediction of instrumental activities of daily living. *Journal of Clinical and Experimental Neuropsychology*, *38*(5), 497–515, doi:10.1080/13803395.2015.1125453.

Badenes, D., Garolera, M., Casas, L., Cejudo-Bolivar, J. C., de Francisco, J., Zaragoza, S., … Aguilar, M. (2014). Driving competences and neuropsychological factors associated to driving counseling in multiple sclerosis. *Journal of the International Neuropsychological Society*, *20*(5), 555–565, doi:10.1017/S1355617714000368.

Ball, K. K., Beard, B. L., Roenker, D. L., Miller, R. L., & Griggs, D. S. (1988). Age and visual search: Expanding the useful field of view. *Journal of the Optical Society of America A*, *5*(12), 2210–2219, doi:10.1364/JOSAA.5.002210.

Ball, K. K., Berch, D. B., Helmers, K. F., Jobe, J. B., Leveck, M. D., Marsiske, M., … Willis, S. L. (2002). Effects of cognitive training interventions with older adults: A randomized controlled trial. *Journal of the American Medical Association*, *288*(18), 2271–2281, doi:10.1001/jama.288.18.2271.

Ball, K. K., Edwards, J. D., & Ross, L. A. (2007). The impact of speed of processing training on cognitive and everyday functions. *The Journals of Gerontology, Series B*, *62B*(special issue 1), 19–31, doi:10.1093/geronb/62.special_issue_1.19.

Ball, K., Owsley, C., & Beard, B. (1990). Clinical visual perimetry underestimates peripheral field problems in older adults. *Clinical Vision Sciences*, *5*(2), 113–125.

Ball, K. K., Owsley, C., Sloane, M. E., Roenker, D. L., & Bruni, J. R. (1993). Visual attention problems as a predictor of vehicle crashes in older drivers. *Investigative Ophthalmology & Visual Science*, *34*(11), 3110–3123. [PubMed] [Article]

Bédard, M., Parkkari, M., Weaver, B., Riendeau, J., & Dahlquist, M. (2010). Assessment of driving performance using a simulator protocol: Validity and reproducibility. *American Journal of Occupational Therapy*, *64*(2), 336–340, doi:10.5014/ajot.64.2.336.

Belchior, P., Marsiske, M., Sisco, S. M., Yam, A., Bavelier, D., Ball, K., & Mann, W. C. (2013). Video game training to improve selective visual attention in older adults. *Computers in Human Behavior*, *29*(4), 1318–1324, doi:10.1016/j.chb.2013.01.034.

Borenstein, M., Hedges, L. V., Higgins, J. P. T., & Rothstein, H. R. (2009). *Introduction to meta-analysis* (1st ed.). Chichester, United Kingdom: John Wiley & Sons, doi:10.1016/B978-0-240-81203-8.00002-7.

Bowers, A. R., Anastasio, R. J., Sheldon, S. S., O'Connor, M. G., Hollis, A. M., Howe, P. D., & Horowitz, T. S. (2013). Can we improve clinical prediction of at-risk older drivers? *Accident Analysis and Prevention*, *59*, 537–547, doi:10.1016/j.aap.2013.06.037.

Broman, A. T., West, S. K., Muñoz, B., Bandeen-Roche, K., Rubin, G. S., & Turano, K. A. (2004). Divided visual attention as a predictor of bumping while walking: The Salisbury Eye Evaluation. *Investigative Ophthalmology & Visual Science*, *45*(9), 2955–2960. [PubMed] [Article]

Burge, W. K., Ross, L. A., Amthor, F. R., Mitchell, W. G., Zotov, A., & Visscher, K. M. (2013). Processing speed training increases the efficiency of attentional resource allocation in young adults. *Frontiers in Human Neuroscience*, *7*, 684, doi:10.3389/fnhum.2013.00684.

Classen, S., Witter, D. P., Lanford, D. N., Okun, M. S., Rodriguez, R. L., Romrell, J., . . . Fernandez, H. H. (2011). Usefulness of screening tools for predicting driving performance in people with Parkinson's disease. *American Journal of Occupational Therapy*, *65*, 579–588, doi:10.5014/ajot.2011.001073.

Crisler, M. C., Brooks, J. O., Drouin, N., Schold Davis E., Healy, S. L., Kopera, K. W., . . . Sifrit, K. (2013). The DrivingHealth® Inventory as a clinical screening tool: Assessment of face validity and acceptance. *Occupational Therapy in Health Care*, *27*(4), 355–371, doi:10.3109/07380577.2013.847297.

Dommes, A., Cavallo, V., & Oxley, J. (2013). Functional declines as predictors of risky street-crossing decisions in older pedestrians. *Accident Analysis and Prevention*, *59*, 135–143, doi:10.1016/j.aap.2013.05.017.

Edwards, J. D., Ross, L. A., Wadley, V. G., Clay, O. J., Crowe, M., Roenker, D. L., & Ball, K. K. (2006). The useful field of view test: Normative data for older adults. *Archives of Clinical Neuropsychology*, *21*(4), 275–286, doi:10.1016/j.acn.2006.03.001.

Edwards, J. D., Vance, D. E., Wadley, V. G., Cissell, G. M., Roenker, D. L., & Ball, K. K. (2005a). Reliability and validity of useful field of view test scores as administered by personal computer. *Journal of Clinical and Experimental Neuropsychology*, *27*(5), 529–543, doi:10.1080/13803390490515432.

Edwards, J. D., Wadley, V. G., Vance, D. E., Wood, K., Roenker, D. L., & Ball, K. K. (2005b). The impact of speed of processing training on cognitive and everyday performance. *Aging & Mental Health*, *9*(3), 262–271, doi:10.1080/13607860412331336788.

Fazeli, P. L., Ross, L. A., Vance, D. E., & Ball, K. K. (2013). The relationship between computer experience and computerized cognitive test performance among older adults. *The Journals of Gerontology, Series B: Psychological Sciences and Social Sciences*, *68*(3), 337–346, doi:10.1093/geronb/gbs071.

Fisk, G. D., Novack, T., Mennemeier, M., & Roenker, D. (2002). Useful field of view after traumatic brain injury. *Journal of Head Trauma Rehabilitation*, *17*(1), 16–25, doi:10.1097/00001199-200202000-00004.

Gray, B. E., Hahn, B., Robinson, B., Harvey, A., Leonard, C. J., Luck, S. J., & Gold, J. M. (2014). Relationships between divided attention and working memory impairment in people with schizophrenia. *Schizophrenia Bulletin*, *40*(6), 1462–1471, doi:10.1093/schbul/sbu015.

Henderson, S., Gagnon, S., Belanger, A., Tabone, R., & Collin, C. (2010). Near peripheral motion detection threshold correlates with self-reported failures of attention in younger and older drivers. *Accident Analysis and Prevention*, *42*(4), 1189–1194, doi:10.1016/j.aap.2010.01.009.

Henderson, S., Gagnon, S., Collin, C., Tabone, R., & Stinchcombe, A. (2013). Near peripheral motion contrast threshold predicts older drivers' simulator performance. *Accident Analysis and Prevention*, *50*, 103–109, doi:10.1016/j.aap.2012.03.035.

Hoffman, L., & McDowd, J. M. (2010). Simulator driving performance predicts accident reports five years later. *Psychology and Aging*, *25*(3), 741–745, doi:10.1037/a0019198.

Hoffman, L., McDowd, J. M., Atchley, P., & Dubinsky, R. (2005). The role of visual attention in predicting driving impairment in older adults. *Psychology and Aging*, *20*(4), 610–622, doi:10.1037/0882-7974.20.4.610.

Lunsman, M., Edwards, J. D., Andel, R., Small, B. J., Ball, K. K., & Roenker, D. L. (2008). What predicts changes in useful field of view test performance? *Psychology and Aging*, *23*(4), 917–927, doi:10.1037/a0013466.

Matas, N. A., Nettelbeck, T., & Burns, N. R. (2014). Cognitive and visual predictors of UFOV performance in older adults. *Accident Analysis and Prevention*, *70*, 74–83, doi:10.1016/j.aap.2014.03.011.

Mathias, J. L., & Lucas, L. K. (2009). Cognitive predictors of unsafe driving in older drivers: A meta-analysis. *International Psychogeriatrics*, *21*(4), 637–653, doi:10.1017/S1041610209009119.

O'Brien, J. L., Lister, J. J., Peronto, C. L., Edwards, J. D. (2015). Perceptual and cognitive neural correlates of the useful field of view test in older adults. *Brain Research*, *1624*, 167–174, doi:10.1016/j.brainres.2015.07.032.

Owsley, C., Sloane, M., McGwin, G., & Ball, K. K. (2002). Timed instrumental activities of daily living tasks: Relationship to cognitive function and everyday performance assessments in older adults. *Gerontology*, *48*(4), 254–265, doi:10.1159/000058360.

R Core Team. (2014). *R: A language and environment for statistical computing*. Vienna, Austria: R Foundation for Statistical Computing. Retrieved from http://www.r-project.org

Roenker, D. L., Cissell, G. M., Ball, K. K., Wadley, V. G., & Edwards, J. D. (2003). Speed-of-processing and driving simulator training result in improved driving performance. *Human Factors*, *45*(2), 218–233, doi:10.1518/hfes.45.2.218.27241.

Rosen, P. N., Boer, E. R., Gracitelli, C. P. B., Abe, R. Y., Diniz-Filho, A., Marvasti, A. H., & Medeiros, F. A. (2015). A portable platform for evaluation of visual performance in glaucoma patients. *PloS One*, *10*(10), e0139426, doi:10.1371/journal.pone.0139426.

Rubin, G. S., Ng, E. S. W., Bandeen-Roche, K., Keyl, P. M., Freeman, E. E., West, S. K., & SEE Project Team. (2007). A prospective, population-based study of the role of visual impairment in motor vehicle crashes among older drivers: The SEE study. *Investigative Ophthalmology & Visual Science*, *48*(4), 1483–1491. [PubMed] [Article]

Rutherford, M. D., Richards, E. D., Moldes, V., & Sekuler, A. B. (2007). Evidence of a divided-attention advantage in autism. *Cognitive Neuropsychology*, *24*(5), 505–515, doi:10.1080/02643290701508224.

Scalf, P. E., Colcombe, S. J., McCarley, J. S., Erickson, K. I., Alvarado, M., Kim, J. S., . . . Kramer, A. F. (2007). The neural correlates of an expanded functional field of view. *The Journals of Gerontology, Series B: Psychological Sciences and Social Sciences*, *62B*(special issue 1), 32–44.

Sekuler, A. B., Bennett, P. J., & Mamelak, M. (2000). Effects of aging on the useful field of view. *Experimental Aging Research*, *26*(2), 103–120, doi:10.1080/036107300243588.

Seong-Youl, C., Jae-Shin, L., & A-Young, S. (2014). Cognitive test to forecast unsafe driving in older drivers: Meta-analysis. *NeuroRehabilitation*, *35*(4), 771–778, doi:10.3233/NRE-141170.

Strauss, E., Sherman, E. M., & Spreen, O. (2006). *A compendium of neuropsychological tests: Administration, norms, and commentary* (3rd ed.). Oxford, UK: Oxford University Press.

Trick, L. M., Toxopeus, R., & Wilson, D. (2010). The effects of visibility conditions, traffic density, and navigational challenge on speed compensation and driving performance in older adults. *Accident Analysis and Prevention*, *42*(6), 1661–1671, doi:10.1016/j.aap.2010.04.005.

Vance, D. E., Dawson, J., Wadley, V., Edwards, J. D., Roenker, D., Rizzo, M., & Ball, K. K. (2007). The accelerate study: The longitudinal effect of speed of processing training on cognitive performance of older adults. *Rehabilitation Psychology*, *52*(1), 89–96, doi:10.1037/0090-5550.52.1.89.

Vance, D. E., Roenker, D. L., Cissell, G. M., Edwards, J. D., Wadley, V. G., & Ball, K. K. (2006). Predictors of driving exposure and avoidance in a field study of older drivers from the state of Maryland. *Accident Analysis and Prevention*, *38*(4), 823–831, doi:10.1016/j.aap.2006.02.008.

Viechtbauer, W. (2010). Conducting meta-analyses in R with the metafor package. *Journal of Statistical Software*, *36*(3), 1–48, doi:10.18637/jss.v036.i03.

Visual Awareness Research Group. (2009). *UFOV user's guide* (version 6.1.4). Punta Gorda, FL. Retrieved from http://www.visualawareness.com/Pages/UFOV_Manual_V6.1.4.pdf.

Whiting, P., Rutjes, A. W. S., Reitsma, J. B., Bossuyt, P. M. M., & Kleijnen, J. (2003). The development of QUADAS: A tool for the quality assessment of studies of diagnostic accuracy included in systematic reviews. *BMC Medical Research Methodology*, *3*(25), 1–13, doi:10.1186/1471-2288-3-25.

Wood, J. M., Chaparro, A., Lacherez, P., & Hickson, L. (2012). Useful field of view predicts driving in the presence of distracters. *Optometry and Vision Science*, *89*(4), 373–381, doi:10.1097/OPX.0b013e31824c17ee.