Validated tests for language research with university students:

Tests of vocabulary, general knowledge, author recognition,
reading comprehension, reading frequency, attention check

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Abstract

We present five studies aimed at developing a new vocabulary test for university students. Such a test is useful as an indication of crystallized intelligence and because vocabulary size correlates well with reading comprehension. In the first study, a list of 100 words based on Nation's Vocabulary Size Test was presented to 195 participants and compared to other tests of crystallized intelligence. Analysis suggested the presence of two distinct factors, which we interpreted as evidence for the possible existence of two types of difficult words: Unfamiliar words for general knowledge and unfamiliar words for specialized knowledge. In the subsequent studies we tried to develop vocabulary tests for each type of words, at the same time trying out various reading comprehension tests to use as validation criterion. However, in the final study a high correlation ($r = .82$) was found between our two vocabulary tests, indicating that they measure the same latent factor, contrary to our initial assumption. Both tests have high reliability ($r > .85$) and correlate well ($r > .4$) with general knowledge, author recognition, and reading comprehension. As part of our research efforts, a collection of new and existing tests was used and (often) improved to verify the validity of the vocabulary tests. An exploratory factor analysis on all tests established 3 factors (text comprehension, crystallized intelligence, and reading rate), with the vocabulary tests loading on the factor of crystallized intelligence, which in turn correlated with reading comprehension. Structural equation modeling corroborated the interpretation. We end by providing an overview of the different tests that were developed or improved throughout the studies. They are freely available for research purposes at <https://osf.io/ef3s4/>.

Language researchers are increasingly interested in individual differences (Kidd et al., 2018). Native speakers differ in language proficiency, even among university students, who form a homogeneous group with a restricted range of abilities. To understand the differences, Perfetti (2007; Perfetti & Hart, 2002) introduced the lexical quality hypothesis, starting from the observation that text comprehension is highly correlated with word knowledge and word recognition speed. According to the hypothesis, word recognition is a central aspect of language proficiency and consists of three components: Spelling, pronunciation, and meaning. The richness of each component, the speed with which the information can be activated, and the mutual redundancy define the lexical quality. Lexical quality can be thought of as the outcome of two main factors: The efficiency with which verbal information can be stored and retrieved from memory (Hamrick et al., 2018), and the amount of exposure to language (Brysbaert et al., 2018; Stanovich & West, 1989). The latter is important to understand differences between words (e.g., high-frequency vs. low-frequency words) and between groups of people varying in exposure (e.g., native speakers (L1) vs. second language (L2) users; Diependaele et al., 2013).

Andrews et al. (2020) tested two measures of lexical quality: a vocabulary test (Nelson-Denny, form H; Brown et al., 1993) and a newly developed spelling test (participants heard words and had to write them down). Text comprehension (measured with the Nelson-Denny test) correlated $r \approx .6$ with vocabulary size and $r \approx .4$ with spelling dictation.

Vocabulary tests are also a core element of IQ-tests. The first IQ-test, published by Binet and Simon (1907), already included questions about words (Gibbons & Warne, 2019), and when Terman adapted the test to English, he was quick to notice the usefulness of a vocabulary test. Terman et al. (1918) reported that a vocabulary test consisting of 100 words randomly selected from a dictionary of 18,000 words correlated $r \approx .9$ with performance on the Stanford-Binet IQ-test in school children from grade 1 to the first year of high school (participants had to explain the meaning of the words). The test also correlated $r \approx .8$ with the IQ-scores of adults from the general population. Terman et al. (1918) further reported that different tests with 180 words randomly selected from the dictionary correlated $r \approx .8$ with each other in a group of college students. Equivalent tests of 60 words correlated $r > .9$ in school children. The lower correlation in college students than in primary school children was due to the fact that there is more variability in school children than in college students, a phenomenon known as the range restriction issue (Pearson, 1903; Sackett & Yang, 2000).

Another IQ-researcher convinced of the importance of a vocabulary test was Raven. This author is best known for the Progressive Matrices test, meant to measure non-verbal reasoning fluency (Raven, 1940), but he also developed a vocabulary test, the Mill Hill Vocabulary Scale (Raven, 1943), intended as the counterpart of the matrices. The test was developed to measure information stored in memory (so-called crystallized intelligence). It consisted of two sets of 44 words of increasing difficulty, with six response alternatives to pick from.

Given the importance of a good vocabulary test, it is surprisingly difficult to find a test for research with university undergraduates (the convenience population in many language studies). There are several commercial tests (sometimes part of a wider IQ test battery), but to our knowledge only two tests for native speakers are freely available to researchers (there are more for L2 speakers, but these are too easy).

The first is the Shipley test (Shipley, 1940). It includes 40 words with four response alternatives. Although it is an old test, it is still used regularly. Brysbaert et al. (2019) administered it to first-year university students from the UK and observed that performance was less than ideal. Reliability was rather low ($r \approx .7$) and several items were no longer useful. Although it was tempting to update the Shipley test, there may be a copyright problem, because a revised edition was developed as part of a commercial test (Shipley et al., 2009).

The second test is the Vocabulary Size Test, compiled by Nation (2020; available at <https://www.wgtn.ac.nz/lals/resources/paul-nations-resources/vocabulary-tests>). It was a test originally created for L2 speakers, but gradually expanded to L1 speakers (Nation & Webb, 2011). It divides the English words in 20 frequency bands of 1000 words each (called levels) and has five words per level. There are two test versions (Version A and B), each including 100 items with four response alternatives. Unfortunately, the test has not yet been validated for L1 users (see Beglar, 2010, for a validation study of the first 14 levels with Japanese-English bilinguals).

We decided to start from Nation's Vocabulary Size Test to develop a free, validated vocabulary test, which we hoped would be useful for both English L1 and L2 speakers.¹ However, as we will see, the story turned out to be more complicated, so that for the time being the test is limited to native speakers. Along the way we also developed (improved versions of) reading comprehension tests, a general knowledge test, an author recognition test, and a reading frequency questionnaire, which we make available as well.

Study 1: Testing the first version of a vocabulary test

We made a selection of 100 items from Version A and Version B of Nation's Vocabulary Size Test, because we wanted to have a test that was difficult enough for high-performing adult English L1 speakers and L2 speakers (mostly university students). So, we included more difficult items than easy ones. The wording of the items was checked and changed if we felt it was necessary.² All materials (also the data and analysis programs) are available at <https://osf.io/ef3s4/>.

To establish the quality of the vocabulary test, we added five more tests. First, we wanted to compare the new test to an established vocabulary test (convergent validity). Building on the work of Andrews et al. (2020), we administered the Nelson-Denny vocabulary test Form H (Brown et al., 1993). Second, in IQ-tests the vocabulary test usually correlates highly with general information questions, forming a factor of verbal comprehension (e.g., Holdnack et al., 2011). A problem with many existing general information tests, however, is that they easily include vocabulary items in disguise (e.g., "How do you call a horse-like animal with black and white stripes?") Another problem is that several existing tests require participants to say or write the answer (making administration and scoring more cumbersome). Therefore, we decided to develop a tailor-made test, consisting of general knowledge questions without a heavy vocabulary burden (e.g., "What causes the difference in seasons? Why is a high blood pressure bad?"). Each item had four response alternatives.

¹ We thank Paul Nation for his kind permission to use the test in any way we wished (personal communication 5/13/2020).

² We thank Sam McCormick for her help.

To measure language exposure, we included an author recognition test (Acheson et al., 2008; Brysbaert et al., 2020; Moore & Gordon, 2015; Stanovich & West, 1989), which we improved slightly (see below). We also developed a reading frequency questionnaire to assess participants' subjective estimates of how much they read.

Finally, vocabulary size is correlated with the Big Five personality trait Openness to experience ($r \approx .2$), as shown in Figure 1. This figure presents a meta-analysis of the 15 studies we could find relating vocabulary size to Big Five personality traits (Dollinger et al., 2008; Downey et al., 2011; Friborg et al., 2005; Furnham, 2005; Gnambs, 2017; Gorgol et al., 2020; McCrae & Costa, 1985; McIntyre, 2010; Nathanson et al., 2006; Ono et al., 2011; Peterson et al., 2002; Simon et al., 2021; Uttl et al., 2013). We included a 60-item Big Five questionnaire (Soto & John, 2017) to verify whether the correlation would also be present in the sample we tested. An extra advantage is that vocabulary size does not correlate (highly) with the other Big Five personality traits, so that we could use these for discriminant validation.

Figure 1: Meta-analysis of the correlations between Big Five personality traits and vocabulary size, showing that only Openness to experience correlates $r \approx .2$ with vocabulary size. Meta-analysis based on the MAJOR module in jamovi (Hamilton, 2017).

Method

Power considerations

We wanted our studies to be capable of detecting correlations as small as $r = .2$. Figure 2 shows the results one can expect if such a Pearson correlation between two normally distributed variables is investigated with sample sizes going from $N = 40$ to $N = 400$ (see also Schönbrodt & Perugini, 2013). Each dot represents the outcome of a single “study” (for a total of 2000 studies). Correlations significantly different from 0 are indicated by +; correlations not significant by •.

Figure 2: Correlations expected in studies of various sample sizes ($N = 40$ to $N = 400$), when a population correlation of $r = .2$ is assumed. Each dot represents one study (for a total of 2000). Significant correlations are indicated by +; non-significant by •.

Figure 2 illustrates why study samples of $N = 40$ are not a good idea. Only one quarter of the studies are expected to result in a significant correlation, observed correlations of $r = .2$ are not significant, and quite a few studies would suggest a correlation **opposite** to the one present at the population level. A formal power analysis indicates that the chances of observing a significant correlation are only .23 and the probability of observing a (non-significant) correlation opposite to the one known to be true is .11.

Sample sizes of $N = 200$ are much better. Here we have a chance of .81 to observe a significant correlation, and a chance of 99.8% of a correlation in the right direction. The outcome is even better for sample sizes of $N = 400$, but the expected gains are small relative to the extra investments required. So, we decided to aim for sample sizes of $N \approx 200$.

Participants

As testing was done online, we made use of the services of Prolific (<https://www.prolific.co/>), a company providing access to paid participants. Participants had to be native English speakers older than 18 years. Because the first batch of 50 participants included many participants older than 25, we limited the age

range to 18-25 years in subsequent batches, as we wanted the test to be useful for college students (older adults are known to know more words than young adults; Brysbaert et al., 2016). The study lasted some 50 minutes for which participants were paid £5.50. Before analysis of the data, participants were screened for lack of commitment (progressing too fast, repetition of the same response). None of the 195 participants who completed the full test battery had to be dropped (103 female, 90 male, 2 other).

Materials

Nation vocabulary test. The first test was based on Nation's Vocabulary Size Test with 20,000 word families (Nation, 2020). Target words were selected from both Version A and B, with extra weight given to the more difficult items. A target word was followed by a short, neutral sentence in which the word was used, and four answer alternatives (Figure 3). There were 100 trials presented in random order (different for each participant). Participants had to check the right alternative (they could not skip trials). Alternatives were also randomized anew for each participant. There was no time limit, but participants were informed about the number of tests and told they would be paid a fixed amount. Our goal was to collect enough useful items, so that we could create a Student Vocabulary (StuVoc) test.

Figure 3: Item of the Nation vocabulary test

awe

They looked at the mountain in <awe>.

1. with a feeling of respect
2. with a worried expression
3. without interest
4. in fear

Nelson-Denny vocabulary test (ND). To validate the new test, performance was compared to the Nelson-Denny test, Form H (Brown et al., 1993). The test has the same format as Nation's Vocabulary Size Test, except for the fact that there are five response alternatives. The test includes 80 trials, which were presented in the same way as described for Nation's test. Expected performance according to the published norms was 49/80 (61%) in first-year university students and 63/80 (79%) in fourth-year university students. Andrews et al. (2020) reported a mean score of 64 (SD = 10) for the participants they tested. For copyright reasons, the test items cannot be made available.

Author recognition test (ART3). Stanovich and West (1989) proposed to use an Author Recognition Test (ART) as an objective to measure students' reading proficiency. The test consisted of fiction author names mixed with non-author names. Participants had to indicate which authors they knew and were warned that the test contained non-author names and that participants would be penalized if they selected these names. So, they were told only to select the names of authors they knew. Acheson et al.'s (2008) updated the Stanovich & West ARC test author recognition test, as some of the original authors were no longer well-known. We used Acheson et al.'s update as the basis of our test, which contained 60

fiction author names mixed with 30 names of unknown people. Participants had to indicate which authors they knew. They were told that the list included foils (people who never published a book). Because the scores on Acheson's et al.'s ART tend to be low, we replaced the author names known by less than 12% of the participants in the study of Moore and Gordon (2015) by writers who are more popular nowadays, in particular among young people (see Brysbaert et al., 2020, for more details on the importance of including youth writers). For instance, Robert Ludlum was replaced by Rick Riordan. Because our ART is the third version of the Stanovich & West test, we call it ART3. There are two ways of calculating the scores of the ART test. The first is to simply calculate the number of questions answered correctly; the second is to subtract the number of yes-responses to non-author names from the number of yes-responses to author names. Because the measures are linearly related to each other, we use the simpler score: total number of questions answered correctly.³

General knowledge test (GK). A test with 80 quiz questions was composed, covering a large number of topics. Some of the items were inspired by Buades-Sitjar et al. (2021). Care was taken to avoid questions that required the retrieval of a single, unfamiliar word as answer. Four response alternatives were provided, from which the participants had to select one. Items were presented randomly and could not be skipped. Response alternatives were randomized as well. Figure 4 shows an example of an item.

Figure 4: Item of the General Knowledge Test

What does the name "IKEA", referring to the largest furniture retailer in the world, mean?

1. First letters of the founder and where he grew up
2. Name of the founder's firstborn child
3. Swedish word for "destiny"
4. Norse goddess of fortune

Questionnaire about reading frequency (RFQ). We further included a subjective questionnaire about reading frequency (with 33 questions). Six reading situations were questioned: fiction, non-fiction, newspapers/magazines, websites, social media, and work/studies. Each type included the following five questions (applied to fiction): "How often do you read fiction books (novels, thrillers, phantasy, ...)?" (5 answer alternatives given), "When did you finish your last fiction book? (5 alternatives)", "Are you reading a fiction book now?" (yes/no), "Which alternative describes you best?" (5 alternatives), "How many fiction books have you read in the past month?" (5 alternatives). In addition, there were questions about how often participants played scrabble, crosswords, cryptograms or word games, and how often participants looked up the meaning of words.

Big Five questionnaire. We used BFI-2 (Soto & John, 2017), which includes 12 questions per personality trait (60 in total). Participants had to indicate how well each item applied to them. An example is: "I am someone who is outgoing, sociable." (1 = disagree strongly, 5 = agree strongly).

³ Applied to Study 1, we found that participants answered correctly to 57/90 questions. By subtracting 30 from this score, we get the response-bias-corrected number of authors recognized. On average 27/60 of the authors were recognized by the participants. Participants said yes to 35.8/60 authors (60%) but also to 8.8/30 non-authors (27%).

Procedure

Participants were recruited via Prolific. Testing happened online (using Limesurvey; <https://www.limesurvey.org/>) without presence of an experimenter. First, participants were asked to indicate their age and gender (we forgot to ask about their education level and the country they lived in). Then they completed the six tests/questionnaires in the order described above. Each test could be completed in less than 10 minutes, but we did not impose a deadline. Participants were informed about the payment, the number of tests and the estimated time requirements before they consented to take part.

Results and discussion

Standard analysis. In the first part, we describe the standard analysis for this type of studies. We report means and standard deviations, information about reliability, and the correlations between the tests. In the second part, we look more in detail at the quality of the tests. The reading frequency questionnaire was not included in the standard analysis (see below for more information).

In the standard analysis, sum scores were used and reliability was calculated on the basis of the split-half correlation (odd items vs. even items), corrected for length with the Spearman-Brown formula. These measures are the easiest to calculate. The findings are summarized in Table 1 and show good reliability for all tests ($r > .77$). They also show that the participants we tested, were of a high level (with an average score of 65 on ND). Vocabulary scores correlated positively with age, author recognition, and general information. The Nation vocabulary test correlated slightly more with age and author recognition. Nelson-Denny correlated slightly more with general information. The only worrying aspect was the correlation between the Nation test and the Nelson-Denny test ($r = .7$), which was lower than expected on the basis of the reliability of the tests.

Variable	M	SD	Reliability	Age	Nation	ND	ART3
Age	24.9	10.0	NA				
Nation vocabulary test (max = 100)	81.6	9.2	0.88	0.30			
Nelson-Denny (max = 80)	65.4	10.5	0.91	0.29	0.72		
Author Recognition Test (max = 90)	57.0	9.4	0.77	0.14	0.48	0.41	
General Knowledge (max = 80)	48.5	9.2	0.83	0.18	0.55	0.64	0.51

Table 1: Information about the tests and their intercorrelations in Study 1. Correlations of .19 or more are significant at $p < .01$, two-tailed and are indicated in bold.

Table 2 shows the correlations with the personality traits. We see the expected positive correlations between openness and scores on the vocabulary tests (Figure 1) and the two other knowledge tests. Older participants gave themselves higher scores on conscientiousness and lower scores on negative emotionality, in line with what has been reported in other studies (e.g., Srivastava et al., 2003).

Variable	M	SD	Reliability	Age	Nation	ND	ART3	GK
BF Open-Mindedness (max = 5)	3.8	0.7	0.88	0.06	0.25	0.37	0.22	0.27
BF Conscientiousness (max = 5)	3.5	0.7	0.89	0.21	0.06	0.09	-0.05	-0.01
BF Extraversion (max = 5)	3.0	0.8	0.92	0.04	-0.01	0.02	0.06	0.06
BF Agreeableness (max = 5)	3.7	0.6	0.83	0.16	0.14	0.20	0.04	0.04
BF Negative Emotionality (max = 5)	3.1	0.9	0.94	-0.24	0.02	0.02	0.12	0.05

Table 2: Correlations between personality traits and scores on the tests. Correlations of .19 or more are significant at $p < .01$, two-tailed and are indicated in bold.

Looking under the hood. The standard analysis is the typical analysis in psycholinguistics. However, there is a whole arsenal of ways to further check the quality of the compiled tests and see whether they can be improved. A worrying finding was the rather low correlation between scores on the Nation vocabulary test and the Nelson-Denny vocabulary test. Given that both tests had a reliability of .9, one would expect a correlation of .9 between both tests as well, if they measured the same construct (vocabulary knowledge).

A simple way to examine whether a test measures a single skill is to run a factor analysis. If the vocabulary tests measure what we think they assess, there should be a single factor accounting for most of the variance. This does not mean that all systematic variance should be captured by a single factor (unless we are presenting very similar words), but that there must not be evidence for multiple, independent factors. Research with general knowledge tests gives a good illustration. In most intelligence tests, this is captured by a single subtest with some 20 questions. However, if you expand the number of questions, the factor begins to fractionate. Steger et al. (2019) developed a test with over 3400 items covering 34 knowledge domains, such as architecture, arts, economics, health, history, housekeeping, law mathematics, and technology. Factor analysis suggested that most variance was captured by five factors that were correlated: humanities, social studies, life sciences, behavioral sciences, and natural sciences. This finding agrees with our intuition that people have diverse interests and know more about some topics than other (hence the different factors) but at the same time differ from each other in the amount of knowledge they have (hence the correlations between the factors, forming a hierarchy with the second-order factor crystallized intelligence).

We started with an exploratory factor analysis of the Nelson-Denny test, given that this is an established test. Sakaluk and Short (2017) give a nice summary of how to run exploratory factor analysis, based on the psych R package (Revelle, 2021; Revelle & Condon, 2019). The advice includes three important aspects: (1) use factor analysis instead of principal component analysis (as we are measuring latent variables/skills), (2) allow correlations between the factors (by using oblimin rotation), and (3) compare the outcome of the test to a parallel evaluation of simulated data. To these three, one more recommendation can be added: If the dependent variable is dichotomous (correct/wrong), it is better to run the factor analysis on the basis of tetrachoric correlations between items (Revelle, 2021). Figure 5 shows the outcome of the analysis for ND.

Parallel Analysis Scree Plots

Figure 5: Exploratory factor analysis of the Nelson-Denny vocabulary test in Study 1 (analysis done with `fa.parallel()` of the R package `psych`) based on tetrachoric correlations.

Although the exploratory factor analysis suggested we could extract several factors (in line with the observation that words address several topics which are not equally familiar to people), it is clear that most of the variance was accounted for by one factor, which we can assume to be general vocabulary knowledge.

We ran the same exploratory factor analysis on the items we selected from the Nation tests. A first step we had to take here was that a considerable number of items were at ceiling level. This was to be expected, given that we selected items in such a way that the test could be useful for English L2 speakers as well. Therefore, we dropped the 29 words with an accuracy of more than 97.5%. Figure 6 shows the outcome of the exploratory factor analysis on the remaining 71 words.

Figure 6: Exploratory factor analysis of the selected Nation vocabulary test in Study 1 (analysis done with `fa.parallel()` based on tetrachoric correlations).

Again, the factor analysis suggested that several factors could be extracted. However, the most obvious deviation from the ND test was the suggestion of two distinct language factors, rather than one in ND. Investigation of the items loading high on the first and the second factor suggested age of acquisition as a differentiating feature: The items loading on factor 1 were acquired considerably earlier than the items loading on factor 2. This was further confirmed in a factor analysis of the combined Nelson-Denny items and Nation items. The words with the highest loadings on factor 1 were: “nozzle, similarity, resource, alter, presumed, fascinated, mesh”. These seem to be less familiar words referring to familiar experiences for which more common words exist (e.g., change instead of alter). In contrast, the items with the highest loadings on factor 2 seemed to be rare words referring to specialized knowledge not shared by everyone, such as: “vitreous, refectory, roughshod, ablution, unequivocal, unscrupulous, edifice”. The latter items figure more dominantly in L2 research because they are rather well-known to university L2 speakers, who are often asked as participants in L2 research (Brysbaert et al., 2021).

We further used exploratory factor analysis to see what was involved in the general knowledge test (the author recognition test will be discussed in the general discussion). As can be seen in Figure 7, the analysis confirmed that the test mainly measured a single factor, although there was also evidence for a fractioning along general knowledge domains. If we look at the three factors with the highest eigen values, we see that items with high loadings on the first factor were: “What food is used as the basis of guacamole?”, “Which is a major concern about the overuse of antibiotics?”, “What do vegans not eat?”,

and “Wine is typically made from which fruit?” These are items falling in the Life Sciences theme postulated by Steger et al. (2019), which includes information about housekeeping and health. The highest loading items on factor 2 were: “How many bits does a byte have?”, “Where are the red blood cells produced?”, “In the game of chess, which piece has the most freedom to move?”, and “How is 77 represented in Roman numerals?” These are items referring more to technical information, resorting under the theme Natural Sciences of Steger et al., including domains like physics, technology, and biology. The highest loading items on factor 3 were: “In the Opening Ceremony of the 2012 Summer Olympic Games, how did Queen Elizabeth II supposedly arrive?”, “According to the Rolling Stones' song, Mick Jagger can't get no ... what?”, “How do astronauts get fresh water during long missions in space?”, and “When was the Oscars award ceremony instituted?”. These seem to relate more to popular culture and possibly pub quizzes.

Figure 7: Exploratory factor analysis of the General Knowledge Test in Study 1 (analysis done with `fa.parallel()` based on tetrachoric correlations).

Finally, we used principal component analysis to analyze the reading frequency questionnaire, as we did not think the underlying structures referred to psychological constructs.⁴ This analysis suggested six components (Figure 8), agreeing with the different activities we outlined: fiction, non-fiction, newspapers/magazines, social media, websites, playing word games. Only the questions about work/studies did not form a stable distinct factor.

⁴ The BFI-2 largely yielded the expected 5-factor solution, although there were some cross-loadings of items and not all items contributed equally to the factors.

Scree Plot

Figure 8: Exploratory factor analysis of the reading frequency questionnaire of Study 1 (analysis done with jamovi; the jamovi project, 2021).

Table 3 shows the correlations between the participants' scores on the principal components of the reading frequency questionnaire and the tests we ran. They show that for the participant pool we used, in particular reading fiction, social media and websites were positively correlated with performance on the tests.

Variable	M	sd	Nation	ND	ART3	GK
Reading_fiction	9.16	3.92	0.29	0.23	0.24	0.04
Reading_nonfiction	8.41	3.92	0.03	0.06	0.08	-0.02
Reading_newspapers/magazines	8.57	4.90	0.13	0.17	0.29	0.10
Reading_socialmedia	17.21	2.30	0.19	0.19	0.12	0.21
Reading_websites	17.04	2.28	0.21	0.38	0.18	0.32
Reading_wordgames	6.44	2.58	-0.07	-0.07	0.15	0.01

Table 3: Correlations between the reading frequency estimates based on principal component analysis and performance on the tests. Correlations of .19 and more are significant at the $p < .01$ level and are printed in bold.

Conclusion

Although the vocabulary test we compiled on the basis of Nation's Vocabulary Size Test had a good reliability (split-half = .88) and correlated well with the author recognition test (.48) and the general knowledge test (.55), we felt that the test was not yet good enough. Two worrying observations were (1) the finding that the test seemed to measure two factors, and (2) the lower than expected correlation with the Nelson-Denny test, which seemed to be a better measure of vocabulary size. We hypothesized that the two distinct factors in the Nation test were: unfamiliar words for familiar experiences with easier names, and unfamiliar words for specialized knowledge. The Nelson-Denny test seemed to measure in particular words of the first type. We decided to try to find more evidence for a distinction between both types of words that can be part of a vocabulary test.

Study 2: Testing more items

Study 1 suggested that there are two types of words in vocabulary tests: unfamiliar words for generally shared experiences and words for specialized knowledge. The Nelson-Denny test included 36 items with factor loadings higher than .3 in the former category and 21 in the latter category. The Nation test included 21 items in each category. To have a better view of the two categories, we collected additional items. In particular, we needed more words in the first category. They are words acquired relatively early but not by everyone. We looked for them by combining information from age-of-acquisition ratings (Kuperman et al., 2012) with information about word prevalence (Brysbaert et al., 2019). We also decided to present the remaining items of Nation's Vocabulary Size Test (Version A + B), except for the ones from the highest frequency bands.

Method

Participants

Prolific was again used for online testing. Participants were prescreened to have English as their native language and to fall in the age range of 18- 21 years. We decided to limit the age more than in Study 1, given the correlation with age there and the fact that we wanted to develop a test specifically for undergraduate students. Time spent on the study varied between participants with a mean of about 50 minutes, resulting in a payment of £5.50. Participants' submissions were discarded when the data suggested a lack of commitment. To do this, the following criteria were used: An extremely short time spent on the vocabulary test (< 5 minutes) and short reading times for the texts in the comprehension test. For the latter we relied on mean number of words per minute. To do this, words per minute were calculated for each text. A reading rate of more than 668 words per minute was used as the upper limit, based on Kuperman et al.'s (2021) assertion that this is 2.5 times the average predicted reading rate on the basis of Brysbaert's (2019a) meta-analysis. This value was also more than two standard deviations above the average reading rate in the present study. We tested until we had 200 participants with approved performance, of whom one was dropped after seeing that their scores were around chance level. All decisions about participant exclusion were made before the analyses reported below started, in order not to influence the outcome of the analysis.

Of the remaining 199 participants 96 were female, 101 male and 2 identified as otherwise. 170 of the participants were students, 15 indicated to be employed and the remaining were unemployed. When

asked for their highest education level, 162 participants responded with high school and 37 indicated to have an undergraduate degree. When asked from where they were, participants indicated a variety of countries. Most people lived in the UK (108) or the US (28). Other countries included Australia, Canada, South Africa, New Zealand, Poland, Mexico, Germany, India, Portugal, Nigeria, Syria and Mauritius.

Materials

Vocabulary test. We started with the words from the previous Nation test that had factor loading higher than .25. This was the case for 25 words loading on Factor 1 and 33 words loading on Factor 2. We changed an answer alternative for the target word “gimmick”, as this word turned out to have two answers that could be plausible. To these words, we added 58 more items from Nation’s Vocabulary Size Test (Version A + B) that had not been retained in Study 1. We further created 74 new items. Fifty of them were meant to measure general vocabulary. They were selected from the words acquired before the age of 14 (Kuperman et al., 2012) and known to 60-99% of the participants in Brysbaert et al. (2019). These included words like “maze, flimsy, elope, sable, dowel, moat, gusset, dogwatch” (see <https://osf.io/ef3s4/> for the complete list). The other 20 items were academic words selected from Gardner and Davies (2014) and not acquired before the age of 14. Examples are: “paradigm, ostensibly, subsequent, allocate, inverse”. Finally, we added the 20 highest loading words on factor 1 from the Nelson-Denny and the 10 highest loading words on factor 2, to increase our chances of measuring the factors well. A random response lure was dropped from the Nelson-Denny items, so that these items had four response alternatives as well. All in all, 240 items were selected/created, which were presented to the participants as one vocabulary test.

Text comprehension test. We also decided to include a text comprehension test, given the high correlations usually found between vocabulary size and text comprehension (Andrews et al., 2020; Perfetti & Hart, 2002). For this, we started from materials first tried out by Siegelman et al. (2022). They consisted of 12 short Wikipedia-type expository texts (about 150 words) followed by two multiple choice comprehension questions (4 response alternatives). The texts informed readers about topics like the life of Morse, the Amazon Rainforest, the Internet, the need for sleep, and the use of leeches in medicine. Care was taken to make sure that the questions did not address small details of the text (which would influence the participants’ spontaneous reading style) and could not be answered on the basis of general knowledge without reading the text (Coleman et al., 2010). As not all questions turned out to load highly on a single text comprehension factor in an analysis of the test reported in Siegelman et al. (2022), reformulations were made when possible. Otherwise, new questions were designed. We decided not to use the Nelson-Denny comprehension test, because (1) we wanted our materials to be freely available for research, and (2) we believed this selection might bias the findings towards the ND vocabulary test, as both were developed in tandem.

Procedure

Participants were recruited via Prolific. Testing happened online (using Limesurvey; <https://www.limesurvey.org/>) without presence of an experimenter. After being informed about the content of the tests, the goal of the study and the importance of taking the study seriously, participants were asked to indicate their age, gender, education level and the country they live in. They were first

given the vocabulary test. Before being presented with the reading comprehension test, participants were again reminded to take the study seriously and to read all texts attentively. Participants were informed about the payment, the number of tests and the estimated time requirements before they consented to take part. After completing the study participants were redirected to Prolific.

Results and discussion

Vocabulary test

Descriptive statistics. Before starting factor analysis, descriptive statistics were gathered. The mean score on the Vocabulary list with 240 words was 179.1 (SD = 25.26, min: 105, max: 231). Reliability was assessed with the intraclass correlation ⁵ (Fletcher, 2015) and equaled .93. One item from the vocabulary list (the word *vocabulary*) was answered correctly by all participants and dropped in further analyses.

Factor analysis. We again performed an exploratory factor analysis based on tetrachoric correlations, using the psych R package (Revelle, 2021). Results from the Kaiser- Meyer-Olkin (overall MSA = .88) test and Bartlett's Test of Sphericity ($p < 0.1$) indicated that the sample was adequate for Factor Analysis. Figure 9 shows the outcome. The analysis was in line with the expected two factors.

Figure 9: Exploratory factor analysis of the vocabulary test of Study 2. Analysis done with `fa.parallel()` based on tetrachoric correlations and minres as factor extraction method.

Item analysis. To select the best items, we relied on Multidimensional item response theory (MIRT) analysis and in particular the R package mirt (Chalmers, 2012). This analysis was developed for items

⁵ All ICC values given are ICC2k for a random sample of participants.

with dichotomous values (correct/wrong) loading on multiple factors. The mirt analysis first confirmed that a solution with 2 factors (AIC: 38041) was much better than a solution with 1 factor (AIC: 38654). An unexpected correlation of -0.38 was found between both factors.

We used the outcome of the 2-factor mirt analysis to select the best items for each factor. In this selection we did not include items from the ND, as we wanted to compare our test with the ND in Study 3. For each factor, we selected the items with a factor loading higher than .3 and a much lower loading on the other factor. Items with high or low loadings on both factors were left out.

The selection resulted in two sets of 50 items with reliabilities of .87 and .89 for the general words and the specialized words respectively. A comparison of a Rasch model and a two-parameter IRT model indicated that the simple Rasch model provided a better fit. This means that all items had the same discrimination power (transition from not being known to being known) and only differed in location (difficulty of the item). Mean scores on the tests were 44.2/50 (88 %) for the general words and 32.7/50 (65%) for the specialized words.

Comprehension test

Descriptive statistics. The mean score on the comprehension test was 18.9 (SD: 3.12, min: 5, max: 24/24). A less interesting aspect was the rather low reliability score (ICC = .63) despite the adjustments to the questions we made. Average reading time was 242 words per minute (SD = 85), in line with reading rates found in other studies (Brysbaert, 2019a). Reliability of reading rate was ICC = .87.

Item analysis. A parallel factor analysis based on tetrachoric correlations suggested that most of the variance was captured by the first factor (Figure 10). This was confirmed by a mirt analysis, which indicated that a 1 factor model was better than a 2 factor model (AIC = 4247 vs. AIC = 4262 respectively). Further analysis showed a better fit for a two-parameter model than a simple Rasch model, indicating that items not only differed in difficulty, but also in their discrimination power. When taking a closer look at the one factor model, we found that several questions had low factor loadings (<.3), in line with the low reliability. This was partly because many questions were too easy.

Parallel Analysis Scree Plots

Figure 10: Exploratory factor analysis of the comprehension test of Study 2 (analysis done with `fa.parallel()` based on tetrachoric correlations).

Correlations between vocabulary size, text comprehension and reading time

Table 4 shows the correlations between the two vocabulary tests we derived, the text comprehension test, and reading time.

	comp	general voc	specialized voc
general vocabulary	0.52		
specialized vocabulary	0.39	0.44	
reading time	-0.21	0.04	-0.07

Table 4: Correlations between performance on the various tests used in Study 2. Correlations of .19 and larger are significant at the $p < .01$ level and indicated in bold ($N = 199$).

Performance on the comprehension test correlated positively with vocabulary size, as expected, despite the meager reliability of the comprehension test. There was no correlation between reading rate and performance on the vocabulary tests, while there was a weak negative correlation between reading rate and performance on the comprehension test ($r = -.21$, $df = 197$, $p < .01$), indicating that in Study 2 participants with faster reading rate performed less well on the comprehension test (as we will see below, the correlation between reading comprehension and reading rate differed in the studies we ran).

Figure 11 shows the correlation between performance on the comprehension test and vocabulary size based on the sum of the two vocabulary tests.

Figure 11: Relation between sumscore of the two vocabulary tests and the comprehension test (analysis done with ggscatter() from the package ggpubr (Kassambara (2020.)) using Pearson correlation)

Conclusion

Study 2 confirmed the existence of two different factors in the vocabulary tests we were establishing. To get a better idea of these factors, we created two tests with 50 items each. Each test loaded maximally on one factor and minimally on the other.

In order to see how well the two types of vocabulary predict reading comprehension, we also tried out a reading comprehension test based on Siegelman et al. (2021). Despite some adjustments made to the test, it still had rather modest reliability ($ICC = .63$), which we tried to improve upon in the next study.

Study 3: Testing the general and specialized vocabulary test

To get a better idea of the two vocabulary tests developed in Study 2, we presented them together with other tests to a new group of participants. These tests were based on what we developed in Study 1 and Study 2, sometimes with further improvements. In addition, we included the Test for Advanced Learners of English (LexTALE) (Lemhöfer & Broersma, 2012), which is currently often used in psycholinguistic research, in particular with participants who speak English as second language. The test is thought to have ceiling problem for participants with English as mother tongue. Therefore, it was interesting to see whether the new vocabulary tests we developed would better predict reading comprehension than LexTALE. Further goals were to present the adapted comprehension test and to gain insight into how our two new vocabulary tests related to an existing English test. We expected to repeat the findings of Study 1 and were particularly interested in the comparison of the test for general words and the test for specialized words.

Method

Participant

Prolific was used for online testing. Participants were prescreened to have English as their native language and to fall in the age range of 18- 21 years. Time spent on the study varied between participants, with a mean of 90 minutes, resulting in a payment of £7.50. Because the study consisted of 9 tests, we paid an extra £5 to participants who completed the study in such a way that we could use their data (i.e., that we were happy with their commitment as assessed on the basis of the time spent on each test and scores above random responding). Participants were informed about the extra payment before they signed the informed consent. In all 200 participants completed the experiment, of whom 4 were excluded for having scores around chance level for multiple tests. Of the remaining participants 86 were female, 105 male and 5 identified as otherwise. 143 participants were students, 28 indicated to be employed and 25 were unemployed. 155 participants indicated to have a high school diploma and 41 indicated to have an undergraduate degree. When asked about where they were, participants indicated a variety of countries. However, most participants lived in the UK and the US. Other countries mentioned were Australia, Bangladesh, Canada, Hungary, Ghana, India, Malaysia and South-Africa.

Materials

Study 3 was based on Study 1. The Nation vocabulary test from Study 1 was replaced by the two new vocabulary tests developed in Study 2. The Nelson-Denny vocabulary test, the author recognition test, and the personality test remained the same.

An item analysis of the General knowledge test with a 1 factor mirt model indicated that 15 items had suboptimal discrimination profiles (i.e., were not responded much better by participants with high mean scores than by participants with low mean scores). These items were deleted, leaving us with a shorter test of 65 questions.

The comprehension test was also further optimized by replacing items with a bad discrimination profile and by adding a new question to each text, so that there were 36 questions in total (rather than the original 24), in the hope that this would bring reliability closer to .8.

The reading frequency questionnaire was pruned by selecting the 4 items with the highest loading on each of the six components in the principal component analysis discussed in Study 1.

Finally, the LexTALE (Lemhöfer & Broersma, 2012) was added. This is a vocabulary test in which participants are presented with 40 words and 20 nonwords and have to indicate whether they know the English word or not. They are warned about the presence of non-word foils (i.e., the same format as in the author recognition test). The test is quick to complete (less than 5 mins), which is a big advantage of the format.

Procedure

Participants were recruited via Prolific. Testing happened online without presence of an experimenter. Before starting the study, participants were informed that the study consisted of 9 tests, what these tests were and how much they would be paid when completing the study. They were also informed about a possible bonus if they completed the study with dedication (i.e. no data that indicated lack of commitment). After being informed of their rights and giving their consent, participants were asked to indicate their age, gender, education level and the country they lived in. We decided to put the LexTALE first as it contained a few words also appearing in one of the later vocabulary tests. Next, participants were presented with the general and specialized vocabulary tests. In order to have a break in the vocabulary tests the general knowledge test was then administered followed by the Nelson- Denny vocabulary test. Before being presented with the Comprehension test, participants were again reminded to take the study seriously and to read every text attentively. Lastly, the author recognition task, the reading frequency questionnaire and the Big Five Inventory were presented. The study was done in rounds of 40 participants to allow us to intervene when something went wrong and to pay participants their bonus in a few days. Initially the study was set to take 2-2,5 hours. However, because prolific gave a maximum time of 5 hours to finish such a study, this allowed participants to take large breaks during the tests. After the first batch, timing was set to 1,5-2 hours with a maximum time of 4 hours. Upon completing the study participants were redirected to Prolific.

Results and discussion

Descriptive statistics and reliability of the language tests

Again, descriptive statistics and reliability values were calculated for the language tests we used (Table 5). Findings showed good reliability for most of the tests. The lowest were for LexTALE and the text comprehension test (which now had an ICC of .70). Part of the low reliability of LexTALE was due to a ceiling effect, in line with the fact that this test was developed for L2 speakers and is too easy for L1 speakers. High scores were also an issue for the general vocabulary test we developed in Study 2. Mean score was 44.9/50 (88%), strongly reducing the standard deviation of the scores observed. Due to the age range restriction, no differences due to age were observed anymore.

variable	mean	sd	ICC	split-half	age	lextale	general	academic	GK	ND	comp	ART3
age	19.70	1.20	NA	NA								
Lextale (max = 60)	54.27	4.66	0.69	0.73	-0.04							
General vocabulary (max = 50)	44.89	4.09	0.75	0.79	0.04	0.50						
Academic vocabulary (max =50)	32.40	7.86	0.84	0.85	-0.08	0.38	0.50					
General Knowledge (max = 65)	43.12	7.39	0.76	0.79	0.05	0.29	0.49	0.68				
Nelson-Denny (max = 80)	63.58	9.11	0.86	0.89	-0.01	0.42	0.73	0.61	0.65			
Tekst Comprehension (max = 36)	27.02	4.51	0.70	0.75	0.09	0.29	0.39	0.22	0.37	0.50		
Author Recognition Test (max = 90)	56.99	9.19	0.77	0.79	-0.12	0.19	0.30	0.53	0.42	0.37	0.06	
Reading time (wpm)	221.79	123.21	0.93	NA	0.00	0.16	0.14	0.06	0.04	0.09	-0.08	0.19

Table 5: Descriptive Information about the language tests and their intercorrelations in Study 3. Order of the tests agrees with the order of presentation to the participants. GK = general knowledge test, ND = the Nelson-Denny vocabulary test, comp = text comprehension test, ART3 = the author recognition test. Correlations of .19 and higher are significant and printed in bold.

Correlations between tests

The correlations between tests are also listed in Table 5. These replicated the correlation of $r = .5$ between reading comprehension and vocabulary, at least if the Nelson-Denny test was used. The other vocabulary tests had lower correlations. For the general vocabulary test and LexTALE this could partly be explained by the reduced range. The specialized vocabulary test correlated less with reading comprehension, but was the best predictor of general knowledge and, interestingly, the author recognition test, suggesting that these tests measured the same latent variable (crystallized intelligence).

None of the accuracy performance scores correlated significantly with reading rate in this study, an observation frequently made, suggesting that comprehension accuracy is not the most important variable determining the speed with which participants read texts (Brysbaert, 2019a).

Reading frequency questionnaire and Big Five inventory

Reliability of the reading frequency questionnaire was calculated in two ways: (1) using the function alpha of the psych package, and (2) using the reliability estimates based on the factor scores from a factor analysis (Table 6). The latter was done using the R script provided by Beauducel et al. (2016) for reliability estimates of factor scores estimates. The script can be used for three different factor scores estimators: Thurstone's regression factor score estimator, Bartlett's factor scores estimator and McDonald's correlation-preserving factor score estimator. Here Thurstone's regression factor score estimators were used. Reliability scores based on factor scores were higher for almost all subfactors of the scale. Nevertheless, both analyses gave good reliability scores, except for the alpha reliability of the social media subscale. To look at the relation with the other tests, the factor scores were used as these are the best estimate of an individual's performance (McNeish & Wolf, 2020). Correlations with the sum scores of the other tests are shown in Table 7. These correlations in general were low, with the exception of the expected correlation between ART3 and fiction reading.

subscale	alpha	rel. factor
RF fiction	0,85	0,9
RF non-fiction	0,88	0,91
RF newspaper	0,92	0,96
RF websites	0,89	0,92
RF social media	0,62	0,96
RF wordgames	0,77	0,83

Table 6: Reliability measures for subscales of the reading frequency questionnaire. Rel. factor are the reliability estimates based on factor score estimates

	Lextale	General	Academic	GK	ND	comp	ART
RF fiction	0,14	0,05	0,25	0,13	0,14	-0,11	0,34
RF non-fiction	-0,03	-0,10	0,09	0,10	-0,10	-0,07	0,23
RF newspapers	-0,06	-0,06	0,09	0,00	-0,03	-0,11	0,14
RF websites	0,12	0,22	0,15	0,18	0,26	0,14	0,08
RF social media	0,11	0,13	0,12	0,20	0,21	0,09	-0,01
RF wordgames	0,10	0,07	0,17	0,13	0,03	-0,06	0,20

Table 7: Correlations between the subscales of the reading frequency questionnaire (factor scores) and the other tests (sumscores). GK = general knowledge test, ND= Nelson-Denny, comp = comprehension test, ART= author recognition test. Correlations of .19 and more are significant at $p < .01$ and printed in bold.

Table 8 lists the descriptives of the Big Five personality test and Table 9 shows the correlations with the language tests. Reliability measures of all subscales are adequate to good. A surprising observation in the correlation matrix is the negative correlation between conscientiousness and Nelson-Denny/reading comprehension, suggesting that participants who indicated they were more conscientious tended to score lower on vocabulary and comprehension questions.

	mean	sd	alpha	rel.factor
BF Nega	3.23	0.82	.9	.93
BF Consc	3.30	0.63	.83	.88
BF Open	3.82	0.63	.82	.87
BF Extra	2.98	0.71	.85	.89
BF Agree	3.76	0.52	.72	.82

Table 8: Descriptive statistics and reliability measures of the Big Five Inventory. Rel. factor = reliability measures based on factor scores.

	BF_Nega	BF_Cons	BF_Open	BF_Extra	BF_Agree
lextale	0,01	-0,09	0,10	0,07	-0,04
general_voc	0,14	-0,17	0,10	0,03	0,06
academic_vo	0,13	-0,13	0,17	0,00	-0,09
GK	-0,02	-0,15	0,16	0,07	-0,08
ND	0,16	-0,29	0,18	-0,01	-0,04
comp	0,13	-0,20	0,00	-0,05	0,08
ART	0,15	-0,04	0,20	0,14	0,04
wpm	0,01	-0,06	-0,01	0,12	0,02

Table 9: Correlations between the Big Five subscales (factor scores) and the other tests (sum/mean scores).

Conclusion

We had hoped that Study 3 would be the end of our journey to compile a good English vocabulary test. However, this was not the case. The tests we developed looked inferior to the Nelson-Denny test. Although the new tests had a good reliability (in particular the test for specialized word knowledge), they correlated less well with text comprehension. On the other hand, the test for specialized word knowledge, correlated well with tests for crystallized intelligence.

As a result, we decided to add an extra round in which we tried to improve the vocabulary test for general words. In addition, it seemed to us that we needed more tests of reading comprehension, given that it proved so difficult to increase the reliability of the test we used.

Study 4: Improving the general vocabulary test

In Study 2 and 3 it became clear that our general vocabulary test was too easy and could use some improvement. A new list of 200 words was generated in order to improve the general vocabulary test. For this list, words were chosen that have a rather early age of acquisition but are not widely known. After selection based on exploratory factor analysis and mirt analysis we hoped to have a vocabulary test with a larger standard deviation and better reliability. Because our comprehension test did not reach the reliability level we desired, three more promising, published comprehension tests were added.

Method

Participants

Again, Prolific was used to gather data for the experiment. Participants were prescreened to have English as their native language and to fall in the age range of 18- 21 years. Participants varied a lot in the time they spent on the experiment with a mean of about 80 minutes, resulting in a payment of £7.50. Submissions were rejected when participants' data suggested a lack of commitment based on a combination of reading time and scores. Reading times were conceptualized as words per minute. Submissions of 200 participants were approved of which 11 were excluded for having scores around chance level or having extreme high reading rates on multiple texts. Of the 189 remaining participants 92 were female, 90 male and 7 identified as otherwise. Most of the participants were students (143), 25 indicated to be employed and the remaining were unemployed. 161 participants indicated to have a high school degree level, 28 participants had an undergraduate degree. Participants came from a variety of countries, although most indicated to be from the UK (90) or the US (39). Other countries included Australia, Canada, China, Greece, Hungary, Indonesia, Malaysia, New Zealand, Poland, Portugal, South Africa, Trinidad & Tobago and Zimbabwe.

Materials

Vocabulary test. In order to build a new (and hopefully improved) general vocabulary test, we compiled a list of 200 words. For this we started from the 30 most difficult items of the version used in Study 3. We also added words from study 2 that correlated highly with the total scores but had not been selected

because there was no clear difference in load on the two factors. Lastly, new words were selected that had an age of acquisition of up to 14 years in the AoA ratings of Kuperman et al. (2012), a large deviation in AoA estimates, and were regularly flagged as not known by the participants.

New text comprehension test 1: Because of the limited success we had in improving the comprehension test of Study 1, we searched in the literature for other tests. This turned out to be a difficult task. Many studies on text comprehension use a commercial test or do not give information about the reliability of the tests they used. The few remaining studies usually reported rather disappointing findings. A typical example is Freed et al. (2017). These authors used the Nelson-Denny reading comprehension test (Forms F and G) and a comprehension test they designed themselves, based on 10 texts with 10 multiple choice questions each (4 response alternatives). When Goring et al. (2021) reanalyzed the data, they obtained reliability of .47 for both comprehension tests, and an intercorrelation of .47 between both tests as well. When entered in a factor analysis with 20+ other language tests, the two reading comprehension tests ended up in different factors.

Better results were reported by Griffin et al. (2008). They used four explanatory texts describing complex causal phenomena from the natural or social sciences (e.g., ice ages or antibiotic use causing allergies). The texts varied from 650–900 words in length and were followed by 16–20 statements that participants had to judge as true or false based on what they had read earlier. The statements were assertions that were either consistent or inconsistent with inferences that were logically implied by one or more statements in the text. Reliability was not reported but the four tests loaded on a single principal component. We decided to use the tests on ice ages (T1) and antibiotic use (T2).⁶ When looking at the assertions it occurred to us, however, that some could be answered correctly without reading the text (e.g., “The total amount of CO₂ in the atmosphere is stable and does not change.” Y/N). Such questions are tricky as they are likely to increase the reliability of the text (because they are measures of crystallized intelligence), without measuring the construct one is interested in (comprehension of a text just read). We changed the assertions we thought could be answered much better than chance without reading the text and tried to replace these questions by better ones. All in all, we had 18 questions for the ice ages text and 19 questions for the text about bacteria.

New text comprehension test 2: The second comprehension test was compiled by Yeari et al. (2015). It contained 10 rather short expository texts (314 to 458 words), after which the participants were presented with four statements they had to judge as true or false. The texts covered a variety of topics such as the Trojan War, Reality TV, and the life of Marie Curie. No information was given about the reliability of the test.⁷

New text comprehension test 3: The final comprehension test was one used by Kane & Miyake (2007). It consisted of 20 short text fragments (40–114 words) ending with a question and five response alternatives. Participants had to indicate which alternative best summarized the fragment or was the most likely continuation of the fragment. Participants could reread the text fragments while thinking

⁶ We thank Jennifer Wiley for kindly sharing the tests with.

⁷ We thank Menahem Yeari for kindly sending us the materials.

about the answer. However, there was a time limit of 10 minutes. Kane & Miyake (2007) reported a reliability of $\alpha = .76$ and a correlation of .59 with the Nelson-Denny comprehension test (no form given).⁸

Procedure

Participants were recruited using Prolific. Testing happened online (using Lime survey; <https://www.limesurvey.org/>) without presence of an experimenter. After being informed about the content of the tests, the goal of the study and the importance of taking the study seriously, participants were asked to indicate their age, gender, education level and the country they live in. Participants were first presented with the vocabulary list, followed by the comprehension tests. They started off with the two texts of Griffin et al. (2008), followed by the test of Yaeri et al. (2015). The study ended with the test of Kane & Miyake (2007), which was the only test with a time limit. Before being presented with the Comprehension tests, participants were informed about the goal and reminded to take the study seriously and to read each text attentively. Participants were informed about the payment (7,50€), the number of tests and the estimated time requirements (1,5 hour) before they consented to take part. After completing the study participants were redirected to Prolific.

Results and discussion

Vocabulary test

Descriptive statistics. Before starting factor analysis, descriptive statistics were gathered. For the Vocabulary test (200 words) a mean score of 137.3 (69%) was found (SD: 25, min: 69, max: 189). This indicates that the new words were more difficult than the list of Study 2 (90%). Using intraclass correlations, a reliability of .94 was obtained. A closer look at the items showed that none of the words were answered correctly by all participants.

Factor analysis. Because the data was dichotomous (correct/wrong), analysis was based on tetrachoric correlations. Results from the Kaiser- Meyer-Olkin (overall MSA = .85) test and Bartlett's Test of Sphericity ($p < 0.1$) indicated that the sample was adequate for Factor Analysis.

Both parallel analysis and Multidimensional item response theory (MIRT) analysis were used to determine the number of factors in the vocabulary list. Figure 12 shows that the parallel analysis suggested that the test mainly measured one factor. This was confirmed in a mirt analysis, where there was no clear preference for a 1-factor or a 2-factor model (AIC and BIC indices led to different conclusions).

⁸ We thank Michael Kane for kindly sending us the materials.

Figure 12: Exploratory factor analysis of the Vocabulary test (analysis done with `fa.parallel()` based on tetrachoric correlations).

Item analysis and selection of the 50 best items. Three approach were taken to select the best 50 items. First, on the basis of AIC the 2-factor model was better than the 1-factor model (35987 vs. 36223). We used the mirt 2-factor model to select the items that loaded high on the first factor. The process was repeated until a list was obtained resulting in a single factor. The resulting list of 50 words had a reliability of ICC = .87 and a mean score of 82% (sd: 13.9).

The second approach was based on the BIC fit. Comparison of a mirt 1-factor and 2-factor model indicated a 1-factor structure (37513 vs. 37919). Using the 1-factor model all items with a factor loading of .4 or higher were selected. Next a Rasch and two parameter model were compared using anova. Results indicated that the test could be analyzed using a simple Rasch model. Next the number of items was reduced to 58 by looking at the local independence of the items and removing those that had high correlations with others. A look at the mean score (86%) suggested that the test might be too easy, so 8 of the easier items were removed resulting in a mean score of 71% (sd:16.8). An intraclass correlation of .87 was found.

Finally, a third list was created on the basis of item-rest correlations. The rationale behind this was that in a 1-factor model the items that correlate highest with the total score are usually the best items. This third list had a mean score of 68% (sd: 19.2) and a reliability of ICC = .90.

Comprehension tests.

Descriptive statistics. For both texts of Griffin et al. (2008) a mean score of 13 was found (T1: M=13.2/18, SD = 2.49, min = 6, max = 18; T2: M=13.4/19, SD = 2.32, min = 7, max = 19). Using intraclass correlations, low reliability scores were found for both texts (T1= .48, T2 = .40). The comprehension test of Yeari et al. (2015) had a mean score of 28/40 (SD = 3.80, min = 16, max = 39), and reliability of ICC =

.50. Lastly the test of Kane & Miyake (2007) had a mean score of 9/20 (SD: 4.8, min: 0, max: 20) and a reliability of ICC = .83. Reading times were rather fast (326 wpm rather than the usual 240-260; Brysbaert, 2019a), indicating that some participants had difficulty remaining motivated to complete all tests. Nevertheless, reliability analysis of the reading times was very high (ICC = .95).

All in all, even though we did our best to find good reading comprehension tests, only the Kane & Miyake did better in terms of reliability than the one we were building ourselves on the basis of Siegelman et al. (2022). The bleak picture was further confirmed by an exploratory factor analysis, showing a clear lack of a reading comprehension factor in the two Griffin et al. tests and the Yeari et al. test (Figure 13).

Figure 13: Exploratory factor analysis of the Griffin et al. Text 1 (A), Text2(B), Kane & Miyake (C) and Yeari et al. (D) (analysis done with `fa.parallel()` based on tetrachoric correlations).

Correlations between the different tests

Correlations between sum scores of all tests and mean reading times (in words per minute) were calculated (Table 10). In line with Study 3, reading rate did not correlate with accuracy scores on any of the tests. Moderate to strong correlations were found between most accuracy scores. The Griffin et al. test on bacteria had low correlations with most other tests, in line with its low reliability. Of the three item selections we made, the one based on item-rest correlations looked the best, with the largest standard deviation and the highest correlations with other tests.

	mean	sd	voc	Griffin_T1	Griffin_T2	Y, et al.	K&M	voc1	voc2	voc3
voc (max = 200)	137.27	25.00								
Griffin_T1 (max = 18)	13.19	2.49	0.33							
Griffin_T2 (max = 19)	13.42	2.32	0.23	0.36						
Y.etal (max = 40)	28.56	3.80	0.34	0.41	0.46					
K&M (max = 20)	8.93	4.80	0.44	0.51	0.37	0.49				
vocAIC (max = 50)	41.26	6.97	0.85	0.32	0.22	0.34	0.45			
vocBIC (max = 50)	35.65	8.39	0.95	0.31	0.19	0.32	0.43	0.84		
vocCor (max =50)	34.08	9.58	0.93	0.40	0.23	0.33	0.51	0.74	0.89	
reading time	326.19	406.97	0.18	-0.02	-0.04	-0.16	-0.03	0.12	0.16	0.13

Table 10: Correlations between sum scores of all tests and mean reading times in Study 4 (in words per minute). Correlations higher than .3 in bold.

Conclusions

Study 4 was set up to improve the vocabulary test of general words. The test derived from Study 2 turned out to be too easy. To draft a new test, we started from a list of 200 candidate words. Using different methods, three new vocabulary lists of 50 words were composed. Although all tests looked useful, the one based on item-rest correlations was the most promising in terms of variability and correlation with the other tests we administered.

We also presented four new comprehension tests, used in past promising articles. Of these, only the Kane & Miyake (2007) test had good reliability. The other tests only had values between ICC = .4 and .6. Furthermore, there was little evidence for a one-factor structure in these tests, partly because of problems with the difficulty and discrimination power of several items. Further improvements for these tests were in order.

Study 5: Validating the new version of the general vocabulary test

Study 5 was an improved version of Study 3. First, in Study 4 we developed a new test for general vocabulary, which we hoped would do better. Second, we tried out new comprehension tests in Study 4, which would allow us to better charter the correlation between vocabulary and reading comprehension.

Method

Participants

Data was gathered using prolific. Participants were prescreened to have English as their native language and to be in the age range of 18- 21 years. We also made sure the participants had not participated in one of our earlier studies. Because the study consisted of 11 tests and required the participants to be attentive for quite some time, we decided to divide the study in two parts, with the possibility of an extended break in-between. Participants were informed at the start about the different tests and the requirement to participate in both parts of the study in order to receive payment. Participants were paid £12 for participation. If their data could be used, they received an additional bonus of £5. Participants were informed about this payment scheme before signing the informed consent.

Submissions of 200 participants were gathered of which 18 had to be excluded due to random responding and abnormally fast response times. Decisions about exclusion were taken before the analyses started. Of the remaining participants, 99 were female, 79 male and 4 identified as otherwise. Most of the participants were students (141) while the remaining participants indicated they were employed or unemployed. 155 participants indicated they had a high school degree; 27 participants had an undergraduate degree. Participants came from a variety of countries, but most of them were from the UK or the US. Other countries included Australia, Canada, China, India, New Zealand, Poland and South Africa.

Materials

Part 1. To ensure quality of the data, the study was divided in two parts with the first part consisting of the comprehension tests. This was done because in our previous studies we noticed that participants liked this part of the study least, increasing the chances that they would pull out at a late stage of data gathering. We thought it was better for all parties if participants stopped before investing too much energy. For that reason, we also started with the most demanding comprehension test, the Griffin et al. text on ice ages. At the start of the first part participants were asked about their age, gender, education level and the country they lived in.

Big Five Inventory. The first test of the study was the Big Five inventory used in the earlier studies. We put it at the start of the study to make sure that the answers participants gave, were not affected by their performance on the tests.

Text comprehension test 1 : Griffin et al. (2008) ice ages. Because Study 4 indicated a poor reliability of the test on bacteria, we decided not to retain that one. In an attempt to improve the reliability of the test on ice ages, poor questions were removed or rephrased and 6 new questions were included, resulting in 24 true or false statements participants had to answer.

Text comprehension test 2: our own test. For the second comprehension test, we improved our own comprehension test used in Studies 2 and 3. One of the original texts was removed (on hibernation) because the items failed to discriminate well between low and high performers. Three new texts (on Valetta, Isle of the dead, and Abhaya mudra) were added resulting in a total of 14 texts. Each text was

followed by 3 questions with four response alternatives. Some of the existing questions were changed because answers to them were at ceiling level.

Text comprehension test 3: Kane & Miyake (2007). This test was the only comprehension test with a good reliability score in Study 4 and it was left unchanged in our new study.

Text comprehension test 4: Yeari et al. (2015). The last comprehension test consisted of the texts used by Yeari et al. (2015). Because of the rather low reliability found in Study 4, we changed some questions and added an extra question to every text, so that participants had to answer five yes/no questions per text for a total of 50.

Part 2. After completing the first part of the study participants were again reminded they had to participate in the second part of the study in order to receive payment and the bonus. They were informed that an invitation for part 2 would appear within the hour and that they could choose to run the second part on the same day or on the next day.

Reading frequency Questionnaire. The second part of the study started with the reading frequency questionnaire used in Study 3.

Author Recognition test (ART3). Participants were further asked to complete the 90 items of the ART, as in Studies 1 and 3.

Vocabulary tests. Three vocabulary tests were administered to the participants: The vocabulary test of specialized words from Study 3, the new general vocabulary test from Study 4, and the Nelson-Denny (Form H). Because one item from the Nelson-Denny also occurred inadvertently in one of the new tests, the following order was used: First the new general vocabulary test from Study 4, followed by specialized vocabulary test from Study 3, and last the Nelson-Denny.

General Knowledge test. The last test participants had to complete was the general knowledge test from Study 3. In the ART3, vocabulary tests and general knowledge test, items were randomized anew for each participant.

The study was run online in rounds of 40 participants to allow us to intervene in case something went wrong and to send the bonus to the participants shortly after they finished the study. On average participants spent 2 -3 hours to complete the study.

Results and discussion

Comprehension tests

Descriptive statistics. Time spent reading was converted into words per minute. Despite our insistence to read all texts in order to understand them, we noticed that participants were very fast on some texts (suggesting they did not read them well) and very slow on other ones (suggesting they did something else in the meantime). Rather than replacing all these participants, we decided to remove the texts with abnormal reading times based on the reasoning of Kuperman et al. (2021). Texts with reading times below 100 wpm or above 668 wpm were removed (these agree with reading rates 1/2.5 and above 2.5

times the average reading rate on the basis of Brysbaert's (2019a) meta-analysis). The answers to texts with abnormally slow or fast reading times were deleted as well. This was the case for 10% of the observations. Missing observations were a particular problem for the Griffin et al. comprehension test on ice ages, as there was only one text to read. This led to 17 missing observations on a total of 182 participants. For the other tests, performance could be estimated on the basis of the remaining data. Because the comprehension test by Kane & Miyake had a fixed completion time of 10 min, no reading rate could be calculated for this test. Answers not answered in this test were given a score of 0, in line with the philosophy of the time limited test.

Table 11 shows the descriptive statistics. These are based on the sum/ mean scores (see below for slightly better estimates). To deal with the missing data, reliability estimates are based on the intraclass correlation based on mixed effect modelling using the psychometric R package (Fletcher, 2015; see Brysbaert, 2019b, for further explanation). As can be seen in the Table 11, two of the comprehension tests continued to have disappointingly low reliabilities (Griffin et al., 2008.; Yeari et al., 2015). Also, the reliability of our own comprehension test remained lower than we had hoped for.

Test	mean	sd	ICC	wpm mean	wpm sd	wpm ICC
Griffin et al (max = 24)	17.25	2.82	.41	261.9	121.78	NA
Own test (max = 1.00)	.74	.12	.65	223.20	62.36	.9
K&M (max = 20)	9.02	4.66	.82	NA	NA	NA
Yeari et al (max = 1.00)	.69	.10	.53	264.93	89.28	.92

Table 11: Descriptive statistics (accuracy and reading rate) based on mean or sum scores and the reliability scores of the comprehension tests administered in Study 5.

Vocabulary tests, Author Recognition test (ART) and General Knowledge (GK) test

Descriptive statistics. Descriptive statistics were calculated based on sum scores. Reliability was estimated in various ways. Because the values were in close agreement, only the ICC estimates are given here (Table 12). All tests had good reliability of around .8 or more. Importantly, the new general vocabulary test scored similarly to the specialized vocabulary test from Study 3.

Test	mean	sd	ICC
Voc1 specialized (max = 50)	31.74	8.60	.86
Voc2 general (max = 50)	33.97	9.29	.89
ND (max = 80)	62.47	10.92	.9
ART3 (max = 90)	57.25	9.37	.78
GK (max = 65)	41.98	7.75	.78

Table 12. Descriptive statistics based on sum scores and the reliability scores for the vocabulary tests.

Correlations based on sum/average performance

Table 13 shows the correlations between the different tests. These correlations do not include the participants with missing values for the Griffin et al. test. So, the number of data pairs was 165 instead of 182 (see below for a more sophisticated analysis including all participants). A first surprising observation was the high correlation of .82 between Voc1 specialized and Voc2 general, almost as high as the reliability of the tests. This was most unexpected, given that we had worked under the assumption of two different vocabulary factors based on the data obtained in Study 1. We will return to this finding in the conclusion section.

Further important observations were that our two vocabulary tests correlated less with the Nelson-Denny test than with each other, less with the reading comprehension scores than the Nelson-Denny, but more with the author recognition test and the general knowledge test, replicating the findings of Study 1. Also good was the observation that the accuracy scores of the comprehension tests intercorrelated .4 - .6, suggesting that they formed a single factor. As before, correlations with reading rate (wpm) were low, but there was a curious dissociation between K&M's test and the other tests. Whereas accuracy on the other tests decreased for fast reading participants, accuracy on the K&M test **increased** for fast reading participants, arguably because the K&M test was the only timed test (as many questions answered correctly as possible in 10 min time).

	G et al.	own test	K&M	Y et al.	wpm_G	pm_own	wpm_Y	ART3	voc1	voc2	ND
own test	0.46										
K&M	0.44	0.45									
Yeari et al.	0.47	0.59	0.46								
wpm_Griffin	-0.18	-0.20	0.05	-0.22							
wpm_own_test	0.03	-0.09	0.41	0.07	0.42						
wpm_Yeari	-0.20	-0.36	0.19	-0.26	0.43	0.71					
ART3	0.21	0.11	0.27	0.24	-0.05	0.26	0.07				
voc1 specialized	0.35	0.25	0.49	0.42	-0.07	0.21	-0.01	0.51			
voc2 general	0.40	0.32	0.56	0.46	0.03	0.30	0.05	0.40	0.82		
ND	0.44	0.44	0.56	0.51	-0.12	0.18	-0.05	0.31	0.73	0.75	
GK	0.36	0.29	0.46	0.39	-0.01	0.33	0.10	0.31	0.67	0.71	0.68

Table 13: Correlation matrix of the ability tests (N = 165 due to missing data for the Griffin et al. comprehension test). Correlations higher than .3 are typed in bold. Order of the tests is the order in which they were presented to the participants. ART3 = author recognition test, ND = Nelson-Denny, GK = general knowledge test

Factor analysis

To get a better feeling for the intercorrelations between the tests, we ran a factor analysis. For this analysis, we estimated the 15 missing observations of the Griffin et al. comprehension test with the R package mice (van Buuren, 2021). We did so for comprehension only, because the missing values of wpm were not random, given that they were the same as the missing accuracy observations. As a result, the reading rate for the Griffin et al. comprehension test was not retained in the factor analysis. We further recalculated reading speed as words per second (wps) instead of words per minute, because otherwise the variance of this variable was more than 1000 times larger than the variance of the other variables, which might interfere with the calculations. Finally, we excluded the items of the comprehension tests

with negative item-rest correlations. This resulted in the exclusion of 4 items from the Griffin et al test and 6 items from the Yeari et al. test.

A further issue was that the data of the comprehension tests contained missing observations. This could affect the means calculated (e.g., because the missing observations could be those to difficult questions). A simple way to tackle this issue is to make use of the complete participants x stimuli matrix, like is done in an IRT analysis to estimate participant ability. De Boeck et al. (2011) showed that the participant intercepts of a binomial generalized linear mixed model (glmer) agree with the ability scores calculated with a Rasch model. The advantage of the glmer analysis is that it can be done on a dataset with (a few) missing observations. We used this procedure to improve the estimates of participants' performance.⁹ A look at the resulting correlation (Table 14) matrix confirmed that the glmer estimates gave the same correlations for tests with all observations present and slightly higher correlations for tests with missing observations.

	G et al.	own test	K&M	Y et al.	ART3	voc1	voc2	ND	GK	wpm_own
own test	0.51									
K&M	0.46	0.44								
Yeari et al.	0.50	0.64	0.49							
ART3	0.20	0.13	0.20	0.19						
voc1 specialized	0.35	0.23	0.42	0.35	0.52					
voc2 general	0.42	0.33	0.52	0.42	0.44	0.82				
ND	0.49	0.48	0.59	0.57	0.31	0.70	0.75			
GK	0.37	0.33	0.43	0.37	0.36	0.65	0.69	0.65		
Wpm_own_test	0.03	-0.15	0.42	0.00	0.18	0.16	0.24	0.20	0.27	
Wpm_Yeari	-0.20	-0.39	0.23	-0.26	0.07	0.00	0.06	-0.03	0.08	0.72

Table 14: Correlation matrix of the ability tests with estimated values for missing observations and participant abilities estimated on the basis of mixed effect models (N = 182). Correlations above .3 in bold.

An exploratory factor analysis with oblimin rotation and minimal residuals suggested 3 factors, as shown in Table 15. The first factor aligned with what is traditionally called crystallized intelligence. It included the vocabulary tests, the general knowledge test, and the author recognition test. The second factor grouped the accuracy scores of the reading comprehension tests. The highest loading were observed for our own comprehension test and the Yeari et al. comprehension test. The Griffin et al. comprehension test had the lowest loading, in line with its low reliability. The comprehension test of Kane & Miyake had a rather low loading as well, because it also loaded on the third factor, reading rate, in line with the fact that this test was time limited. Factor 1 and 2 had an intercorrelation of .50. Factor 3 was not correlated with the other two factors. Together, the three factors accounted for 65% of the variance: 27% due to Factor 1, 22% to Factor 2, and 16% to Factor 3. The same outcome was observed if three participants were omitted who according to the outlier function of the psych package had too high Mahalanobis distances. Further interesting was that the Nelson-Denny vocabulary test loaded both on factor 1

⁹ The code is `fit <- glmer(value ~ (1|subject + 1|question, family = binomial)` and `coef(fit)$subject` in the lme4 R package (Bates et al., 2011).

(crystallized intelligence) and factor 2 (reading comprehension). A possible reason for this finding will be given below.

Factor Loadings

	Factor			Uniqueness
	1	2	3	
voc1 academic	1.014			0.101
voc2 general	0.832			0.182
GK	0.633			0.438
ND	0.559	0.416		0.271
ART	0.533			0.742
comp2		0.804		0.315
comp4		0.718		0.397
comp3		0.659	0.421	0.335
comp1		0.574		0.563
Wps_comp4			0.891	0.161
Wps_comp2			0.829	0.295

Note. 'Minimum residual' extraction method was used in combination with a 'oblimin' rotation

Table 15: Factor structure resulting from factor analysis with extraction method minres. Only loadings larger than .3 are given.

The findings from the exploratory study were checked with the structural equation analysis based on the lavaan R package (Rosseel, 2012). This package failed to calculate a solution with all tests included, but confirmed the solution with the first two factors when reading rates were omitted, as shown in Figure 14. The Nelson-Denny test loaded both on factor 1 and on factor 2. The same was true for the Kane & Miyake comprehension test. All paths had strengths that were strong enough ($p < .001$) to assume that

the alternative hypothesis is more likely than the null hypothesis of no relationship. Model fit was good (RMSEA = .06; CFI = .98; TLI = .98), also when robust maximum likelihood estimation (MLM) was used.

Figure 14: Confirmatory factor analysis of the vocabulary and reading comprehension tests used in Study 5

The Reading frequency questionnaire and the Big Five inventory

Table 16 gives the descriptives of the reading frequency questionnaire. Reliability was calculated in two ways: with the alpha coefficient of the psych package (Revelle) and with the factor score estimates as recommended by Beauducel et al. (2016).

	mean	sd	alpha	rel. factor
RF-Fiction	7.40	3.54	.88	.93
RF-NonFiction	8.48	3.71	.88	.92
RF-Newspaper	7.79	4.75	.93	.97
RF- Websites	17.17	1.70	.83	.87
RF-socialmedia	17.67	1.38	.87	.93
RF-Wordgames	6.64	2.61	.75	.82

Table 16: Descriptives for the reading frequency questionnaire. Chronbach alpha is calculated using Alpha() from the r package Psych. Rel. factor= reliability scores based on factor score estimates.

Table 17 lists the correlations between the reading frequency scores and the various tests we administered. Most correlations were below .2, except for those between reading fiction and the tests scoring high on crystallized intelligence and reading rate. Participants who indicated they read a lot of fiction (and to a lesser extent social media), scored better on tests of crystallized intelligence and read faster. They also tended to be more accurate on the reading comprehension questions, although correlations were low. To further investigate this, we also correlated the reading frequency scores with the factor scores from the exploratory factor analysis shown in Table 14. This confirmed that the factor of crystallized intelligence and reading rate correlated significantly with reading frequency fiction.

	RF fiction	RF nonfiction	RF newspaper	RF socialmed	RF websites	RF wordgame
Griffin et al,	0.17	-0.03	0.00	0.14	0.06	0.09
own test	0.04	-0.08	-0.06	0.19	0.09	-0.05
K&M	0.22	-0.14	-0.03	0.14	0.16	0.00
Yeari et al.	0.15	-0.09	-0.13	0.16	0.09	-0.06
ART	0.20	0.12	0.05	0.09	0.13	0.10
voc1 specialized	0.26	0.05	0.07	0.16	0.13	0.11
voc2 general	0.25	0.02	0.06	0.13	0.17	0.02
ND	0.26	0.04	-0.01	0.19	0.17	0.00
GK	0.11	-0.05	0.03	0.20	0.21	0.06
Wpm own test	0.20	-0.05	0.10	0.03	0.14	0.02
Wpm Yeari et al.	0.18	0.02	0.04	-0.04	0.09	0.04
f1 (crys)	0.27	0.03	0.07	0.17	0.17	0.08
f2 (comp)	0.16	-0.10	-0.07	0.20	0.14	-0.04
f3 (speed)	0.22	-0.02	0.06	0.00	0.13	0.03

Table 17: Correlations between factor scores of the reading frequency Questionnaire and estimated scores via lme4 of the other tests. Values above .19 are significant at the $p < .01$ level and printed in bold. Comp 1= academic comprehension test, comp2 =

own comprehension test, comp3= comprehension test by Kane & Miyake, comp4 = YvdB comprehension test, Art = author recognition test, ND = Nelson-Denny, GK = general knowledge test.

Table 18 lists the descriptives of the Big Five personality test and Table 19 shows the correlations with the tests. A surprising observation here was the negative correlation between conscientiousness and reading comprehension, suggesting that participants who indicated they were more conscientious tended to score lower on the comprehension questions. The findings were confirmed when we looked at the correlations with the factor scores. The same negative correlation was also observed in Study 3 (but not in Study 1) and seems to agree with the trend towards a negative correlation between conscientiousness and vocabulary size in the meta-analysis shown in Figure 1. Possibly the negative correlation was accentuated in Study 5, because the personality questionnaire was given before participants completed the tests, instead of after completing them.

	mean	sd	alpha	rel. factor
BF-Open	3.7	.6	.79	.85
BF-Consc	3.31	.65	.83	.89
BF-Extra	2.91	.71	.85	.9
BF-Agree	3.63	.56	.76	.85
BF-Nega	3.26	.8	.89	.92

Table 18: reliability measures for subscales of the Big five inventory and the reading frequency questionnaire. .Chronbach alpha is calculated using Alpha() from the r package Psych. Rel. factor= reliability scores based on factor score estimates.

	BF Neur	BF Cons	BF Extr	BF Open	BF Agree
Griffin et al.	-0.09	-0.22	-0.10	0.12	0.12
own test	-0.01	-0.28	-0.12	0.10	0.12
K&M	0.13	-0.27	-0.14	0.05	0.15
Yeari et al.	0.05	-0.25	-0.07	0.08	0.15
ART	0.09	0.01	0.04	0.14	-0.02
voc1 specialized	0.06	-0.14	0.03	0.22	0.09
voc2 general	0.03	-0.28	0.00	0.17	0.09
ND	0.02	-0.19	-0.10	0.20	0.15
GK	0.01	-0.17	-0.01	0.07	0.03
Wpm own test	0.12	-0.16	0.02	-0.03	-0.01
Wpm Yeari et al.	0.11	0.05	0.10	-0.08	-0.05
f1 (crys)	0.05	-0.21	0.01	0.21	0.10
f2 (comp)	0.02	-0.31	-0.15	0.12	0.17
f3 (speed)	0.13	-0.12	0.05	0.06	-0.02

Table 19: Correlations between factor scores of the Big Five Inventory and estimated scores via lme4 of the other tests. Correlations above .19 are significant at $p < .01$ and typed in bold. Comp 1= academic comprehension test, comp2 = own comprehension test, comp3= comprehension test by Kane & Miyake, comp4 = YvdB comprehension test, Art = author recognition test, ND = Nelson-Denny, GK = general knowledge test.

Conclusions

The goal of Study 5 was to test and validate our new general vocabulary test that was created in Study 4. To do this, the new test was presented to participants together with all the other tests we used in Study 3 and Study 4, except for Lextale, which was found to be too easy for native English speakers.

The biggest surprise was that after all our efforts to create two different vocabulary tests based on the findings in Study 1, one with general words and one with specialized words, we ended up with two vocabulary tests that assessed very much the same skill. Indeed, the correlation between both tests was almost as high as the reliability of the tests. So, it very much looks like the distinction suggested in Study 1 does not exist and led us on a wild goose chase. The more positive news is that our research efforts resulted in the creation of two useful English vocabulary tests for university students. As a cautionary note, it will be interesting to see how non-native speakers perform on both tests. We expect them to do better on the specialized test with late acquired words.

The vocabulary tests we developed loaded on a crystallized intelligence factor, which correlated $r = .5$ with reading comprehension. Other tests loading on the factor were general knowledge and the author recognition test. The latter was not fully expected. Stanovich and West (1989) postulated a high correlation between vocabulary size and author knowledge based on the assumption that people who read a lot, at the same time know more words and more authors. Instead, our results suggest that author recognition is a result more of general knowledge than of having read the authors' books (see also Moore & Gordon, 2015). Ideally, we would have had more tests of crystallized intelligence that were not vocabulary-based, as in our studies the factor of crystallized intelligence was strongly dominated by the three vocabulary tests.

The Nelson-Denny vocabulary test deviated from our vocabulary tests because it loaded more on reading comprehension. In Study 1 we thought this pointed to a higher quality of the Nelson-Denny test than ours, but this was not confirmed in the further tests we ran. Nelson-Denny correlates more with reading comprehension, but *less* with tests of crystallized intelligence. A possible reason for this is that the authors of the Nelson-Denny test selected words not only on the basis of their similarity to the other words in the vocabulary test (as we did) but also on how well the words correlated with the reading comprehension part of the Nelson-Denny test, which is the more frequently used test of the package. As we have seen on several occasions, vocabulary knowledge is not a monolithic variable, but a hierarchy of factors representing different knowledge domains and language registers. Arguably, it is possible to select words that figure frequently in the type of texts used for reading comprehension. The outcome is

that the vocabulary test is more predictive of reading comprehension at the expense of other knowledge areas. This makes the Nelson-Denny vocabulary test good for predicting reading comprehension, the main aim of the Nelson-Denny package.¹⁰ A downside of this strategy, however, may be that the contribution of vocabulary to reading comprehension is overestimated, at the expense of other variables contributing to reading comprehension.

Study 5 further confirmed that the four reading comprehension tests we used, loaded on a common factor of reading comprehension. Unfortunately, this was about the only good news about the tests, as their reliability seemed to remain rather low. It looks extremely difficult to find questions about short texts that are answered incorrectly by low performing participants and correctly by a high performing group. Item factor loadings are rarely higher than .3, meaning that many questions are needed. At the same time, participants seem to give up rather easily when too many texts and questions have to be completed. Also using longer texts with more questions did not seem to help. Rather the reverse; quite some participants dropped out when they were shown the Griffin et al. text. Another risk is that long texts reduce the range of topics that can be tested, increasing the chances that background knowledge plays a role in test performance. The only reading comprehension test that seemed to score well in terms of reliability (the Kane & Miyake test) turned out to be an impure measure of reading comprehension, as it correlated substantially with general knowledge and reading speed (due to the time pressure under which it had to be performed).

General discussion

We started the present research line to develop a vocabulary test specifically targeted at undergraduate students. This is more challenging than a vocabulary test for the general population, because students are a relatively homogenous sample with respect to language proficiency. So, the test must be difficult enough to differentiate between students. A good vocabulary test is important in language research whenever authors are interested in individual differences, given that vocabulary size is a core measure of crystallized intelligence and correlates well with language comprehension. Having access to a free, valid vocabulary test also helps to compare proficiency levels across studies. Despite these qualities, there was no free test available for students with English as native or dominant language.

For the development of our vocabulary test we started from Nation's Vocabulary Size Test (Nation, 2020). Although the findings were promising in terms of reliability and convergent validity with the Nelson-Denny Form H vocabulary test (Study 1), we did not feel satisfied, because the test seemed to measure two distinct factors and correlated less with the Nelson-Denny than expected on the basis of the reliability of the tests. In four subsequent studies we discovered that our initial test could be improved indeed, but that the low correlation with the Nelson-Denny test is likely to be a consequence of the word selection process used for the Nelson-Denny test, which seems to result in higher prediction power of reading comprehension, but in lower correlations with other measures of crystallized intelligence (or general knowledge). As part of our investigations, we also tested and improved a series of other tests and questionnaires, which may be of interest to language researchers.

¹⁰ Another advantage of the Nelson-Denny test is that it is validated for younger participants.

Below, we give a short overview of the different tests we developed/improved. For each test, we give information about the distribution of participant scores in our study, various reliability measures, and information about the difficulty of the items. Further information about the tests, including the full items with the answer alternatives, can be found on <https://osf.io/ef3s4/>.

Flora (2020) described how various reliability indices of a scale can be calculated using the R packages lavaan (Rosseel, 2012), semTools (Jorgensen et al., 2020), and psych (Revelle, 2021). In addition to the measures reported above, two more indices are of interest. The first is ω_{u-cat} or omega3. It indicates how much of the variance in a categorical dependent variable (binary or Likert scale) can be explained by a single underlying latent variable. The second index of interest is ω_{h-cat} or omega h. This index does not assume unidimensionality of the measurement scale, but provides an estimate of the proportion of total-score variance due to a general factor common to all items, despite the multidimensional/hierarchical nature of the skills underlying performance. As our exploratory factor analyses showed, multidimensionality was the case for all tests we investigated. When there is no clear a priori information about the structure of the test, the reliability index recommended by Flora (2020) was the omega function from the psych package based on the parallel EFA model.

Vocabulary tests

StuVoc1. The student vocabulary test we recommend most, is the so-called test for specialized words developed in Study 2 and further tested in Studies 3 and 5. It consists of 50 words presented with four response options. All in all, we have data of 199 (Study 2) + 196 (Study 3) + 182 (Study 5) = 577 participants. Figure 15 shows the distribution of the scores, the various reliability measures, and the validity indices (correlations with general knowledge, author recognition, Nelson-Denny, the reading comprehension factor of Study 5, and the Big-Five openness trait; validity values based on the numbers of participants that were presented with the respective tasks).

Figure 15: Distribution of sum scores (mean = 32.3, sd = 8.36) on StuVoc1 based on 577 participants.

reliability measure	alpha	ICC	split-half	omega3	omega h
value	.88	.86	.87	.88	.69

Tests	cor stuvoc1
GK (n =378)	.67
ART (n=378)	.52
ND (n=378)	.65
BF open (n=378)	.24
F2_comp (n = 182)	.43

Table 20 shows the percentage of participants responding correctly on each item and the item-rest correlations.

word	correct	item-rest cor	word	correct	item-rest cor
compost	0.97	0,13	salient	0.42	0,29
delve	0.96	0,24	azalea	0.78	0,32
scrumptious	0.98	0,14	instantiate	0.39	0,29
panacea	0.47	0,37	anoint	0.48	0,30
authentic	0.97	0,14	impious	0.46	0,42
requisite	0.83	0,36	refectory	0.39	0,25
ablution	0.33	0,38	scintillating	0.57	0,35
tumult	0.49	0,49	marsupial	0.78	0,37
paltry	0.66	0,43	feint	0.64	0,37
sagacious	0.32	0,32	spangled	0.6	0,42
amulet	0.92	0,27	flank	0.84	0,35
torpor	0.55	0,35	cranny	0.73	0,29
jovial	0.78	0,37	elope	0.79	0,33
aperitif	0.57	0,39	atoll	0.45	0,29
ubiquitous	0.59	0,43	bassoon	0.85	0,36
alimony	0.74	0,37	desist	0.77	0,36
tresses	0.48	0,42	ineffable	0.57	0,30
sable	0.43	0,25	rigmarole	0.75	0,36
talon	0.90	0,35	taxon	0.44	0,25
trill	0.58	0,48	anvil	0.81	0,29
fracture	0.93	0,21	coven	0.81	0,29
sloop	0.35	0,37	augur	0.35	0,28
pragmatic	0.66	0,45	warbler	0.61	0,40
rouble	0.60	0,37	candid	0.75	0,33
pumice	0.71	0,38	emir	0.5	0,30

Table 20: Words included in StuVoc1 with percentage of correct answers and item-rest correlation.

StuVoc2. In Study 4 we developed a second list of 50 words that were meant to tap into familiar concepts with other, more familiar names. In Study 5, this test correlated highly with *StuVoc1*, suggesting that it does not measure a separate latent variable. Therefore, the test can be used as a parallel test for university students with English as first language, certainly if reading comprehension is to be predicted (Table 14). Further studies will have to indicate how well it performs in other populations. All in all, we have data of 189 (Study 4) + 182 (Study 5) = 371 participants on this test. These are shown in Figure 16 and Table 21.

Figure 16: Distribution of sum scores on *StuVoc2*(mean 34.0, sd =9.43)., reliability information, and correlation with validity tasks.

reliabilty measure	alpha	ICC	split-half	omega3	omegah
value	.91	.90	.89	.91	.68

word	correct	item-rest cor	word	correct	item-rest cor
autonomy	0.9	0,33	inebriation	0.67	0,58
deficit	0.69	0,32	decrepit	0.9	0,41
maze	0.83	0,30	rustler	0.64	0,30
retch	0.92	0,34	muck	0.95	0,32
barter	0.83	0,33	dawdle	0.84	0,37
veneer	0.63	0,42	dissent	0.73	0,37
madden	0.87	0,22	innocuous	0.44	0,45
nosedive	0.73	0,40	sarcophagus	0.65	0,45
stature	0.67	0,38	gruel	0.69	0,57
urchin	0.53	0,51	exultation	0.41	0,17
cutlass	0.68	0,53	wren	0.82	0,43
cobble	0.38	0,33	myrrh	0.52	0,36
devout	0.83	0,41	parry	0.77	0,28
squelch	0.85	0,31	purloin	0.38	0,36
gristle	0.53	0,35	threadbare	0.86	0,37
wharf	0.75	0,47	belfry	0.56	0,52
swanky	0.71	0,47	granary	0.72	0,52
cyan	0.82	0,34	warble	0.41	0,46
cinch	0.48	0,23	loam	0.45	0,37
nigh	0.75	0,37	mercurial	0.37	0,36
fervor	0.56	0,51	baneful	0.85	0,36
spire	0.74	0,45	yawl	0.77	0,28
wallop	0.63	0,33	lectern	0.63	0,38
instate	0.60	0,51	malign	0.69	0,43
raze	0.65	0,35	parchment	0.75	0,55

Table 21: Items included in StuVoc2, together with percentage of correct answers and item-rest correlations.

StuVoc3. In Study 2 we developed a vocabulary test similar to StuVoc2, which in Study 3 turned out to be too easy for the participants we tested. Although this test is not recommended for university undergraduates, it may be of interest for less proficient populations (younger participants, participants with English as second language). It is best to consider this test as a beta version, which still needs to be validated in less proficient samples. StuVoc3 shares three words with StuVoc2 (autonomy, deficit, maze). Figure 17 and Table 22 give the relevant information, based on the 199 (Study 2) + 196 (Study 3) = 395 participants we tested.

Figure 17: Distributions of sum scores on vocabulary test 3 (mean = 44.5, sd= 4.94)

reliabilty measure	alpha	ICC	split-half	omega3	omegah
value	.84	.82	.85	.83	.6

Item	correct	item-rest cor	Item	correct	item-rest cor
ricochet	0.96	0,29	ambiguity	0.98	0,36
heyday	0.95	0,25	curb	0.94	0,28
autonomy	0.89	0,32	conformity	0.91	0,36
rollick	0.85	0,36	fleeced	0.49	0,29
puritan	0.92	0,30	shudder	0.93	0,43
retro	0.95	0,27	pussyfoot	0.63	0,25
pave	0.90	0,39	maze	0.86	0,29
homogeneous	0.93	0,27	quilt	0.94	0,33
canoodle	0.87	0,24	chuck	0.95	0,38
dachshund	0.93	0,26	miniature	0.95	0,23
headstrong	0.94	0,22	awe	0.92	0,34
impale	0.96	0,31	wafer	0.94	0,27
strap	0.97	0,24	peasantry	0.93	0,41
dingy	0.88	0,35	devious	0.94	0,36
caboodle	0.85	0,55	excrete	0.93	0,31
soppy	0.74	0,31	flaunt	0.96	0,45
frankincense	0.8	0,21	caffeine	0.93	0,13
paradigm	0.56	0,25	upbeat	0.97	0,31
allocate	0.87	0,21	bylaw	0.77	0,35
compound	0.93	0,18	spleen	0.95	0,27
deficit	0.67	0,28	veer	0.89	0,24
gimmick	0.88	0,27	threshold	0.92	0,29
mainstream	0.95	0,18	speedometer	0.97	0,35
drawer	0.87	0,29	furnace	0.98	0,17
erratic	0.94	0,32	rascal	0.99	0,26

Table 22: Items of StuVoc3 and percentage of correct answers.

General knowledge test

GK. As part of the validation efforts for our vocabulary tests, we also developed a general knowledge test, consisting of questions with 4 response alternatives that covered a wide range of topics and did not require recall of an unfamiliar word. The test was used in Studies 1, 3, and 5. It consists of 65 questions (after the pruning done for Study 3). Figure 18 and Table 23 give the information of the GK test (n = 573).

Figure 18: distributions of sum scores on the general knowledge test (mean= 42.2, sd = 7.95)

reliabilty measure	alpha	ICC	split-half	omega3	omegah
value	.83	.79	.82	.81	.43

item	correct	item- rest cor
How many Wonders of the Ancient World were there?	0.84	0,30
Which country gifted the Statue of Liberty to the United States of America?	0.84	0,31
How did Vincent van Gogh die?	0.85	0,28
What is the main cause of seasons on Earth?	0.70	0,26
Why is it imperative that astronauts work out in space?	0.65	0,38
How do astronauts get fresh water during long missions in space?	0.51	0,29
What have Jupiter, Saturn, Uranus and Neptune in common?	0.75	0,32
During a solar eclipse the sun disappears; what takes place?	0.89	0,30
What happens to the breathing rate when there is a decrease in the concentration of oxygen in the blood?	0.52	0,23
Where are the red blood cells produced?	0.55	0,32
Why are bees, and other insects, attracted to flowers?	0.74	0,25
Where are the headquarters of Samsung?	0.47	0,27
Which company is owned by Bill Gates?	0.9	0,15
Many diseases have an incubation period. This means that	0.89	0,30
What does the name "IKEA", referring to the largest furniture retailer in the world, mean?	0.37	0,27
What other profession did the composer Vivaldi have?	0.32	0,24
What impairment did the composer Beethoven develop in later life?	0.8	0,29
In the 18th century Siberia, Mongolia, Tibet and China, solid blocks of what were used as currency?	0.23	0,18
What does "al dente" mean in cooking?	0.78	0,30
Mozzarella cheese is traditionally made with the milk of which animal?	0.26	0,27
Which is a major concern about the overuse of antibiotics?	0.91	0,28
Wine is most typically made from which fruit?	0.98	0,25
What do vegans not eat?	0.93	0,25
What is basmati?	0.82	0,21
What food is used as the base of guacamole?	0.97	0,30
Which continent has the most countries?	0.6	0,21
What is the hardest known substance?	0.85	0,24
During World War II, in which year did Germany attack France?	0.34	0,22
Where on the human body is the skin the thinnest?	0.76	0,14
How many chambers are there in the human heart?	0.77	0,26
In which decade was the telephone invented?	0.29	0,18
What is true about Othello in Shakespeare's play?	0.12	0,17
On what does the Brother Grimm's Sleeping Beauty prick her finger before falling into a deep sleep?	0.66	0,22
How can the circumference of a circle be calculated if the diameter is given?	0.55	0,27
What is the square root of 49?	0.95	0,18
When was the Oscars award ceremony instituted?	0.31	0,33
In "The Life of Brian", Monty Pythons' song recommends which life philosophy?	0.61	0,21
What is on the United Nations' flag?	0.6	0,34
What is the number of permanent members of the United Nations Security Council?	0.3	0,15
What color is obtained by mixing red and blue?	0.87	0,17
What color of visible light is the shortest in wavelength?	0.55	0,28
With which slogan did Barack Obama win his first presidential election, apart from "Change we can believe in"?	0.88	0,20
In the Opening Ceremony of the 2012 Summer Olympic Games, how did Queen Elizabeth II supposedly arrive?	0.41	0,28
ABBA won the Eurovision Song Contest in which year?	0.42	0,28
According to the Rolling Stones' song, Mick Jagger can't get no ... what?	0.78	0,26
Which religion forbids cremation?	0.49	0,13
What is the oldest swimming stroke, invented in the 16th century?	0.65	0,20
How many players are in a basketball team?	0.34	0,20
What magnitude of handicap is indicative of a good golf player?	0.34	0,20
How many bits does a byte have?	0.39	0,29
In the TV show "Buffy", what was her character?	0.8	0,24
How many states make up the United States of America?	0.89	0,27
What color is the blood of an octopus?	0.62	0,21
With which organ does a snake smell?	0.86	0,18
How many legs does an ant have?	0.71	0,33
Which animal is commonly used to find truffles?	0.68	0,22
How is 77 represented in Roman numerals?	0.62	0,31
Which keyboard letter do we press with the control button to undo an action in a computer program?	0.73	0,22
.MOV extension refers to what kind of file on a computer?	0.79	0,19
What are you trying to get in Sonic the Hedgehog game?	0.95	0,22
How many fighters are playable in the game Street Fighter II?	0.35	0,19
In the game of chess, which piece has the most freedom to move?	0.76	0,29
How many tiles does a player get in the game Scrabble?	0.51	0,21
What is the minimal number of pictures you must have in a row to score in the games Candy Crush Saga or Bejeweled?	0.7	0,13
Why is high blood pressure bad?	0.89	0,27

Table 23: Questions asked in the GK test and percentage of correct responses (out of 4 alternatives).

Author recognition test

ART3. Stanovich and West (1989) developed the author recognition test to estimate reading frequency, based on the assumption that people who read a lot know the names of more fiction authors than people who do not read much. Acheson et al. (2008) updated the list of authors. We further improved the test by replacing less known authors in Acheson et al. by authors who are popular nowadays, in particular among children and adolescents (the type of books university undergraduates are likely to have read). Because it is the third version of the original ART test, we call it ART3. The ART3 consists of 60 fiction author names and 30 non- author names. As shown in Study 5, against expectations, this test did not correlate more with reading comprehension than expected on the basis of the correlation between reading comprehension and crystallized intelligence. On the basis of this finding, it looks like the test is better conceived as a test of general knowledge rather than a test of book reading itself. Figure 19 and Table 24 show the relevant information (N= 573). A principal component analysis of the test indicated three big groups of items: (1) The non-authors, (2) the majority of authors, and (3) a group of British (child) authors. Because the test consists of two independent types of stimuli (authors and non-authors), the omega indices were calculated on the author items only.

Figure 19: distributions of sum scores on the author test (mean= 57.1, sd = 9.31)

reliabilty measure	alpha	ICC	omega3	omegah
value	.9	.88	.87	.44

Item	correct	Item	correct
DanielAcheson	0.76	TheresaZiegler	0.67
<i>JohnGrisham</i>	0.59	MarkRobin	0.6
JohnPunnett	0.59	<i>SuzanneCollins</i>	0.82
<i>JohnGreen</i>	0.82	<i>LemonySnickett</i>	0.67
<i>JacquelineWilson</i>	0.73	<i>DanielleSteel</i>	0.54
<i>DanBrown</i>	0.67	<i>KarinSlaughter</i>	0.28
<i>ErnestHemingway</i>	0.87	JustineWells	0.54
SaraLakin	0.63	KathrynLightner	0.73
<i>VladimirNabokov</i>	0.52	ELWilford	0.47
<i>HarperLee</i>	0.83	<i>RickRiordan</i>	0.5
<i>HilaryMantel</i>	0.39	<i>ToniMorrison</i>	0.45
<i>KurtVonnegut</i>	0.43	<i>MayaAngelou</i>	0.62
<i>ThomasWolfe</i>	0.64	<i>LisaWingate</i>	0.36
<i>CassandraClare</i>	0.46	<i>ELJames</i>	0.7
<i>RainbowRowell</i>	0.36	<i>IsabelAllende</i>	0.32
<i>JeffKinney</i>	0.61	<i>MichaelMorpurgo</i>	0.61
<i>SamuelBeckett</i>	0.71	JorgeEudoroRemache	0.78
<i>TerryPratchett</i>	0.64	KellyWeaver	0.69
KyraAppels	0.83	KimWassing	0.77
KetilChristoffersen	0.77	RoyLeeman	0.71
LudwigLorenz	0.67	JudithLSchecter	0.58
<i>TSEliot</i>	0.81	PeterMitchell	0.6
<i>AngieThomas</i>	0.37	ElizabethWigelsworth	0.7
<i>FScottFitzgerald</i>	0.88	<i>PauloCoelho</i>	0.34
<i>AnthonyHorowitz</i>	0.72	<i>HarukiMurakami</i>	0.55
<i>RoaldDahl</i>	0.88	JaneJessup	0.74
<i>TomClancy</i>	0.74	<i>HollyBlack</i>	0.36
TimSingler	0.73	<i>SarahJMaas</i>	0.48
<i>JDSalinger</i>	0.78	MelanieMarreroMorale	0.71
<i>DavidWalliams</i>	0.64	<i>StephenKing</i>	0.97
<i>JamesJoyce</i>	0.60	<i>JRR Tolkien</i>	0.89
RobertTeesdale	0.65	<i>IsaacAsimov</i>	0.47
<i>StephanieMeyer</i>	0.78	<i>VeronicaRoth</i>	0.55
<i>KateDicamillo</i>	0.31	RichardGrigley	0.71
<i>KhaledHosseini</i>	0.34	<i>GabrielGarciaMarquez</i>	0.41
EBuxton	0.6	<i>EBWhite</i>	0.61
JohnKestley	0.67	<i>AgathaChristie</i>	0.80
MahmoudAbdellah	0.73	<i>JackLondon</i>	0.42
<i>GeorgeOrwell</i>	0.93	<i>JamesPatterson</i>	0.77
ChiaraRicci	0.79	RobertoBorsani	0.75
<i>RayBradbury</i>	0.53	<i>VirginiaWoolf</i>	0.76
<i>JKRowling</i>	0.99	YasushiSugawara	0.61
<i>MargaretAtwood</i>	0.73	<i>WilliamFaulkner</i>	0.7
<i>LucindaRiley</i>	0.36	GabrielJust	0.81
<i>RalphEllison</i>	0.46	<i>AynRand</i>	0.4

Table 24: Items presented in ART3 with percentage of correct answers. Items in italics are authors.

Reading comprehension tests

We tried out four reading comprehension tests, of which we felt compelled to try to improve three. As indicated in Study 5, our efforts were not yet fully satisfactory. Therefore, we deleted the items not doing well from the tests we present here. Readers are invited to try to find better questions and response alternatives if they want to improve the reliability of the tests. Another option is to present more than one test and use factor analysis to extract the latent reading comprehension variable, as we did in Study 5.

Based on our experiences, we think the most promising reading comprehension tests include the following features:

1. The test is based on more than 12 texts addressing various topics, in order to reduce the influence of individual differences in background knowledge. Several short texts further reduce the risk of missing observations due to participants not reading a text properly.
2. The test is based on more than 30 questions, because factor loadings of questions tend to be low.
3. The texts include information participants are unlikely to know, because otherwise the test risks being a test of crystallized intelligence rather than a reading comprehension test. Good candidates are texts on topics students can relate to, but don't know yet. Topics that work well are historical and geographical facts, cultural events, and findings from behavioral and social sciences.

StuComp1. The comprehension test for university students we recommend most, is the one we tried to improve starting from Siegelman et al. (2022). In its final version, it consists of 14 texts (Wikipedia-type entries) with three questions each (four answer alternatives). Figure 20 and Table 25 provide the necessary information based on Study 5.

Figure 20: distributions of mean scores (mean = .74, sd = .12) on our own comprehension test

reliability measures	alpha	ICC	omega3	omegah
value	.73	.65	.58	.43

*ICC calculated based on mixed effect modelling: .65

Item	correct	item- rest cor	Item	correct	item- rest cor
Morse Q1	0.51	0.23	Leeches Q1	0.9	0.16
Morse Q2	0.33	0.22	Leeches Q2	0.91	0.04
Morse Q3	0.88	0.25	Leeches Q3	0.74	0.06
daVinci Q1	0.65	0.05	File-sharing Q1	0.94	0.19
daVinci Q2	0.87	0.24	File-sharing Q2	0.85	0.22
daVinci Q3	0.86	0.01	File-sharing Q3	0.9	0.1
Rainforest Q1	0.76	0.22	Pencil Q1	0.84	0.22
Rainforest Q2	0.76	0.07	Pencil Q2	0.96	0.34
Rainforest Q3	0.93	0.25	Pencil Q3	0.81	0.3
H, Gardner Q1	0.82	0.53	Technology Q1	0.39	0.14
H, Gardner Q2	0.82	0.31	Technology Q2	0.92	-0.04
H, Gardner Q3	0.85	0.28	Technology Q3	0.54	0.22
Internet Q1	0.71	0.13	Valletta Q1	0.7	0.3
Internet Q2	0.82	0.16	Valletta Q2	0.75	0.13
Internet Q3	0.74	0.28	Valletta Q3	0.4	0.36
Sleep Q1	0.96	0.07	Isle of the Dead Q1	0.49	0.24
Sleep Q2	0.91	0.43	Isle of the Dead Q2	0.5	0.09
Sleep Q3	0.97	0.13	Isle of the Dead Q3	0.5	0.02
Preening Q1	0.64	0.08	Abhaya mudra Q1	0.48	0.14
Preening Q2	0.82	0.34	Abhaya mudra Q2	0.85	0.05
Preening Q3	0.58	0.19	Abhaya mudra Q3	0.5	0.21

Table 25: Performance on StuComp1: For each item we give percentage correct responses and item-rest correlation.

StuComp2. The second best reading comprehension test in the factor analysis of Study 5 was based on the test published by Yeari et al. (2015). It includes 10 texts covering a variety of subjects shown in Table 26. After each text participants are presented with statements and have to judge whether they are true or false. In the analysis below we give the data for the 4 best statements (leaving out the worst according to Study 5). Readers are invited to find other statements that may work better. Figure 21 and Table 26 provide the necessary information.

Figure 21: distributions of mean scores on StuComp2(mean = .70, sd = .12)

reliability me	alpha	ICC	omega3	omegah
value	.67	.60	.65	.32

*ICC based on mixed effect modelling: .53

item	correct	item-rest cor	item	correct	item-rest cor
Language Q1	0,59	0,14	Vesuvius Q1	0,67	0,05
Language Q2	0,72	0,46	Vesuvius Q2	0,86	0,06
Language Q3	0,92	0,06	Vesuvius Q3	0,61	0,08
Language Q4	0,9	0,26	Vesuvius Q4	0,93	0
Language Q5	0,45	-0,39	Vesuvius Q5	0,78	0,22
Reality TV Q1	0,68	0,36	Einstein Q1	0,69	0,25
Reality TV Q2	0,55	0,08	Einstein Q2	0,68	0,08
Reality TV Q3	0,89	0,10	Einstein Q3	0,43	-0,02
Reality TV Q4	0,7	0,09	Einstein Q4	0,86	0,15
Reality TV Q5	0,91	0,12	Einstein Q5	0,89	0,03
Cheating Q1	0,32	0,32	Trojan War Q1	0,46	0,28
Cheating Q2	0,31	-0,01	Trojan War Q2	0,77	0,21
Cheating Q3	0,7	-0,09	Trojan War Q3	0,7	0,36
Cheating Q4	0,42	0,00	Trojan War Q4	0,79	0,26
Cheating Q5	0,78	0,14	Trojan War Q5	0,73	0,02
Chinese wall Q1	0,56	0,26	Airplane Q1	0,9	0,34
Chinese wall Q2	0,62	-0,10	Airplane Q2	0,86	0,01
Chinese wall Q3	0,69	0,21	Airplane Q3	0,84	0,22
Chinese wall Q4	0,79	0,02	Airplane Q4	0,56	-0,03
Chinese wall Q5	0,62	0,24	Airplane Q5	0,51	0,12
Marie Curie Q1	0,84	0,39	Anastasia Q1	0,7	0,02
Marie Curie Q2	0,7	0,05	Anastasia Q2	0,42	0,11
Marie Curie Q3	0,89	0,36	Anastasia Q3	0,61	0,18
Marie Curie Q4	0,65	0,05	Anastasia Q4	0,93	0,37
Marie Curie Q5	0,2	0,21	Anastasia Q5	0,8	0,12

Table 26: Items in StuComp2 with percentage correct and item-rest correlation. Bold items: items that were deleted for Figure 21.

StuComp3. The third best student comprehension test according to the factor analysis in Study 5 is the test we took from Kane & Miyake (2007). Participants get 10 minutes to read 20 short paragraphs and select the best continuation out of 5 options. As can be seen in Table 13, the test has a good reliability and correlates .4 - .5 with the other comprehension tests, but it correlates slightly higher with the tests loading on crystallized intelligence and also with reading rate (the faster participants read, the higher the score). As a result, the test loads on two factors rather than one. When reading rate is included, it loads on the reading speed factor. When reading rate is not included, it additionally loads on crystallized intelligence. So, it does not seem to be a pure test of reading comprehension, as it depends exceedingly on participants' background knowledge and speed of reading. Time-limited tests usually have higher reliability, but this may be due to speed of processing rather than to the quality of processing (Gernsbacher et al., 2020). Figure 22 summarizes the findings of StudComp3.

Figure 22: Distributions of sum scores in StuComp2(mean= 9.0, sd = 4.66)

reliability measure	alpha	ICC	omega3	omegah
value	.85	.82	.89	.64

StuComp4. The final comprehension test we tried out, was based on Griffin et al. (2008). It consisted of a rather long text on ice ages, followed by 24 yes/no statements. Of these 4 were bad and are left out from the final test, leaving 20 useful. Users are invited to try to find more good statements. Because of the length and the difficulty of the text, the test does not seem to work well in online testing, resulting in low reliability. On the other hand, despite the low reliability the test correlated well with the other reading comprehension tests, so that most systematic variance seems to be shared with the other tests. Figure 23 and Table 27 summarize the findings with the test.

Figure 23: Distributions of sum scores on StuComp4(mean = 14.4, sd = 2.72), together with reliability information.

reliability measurement	alpha	ICC	omega3	omegah
value	.53	.48	.52	.47

* ICC based on mixed effect modelling

item	correct	item-rest cor
Higher levels of CO2 in the atmosphere make a new ice age on Earth impossible.	0,68	0,23
The Earth is almost completely covered by glaciers during an ice age.	0,4	0,02
Average global temperatures are 25 degrees Celsius cooler during an ice age.	0,68	0,11
The planet Earth's path around the sun is connected to cycles of temperature change.	0,77	0,15
Ocean currents follow the same path around the globe as they did 20 thousand years ago.	0,74	0,27
Earth's axis relative to the Sun vary varies over time.	0,91	0,2
During an ice age, ice sheets advance repeatedly from the North Pole to the South and then retreat again.	0,65	0
The formation of mountain ranges decreases the amount of solar radiation heating the Earth.	0,61	0,07
At any given time, it is possible that more CO2 is stored by nature than is released, and vice versa.	0,91	0,14
The presence of sunspots on the Sun's surface decreases the amount of solar radiation that the Earth receives.	0,65	0,25
In the past 2 million years, there has been more Ice Age than time without vast glaciers.	0,58	0,06
Plants form carbohydrates.	0,84	0,07
CO2 is released when plants or animals decay.	0,96	0,15
When sea levels are high, more heat is stored in the oceans.	0,78	-0,01
The distance between the Earth and the Sun does not change.	0,78	0,37
To stop global warming we must try to decrease the amount of radiation from the Sun.	0,71	0,24
Global temperature changes are random and unpredictable.	0,75	0,13
Ice ages occur because the temperature of the core of the Earth cools.	0,58	0,24
Global temperature changes in cycles of 100,000 years.	0,71	0
Fluctuations in solar radiation can change average global temperatures by up to 10 degrees Celsius.	0,49	0,14
There is more solar radiation at the South Pole than at the Equator.	0,75	0,19
The formation of snow and ice can absorb huge amounts of CO2 from the atmosphere.	0,78	-0,02
Land masses on Earth rise and fall.	0,88	0,1
Minerals on land that are carried to the sea by rivers, bring CO2 into the atmosphere.	0,65	0

Table 27: Questions from StuComp4, with accuracy rates and item-rest correlations. Items in bold are items that ideally are replaced.

Reading frequency questionnaire

As part of our validation efforts, we also designed a reading frequency questionnaire. It contains 24 items gauging how frequently people take part in six reading activities (4 questions per activity). The test was administered in Studies 1, 3, and 5, to a total of 573 participants. As can be seen in Table 28, reliability of the scales is good. Still, the information from the questionnaire is limited (low correlations with other tests) and we did not think it right to include the questionnaire in a factor analysis, given the asymmetric frequency distributions (Figure 25). If this type of information is to be used, it looks like a rethink of the approach may be useful. All in all, it looks like the reading frequency questionnaire we developed does not improve much on existing reading frequency questionnaires consisting of a single question (Wimmer & Ferguson, 2022).

	alpha	rel. factor
RF-Fiction	.87	.91
RF-NonFiction	.88	.91
RF-Newspaper	.83	.96
RF- Websites	.88	.91
RF-socialmedia	.9	.94
RF-Wordgame	.77	.81

Table 28: Reliability of the reading frequency scales (N = 573)

Attention check for vocabulary testing

A problem in test situations is how to decide that participants are taking the task seriously. In our studies we decided on the basis of unrealistically rapid or slow processing and on performance close to random responding. Another approach often used consists of attention checks (e.g., Hauser & Schwarz, 2016; Kees et al., 2017). These are questions that are easy to answer correctly if attention is paid to the question. Participants who (consistently) fail the attention checks are not considered for analysis.

It is fairly easy to include attention checks in vocabulary tests. All we have to do, is include a few items that should be known to everyone with a minimal knowledge of English. Failing to answer one or two of these checks would then be a red flag.

The data of Study 1 included a few such stimuli, which were answered correctly by nearly all participants and still not easy enough to be obvious decoys. Ten of them are listed in Table 29. A number of these items can easily be integrated in the vocabulary tests we presented and in other tests as well, offering researchers an extra tool for quality assurance.

Word	Extra	Alt1	Alt2	Alt3	Alt4	Pcorrect
period	It was a difficult <period>.	question	time	thing to do	book	0.975
dig	Our dog often <digs>.	solves problems with things	makes a hole in the ground	wants to sleep	enters the water	0.975
drive	He <drives> fast.	swims	learns	throws balls	controls a car	0.975
poor	We are <poor>.	have little or no money	feel happy	are very interested	do not like to work hard	0.975
haunt	The house is <haunted>.	full of decorations	rented	empty	occupied with ghosts	0.975
crowd	He got hurt in the <crowd>.	region between the stomach and the top of the leg	noisy fight	group of people	race across a field of snow	0.975
nun	We saw a <nun>.	long thin creature that lives in the earth	terrible accident	woman following a strict religious life	unexplained bright light in the sky	0.975
maintain	Can they <maintain> it?	keep it as it is	make it larger	get a better one than it	get it	0.970
soldier	She is a <soldier>.	person in a business	person who studies	person who uses metal	person in the army	0.970
lonesome	He felt <lonesome>.	ungrateful	very tired	without company	full of energy	0.970

Table 29: Easy items that can be added as attention checks to language tests with four response options

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Figure 1: Meta-analysis studies examining the relationship between scores on a vocabulary test and Big Five personality traits. Studies ordered in time.

Analysis: Hamilton (2017) for The jamovi project (2020) version 1.2.

Forest Plot Openness

Forest Plot Conscientiousness

Forest Plot Extraversion

Forest Plot Agreeableness

Forest Plot Neuroticism