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B Data collection/entry
C Data analysis/statistics
D Data interpretation
E Preparation of manuscript
F Literature analysis/search
G Funds collection

INVESTIGATING THE ASSOCIATION BETWEEN WORKING MEMORY, SPEECH IDENTIFICATION IN NOISE, AND P300 IN ADULTS WITH HEARING IMPAIRMENT

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Abstract

This study investigated the association between working memory capacity (WMC), P300 amplitude and latency, and their relation to speech identification in noise (SiN) in individuals with sensorineural hearing impairment (HI). Twenty adults (mean age=58 years) were recruited and their WMC was measured using a reading span task. SiN was evaluated using the clinical Quick speech-in-noise test. Auditory P300 latency and amplitude, which are known to index information processing, were recorded using a conventional oddball paradigm. WMC was significantly correlated with P300 latency, but was not associated with P300 amplitude (before or after controlling for age and magnitude of HI). In addition, SiN was not significantly correlated with WMC, P300 latency, or amplitude. P300 using tonal stimuli may be a good measure of speed of information processing and attentional control within the working memory system; however, it does not appear to be related to SiN in adults with HI.

Key words: speech identification in noise • working memory • attention control • P300 latency • P300 amplitude

ESTUDIO DE CORRELACIONES ENTRE LA MEMORIA OPERATIVA, EL RECONOCIMIENTO DEL HABLA EN PRESENCIA DE RUIDO Y EL P300 EN PERSONAS ADULTAS CON HIPOACUSIA

Resumen

En el presente trabajo se estudió la relación entre la capacidad de la memoria operativa (inglés: *working memory capacity*, WMC), la amplitud y la latencia del potencial P300, así como su relación en función del reconocimiento del habla en presencia de ruido (inglés: *speech identification in noise*, SiN) en personas con hipoacusia neurosensorial. Se examinaron veinte personas (edad promedia=58 años). En dichas personas se midió la capacidad de la memoria operativa (WMC) utilizando el test de alcance de la memoria de trabajo (*span test*); se examinó el reconocimiento del habla en presencia de ruido (SiN), el que se evaluó en base al test clínico Quick speech-in-noise. La latencia y la amplitud del potencial auditivo P300, de los que se sabe que son un indicador del procesamiento de la información, se registraron utilizando el procedimiento estándar *oddball*. La capacidad de la memoria operativa (WMC) no estaba correlacionada de manera importante con la latencia del potencial P300, sin embargo no manifestaba ninguna relación con la amplitud P300 (tanto antes como después de contemplar la edad o el grado de pérdida de audición). Además, el reconocimiento del habla en presencia de ruido (SiN) no estaba correlacionado de manera importante ni con la latencia ni con la amplitud de potencial P300. El potencial P300 registrado en respuesta a un estímulo tonal puede ser buen indicador para medir la rapidez del procesamiento de la información y el control atencional en el sistema de memoria operativa, aunque parece no estar correlacionado con el reconocimiento del habla en presencia de ruido (SiN) en personas con hipoacusia.

Palabras clave: reconocimiento del habla en presencia de ruido • memoria operativa • control atencional • latencia P300 • amplitud P300

ИССЛЕДОВАНИЕ СВЯЗЕЙ МЕЖДУ РАБОЧЕЙ ПАМЯТЬЮ, РАСПОЗНАВАНИЕМ РЕЧИ В ШУМЕ И P300 У ВЗРОСЛЫХ С ТУГОУХОСТЬЮ

Изложение

В настоящей работе изучалась связь между объемом рабочей памяти (англ. *working memory capacity*, WMC), амплитудой и латентностью потенциала P300, а также их зависимость от распознавания речи в шуме (англ. *speech identification in noise*, SiN) у лиц с нейросенсорной тугоухостью. Было обследовано двадцать человек (средний возраст=58 лет). У этих лиц был исследован WMC с помощью задания на объем памяти; проверено SiN, оценивавшееся с помощью клинического теста Quick speech-in-noise. Латентность и амплитуда слухового вызванного потенциала P300, о которых известно, что они являются показателем обработки информации, регистрировались с использованием стандартной процедуры oddball. WMC демонстрировал значимую корреляцию с латентностью потенциала P300, однако не показывал связи с амплитудой P300 (как до, так и после учета возраста или степени нарушения слуха). Кроме того, SiN не показывала значимой корреляции ни с латентностью, ни с амплитудой потенциала P300. Потенциал P300, регистрируемый в ответ на тональный раздражитель, может являться хорошим показателем, измеряющим скорость обработки информации, а также контроль внимания в системе рабочей памяти, хотя, как представляется, не имеет корреляции с SiN у лиц с нейросенсорной тугоухостью.

Ключевые слова: распознавания речи в шуме • рабочая память • контроль внимания • латентность P300 • амплитуда P300

BADANIE ZWIĄZKÓW MIĘDZY PAMIĘCIĄ ROBOCZĄ, ROZPOZNAWANIEM MOWY W SZUMIE I P300 U OSÓB DOROSŁYCH Z NIEDOSŁUCHEM

Streszczenie

W niniejszej pracy badano związek między pojemnością pamięci roboczej (ang. *working memory capacity*, WMC), amplitudą i latencją potencjału P300 oraz ich zależność od rozpoznawania mowy w szumie (ang. *speech identification in noise*, SiN) u osób z niedosłuchem czuciowo-nerwowym. Zbadano dwadzieścia osób (średni wiek=58 lat). U osób tych zmierzono WMC, wykorzystując zadanie na zakres pamięci; zbadano SiN, który oceniano, wykorzystując kliniczny test Quick speech-in-noise. Latencję i amplitudę słuchowego potencjału P300, o których wiadomo, że są wskaźnikiem przetwarzania informacji, zarejestrowano z wykorzystaniem standardowej procedury oddball. WMC znacząco korelowała z latencją potencjału P300, jednak nie wykazywała związku z amplitudą P300 (zarówno, gdy przed jak i po uwzględnieniu wieku czy stopnia ubytku słuchu). Ponadto, SiN nie korelował w sposób istotny ani z latencją, ani z amplitudą potencjału P300. Potencjał P300 rejestrowany w odpowiedzi na bodziec tonalny może być dobrym wskaźnikiem mierzącym szybkość przetwarzania informacji oraz kontrolę uwagową w systemie pamięci roboczej, choć wydaje się nie korelować z SiN u osób z niedosłuchem.

Słowa kluczowe: rozpoznawanie mowy w szumie • pamięć robocza • kontrola uwagowa • latencja P300 • amplituda P300

Introduction

Working memory (WM) is as a multi-component system that is crucial for temporarily storing relevant information while performing a wide range of complex cognitive tasks. WM differs from short-term memory in that it involves a number of subsystems, such as executive attention and episodic buffer, which are crucial for performing complex tasks such as language comprehension, reasoning, and learning [1]. The P300 event-related potential (ERP) has long been thought to reflect several cognitive processes including WM, information updating, auditory discrimination, attention, decision-making, sequential information processing, and resolution of uncertainty [2,3]. Recent studies suggest that the P300 amplitude reflects the attention control mechanism within WM [4]. The latter reference describes how switching attention in an updating task leads to a significant increase in the positive ERP component. WM has been found to be crucial for speech identification in noise (SiN) for older individuals with hearing impairment (HI) [5,6]. However, when age is controlled for, either by limiting the study to younger participants or by factoring out the effect of age, the association between working memory capacity (WMC) and SiN is often no longer significant [7–9].

Based on these facts, we hypothesized that P300 may be a viable clinical tool to objectively quantify information processing ability within the WM system, which may be important for achieving good SiN. To date, the relationship between the P300 and SiN is unclear. This study is an exploratory study to find potential associations among WMC, P300, and SiN ability in individuals with sensorineural hearing impairment (HI).

Material and Methods

Participants

Out of 28 volunteers with sensorineural HI, 20 adults (M=58 years; range=25 to 71 years; 4 females; 16 males) with recordable P300 were recruited for this study. Participants' hearing thresholds were measured using a calibrated Grason–Stadler GSI-61 audiometer using a standard clinical procedure in a double-walled sound-treated room. All participants had bilaterally symmetric sensorineural HI based on a current comprehensive audiological evaluation performed by the clinical audiologist. Only participants who were native English speakers were recruited for the study. Figure 1 shows the participants' air-conduction hearing thresholds (right and left ear averaged) for 250 Hz to 8000 Hz. The study was conducted in full compliance with the University of Arkansas for Medical Sciences Institutional Review Board procedures.

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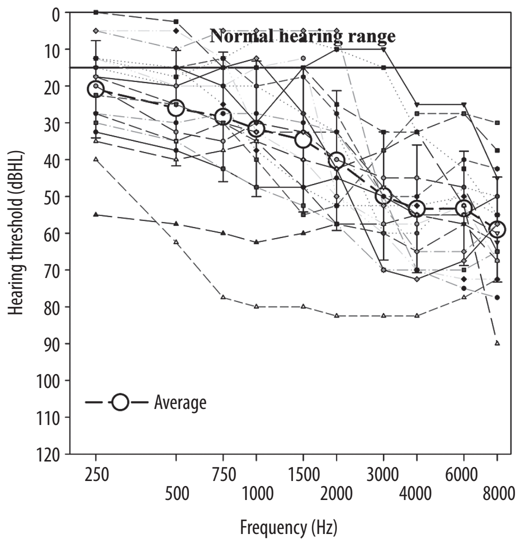

Figure 1. Individual air conduction hearing thresholds (averaged across ears), together with the grand average (circles)

Auditory evoked potential measurements

P300 recordings were obtained using a Bio-logic Navigator Pro evoked potential system. Two blocks of trials with 200 standard (1000 Hz; 80% probability) and 50 deviant (2000 Hz; 20% probability) tonebursts were presented. Recordings continued until responses to 50 deviant tones were collected in the average. Tonal stimuli were 50 ms in duration (10 ms rise/fall) presented pseudorandomly at a stimulation rate of 1.1/sec. The presentation level was set to 40 dB SL re PTA, which determined the dB HL setting on the Bio-Logic system. A physical measurement of the stimulus was obtained to determine the peak-to-peak reference equivalent threshold sound pressure level (RETSPL) using a calibrated digital Type 1 sound level meter, 2 cc coupler, pure tone generator with insert earphones, and digital oscilloscope. The tonal stimuli used had a measured RETSPL of 18.1 dB ppeSPL. The electrode montage included Cz (non-inverting), EOG (non-inverting), A1 and A2 (linked inverting), and Fz (ground). Electrode sites were prepared with disposable alcohol wipes and Nuprep skin prep gel (Weaver and Company, Aurora, CO). Disc electrodes were Ag/AgCl filled with Ten20 conduction paste (Weaver and Company, Aurora, CO) held in place with medical grade tape. All electrode impedances were less than 5 kΩ with interelectrode impedances less than 2 kΩ. Recording parameters were 533 ms epoch, 960.6 Hz sampling rate (512 points), 0.1–100 Hz bandpass filter, and 50,000×gain. The EOG channel was set with an artifact rejection level of ±100 µV. Participants were engaged in an active task of silently counting the number of higher pitch (deviant) tones they heard and report them after each stimulus run. For each participant, the recordings in response to the deviant tones were averaged together for later analysis.

Sentence identification in noise (SiN)

The Quick speech-in-noise test [10] was administered using a standard clinical procedure following practice trials to measure the participant's ability to identify speech in noise. Two separate lists of sentences (12 sentences with 60 keywords) were presented to measure SiN. Participants were asked to repeat the sentences they heard. They were instructed to recall all the words they were able to identify; if they could not repeat the whole sentence. Participants' SNR loss was calculated as per instructions to index SiN. Quick speech-in-noise sentences along with multitalker babble were amplified based on individual hearing thresholds using a Tucker-Davis Technologies RZ6 real-time signal processor to compensate for decreased audibility and delivered via Sennheiser HD280 Pro headphones. The NAL-R linear formula was used to calculate the gain for each ear at octave frequencies ranging from 250 Hz to 6000 Hz [11]. The level of speech stimuli was fixed and calibrated at 65 dBA SPL before the frequency-specific gain was applied.

Reading span task (Rspan)

Participants' WMC was measured using a widely used reading span task [12]. This task was designed to include processing of sentences interleaved with letters to be remembered for later recall. For each trial in the Rspan task, participants were presented with sentences (to be read) and asked to make true/false judgments about each sentence by pressing the respective button on the response box. Immediately after each sentence, a letter was presented to be remembered for later recall. After a series of sentences and letters (set size ranged between 3 to 7), participants had to recall the letters in correct serial order. Each participant's WMC was calculated based on number of letters recalled in correct serial order across all trials. A participant's reaction time for each trial for sentence judgment was recorded as an index of their WM processing speed.

Results

Reliable P300 was recorded in 20 out of 28 participants. One participant with poor scores on both Rspan (0.16) and SiN (10.5) tasks was removed from the analysis. Statistical analysis was performed only on 19 participants with recordable P300. All statistical analyses were performed using SPSS version 24. Descriptive statistics for measures from all tasks are presented in Table 1. For analysis, speech frequency – pure tone threshold average (SF-PTA) at 500, 1000, 2000, and 4000 Hz were combined for both ears and used as their magnitude of HI. Table 2 shows the correlations among variables and partial correlation controlling for age and magnitude of HI. Partial correlation analysis controlling for age was performed because evidence suggests that the strength of the association between WMC and SiN might vary with age [8,13]. Correlational analysis showed that P300 latency was negatively related to WMC even after controlling for age and magnitude of HI.

The top panel of Figure 2 shows the P300 waveforms for four participants with high WMC scores (>75th percentile) and the bottom panel shows the P300 waveforms for four participants with low WMC scores (<25th percentile). There was a positive correlation between P300 latency and WM processing speed. However, this correlation was not significant after controlling for age and magnitude of HI. P300 amplitude was not related to P300 latency and WM

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Table 1. Descriptive statistics for all measures (N=19)

Measures	*M*	*SD*	Skewness
SF-PTA (dB HL)	37.69	14.68	0.86
SNR loss (dB)	1.74	2.60	0.39
WMC (proportion)	0.67	0.15	–0.69
WM RT (ms)	1004.78	205.03	0.10
P300 lat (ms)	316.36	33.98	–0.05
P300 amp (μV)	6.97	2.78	–0.24

SF-PTA – speech frequency-pure tone average threshold; RT – reaction time; lat – latency; amp – amplitude.

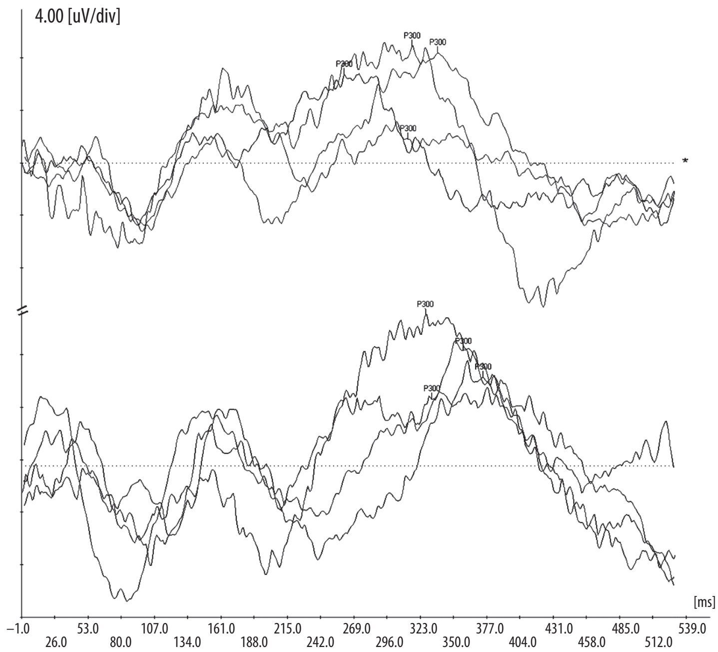

Figure 2. P300 waveforms for four participants with high WMC scores (>75th percentile, top panel) and for four participants with low WMC (<25th percentile, bottom panel)

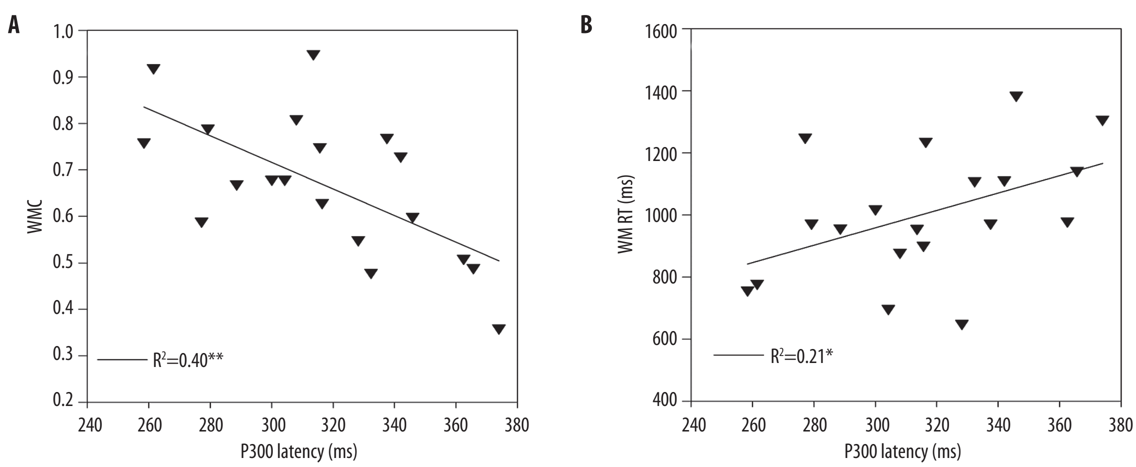

Figure 3. Scatterplots with regression line showing the association between WMC and P300 latency (**A**), and WM processing speed (WM RT) and P300 latency (**B**)

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Table 2. Zero-order correlation above the diagonal; partial correlation (controlling for age and SF-PTA) below the diagonal (N=19)

	Age	SF-PTA	SNR loss	WMC	WM RT	P300 lat	P300 amp
Age	1	–0.31	0.16	–0.26	0.40	0.45	–0.35
SF-PTA		1	0.24	–0.16	–0.13	–0.12	0.15
SNR loss			1	–0.27	–0.17	–0.19	0.16
WMC			–0.17	1	**–0.48***	**–0.63****	–0.09
WM RT			0.13	–0.43	1	**0.46***	–0.23
P300 lat			–0.32	**–0.61****	0.34	1	0.44
P300 amp			0.23	–0.19	–0.11	–0.34	1

* $p<0.05$; ** $p<0.01$ (two-tailed). SF-PTA – speech frequency-pure tone average threshold; RT – reaction time; lat – latency; amp – amplitude.

measures. SiN as indexed by SNR loss was not significantly related to WMC, P300 amplitude, or P300 latency.

Discussion

The goal of this exploratory study was to investigate the potential association among P300, WM, and SiN in individuals with HI. Stimuli for P300 and SiN tasks were amplified to compensate for reduced audibility due to HI. WMC was measured using the Rspan task which demands "attention control" to successfully perform both processing of sentences and maintenance of letters [14,15]. As shown in Figure 3A, we did find a moderate negative correlation between WMC and P300 latency, which supports the notion that P300 latency might reflect general attentional control mechanism within the WM system. This view is consistent with the popular context updating theory, which suggests that P300 represents an attention-mediated process that compares and evaluates current and previous events within WM [16].

Individuals with early (shorter) P300 latencies were also faster in processing information (reaction time in the WM task); Figure 3B. The negative correlation between WMC and WM processing speed suggests that individuals who processed the sentences faster were the ones who also recalled the letters more accurately. These results suggest that P300 latency may possibly index the speed of information processing, which is proportional to the time taken to evaluate the stimuli [19,20]. However, after controlling for age and magnitude of HI, there was a lack of correlation between WM processing speed and P300 latency, suggesting that these factors may mediate the auditory information processing indexed by P300 latency and Rspan task.

We also found no significant relationship between WMC and SiN [5]. Substantial research evidence supports that SiN relates to listeners' WMC [21–24], especially for older adults with HI. However, lack of association between WMC and SiN found in the current study is consistent with some of the recent studies in normal hearing [13] and older adults with HI [25]. One reason for lack of association between WMC and SiN found in the current investigation is probably due to the limited ecological validity of the SiN test [25]. Another potential reason for lack of association may be due to participant selection criteria used in this study. We selected only participants with measurable P300, which might have reduced the variability in WMC and SiN measures. Furthermore, there was no significant association between P300 latency and SiN. The use of speech stimuli (e.g., /da/ and /ba/) instead of tonal stimuli to elicit P300 response may have produced greater variability among participants in its relation to SiN results. However, the conventional P300 oddball paradigm using 1000 Hz and 2000 Hz tone-bursts can be a useful measure of auditory-related speed of processing which reflect WM mechanisms in adults with HI.

Conclusions

The current study explored the relation between WMC, P300 amplitude and latency, and aided SiN in individuals with sensorineural HI. It can be inferred from the results of this preliminary investigation that P300 latency may reflect individual's speed of information processing and attention control mechanisms within the WM system. However, P300 measured using a typical oddball paradigm using tonal stimuli was not related to SiN in adults with HI.

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