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Predicting Speech-in-Noise Recognition from Performance on the Trail Making Test: Results from a Large-Scale Internet Study

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Running title: Predicting speech perception using the trail making test

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Short summary (100 words)

The purpose of the study was to investigate the relation between performance on the Trail Making Test and speech-in-noise recognition. All tests were administered over the internet and a sample of 1509 adults aged between 18 and 91 years old was recruited. The results of the study indicate that better performance in the TMT is associated with better speech-in-noise recognition scores. This association was not limited to the higher order processes indexed in the TMT-B test but was also observed in relation to performance in the simple TMT-A test, thought to index processing speed.

ABSTRACT (250 words)

Objective: The aim of the study was to investigate the utility of an internet-based version of the trail making test to predict performance on a speech in noise perception task

Design: Data were taken from a sample of 1509 listeners aged between 18 and 91 years old. Participants completed computerized versions of the Trail Making Test and an adaptive speech-in-noise recognition test. All testing was conducted via the internet.

Results: The results indicate that better performance on both the simple and complex subtests of the TMT are associated with better speech-in-noise recognition scores. 38 percent of the participants had scores on the speech in noise test that indicated the presence of a hearing loss.

Conclusions: The findings suggest that the TMT may be a useful tool in the assessment, and possibly the treatment, of speech-recognition difficulties. The results indicate that the relation between speech-in-noise recognition and TMT performance relates both to the capacity of the TMT to index processing speed and to the more complex cognitive abilities also implicated in TMT performance.

Key words: trail making test, cognition, internet screening, speech-in-noise perception

INTRODUCTION

The link between cognitive and speech perception abilities has been the subject of a growing body of research. It is now generally accepted that better cognitive skills are associated with better speech perception, especially in conditions in which the speech has been degraded in some way (for example, by noise, hearing loss or hearing aid signal processing). Working memory span, in particular, has been found to be a significant predictor of speech recognition (see Akeroyd, 2008 for a review). The aim of this study is to investigate the relation between cognition and speech-in-noise perception in a large sample of participants, tested over the internet.

Working memory is typically measured using some version of a complex span task, most commonly the reading span test (Daneman and Carpenter, 1980; Rönnberg et al, 1989). Complex span tests consist of a processing and a storage task. In the case of the reading span test, thought to measure verbal working memory, participants are presented with a series of sentences in blocks of increasing size. At the end of each sentence, the listeners must indicate whether the sentence made sense or not (processing element) and at the end of each block, they must recall either the first or last word of each sentence in the block (the storage element).

While there is much evidence of a relation between speech in noise perception and working memory, the mechanisms behind this association are less well understood. Rönnberg and colleagues (2003, 2008, 2013) proposed the Ease of Language Understanding model which posits that when an incoming speech signal cannot be matched to a representation stored in the long-term memory, explicit processing of the signal occurs. The greater a person's working memory capacity, the more resources are available for this explicit processing and thus better speech in noise recognition performance is observed relative to people who have poorer working memory capacities.

As such, performance in complex working memory span tasks have been shown to be the best cognitive predictors of speech in noise recognition in both listeners with and without hearing loss (Akeroyd, 2008). However, the nature of the precise cognitive processes measured by complex span tasks has been the subject of some debate with executive functions (Whitney et al, 2001), resistance to proactive interference (Kane and Engle, 2000), attention (Sörqvist et al, 2012), task switching (Liefooghe et al, 2008) and information processing speed (Salthouse, 1992) all having been suggested to influence performance in complex span tasks. However, if the relation between complex span test performance and speech recognition is due to one of these suggested subcomponents of working memory, it may be possible to use simpler tests to investigate this relationship.

One test that may be suitable is the trail making test (TMT, Reitan, 1958, 1992). Compared to complex span tests, the TMT is simpler to understand and less time-consuming. The TMT consists of two parts. The TMT-A requires the participant to join together a series of points in numerical order while the TMT-B requires the participant to join together a series of points alternating between numerical and alphabetical order. Performance on the trail making test is thought to be influenced by a number of cognitive processes including task switching, attention and executive control in the TMT-B and processing speed in the TMT-A, many of the same components thought to be involved in complex span task performance and hence, language recognition (see for example, Sánchez-Cubillo et al, 2009).

Indeed, the few studies that have investigated the relationship between performance in the TMT and speech recognition have shown promising results with TMT performance being shown to predict recognition of speech in a novel accent (Adank and Janse, 2010), unaided speech in noise recognition in young listeners with normal hearing (Ellis and Munro, 2013) and aided speech recognition in older listeners with hearing impairment (Ellis and Munro, in press). However, Woods et al (2013) found that, once the effects of age and hearing loss had been partialled out, TMT scores predicted speech recognition in a background of speech shaped noise and multi-talker babble, yet not when speech was presented in quiet or in a background of only speech shaped noise.

The TMT is also known to be sensitive to age-related cognitive deficits and is commonly included in test batteries developed to identify such decline (see for example, Nasreddine et al, 2005). These findings mean that the TMT may potentially be a promising tool in the assessment and treatment of hearing loss. Additionally, the speed and ease with which the test can be administered makes it particularly suitable for internet-based delivery. A number of previous studies have used the internet to administer screening tools relating both to hearing (see for example, Nachtegaal et al, 2009; Molander et al, 2013) and to cognitive decline (see for example, Dougherty et al, 2010). Administering the tests via the internet is cheaper and easier than face-to-face testing, meaning that tests can be administered to a greater number of participants than would usually be the case. The fact that large numbers of people can be tested may compensate for the reduced control over the conditions in which the tests are completed (relating to equipment, environment, internet speed etc) compared to laboratory-based tests. The internet may also prove to be an important medium via which to make cognitive interventions or screening tools accessible to a greater number of people, potentially leading to improvements in the early-detection of hearing/cognitive issues and easier implementation of subsequent interventions.

The aim of this study was, therefore, to investigate the relationship between performance on a computerised version of the TMT and speech in noise perception in a large sample of participants with and without hearing loss. It is expected that better performance in the TMT will be associated with better speech in noise perception.

MATERIALS AND METHODS

Participants

A total of 1509 Swedish-speaking participants (94% of whom were native speakers), recruited via newspaper advertisements, completed at least part of the internet screening trial. The focus of the advertisements was on recruiting people for a hearing screening test, thus cognitive testing was not emphasized. The only selection criterion applied was that all participants were required to be at least 18 years old. Participants (52% male) were aged between 18 and 91 years, with a mean age of 63 years. Of these participants, 1369 completed the speech in noise test, 1139 completed the TMT-A and 1139 completed the TMT-B.

Study Design

Participants completed a number of auditory, cognitive and subjective tasks relating to hearing and speech perception. Testing took place via the internet and completion of all tests took approximately 45 minutes. The analyses presented will be based on a subset of these data, namely the results of the TMT A & B and the Hearing Bridge speech-in-noise recognition tests. Further details of the other tests administered can be found in Molander et al (in review).

Outcome measures

Speech in Noise Recognition (SR) Test

The Hearing Bridge speech in noise test (see Laplante-Lévesque et al, 2015; Molander et al, 2013) was administered to participants. This is an adaptive closed-set test in which di-syllabic words, spoken by one female speaker, are presented in a background of speech-shaped noise. Ten words were used in the test, each repeated once giving a total of 20 trials. The order of presentation of the stimuli was randomized. After presentation of a stimulus, participants were required to indicate which word they heard by using a mouse to click on one of ten icons on the screen corresponding to the ten words used in the test. Participants were also able to give a 'don't know' response (by clicking on an additional icon) if they could not identify the stimulus. A 'don't know' response was treated as an incorrect response. A 1-up-1-down adaptive procedure was used with a step of 2 dB SNR and an initial presentation level of 4 dB SNR. The outcome measure was the SNR at which responses, based on the last 10 trials, were correct 50% of the time. According to Laplante-Lévesque et al (2015), who report the results of a subsample of the data analysed in this study, a score of -3.8 dB SNR or higher is considered to indicate the presence of a hearing loss.

Trail Making Test

A computerized version of the TMT was developed for use in the study. The TMT-A consisted of a series of points labeled 1-15, the participants' task was to join the points in the correct numerical order using the mouse or trackpad. The TMT-B again required participants to join a series of 15 points, only this time they were required to alternate between numerical and alphabetical order (i.e. 1-A-2-B-3….). If an incorrect response was made, the selected point flashed red to indicate that an alternative response should be made. The outcome measure was the time taken to complete each test. Errors were penalized only in that they increased the total time taken to complete the tests, thus accuracy was always 100%. Prior to administration of either the TMT-A or B, instructions were presented on the screen along with an animation showing how to correctly complete the test and demonstrating what would happen if an incorrect response was made. Participants were given the option of re-reading the instructions or seeing the animation again if they so wished prior to commencing the test. The traditional paper and pencil of the TMT has been criticized due to differences in the total trail length between the TMT-A and the TMT-B with the TMT-B trail being substantially longer than the TMT-A trail. It has been argued that it may be these differences, rather than additional complexity, that result in the longer time required to complete the TMT-B compared to the TMT-A (see for example, Gaudino et al, 1995). In order to minimize this confound, the spatial configuration of the points on the screen was randomized each time and the overall distance between the points (that is, the total length of the trail) was kept the same in all possible configurations of both the TMT-A and B.

Analysis

Descriptive statistics were calculated and the assumptions for the use of parametric statistics were checked. Where appropriate, variables were transformed, converted to z-scores and outliers removed (see results section for further details). Correlational analyses were then conducted using Pearson's r statistic. Partial correlations, with the effect of age controlled for, are also reported, as are the results of a multiple regression analysis. Missing data points were excluded on a pairwise basis from the correlational analyses. The reported p-values are based on one-tailed tests, with better performance in the cognitive tests being expected to correlate with better performance in the speech recognition test.

RESULTS

Descriptive Statistics

The group mean time taken to complete the TMT-A test was 23.67 seconds (median = 21.9 seconds) with a standard deviation of 9.18. The group mean time taken to complete the TMT-B was somewhat higher at 38.79 seconds (median = 33.25) with a standard deviation of 20.1. The group mean SNR required to identify words 50% of the time was -5.10 dB (median = -5.51) with a standard deviation of 4.6. 38% of participants required an SNR of -3.8 dB or above to identify words 50% of the time, suggesting the presence of a hearing loss.

Data Preparation

In order to compensate for a non-normal distribution of scores in both the TMT-A and TMT-B tests, data were transformed using a logarithmic transformation. Data were then converted to z-scores and outliers (defined as any case with a z-score greater than 3.29) were removed. This led to the removal of 9 scores from the TMT-A and 9 scores from the TMT-B, all of which related to completion times substantially longer than the mean. It should be noted that the following analyses and figures are based on the z-scores of the transformed variables, therefore, the resulting values do not correspond directly with raw scores on the administered tests.

Correlational analyses

Figure 1 depicts scatterplots showing the relation between scores on the TMT-A and TMT-B ($n=1130$, $r = .59$, $p < .001$, upper-left panel), TMT-A and SR ($n = 1054$, $r = .37$, $p < .001$, upper-right panel), and TMT-B and SR ($n = 1055$, $r = .33$, $p < .001$, lower-left panel) respectively.

Figure 1 here

The scatterplots in Figure 2 show the relation between age and scores on the SR (n = 1369, r = .51, p <.001, upper-left panel), TMT-A (n = 1134, r = .49, p = <.001, upper-right panel), and TMT-B (n = 1134, r = .37, p <.001, lower-left panel) respectively.

Figure 2 here

Due to the significant correlations between the participants' age and TMT-A, TMT-B and SR scores, a series of partial correlations, controlling for the effects of age, were carried out. The scatterplots in Figure 3 show the relation (with the effect of age controlled for) between TMT-A and TMT-B (r = .50, p < .001, df = 1127, upper-left panel), TMT-A and SR (r = .17, p <.001, df = 1051, upper-right panel), and TMT-B and SR (r = .19, p <.001, df = 1052, lower-left panel) respectively.

Figure 3 here

Multiple Regression analysis

The data were then further investigated using a multiple regression analysis in which the outcome variable was performance in the SR test and the predictor variables were age, TMT-A score, and TMT-B score, entered into the model in that order. The results of the analysis are presented in Table 1. Each of the three predictors contributed significantly to the model and were thus retained. The resulting model produced $R^2 = .274$, F (3, 1050) = 131.83, p < .001. Each of the three predictors has a significant positive regression weight indicating that poorer performance (indicated by higher thresholds) in the speech recognition test is associated with increasing age and poorer performance in the TMT-A and –B tests (in which higher scores indicate poorer performance).

Table 1 here

DISCUSSION

The results of the study show that performance on the TMT can be used to predict speech-in-noise recognition in adults with and without hearing loss. Both performance on the TMT-A and the TMT-B were significantly correlated with speech-in-noise recognition, an effect that retained its significance even when the effects of age had been partialled out. The results of the multiple regression analysis suggest that of the predictors assessed, age was by far the strongest, yet scores on both the TMT-A and -B contributed significantly to the final model.

This study is not the first to have used an internet-based method of hearing screening (see for example: Nachtegaal et al, 2009 and Molander et al, 2013), however, it is the first to validate the relation between cognition and speech-in-noise recognition using such a method of administration. In addition to the use of an internet based method of administration, the version of the TMT used in this study differs from the traditional version in a number of ways. Firstly, there are fewer points in the internet based version of the test, 15 compared to 24 in the traditional pen-and-paper version. This method of administration also means that the spatial configuration of the points in the TMT can be varied in order to control for this confounding factor (Arnett and Labowitz, 1995; Gaudino et al, 1995). Additionally, in the internet-based version of the test, the total trail length (that is, the length of the line required to join the points in sequential order) is controlled such that the length is always equal in the TMT-A and TMT-B. In the traditional paper-and-pencil version of the TMT, the trail length of the completed TMT-B is 56cm longer than that of the completed TMT-A leading some researchers to argue that, in addition to being more cognitively demanding than the TMT-A, the TMT-B is also likely to be influenced by individual differences in motor speed and visual search (Gaudino et al, 1995). Therefore, by ensuring that the trail length remains constant between the TMT-A and the TMT-B, the influence of motor speed on performance can be reduced.

Salthouse and Fristoe (1995) developed a computerized test based on the TMT. This test, known as the connections test, consisted of 25 points that were to be joined in sequential order (in simple and alternating conditions, akin to the TMT-A and TMT-B) by pressing the arrow keys on the keyboard. While trail length and spatial characteristics of the test were not controlled for, by examining the time needed per keystroke along with the total number of keystrokes used and the time required to complete the test, the effects of spatial configuration and trail length could essentially be partialled out. The results of the two experiments reported by Salthouse and Fristoe (1995) showed that, while increasing age was associated with slower performance overall, all age-related effects seemed to be mediated by performance in the simple condition, there being no significant ageing effects unique to performance in the alternating condition of the test.

The fact that numerous studies report additional effects of aging specific to performance in the alternating condition of the TMT (see for example: Rasmusson et al, 1998; Periáñez et al, 2007) is likely to reflect the additional motor demands required for the completion of the TMT, decreased motor speed being significantly associated with increased age (see for example, Seidler et al, 2010) and poorer performance in tests of long-term memory (Rönnberg, 1990). Further evidence for the influence of spatial characteristics of the TMT on test performance can be seen by comparing the mean relative difference in performance in the TMT-A and B when the spatial characteristics of the test have and have not been controlled for. In the present study, participants took 63% longer to complete the TMT-B than the TMT-A. This is a substantially lower figure than that derived from data reported in other studies using the TMT in similar populations. Additional calculations conducted on the data reported by Tombaugh (2004) show that in a sample of 911 participants aged between 18 and 89 years old, it took on average 113% longer to complete the TMT-B compared to the time taken to complete the TMT-A. This is similar to the figure derived from the data reported by Periáñez et al (2007) based on a sample of 223 participants aged between 15 and 80 years old, in which completion of the TMT-B took on average 115% longer than completion of the TMT-A. Furthermore, based on data reported by Arnett and Labowitz (1995) from a sample of 54 young adults, when the spatial characteristics of the TMT were controlled for, it took an average of 49% longer to complete the TMT-B than the TMT-A, compared to 135% longer when the spatial characteristics of the TMT were not controlled for.

Previous studies investigating the role of cognition in speech-in-noise recognition have shown that complex tests, such as those measuring working memory capacity, are better predictors of speech-in-noise recognition than are simpler tests such as those indexing basic reaction times, which do not tend to be significantly associated with speech-in-noise recognition (see Akeroyd, 2008 for a review). Whilst significant effects of performance in both the TMT-A and –B were observed in the results of the current study, the difference in the magnitude of the effects was very small. This suggests, in contrast to previous research, that the complex cognitive abilities indexed by the TMT-B do not play a substantially greater role in predicting speech-in-noise recognition performance than do the relatively simple abilities indexed by the TMT-A. One possible explanation for this discrepancy may relate to differences in the stimuli used in the speech-in-noise test. The speech-in-noise test used in the present study was relatively simple in that it was closed set, required the listener only to identify single words and used a noise signal that did not have any informational content. Thus the complex cognitive processes needed to inhibit irrelevant semantically meaningful noise, or to use contextual information to aid speech-recognition, were unlikely to have played a significant role in performance in the test used in this study. It is therefore likely that the relatively small contribution of cognition to speech recognition observed in this study is an underestimate of the degree to which cognitive abilities may influence speech perception in everyday life. It is also possible that the decision to use 4 dB SNR as the starting point of the adaptive track may have resulted in floor effects for some of the participants. In order to examine this possibility, the data were reanalyzed after removing the scores from all participants who required an SNR of 3 dB or above to achieve a score of 50% correct. The pattern of statistical significance was unaffected. Thus, while the observed effects of TMT scores on speech – in –noise recognition were small, the fact that these effects were significant, even when the effects of age had been partialled out, suggests that further investigation of the relation between the TMT and speech recognition is merited. Another possible explanation is that age-related decline in processing speed, which in the case of the TMT is likely to reflect both motoric and cognitive mechanisms, is in itself associated with higher-order cognitive decline. According to a review by Seidler et al (2010), age related declines in the dopaminergic system may result in both cognitive and motor decline. That being the case, it may be that a decline in motor speed, which would affect performance in both the TMT-A and the TMT-B, may mask the effects of a decline in higher-order cognitive functions that would affect performance in the TMT-B only. Thus it may be that aging itself affects which processes are indexed by the TMT.

Conclusions

The findings of the study validate the association between cognition and speech-in-noise recognition in a large sample and show that the TMT may be a promising tool in online screening. That the test can be administered over the internet with comparable results to those obtained in earlier laboratory-based studies means that the test can be made accessible cheaply and easily and can be completed at home without the involvement of a clinician. The fact that the spatial characteristics of this version of the TMT can be varied and controlled for between the TMT-A and B mean that it may be particularly suitable for use in cases in which an individual may have to complete the test more than once, for example in cognitive screening test batteries, in longitudinal studies or in cognitive training programmes. Such studies may also shed further light on the specific cognitive abilities being measured by the TMT and the precise way in which these affect speech perception, an aim outside the scope of the present study.

In order to determine the extent to which the TMT could be utilized in a clinical audiology setting, it is necessary to first determine whether the TMT can be used to predict individual differences in speech recognition in everyday environments and /or hearing aid benefit, be this in terms of amplification in general or to specific signal processing options. Whether hearing loss itself moderates the relation between the TMT and speech-in-noise recognition should also be investigated. As performance in the speech-in-noise test was itself used to indicate the presence of a hearing loss, it was not possible to investigate this using the data from the present study. The effect of speech and/or noise type on the relation between performance in the TMT and speech-in-noise recognition should also be examined further.

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Figure 1. Scatterplots showing the relation between performance in the TMT-A and TMT-B (upper left panel); TMT-A and SR test (upper right panel); TMT-B and SR test (lower left panel). Regression lines indicate a significant correlation.

Figure 2. Scatterplots showing the relation between performance in the SR test and age (upper left panel); TMT-A and age (upper right panel); TMT-B and age (lower left panel). Regression lines indicate a significant correlation.

Figure 3. Scatterplots showing the relation, with the effect of age removed, between performance in the TMT-A and TMT-B (upper left panel); TMT-A and SR test (upper right panel); TMT-B and SR test (lower left panel). Regression lines indicate a significant correlation.

Variable	Model 1			Model 2			Model 3		
	B	*SEB*	*β*	*B*	*SEB*	*β*	*B*	*SEB*	*β*
Age	0.17	0.01	0.50*	0.14	0.01	0.41*	0.13	0.01	0.40*
TMT-A				0.80	0.15	0.17*	0.47	0.17	0.10**
TMT-B							0.62	0.16	0.13*
R^2		.24			.26			.27	
F for change in R^2		334.13*			30.8*			15.8*	

* p < .001 ** p < .005

Figure 1

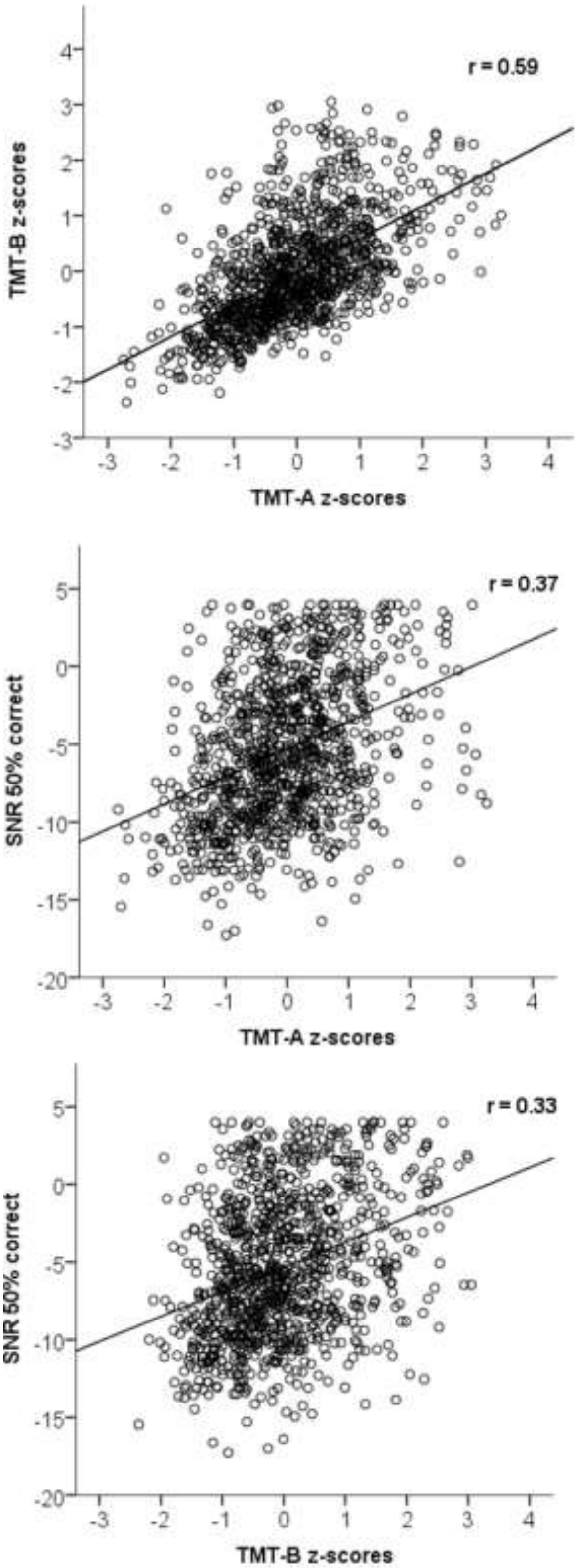

r = 0.59
TMT-B z-scores
TMT-A z-scores
r = 0.37
SNR 50% correct
TMT-A z-scores
r = 0.33
SNR 50% correct
TMT-B z-scores

Figure 2

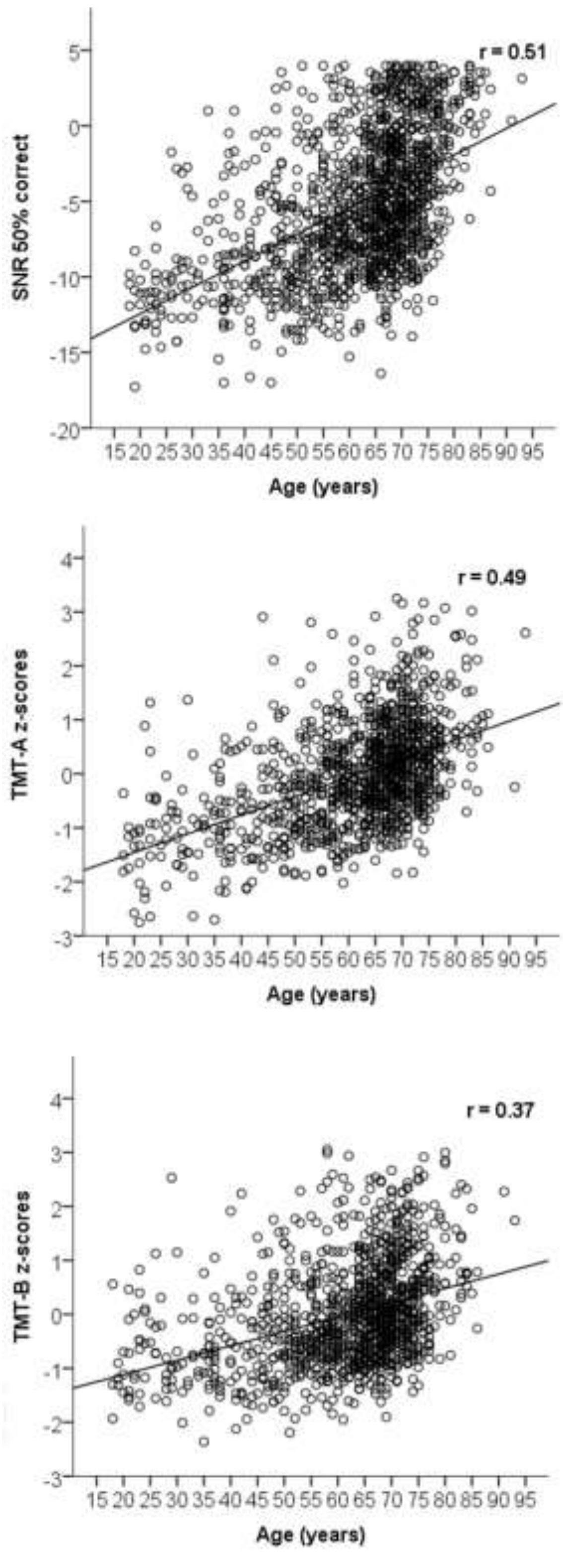
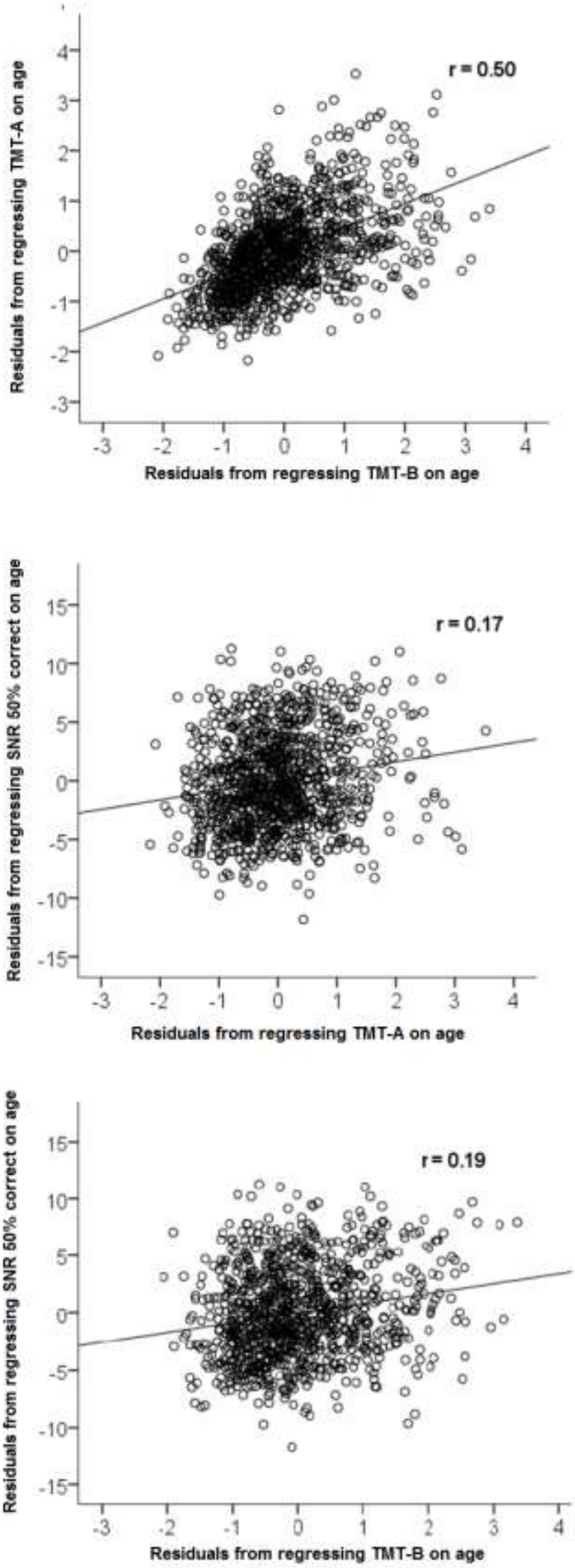

r = 0.51
SNR 50% correct
5
0
-5
-10
-15
-20
15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95
Age (years)
r = 0.49
TMT-A z-scores
4
3
2
1
0
-1
-2
-3
15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95
Age (years)
r = 0.37
TMT-B z-scores
4
3
2
1
0
-1
-2
-3
15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95
Age (years)

Figure 3


r = 0.50
Residuals from regressing TMT-A on age
Residuals from regressing TMT-B on age
r = 0.17
Residuals from regressing SNR 50% correct on age
Residuals from regressing TMT-A on age
r = 0.19
Residuals from regressing SNR 50% correct on age
Residuals from regressing TMT-B on age