Intelligence and Information Processing

Article *in* Journal of Individual Differences · January 2012

DOI: 10.1027/1614-0001/a000078

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(September 1, 2011)

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Original Article

Intelligence and Information Processing

A Mismatch Negativity Analysis Using a Passive Auditory Backward-Masking Task

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Abstract. The relationship between mental ability (MA, Raven Progressive Matrices) and speed of information processing was examined by recording mismatch negativity (MMN) parameters from 41 women during passive listening to auditory standard and deviant stimuli with backward masking. The intertone interval (ITI) between the offset of the standard or deviant tone and the onset of the masking tone was varied between conditions (25, 50, or 150 ms). Three versions of a trail-making test (Zahlen-Verbindungs-Test, ZVT) were also presented to obtain a behavioral index of information processing speed. Multiple regression analysis showed that the more difficult versions of the ZVT and midline frontal MMN latency at 25-ms ITI were both significant predictors of MA. Across all ITI conditions, the higher ability (HA) group exhibited a shorter MMN latency than the lower ability (LA) group. Finally, the HA group also had a larger MMN amplitude than the LA group for the 25-ms ITI condition. These results indicate that low-level auditory discrimination, indexed by MMN, contributes to individual differences in fluid intelligence. In this regard, MMN provides a valuable tool for examining individual differences in intelligence in individuals who are not able to comply with psychometric testing.

Keywords: intelligence, passive auditory backward-masking, information processing, mismatch negativity, trail-making test

Introduction

There is strong evidence for a robust and reliable relationship between higher mental ability (MA), as defined by psychometric tests of intelligence, and faster performance on simple tasks using inspection time (IT) and response time (RT) measures (for reviews, see Deary, 2000; Jensen, 1998, 2006; Vernon, 1990). IT is defined as the time required to accurately discriminate between two stimuli that are easily discernable at longer exposure durations. Vickers, Nettlebeck, and Willson (1972) defined IT as the minimum exposure duration of a stimulus pair for allowing a discrimination of relative magnitude. Higher ability (HA) subjects accurately discriminated the stimuli at shorter exposure durations than those of lower ability (LA). Backward-masking has been added to the IT paradigm and successfully applied to the study of individual differences in MA (Vickers & Smith, 1986). In the backward-masking procedure, the target to be discriminated is presented briefly (usually less than 100 ms) and then followed by an overwriting masking stimulus. The duration of the interval between the target stimulus and the mask is widely used as an index of the time required for a target stimulus in sensory memory to be further processed to short-term memory (Atkinson & Shiffrin, 1968). More specifically, it has been suggested that, at shorter interstimulus intervals, the masking stimulus degrades the contrast of the target stimulus by means of a temporal integration with it (DiLollo, 1980; Eriksen, 1966). Previous studies indicated that HA individuals have better attention focusing and memory abilities (Jausovec & Jausovec, 2000; Schweizer & Moosbrugger, 2004), but it is to date unknown which stages of information processing are enhanced in HA individuals.

The importance of mental speed for the understanding of human intelligence is supported by a number of robust relationships found between response time (RT) and MA (Deary & Stough, 1996; Neubauer & Bucik, 1996; Vernon, 1990; Zhang, Caryl, & Deary, 1989).

Research on MA using behavioral RT measures is augmented by event-related potential (ERP) measures (Stelmack & Houlihan, 1995). ERP studies using the backward-masking paradigm provide a window into the neural processes underlying individual differences in speed of information processing, although these studies failed to show a consistent pattern of effects (for a review Stelmack & Beauchamp, 2001). In a later study Bazana and Stelmack (2002) reported a robust relationship between MA and

DOI: 10.1027/1614-0001/a000078

speed of information processing by employing a backward masking procedure in which the frequency and duration of the stimulus is held constant and the intertone interval (ITI) is varied. HA subjects had both shorter ITs and ERP latencies than LA subjects. These effects were interpreted in terms of more efficient information processing in HA subjects.

From ERP recordings, an index of sensory discrimination, called mismatch negativity (MMN), can be derived that is not affected by attention or cognitive activity (Näätänen, 1992). The MMN is typically elicited in a passive task (i.e., the subject is reading a book) when infrequent (deviant) stimuli are presented in a sequence of frequent (standard) stimuli. MMN is obtained by subtracting ERPs to the standard stimuli from ERPs to the deviant ones. This negative wave is believed to reflect the function of an automatic detector of stimulus change and thus can provide information on preconscious auditory discrimination (Näätänen, Paavilainen, Tiitinen, Jiang, & Alho, 1993). Given that larger MMN amplitude responses are indicative of enhanced accuracy of sensory discrimination this measure can be used as an index of discrimination ability (Näätänen & Alho, 1997). Since it was demonstrated that MMN wave can be cancelled with appropriate backward masking arrangements, it has been argued that the amplitude of MMN reflects the strength of the memory trace in the echoic memory buffer (Näätänen & Winkler, 1999).

The present study aimed at investigating whether individual differences in MA, as defined by the Raven's Standard Progressive Matrices (RSPM; Raven, 1954), are manifested in MMN measures. Robust effects, consisting of a larger P300 amplitude and shorter MMN latency for HA, were observed using an oddball paradigm with backward masking in which the standard and deviant tones were followed by a masking tone (Bazana & Stelmack, 2002; Beauchamp & Stelmack, 2006; De Pascalis, Varriale, & Matteoli, 2008). Shorter MMN latencies for HA versus LA were observed at ITIs of 25, 50, and 150 ms between the deviant and masking tones (Bazana & Stelmack, 2002). Higher MMN amplitudes were associated with HA at the 25 ms ITI. Since MMN latency decreased with shorter ITIs (rather than increasing, as expected) the authors suggested that the deviant tone and masking tone were processed as a gestalt rather than a pure tone stimulus. This hypothesis was confirmed in a later auditory oddball study by replicating the MA effects and demonstrating that the mask does not interfere with the detection of the deviant target stimulus, but rather that target and mask are integrated as a single compound stimulus (Beauchamp & Stelmack, 2006)

In a similar study (Sculthorpe, Stelmack, & Campbell, 2009), HA was associated with larger MMN amplitudes to deviant tones of an auditory pattern violation task, while no significant relationship was found between MA and MMN latency. The effect on MMN amplitude replicates the findings previously reported by Bazana and Stelmack (2002), and was seen as indicating that HA individuals detect violations of a pattern more easily than LA individuals, and that pattern violation discrimination occurs prior to consciousness.

The present study employed a traditional oddball paradigm using a backward-masking discrimination task similar to that reported by Bazana and Stelmack (2002) in which standard and deviant tones were followed by a masking tone. Auditory sequences were first presented in a passive condition during which participants were instructed to read a book while ignoring the tones, and then in an active condition requiring participant to detect the target tones within the series of standard tones. Considering that previous MA findings (Bazana & Stelmack, 2002) were obtained using a mental ability measure derived the WAIS-R, the aim of the present study was to extend the previous findings to figural-fluid intelligence as measured by Raven Matrices (Raven, 1938). There is convincing evidence that the various forms of the Raven Matrices provide a specific estimate of intelligence linked to two distinguishable processes, one that has been variously coined "figural" and the other "analytical" or "analogical" (Lynn, Allik, & Irwing, 2004; Mackintosh & Bennett, 2005; Van der Ven & Ellis, 2000). It was expected that higher Raven MA would be associated faster information processing speed (as assessed by a trail-making test), larger MMN amplitudes, and shorter MMN latencies. Moreover, it was expected that the accuracy of target vs. standard discrimination in the active condition would be associated with larger MMN amplitudes at shorter ITIs.

Method

Participants

A group of 42 right-handed psychology students (all female; $M = 24.9$, $SD = 3.9$ years) participated in the study. All participants were unacquainted with their MA. Women who were in a menstrual period were invited for the EEG recordings on another occasion. All participants reported no history of neurological or hearing problems. The subjects were seen individually in the lab, and upon arrival they were informed about the nature of the study. Participants who agreed to participate were required to fill out a written consent. The study was conducted according to the ethical norms of the Italian Association of Psychology (AIP).

Auditory Discrimination Task

Participants were first tested for normal hearing by delivering 8 tones (duration 25 ms, 1000 Hz) in steps of 10 dB (SPL) starting from –90 to 0 dB in ascending intensity. Stimuli were prepared by using a WaveLab-3.0 system and tested by a Bruel and Kjaer (type 221B) precision sound-level meter. All auditory stimuli were presented by using

E-prime-1.1 system (Schneider, Eschman, & Zuccolotto, 2002). All participants had normal hearing. Participants were then enrolled in a passive auditory oddball task consisting of a series of frequently occurring standard tones (81% of trials) and infrequently occurring deviant tones (19% of trials). Standard and deviant tones were followed by a masking tone. The tones were presented binaurally through headphones. The standard tones had a frequency of 600 Hz. The target tones had a frequency of 700 Hz. The duration of the standard and deviant tones was 25 ms. The masking tone had a frequency of 1000 Hz and a duration of 50 ms. The intensity level of all tones was 88 dB. The ITI between the offset of the standard tone or deviant tone and the onset of the masking tone was varied between trial blocks (between 150, 50, or 25 ms). The intertrial interval, i.e., the time from the offset of the mask to the onset of the standard tone, was held constant at 600 ms. For each of the three ITI conditions there was one block of 500 trials. The ITI conditions were administered in random order.

Each participant performed on two versions of the backward-masking auditory discrimination task. In the active condition, the participant was instructed to detect the occurrence of the target tone; in the passive condition, the participant was instructed to read a piece from a novel book and to ignore acoustic tones delivered via headphone. The order of presentation of the passive and active conditions was fixed across participants with the passive condition always preceding the active one. This was done because, in the passive condition, participants were kept ignorant of the frequency differences tones. At the end of the passive condition, the participant was requested to shortly report the content of the read piece and was asked the following question: "During your reading, were you aware of any difference in the acoustic frequency of the tones?" None of the participants indicated that they were aware of the difference in the tonality between the standard and deviant tones.

In the active condition the participants were instructed to press the space bar of the computer keyboard when they detected a target stimulus. The electrocortical results of the active condition were published elsewhere (De Pascalis et al., 2008). The performance data associated with the active condition are used in the current report to provide a behavioral measure of auditory discrimination.

Procedure

The experiment was carried out in two sessions. In the first session, participants completed the RSPM (M = 50.2, SD = 7.0; Italian norms IQ scores: M = 117.4, SD = 10.3, n = 41). The RSPM scores were piled on the right of a platykurtic distribution (skewness = –0.34, SE = 1.06; kurtosis = –1.32, SE = 0.75) with a range of 38–60. The Cronbach's coefficient α for RSPM scores was α = 0.86. One outlier scoring lower than 2 SD from the RSPM sample mean was excluded from data analyses.

In addition, participants completed the Zahlen-Verbindungs-Test (ZVT; Oswald & Roth, 1978), a trail-making test used to obtain a behavioral index of information processing speed. Three versions of the ZVT – versions 1, 4, and 6 – were selected from Vernon's study (Vernon, 1993). Each of these versions of the ZVT was administered using a speeded format (i.e., the number of items completed in 45 s). Task complexity increases with successive versions of the task. In version 1, participants were required to connect numbers in a forward fashion (1, 2, 3, 4, and so on); in version 4, number/letter should be connected in a backward fashion (adapted for the Italian alphabet: 21, Z, 20, V, 19, U, and so on); in version 6, odd numbers should be connected in a backward fashion (179, 177, 175, and so on). The more complex versions 4 and 6 of the ZVT have high reliabilities (0.83 and 0.91, respectively) and account for as much as 50% of the IQ variance in IQ scores. In this regard, the ZVT findings provide considerable support for the notion that speed of information processing is an integral component of general intelligence (Vernon, 1993; Vernon & Weese, 1993).

Participants were assigned to a higher (HA, n = 20) and lower (LA, n = 20) ability group on the basis of a median split (median = 48; IQ Md = 117.0) of RSPM scores (one subject was excluded since she had a RSPM score falling on the median). The mean RSPM for HA participants was M = 56.5, SD = 3.6 (IQ: M = 126.6, SD = 3.1) and for LA participants it was M = 44.4, SD = 2.8 (IQ: 108.3, SD = 5.8). The HA and LA groups had a similar mean age (M = 24.4, SD = 2.8, and M = 24.2, SD = 2.7, respectively).

Participants returned within 2 weeks for a second session during which their EEG was recorded when performing on the two versions of the auditory discrimination task.

Electrophysiological Recordings

EEG and electro-ocular (EOG) activity were acquired continuously in a DC mode via a 40-channel NuAmps DC amplifier system (Neuroscan Inc., ~~[location of company?]~~). The gain was set at 200, digitization rate of 500 Hz with a 200 Hz cutoff. Electrode impedance was under 4 kΩ. An offline EOG correction routine was used (Gratton, Coles, & Donchin, 1983). The horizontal EOG was monitored via a pair of tin electrodes placed 1 cm lateral to the outer canthus of each eye, and the vertical EOG was monitored via a separate bipolar montage placed above and below the center of the left eye. The EEG was recorded continuously with an electrocap using pure tin electrodes from 30 scalp sites (Fp1, Fp2, F7, F8, F3, F4, FT7, FT8, T3, T4, FC3, FC4, C3, C4, CP3, CP4, TP7, TP8, T5, T6, P3, P4, O1, O2, Fz, FCz, Cz, CPz, Pz, Oz) referenced to linked-ears electrodes. The ground electrode was located 10 mm anterior to Fz.

The EEG was analyzed offline into discrete, single-trial epochs. Each epoch began 50 ms prior to stimulus onset and continued for 850 ms after stimulus. EEG traces exceeding +100 µV were rejected. Single trials were sorted and averaged for each ITI condition (150, 50, or 25 ms), stimulus type (standard or deviant), and electrode site (30). For each electrode location, waveforms were referenced to a 50 ms baseline preceding the standard or deviant tone. Averaged waveforms associated with standard tones were then subtracted from averaged waveforms associated with deviant tones resulting in a difference waveform. This was done for each ITI condition, separately. The maximum peak amplitude of this difference wave and its corresponding peak latency were determined within a 100–350-ms window following stimulus onset to provide MMN amplitude and latency scores, respectively.

Data Analysis

The percentage of correct discriminations associated with the active condition was calculated and used as a performance measure of auditory discrimination.

Since the largest MMN amplitudes were observed at Fz and FCz, only MNN peak amplitudes and latencies at Fz and FCz were considered for statistical analyses. This choice was made to reduce problems of multicollinearity in the multiple regression analysis.

Repeated measures ANOVAs were performed on MMN amplitude and latency scores, with Location (Fz, FCz) and ITI (150, 50, 25, ms), as within-subjects factor, and MA (HA, LA by median split) as a between-subjects factor. Huynh–Feldt e correction of significance levels was applied when necessary (Vasey & Thayer, 1987). Partial η^2 and ω^2 values are also reported. Posthoc comparisons of the means were carried out by using a Scheffé test with an overall (or family-wise) a of $p < .05$.

The associations of MA with ZVT Z21-V20 performance scores, and MMN measures were evaluated using Spearman's correlation coefficients. MMN measures at Fz and FCz and behavioral measures correlating significantly with MA were considered predictors of MA scores by using a multiple regression model. To prevent type-I error probability, the significance level was set at $p < .01$ for the regression analysis.

Results

Performance and MMN Differences Between MA Groups

The ANOVA performed on discrimination accuracy scores yielded a main effect of group, $F(1, 39) = 4.90$, $p < .05$; $\eta^2 = .12$, $\omega^2 = .06$. Accuracy was higher for the HA group compared than for the LA group, 70.8 vs. 51.8, respectively. The ITI main effect was also significant, $F(2, 78) = 7.58$, $p < .001$; $\eta^2 = .18$, $\omega^2 = .07$. Accuracy increased with ITI (52.7%, 62.3%, and 73.1%, respectively). The interaction between MA group and ITI far from ~~significant,~~ $p = .52$.

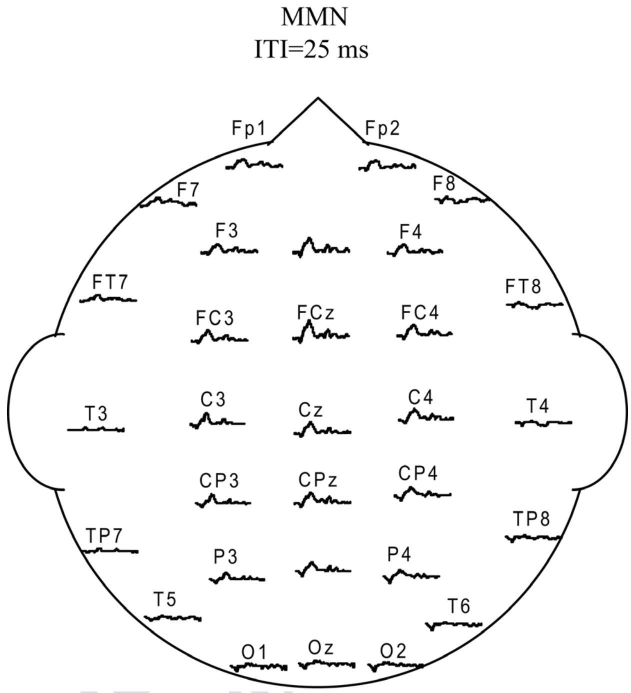

Figure 1. Scalp distribution of event-related potential difference waveforms (deviant – standard) during a passive ignore condition with 25-ms intertone intervals (ITIs).

The MMN wave revealed the largest MMN amplitudes at Fz and FCz sites. As a sample of this distribution, Figure 1 displays the topographical map of the MMN difference wave associated with the 25-ms ITI; Figure 2 presents the MMN waveform at Fz for both groups and each ITI. MMN amplitude is larger for the HA group compared to the LA group, but only in the 25 ms ITI condition.

The ANOVA on MMN amplitudes at Fz and FCz did not yield a significant main effect for MA and ITI. However, the interaction between MA and ITI was significant, $F(2, 78) = 3.36$, $p = .044$, $\eta^2 = .16$, $\omega^2 = .09$. Posthoc multiple comparisons verified that the HA group had a larger MMN for the 25-ms ITI than the LA group (2.5 µV vs. 1.4 µV, $p < .05$). As Figure 2 suggests, group differences were not significant in the 50 ms and 150 ms ITI. The main effect of Location was significant, $F(1, 39) = 10.25$, $p = .0027$, $\eta^2 = .26$, $\omega^2 = .23$. Posthoc comparisons indicated that MMN amplitude was more pronounced over FCz than over Fz (–3.0 µV and 2.1 µV, respectively; $p < .05$).

The ANOVA on MMN latencies at Fz and FCz yielded a significant main effect of MA group, $F(1, 39) = 12.65$, $p = .001$, $\eta^2 = .32$, $\omega^2 = .29$. This effect showed that the HA group had shorter latencies than the LA group (178 ms vs. 218 ms, respectively). The main effect of ITI was also significant, $F(2, 78) = 3.80$, $p < .05$, $\eta^2 = .09$, $\omega^2 = .05$. MMN latency was longer in the 150 ms ITI condition compared to the two shorter ITI conditions (216 ms vs. 198 and 192 ms). There were no other significant effects.

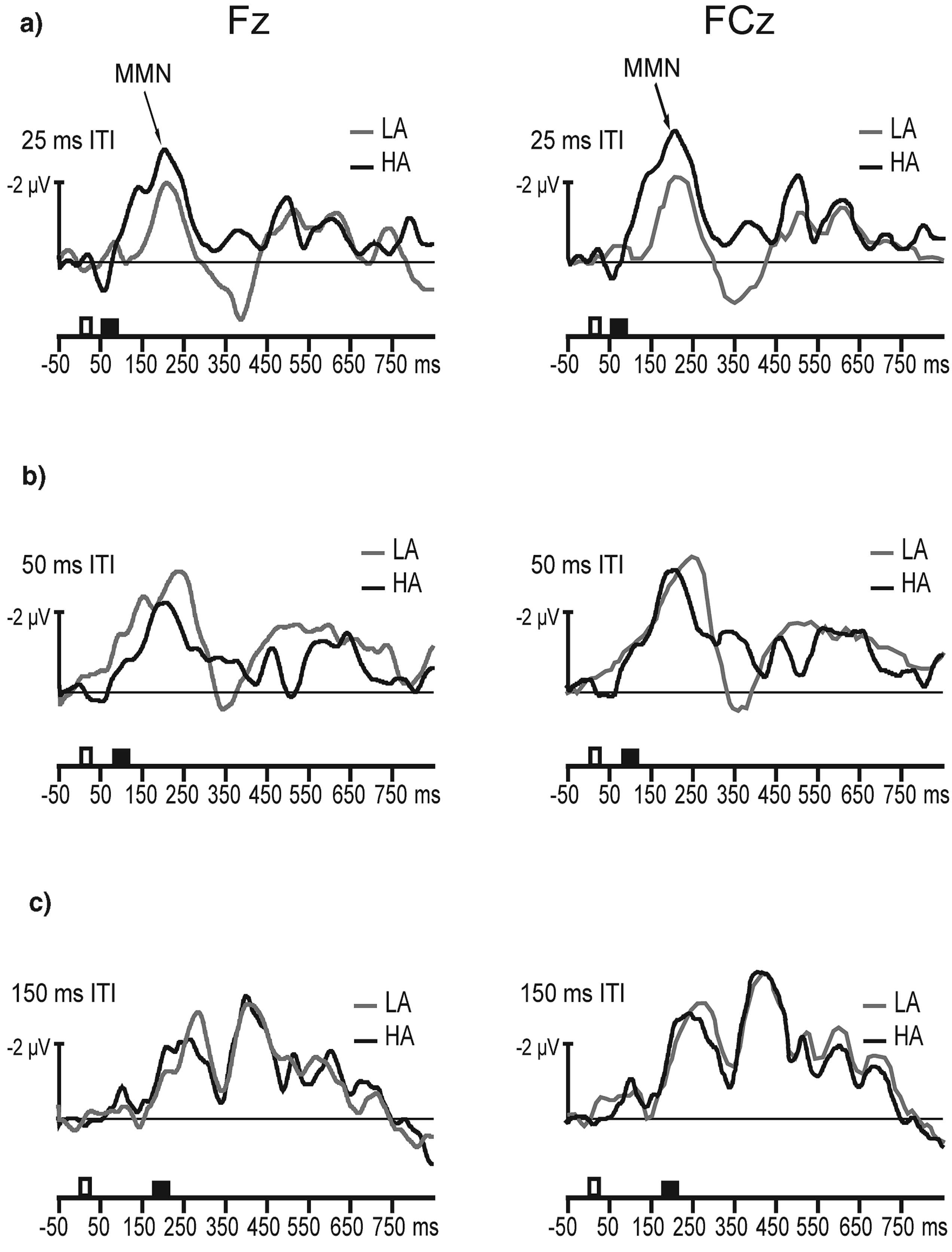

Figure 2. Stimulus-locked difference wave at frontal sites Fz and FCz (deviant minus standard) for higher ability (HA) and lower ability (LA) groups during a passive ignore condition with (a) 25-ms, (b) 50-ms, and (c) 150-ms intertone intervals (ITIs).

Table 1. Spearman correlations of Raven's Mental Ability with MMN measures at Fz and FCz scalp sites and Accuracy at 150-ms, 50-ms, and 25-ms intertone intervals (ITIs), and Zahlen-Verbindungs-Test

	Passive condition		
MMN measures	150-ms	50-ms	25-ms
Fz			
Amplitude	.11	.10	–.20
Latency	–.33*	–.54**	–.42**
FCz			
Amplitude	.13	.07	–.27
Latency	–.23	–.45**	–.28
	Active condition		
Accuracy (tonal discrimination)	.29*	.25	.33*
Zahlen-Verbindungs-Test			
ZVT 1–2–3 .35*	–	–	–
ZVT 179–177 .32*	–	–	–
ZVT Z21-V20 .46**	–	–	–

Notes. MMN = mismatch negativity; Fz = frontal; FCz = fronto-central. $^*p < .05$. $^{**}p < .01$; $n = 41$.

Relationships Between Performance and MMN Measures and MA

Discrimination accuracy in the active task correlated significantly with MA in the 150-ms and 25-ms ITI conditions. These correlations are presented in the upper part of Table 1.

All ZVT measures correlated significantly and positively with MA, as can be seen in the middle part of Table 1.

MMN latencies at Fz correlated significantly and negatively with MA for all three ITIs, but at FCz a significant correlation was obtained only for the 50 ms ITI. MMN amplitudes were not associated with MA (see bottom part of Table 1).

Finally, discrimination accuracy correlated with MMN amplitude, but only in the 25 ms ITI condition ($r = –0.49$, $p < .01$, and $r = –0.46$, $p < .01$, for Fz and FCz, respectively). Discrimination accuracy was not associated with MMN latency.

A multiple linear regression model was tested to predict RSPM scores from performance and MMN measures. The model included as predictors the MMN latency scores and ZVT Z21-V20 scores that were correlated highest with RSPM scores (at least $p < .01$, see Table 1). MMN latencies were those obtained at Fz for the 25-ms and 50-ms ITIs, and at FCz for the 50-ms ITI condition. The results of the regression analysis are presented in Table 2. The predictors accounted for 47% of the total variance in RSPM scores. The results indicated that speed of performance, indexed by the ZVT Z21-V20, and MMN latency at Fz, associated with 25-ms ITI condition, are two statistically significant predictors of RSPM scores (see Table 2).

Table 2. Summary of multiple regression analysis for Zahlen-Verbindungs-Test (ZVT Z21-V20) and MMN latency scores predicting Raven's Mental Ability scores

	Mental ability			
Variable	*B*	*SE B*	β	Variance inflation
ZVT Z21-V20	.260	.090	.351**	1.015
Fz_25	–.060	.029	–.483	3.757
Fz_50	–.033	.018	–.232	1.165
FCz_50	.008	.026	.075	3.540

Notes. MMN = mismatch negativity; Fz = frontal; FCz = fronto-central. $F(5, 40) = 8.01$, $p < .0001$; $R^2 = 0.47$, Adj. $R^2 = 0.41$. $^*p < .05$; $^{**}p < .01$ ~~[Author: Please explain *B* and *SE B*]~~.

Discussion

The ability of the brain to automatically detect violation of regularities has been described as a kind of "primitive intelligence" in the auditory cortex (Näätänen, Tervaniemi, Sussman, Paavilainen, & Winkler, 2001). There is an abundance of experimental evidence indicating that MMN amplitude reflects sensory discrimination difficulty (Näätänen, Paavilainen, Rinne, & Alho, 2007). More specifically, as the difference between deviant and standard stimuli is reduced (e.g., by varying physical characteristics of sound), it has been observed that smaller MMN amplitudes and longer latencies are associated with lower detection rates (Winkler, Reinikainen, & Näätänen, 1993).

The current study manipulated discrimination difficulty using a backward masking procedure. Discrimination accuracy in the active task decreased with shorter intervals between tones and masking stimuli. Most importantly, discrimination accuracy in the active task was higher in the HA group. In addition, MMN latencies in the passive task correlated negatively with MA. Finally, MMN amplitudes in the shortest ITI condition of the passive task were larger in the HA group than in the LA group.

The performance results are consistent with an interference model suggesting that backward masking hampers tone processing in echoic memory (e.g., Näätänen & Winkler, 1999). It should be noted, however, that the notion of interference seems to be challenged by the current observation that MMN latency was shorter in the shortest ITI condition – rather than longer as would be predicted by the Näätänen and Winkler (1999) interference model. The current observation, however, may be compatible with an integration-theory perspective in which the deviant stimulus and the masking stimulus are integrated (Tervaniemi, Saarinen, Paavilainen, Danilova, & Näätänen, 1994). This is consistent with findings reported previously by Stelmack and colleagues (Bazana & Stelmack, 2002; Beauchamp & Stelmack, 2006). These authors suggested that at shorter ITIs the target and mask may be perceived as a compound stimulus. Thus, on the basis of the present findings, it is not simple to derive a clear explanation of the fact that the relationship between MMN amplitude/latency and MA is dependent on length of the ITI.

The primary focus of the present study was on the relationship between figural-fluid intelligence, as indexed by Raven matrices, and MMN parameters obtained in a passive oddball task. We observed that scores derived from the ZVT-type tests were all significantly correlated with Raven MA scores. Moreover, the more difficult ZVT-type test score was a robust predictor of MA. This pattern of findings is in accordance with previous findings showing an association between ZVT-type test measures and individual differences in general intelligence indexed by the WAIS-R (Bazana & Stelmack, 2002; Vernon, 1993; Vernon & Weese, 1993).

More importantly, the current findings show larger frontal MMN amplitudes in HA than in LA participants in the shortest ITI condition (25 ms). This observation is in line with the results reported recently by Sculthorpe et al. (2009), who employed an auditory pattern-violation paradigm. In this study, MMN amplitude was found to be larger also in HA than in LA participants in the more difficult auditory discrimination condition. In addition, the regression model including ZVT Z21-V20 and MMN latency scores as predictors accounted for 47% of the total variance in Raven scores. The results indicate that, in addition to ZVT Z21-V20 performance, frontal MMN latency is a significant predictor of individual differences in fluid intelligence. This finding demonstrates that the speed of low-level auditory information processing is an integral component of this measure of intelligence. Within this context, "low-level" refers to information processing outside awareness, as it has been demonstrated that the MMN in passive oddball tasks develops prior to information reaching consciousness (Näätänen et al., 2007; Sussman, 2007).

In conclusion, the current findings indicate that information processing reflected in the MMN recorded during the performance of a passive oddball task contributes to individual differences in figural-fluid intelligence. Our MMN findings suggest that the model of auditory stimulus representation and selective attention proposed by ~~Naatanen~~ and collaborators (Näätänen, 1990; Näätänen & Winkler, 1999) may be sufficiently general to include those higher order memory operations in the visual system that are demanded by mental ability tests such as the Raven Matrices. In this sense, the current findings extend previous findings demonstrating a relationship between electrocortical manifestations of higher-level visual information processing and intelligence. Thus, it has been observed that the latency of the P300 component of the brain potential recorded during digit matching and synonym/antonym detection tasks is negatively correlated with mental ability (Houlihan, Stelmack, & Campbell, 1998; McGarry-Roberts, Stelmack, & Campbell, 1992). Finally, the MMN would provide a powerful tool for obtaining estimates of mental ability in clinical populations from whom psychometric intelligence measures are difficult to obtain (e.g., in severely mentally retarded individuals) as the MMN can be recorded without rapport or focused attention requirements (e.g., van der Molen et al., 2011).

Acknowledgments

We would like to thank all our participants for being part of the study. Special thanks are due to Maurits van der Molen who checked the manuscript for word choice and syntax and did data analyses.

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