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Research Paper

EEG correlates of spatial shifts of attention in a dynamic multi-talker speech perception scenario in younger and older adults

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ABSTRACT

Speech perception under “cocktail-party” conditions critically depends on the focusing of attention toward the talker of interest. In dynamic auditory scenes, changes in talker settings require rapid shifts of attention, which is especially relevant when the position of a target talker switches from one location to another. Here, we explored electrophysiological correlates of shifts in spatial auditory attention, using a free-field speech perception task, in which sequences of short words (a company name, followed by a numeric value, e.g., “Bosch–6”) were presented in the participants’ left and right horizontal plane. Younger and older participants responded to the value of a pre-defined target company, while ignoring three simultaneously presented pairs of concurrent company names and values from different locations. All four stimulus pairs were spoken by different talkers, alternating from trial-to-trial. The location of the target company was within either the left or right hemisphere for a variable number of consecutive trials (between 3 and 42 trials) and then changed, switching from the left to the right hemispace or vice versa. Thus, when a switch occurred, the participants had to search for the new position of the target company among the concurrent streams of auditory information and re-focus their attention on the relevant location. As correlates of lateralized spatial auditory attention, the anterior contralateral N2 subcomponent (N2ac) and the posterior alpha power lateralization were analyzed in trials immediately before and after switches of the target location. Both measures were increased after switches, while only the increase in N2ac was related to better speech perception performance (i.e., a reduced post-switch decline in accuracy). While both age groups showed a similar pattern of switch-related attentional modulations, N2ac and alpha lateralization to the task-relevant stimulus (the target company’s value) was overall greater in the younger, than older, group. The results suggest that N2ac and alpha lateralization reflect different attentional processes in multi-talker speech perception, the first being primarily associated with auditory search and the focusing of attention, and the second with the in-depth attentional processing of task-relevant information. Especially the second process appears to be prone to age-related cognitive decline.

1. Introduction

Language comprehension under cocktail-party conditions, that is, in the presence of noise and concurrent speech stimuli (Cherry, 1953), critically depends on auditory attention (for reviews, see Carlile, 2014; Shinn-Cunningham et al., 2015). This comprises both the attentive focussing on a task-relevant target talker and the suppression of task-irrelevant noise (for review, see Bronkhorst, 2015), two sub-processes that go hand in hand in natural auditory scenes (e.g., Klatt et al., 2020a). Auditory attention appears to be particularly important when a talker of interest changes in an ongoing conversation with more than one partner, that is, the moment the thread of a conversation switches from one partner to another. It has been proposed that at least two different attentional mechanisms come into play here: first, the voluntary *attentional control* to shift attention to a talker of interest, and second, the *attentional selection* to distinguish the relevant information from concurrent input (Hill and Miller, 2010). Thus, after a change of target talker, it can be assumed that the listener’s auditory system has to *(a)* release the previously inhibited speech input from suppression in order to search for the new target talker, *(b)* shift attention to this new target, and *(c)* suppress the now irrelevant speech input (Kerlin et al., 2010). This sequence closely corresponds to the three phases proposed for shifts in visual attention, comprising the disengagement of attention from the current

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location, moving, and engagement at the new location (Posner and Petersen, 1990). Previous studies have demonstrated that switches in target talker are a great challenge for the auditory system, which usually result in a decline in language comprehension (e.g., Koch et al., 2010, 2011; Lawo et al., 2014; Lin and Carlile, 2015; Mondor and Zatorre, 1995; Singh et al., 2008). Switches of talker locations in an ongoing stream of syllables, for example, significantly reduced stimulus processing, relative to non-switch trials (Mehraei et al., 2018). In a series of previous experiments, it could also be shown that these “switch costs” are especially pronounced immediately after a switch, while they gradually fade away the longer the switch is behind (Getzmann et al., 2015a). This has been interpreted as a kind of “inertia” of auditory attention, requiring some time before “homing in” at the new position (Best et al., 2008; Koch et al., 2011). It has also been shown that cues indicating an upcoming switch are utilized to prepare the shift of attention (Kidd et al., 2005), with the decline in performance being attenuated in a cued relative to an uncued switch condition (Getzmann et al., 2017; Getzmann and Wascher, 2017).

Talker changes pose a challenge especially to older people, who are known to have reduced speech-in-noise perception abilities in cocktail-party situations in general (for review, see Pichora-Fuller et al., 2017). These deficits are mainly based on age-related changes in peripheral hearing (e.g., presbycusis) and in central auditory processing (Humes and Dubno, 2010). In addition, changes in general cognitive abilities such as working memory capacity, information processing speed, and inhibitory control play a role (Burke and Shafto, 2008; van der Linden et al., 1999). In particular, changes in top-down attentional control have been associated with a variety of age-related issues such as declines in postural instability of older adults (Maki et al., 2001), whereas other functions like object-based attentional selection and oculomotor control seem to be less affected by normal aging (Kramer et al., 1999; Kramer and Weber, 1999). With regard to speech comprehension, age-related deficits in top-down control may lead to a reduced focusing of attention on the talker of interest and (according to the inhibition deficit hypothesis; Hasher and Zacks, 1988; Lustig et al., 2007) to a deficient suppression of irrelevant auditory information in multi-talker environments (for review, see Schneider et al., 2010). Less flexible inhibitory control and increased distraction are assumed to be relevant especially in switch situations, in which older adults showed higher general switch costs (Meister et al., 2020) and needed more time to process a shift of attention than younger ones (Getzmann et al., 2015a; 2016; Getzmann and Wascher, 2017). However, the respective studies also showed that older adults are able to compensate for these deficiencies, at least in part, by an increased allocation of mental resources, quite in line with the decline-compensation hypothesis (Wingfield and Grossman, 2006).

In addition to behavioral performance measures, electrophysiological methods have proven very effective for studying such age effects and the neural underpinning of switches in spatial attention in general. It could be shown, for example, that switches are associated with a modulation of event-related potentials (ERPs), indicating an enhanced attentional effort to manage the switch (Getzmann et al., 2015a). Contrasting ERPs before and after target switches revealed a change-related N400 component and late positive complex (LPC) over parietal areas. These have been interpreted as correlates of the mismatch resulting from the unexpected linguistic input due to the change in target talker, and the spatial reorientation of the focus of attention to the new talker location, respectively. In addition, an extra activation over frontal scalp areas has been found in older adults in form of a pronounced frontal LPC. This was associated with better performance and assumed to reflect increased allocation of attentional resources after talker switches (Getzmann et al., 2015a). Similarly, associations between behavioral costs of a switch in talker location and modulations of electrophysiological correlates of auditory attention have been found, with a reduction in ERPs and a suppression in the power of alpha oscillations (8–12 Hz) coming along with a better ability to maintain attention in an ongoing stream of target stimuli (Mehraei et al., 2018).

Two electrophysiological measures that have recently come into the focus of interest and are considered here in the context of switches of target talker locations, are the anterior contralateral N2 subcomponent (N2ac; Gamble and Luck, 2011) and the lateralized oscillatory alpha power. The N2ac is a broad negative deflection contralateral to the focus of attention over fronto-central scalp areas in the N2 latency range. It is derived as the difference wave of the contra- minus ipsilateral activity relative to the target position. It has been demonstrated for laterally presented artificial sounds (Gamble and Luck, 2011), animal vocalizations (Klatt et al., 2018a; Lewald and Getzmann, 2015), and speech (Lewald et al., 2016). Analogous to its visual counterpart, the posterior contralateral visual N2 subcomponent (N2pc; Eimer, 1996; Luck and Hillyard, 1994; Wascher and Wauschkuhn, 1996), it is assumed to reflect the allocation of selective spatial attention to a target stimulus among multiple concurring stimuli (Gamble and Luck, 2011). Accordingly, there is evidence that the N2ac amplitude is associated with performance in auditory search tasks (Lewald et al., 2016), while its functional significance is not yet fully understood (Klatt et al., 2020b).

As a second neural measure of interest, lateralized modulations of alpha power were considered, that have been shown to be associated with shifts of attention in visual (e.g., Foster et al., 2017; Ikkai et al., 2016; Schneider et al., 2019; Rösner et al., 2020) and in auditory space (Klatt et al., 2018b; Wöstmann et al., 2016, 2018). In the presence of a lateralized target, alpha power is usually decreased contralaterally to the attended location (Kelly et al., 2009; Sauseng et al., 2005), and increased contralaterally to the unattended or ignored location (Kelly et al., 2006). Given its close relationship to performance (Tune et al., 2018; Wöstmann et al., 2016), lateralized alpha power is assumed to be a correlate of the orienting of spatial attention. This orienting can either be related to the anticipatory allocation of spatial attention following a cue indicating an upcoming lateral target location (i.e., *pre*-stimulus alpha lateralization). Alternatively, it can be related to the ongoing processing of a lateralized stimulus without knowing its position in advance (i.e., *post*-stimulus alpha lateralization). There is evidence that these two processes, i.e., the preparation for an upcoming target and the search and processing of an ongoing stimulus, comprise distinct attentional mechanisms (van Ede et al., 2014).

In the present study, we utilized N2ac and alpha power lateralization to explore how switches in target location are represented in neural correlates of the spatial focusing of attention in the auditory domain. We focused especially on the moment before and after switches of a target talker across the left and right hemispaces. We hereto analyzed EEG data of an experimental paradigm that allowed us to temporally separate the shift of attention to a target position from the subsequent response to a task-relevant feature of the speech content. In the "stock-price monitoring task” (Getzmann et al., 2015a), the participants are confronted with an ongoing sequence of simultaneously presented pairs of words, consisting of brief company names and values. Importantly, the pairs of company names and values are spoken by different talkers and from different locations. While one stimulus pair comprises a predefined target company name followed by a numeric value, the other three concurrently presented pairs serve as irrelevant distractors, comprising different company names and values. The participants have to attend to the target company and respond to its value (assessing whether this is below or above a critical threshold), while ignoring all other companies and values. After a random number of trials, in which the target company has been presented from a constant location, a switch occurs to another location, and the participants have to re-orient spatial attention towards this new location to assess the target company value. In other words, a switch from the current target position to a new position (occurring after a number of no-switch trials) should trigger the release of attention from the previous location, the search for the new location, and finally the focusing of attention on that new location. Thus, the company *name* can be regarded as the *cue* indicating the location of the talker of the target company,[1] while the company *value* can be regarded as the task-relevant *target*.

Assuming that the cognitive processes reflected by N2ac and alpha power lateralization contribute to the successful shift of attention from one target position to another, we expected that both measures should be increased after a target switch. Separate analyses of the processing of the cue (company name) and the target stimuli (company value) should reveal differences in the processing of *(a)* the cue triggering the auditory search for the new target position after a switch occurred and *(b)* the target containing the task-relevant (non-spatial) information. More specifically, the cue-related N2ac and alpha lateralization should be associated with the feature-based search for and selection of the target company name within the auditory stimulus array, whereas the target-related N2ac and alpha lateralization are associated with the speech content-related processing of the company value at the relevant lateralized position. We further expected a relationship between N2ac amplitude and alpha power lateralization and the to-be-expected decline in performance after a switch (e.g., Klatt et al., 2020b; Lewald et al., 2016; Tune et al., 2018; Wöstmann et al., 2016). Finally, we explored whether the difficulties that older adults have in managing switches in target location are reflected in neural correlates of spatial attentional orienting. Age-related differences in N2ac and alpha power lateralization to cue (i.e., company name) and target (i.e., company value) would suggest that difficulties of older adults not only stem from a reduced attentional control in general (e.g., Getzmann 2015a,b), but also from a decline in the spatial (lateralized) focusing of attention.

2. Materials and methods

The data analyzed here were taken from a previous experiment that investigated the effect of switches in target talker voice and location on speech perception and EEG correlates in a multi-talker environment in younger and older adults (Getzmann et al., 2015a).

2.1. Participants

The sample included 22 younger (11 female, mean age 24.0 years, age range 18–35 years) and 22 older (11 female, mean age 64.3 years, age range 55–72 years) adults. All participants reported to be right-handed, healthy, and free of medication during the experimental sessions. A pure-tone audiometry (Oscilla USB 330; Inmedico, Lystrup, Denmark) at 125–8000 Hz indicated normal hearing (thresholds $\leq$ 30 dB hearing level) in the speech range (below 4000 Hz) in both age groups. The study conformed to the Code of Ethics of the World Medical Association (Declaration of Helsinki) and was approved by the local Ethical Committee of the Leibniz Research centre for Working Environment and Human Factors, Dortmund, Germany. All participants gave their written informed consent for participation.

2.2. Experimental setup, procedure, and stimuli

Details of the experimental material and method have been previously described (Getzmann et al., 2015a). Briefly, the experiment took place in an electrically shielded, sound-proof room with pyramid-shaped foam acoustic panels on ceiling and walls and a sound-absorbing woolen carpet. The participant was seated in a vertically adjustable chair with the head position stabilized by a chin rest. Speech stimuli were presented via four loudspeakers (SC 5.9, Visaton, Haan, Germany) mounted in the participant's horizontal plane at $-45°$, $-15°$ (left), 15°, and 45° (right) azimuth (Fig. 1A). Sound presentation and recording of the participants' responses were controlled by custom-made amplifiers and software, respectively. The speech stimuli consisted of eight one or two syllable names of companies (Audi; Bosch; Deutz; Eon; Gerri; Otto; Merck; Tui) and eight one or two syllable German numerals (Eins [1]; Zwei [2]; Drei [3]; Vier [4]; Sechs [6]; Sieben [7]; Acht [8]; Neun [9]), spoken by two male and two female adults. Stimulus duration was 500 ms and sound pressure level was 65 dB(A).

In the stock-price monitoring task, pairs of words consisting of a company name and a numeral simulating its stock price (e.g., "Bosch—eins" ["Bosch—one"] or "Deutz—acht" ["Deutz—eight"]) were presented, separated by a 100-ms silent interval (Fig. 1C). Participants had to attend to a previously specified target company (either "Bosch" or "Deutz", balanced across participants) and respond to the value of the target company, by pressing one of two keys, the upper one for values above five, and the lower one for values below five. They were instructed to respond after presentation of the company value, using the index and the middle finger of the dominant right hand. The combination of target company and numeric value was always spoken by the same talker and presented at the same loudspeaker location, whereas the three concurrently presented company names and numerals (i.e., different from the target stimulus pair) were presented via the three other loudspeaker locations and spoken by three different talkers (Fig. 1B). Thus, participants were confronted with four simultaneously present speech streams, one of which contained the target information, while the other three contained task-irrelevant information. Within each trial, each company name and value occurred only once and two numerals each were above and below the critical value of five. Importantly, after a variable number of subsequent trials (3 - 6; 4.5 trials on average), in which the target company name and value were presented by the same talker and from the same location, either the talker, the location, or both talker and location of the target company changed following a pseudo-randomized scheme. The participants performed 1472 trials presented in four blocks, each lasting for about 20 min. The inter-trial onset interval was 3000 ms, including a stimulus duration of 1100 ms, a response period of 1700 ms, and an inter-trial interval of 200 ms. There were overall 324 changes, out of which 108 changes referred to target talker voice, location, or both voice and location, respectively. Prior to experimentation, the participants were familiarized with the task in a practice block of about 20 trials, but no feedback was given at any time during the experiment.

2.3. Data analysis

The focus of the present study was on lateral (inter-hemispheric) shifts of attention. Therefore, only switches in target location across the participant's median plane were analyzed, while changes in target location within each hemifield (e.g., from the outer right 45° location to the inner right 15° location) or changes in target talker voice were not considered. Only the trials immediately before a switch occurred (*Pre* sequences) and the three trials following a switch (*Post1, Post2, Post3* sequences) were

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[1] It should be noted that the term "cue" is used here somewhat different than in most previous studies on spatial attention, given it does not indicate an upcoming target position by a preceeding singular stimulus like an arrow, but is itself embedded in a mixture of competing stimuli.

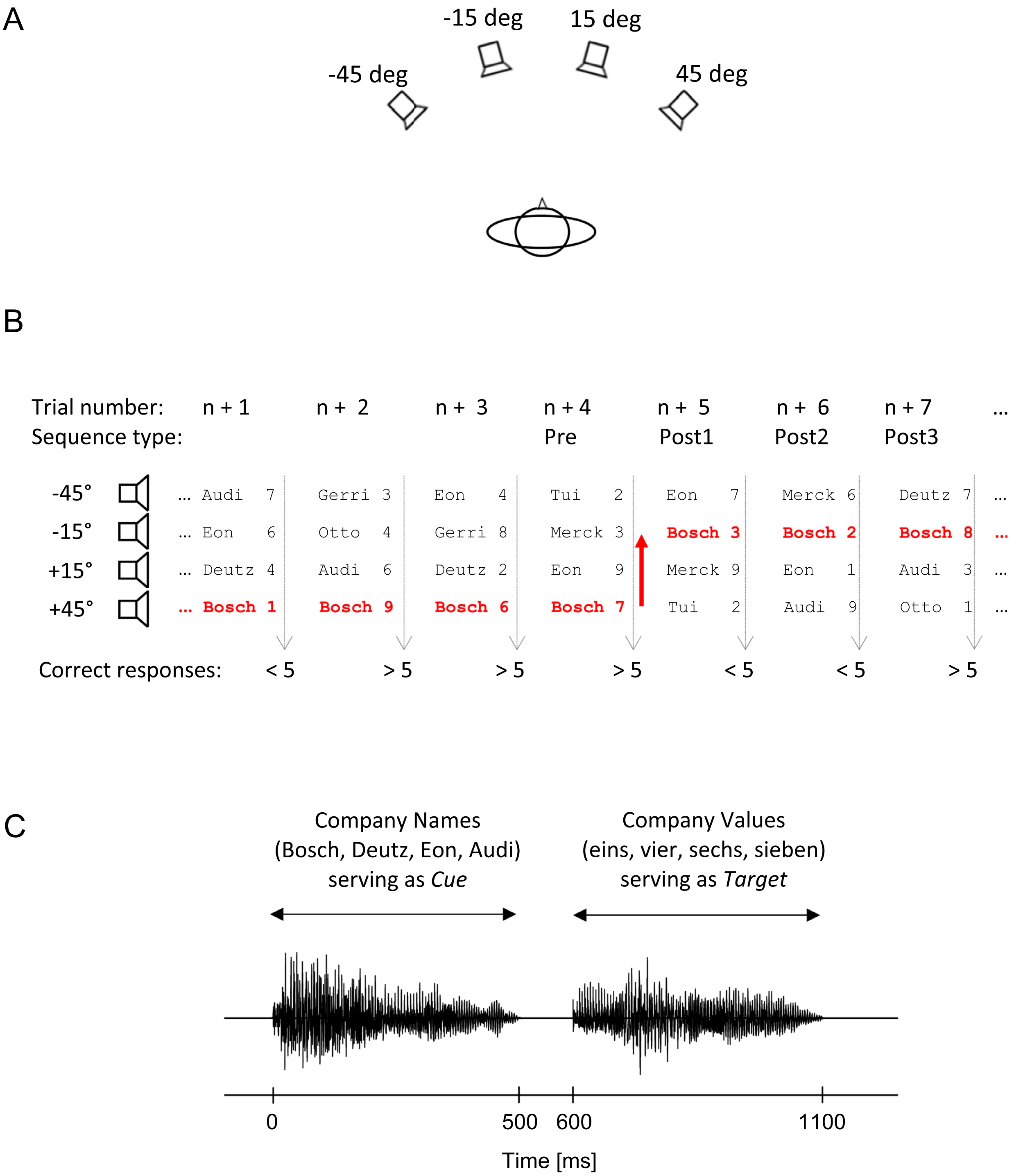

Fig. 1. Schematic illustration of the simulated stock-price monitoring scenario (modified after Getzmann et al., 2015). (A) Speech stimuli were presented by four loudspeakers mounted at different locations to the left (−45°, −15°) and right (45°, 15°) of the participant's median plane. (B) Within a given trial, four pairs of words consisting of short company names and numbers (e.g., "Merck" "zwei") were simultaneously presented. Each pair was spoken by a different talker and presented from a different location. The participants attended to a pre-defined target company (here "Bosch", in red bold print) and rated its value as above or below 5. After a number of trials, in which the task-relevant information has been presented from a constant location, the location of the talker of the target company and value changed following a pseudo-random scheme. For example, the target location switched from +45° in trial $n + 4$ to −15° in trial $n + 5$, as indicated by the red vertical arrow. The switch of the company name always occurred in the silent period between two subsequent trials. Given that the switch should trigger the search for the new target location, company name is defined as *cue*, while company number is the task-relevant *target*. Analyses were focused on trials preceding (Pre sequences) and following (Post1, Post2, Post3 sequences) switches of the target company location from the left-to-right or right-to-left hemispace. (C) Superimposed acoustic waveforms of four pairs of words (here: company names "Bosch", "Deutz", "EON", "Audi", and values "eins", "vier", "sechs", "sieben") each lasting 500 ms. The target company name (here "Bosch") served as *cue* to the location of the company value as the *target* information.

analyzed (Fig. 1B). Importantly, the target location always changed "between" two subsequent trials (i.e., in the silent period in between), so that Post1 sequence refers to the trial in which the target talker first appears at another position. In order to improve the signal-to-noise ratio of the EEG data and to reduce the complexity of the analysis, location switches with and without changes in target talker voice were pooled. This resulted in an overall amount of 144 switches, 72 from left to right hemispace, and 72 from right to left hemispace. The number of trials between two switches ranged from 3 to 42 (mean 10.22 trials; standard deviation 7.57 trials).

2.3.1. Behavioral data

Percentages of correct responses of younger and older participants in trials preceding and following a switch were subjected to a two-way repeated-measures analysis of variance (ANOVA) with the between-subjects factor Age (younger, older) and the within-subjects factor Sequence (Pre, Post1, Post2, Post3; see Fig. 1B). Bonferroni-Holm-corrected post-hoc *t*-tests were used for comparison between sequence conditions. Levene's tests were used to assess the homogeneity of variance, and the degrees of freedom were adjusted if variances were unequal. Effect sizes are provided, using the partial eta-squared coefficient ($\eta_p{}^2$). Reaction times were not analyzed, since response speed was not prioritized and the participants had to withhold their responses until the company value was presented.

2.3.2. EEG recording and pre-processing

The continuous EEG was recorded using a BioSemi amplifier (Active Two; Biosemi, Amsterdam, Netherlands; 2048 Hz sampling rate; 0.01–140 Hz amplifier bandpass; $<$10 kΩ electrode impedances) and 64 electrodes arranged according to the international 10/10 system. Two additional electrodes were placed on the left and right mastoids. For offline data pre-processing the open-source toolbox EEGLAB (v14.1.2b, Delorme and Makeig, 2004) for Matlab (R2018a) was employed. The raw EEG was downscaled offline to a sampling rate of 512 Hz, digitally band-pass filtered from 0.5 to 25 Hz, and re-referenced to the average of the left and right mastoid electrodes. Data were segmented into epochs ranging from −1000 to 2000 ms, relative to the speech stimuli onset, with a 100-ms pre-stimulus time window serving as baseline. An independent component analysis (ICA) was performed on a subset of the data that was downsampled to 256 Hz and included only every second trial to speed up the ICA procedure. The derived independent component (IC) decomposition was then projected onto the original dataset with a sampling rate of 512 Hz covering all trials. Using the DIPFIT plugin of the EEGLAB toolbox, a single-equivalent current dipole model was calculated for each of the independent component scalp maps using a spherical head model (Kavanagk et al., 1978). Artefactual ICs were detected and rejected in two successive steps: The automated algorithm ADJUST (Mognon et al., 2011) was applied to identify and exclude ICs associated with blinks, eye movements, and generic discontinuities. Then, since artefactual ICs usually do not resemble the projection of a single dipole (Onton and Makeig, 2006), all ICs with a residual variance of more than 40% of the dipole solution were rejected. These procedures resulted in an average rejection of 14.02 ICs per participant (range: 3 – 22). Finally, the automated artifact rejection procedure implemented in EEGLAB (threshold limit: 1000 μV, probability threshold: 3 standard deviations) was run, resulting in an average rejection of 224.57 trials per participant (range: 51 – 435), that is, 15.26% of trials (range: 3.74 – 29.55%). Only trials with correct responses were submitted to further analyses of EEG data.

2.3.3. ERP analysis

Trials were averaged separately for left-to-right and right-to-left cross-hemispatial switch sequences, and for Pre, Post1, Post2, and Post3 sequences. To analyze the N2ac component (Gamble and Luck, 2011), we computed the contralateral minus ipsilateral ERP waveforms at electrodes FC3/4 and C3/4. This comprised the mean signals at FC3 and C3 for right targets and at FC4 and C4 for left targets (the contralateral portion), and the mean signals at FC3 and C3 for left targets and at FC4 and C4 for right targets (the ipsilateral portion). The choice of electrode positions was based on previous knowledge of the N2ac topographical scalp distribution (Gamble and Woldorff, 2015; Klatt et al., 2018b) and confirmed by visual inspection of the grand average waveforms. For each participant and each sequence type (Pre, Post1, Post2, Post3), N2ac amplitudes were computed as mean amplitude values within a 50-ms time frame around the maximum negativity within two particular latency windows. These ranged from 300 to 550 ms (time window 1) and from 900 to 1150 ms (time window 2) relative to the speech onset in a given trial. The time windows were chosen to comprise relevant modulations related to the processing of the company name (*cue*-related activity to the company names in time window 1) and value (*target*-related activity to the company values in time window 2), respectively. Mean N2ac amplitudes were subjected to an ANOVA with between-subjects factor Age (younger, older) and within-subjects factors Sequence (Pre, Post1, Post2, Post3) and Stimulus (cue, target).

2.3.4. Time-frequency data

Complex Morlet wavelet convolution was applied to the epoched EEG data to extract spectral power. A total of 52 wavelets with logarithmically increasing frequencies in-between 4 and 30 Hz were created. The number of wavelet cycles was varied as a function of frequency to adjust the balance between temporal and frequency precision. At the lowest frequency, a 3-cycle wavelet was used. The number of cycles then increased linearly, resulting in a 11.25 cycle wavelet at the highest frequency. The resulting event-related spectral perturbation (ERSP) epochs ranged from −582 to 1582 ms relative to speech stimulus onset. The time interval for baseline normalization was −500 to −200 ms prior to speech stimulus onset.

Oscillatory alpha power was extracted in the 8–12 Hz frequency band at clusters of electrode positions over the left (P3, P7, PO3, PO7, O1) and right (P4, P8, PO4, PO8, P4, O2) hemispheres. The selection of parieto-occipital electrodes overlaps with previous studies, measuring posterior alpha lateralization (e.g., Klatt et al., 2020a; Myers et al., 2015, Thut, 2006; van Driel et al., 2017). To quantify the effect of attention on the hemispheric modulation of alpha power, the ipsilateral and contralateral portions of alpha power were computed. The contralateral portion comprised the mean signal at the left electrode cluster for right targets and at the right cluster for left targets, whereas the ipsilateral portion refers to the mean signals at the left cluster for left targets and at the right cluster for right targets. The contralateral minus ipsilateral difference waveforms served as a measure of alpha lateralization. Effects on bilateral, posterior alpha power were assessed as the average across those contralateral and ipsilateral signals. For both alpha lateralization as well as bilateral alpha power modulations, the time windows for statistical analysis were determined as follows: (1) For each participant, the maximum negativity in the average waveform for each sequence type (i.e., Pre, Post1, Post2, Post3) was determined within two broad time windows ranging from 0 to 600 ms (*cue*-related activity to the company names; time window 1) and from 600 to 1300 ms (*target*-related activity to the company values; time window 2). (2) Mean oscillatory power was then calculated across a 100-ms time window surrounding the peak (i.e., −50 to 50 ms relative to the peak determined in step one). Two separate mixed ANOVAs were conducted for alpha lateralization and bilateral alpha power as dependent variables, respectively, each of which contained the between-subjects factor

Age (younger, older) and the within-subject factors Sequence (Pre, Post1, Post2, Post3) and Stimulus (cue, target).

3. Results

3.1. Correct responses

There was a main effect of Sequence ($F_{(3126)} = 112.061$, $p < .001$, $\eta_p^2 = 0.72$) and post-hoc t-tests indicated a significant reduction of the rate of correct responses relative to Pre trials (86.7%) in Post1 (68.30%), Post2 (75.75%), and Post3 (83.74%) trials (all $p < .001$; Bonferroni-Holm corrected p values). There was also a main effect of Age ($F_{(1,42)} = 4.841$, $p = .033$, $\eta_p^2 = 0.103$), with older participants responding less correct than the younger ones, but no interaction of Age and Sequence ($F_{(3126)} = 0.542$, $p = .654$, $\eta_p^2 = 0.013$).

3.2. N2 anterior contralateral component

Fig. 2 shows the event-related potentials averaged across the fronto-central and central lateral (FC3/4 and C3/4) electrodes and the corresponding contralateral minus ipsilateral difference waveform, representing the N2ac components, separately for both age groups and pre- and post-switch sequences (A) as well as the distribution of N2ac amplitudes across single subjects (B). Averaged across sequences, N2ac peaked at 425 ms (young group) and 430 ms (older group) after cue onset, and at 431 ms (younger group) and 441 ms (older group) after target onset. While the N2ac was only slightly pronounced in Pre sequences, it became evident especially in Post1 sequences, both in response to the company names (cue-related in time window 1) and values (target-related in time window 2). The ANOVA indicated a significant main effect of Sequence on N2ac amplitudes ($F_{(3126)} = 4.908$, $p = .003$, $\eta_p^2 = 0.11$; Fig. 4A) and post-hoc t-tests indicated significantly increased N2ac amplitudes in Post1 sequences (−0.59 µV) relative to Pre (−0.30 µV; $t_{(42)} = 3.127$; $p = .030$), Post2 (−0.28 µV; $t_{(42)} = 2.792$; $p = .036$), and Post3 sequences (−0.31 µV; $t_{(42)} = 3.110$; $p = .024$; Bonferroni-Holm corrected p-values), while the N2ac amplitudes in Pre, Post2, and Post3 sequences did not differ significantly (all $t < 0.284$; $p > .05$). There was no main effect of Age ($F_{(1,42)} = 1.507$, $p = .226$, $\eta_p^2 = 0.04$), but a significant interaction of Age and Stimulus ($F_{(1,42)} = 7.871$, $p = .008$, $\eta_p^2 = 0.16$): While the two age groups did not differ in N2ac amplitude to the company names ($t_{(42)} = 1.063$, $p = .308$), the N2ac to the company values was stronger in the younger, than the older age group ($t_{(42)} = 5.20$, $p = 0.028$; Fig. 4D). No further main effects or interactions were significant (all $p > .05$).

3.3. Alpha power suppression (non-lateralized)

Fig. 3A illustrates the asymmetric modulation of alpha power (8–12 Hz) at posterior-occipital electrode clusters time-locked to the speech onset for contra- and ipsilateral electrode sites, shown separately for both age groups. Alpha suppression was clearly two-capped, with two peaks emerging relative to the onset of the company names and values, respectively. Averaged across all four sequences and the contra- and ipsilateral sites, alpha power suppression peaked at 381 ms (young group) and 418 ms (older group) after onset of company names, and at 384 ms (younger group) and 534 ms (older group) after onset of company values. Alpha suppression in general was stronger in response to the values than to the names ($F_{(1,42)} = 23.833$, $p < .001$, $\eta_p^2 = 0.36$). Alpha suppression was increased after a switch in target location (main effect of Sequence: $F_{(3126)} = 6.765$, $p < .001$, $\eta_p^2 = 0.14$; Fig. 4B). Post-hoc t-tests showed that alpha suppression in Post1 sequences (−2.11 dB) was stronger than in Pre (−1.57 dB; $t_{(42)} = 3.672$; $p = .004$) and Post3 (−1.67 dB; $t_{(42)} = 3.550$; $p = .005$) sequences, but not in Post2 sequences (−1.82 dB; $t_{(42)} = 1.974$; $p > .05$; Bonferroni-Holm corrected p-values). Alpha suppression in Pre, Post2, and Post3 sequences did not differ significantly (all $t\langle$ 0.198; $p\rangle$ .05). This pattern was more pronounced in response to the company value, than name (Sequence by Stimulus interaction: $F_{(3126)} = 14.194$, $p < .001$, $\eta_p^2 = 0.25$). The older group showed an overall stronger alpha suppression than the young group (main effect of Age: $F_{(1,42)} = 7.370$, $p = .010$, $\eta_p^2 = 0.15$), which was especially pronounced in response to the company values (Age by Stimulus interaction: $F_{(1,42)} = 8.324$, $p = .006$, $\eta_p^2 = 0.17$; Fig. 4E).

3.4. Alpha power lateralization

The lateralization of alpha power, represented by the corresponding contralateral minus ipsilateral difference waveform in Fig. 3 (A,B) did not strictly follow the temporal shape of general (non-lateralized) alpha suppression, with the maxima of alpha lateralization not perfectly overlapping with the peaks of alpha suppression. Nevertheless, the analysis revealed a significant modulation of alpha lateralization following a change in target location (main effect of Sequence: $F_{(3126)} = 5.115$, $p = .002$, $\eta_p^2 = 0.11$; Fig. 4C), with alpha lateralization being increased in Post1 sequences (−0.62 dB; $t_{(42)} = 3.052$; $p = .016$), Post2 sequences (−0.68 dB; $t_{(42)} = 3.352$; $p = .010$), and Post3 sequences (−0.65 dB; $t_{(42)} = 3.265$; $p = .011$), relative to Pre sequences (−0.37 dB), while the other differences were not significant (all $t < 0.55$; $p > .05$; Bonferroni-Holm corrected p values). Alpha lateralization in general was stronger to the company values than names ($F_{(1,42)} = 12.506$, $p = .001$, $\eta_p^2 = 0.23$). Furthermore, there was a significant interaction of Age and Stimulus ($F_{(1,42)} = 7.114$, $p = .011$, $\eta_p^2 = 0.15$): Alpha lateralization to the company values was stronger in younger than older participants ($t_{(42)} = 2.502$, $p = 0.016$; Fig. 4F), while the two age groups did not differ in alpha lateralization to the company names ($t_{(42)} = 0.695$, $p > .05$). No further main effects or interactions were significant (all $p > .05$).

3.5. Brain-behavior relationship

In order to examine the relationship between the decline in performance following a switch in target talker location and the increases in N2ac amplitudes and in alpha power lateralization, an analysis of covariance (ANCOVA) was computed. Pre and Post1 sequences were contrasted since these revealed the most prominent post-switch differences in both the performance and the electrophysiological measures. The Pre- vs. Post1-switch percentage changes in correct responses served as the dependent variable, age as the categorical independent variable, and the Pre- vs. Post1-switch changes in N2ac amplitude and in alpha power lateralization at time window 1 (company names, cue-related) and 2 (company values, target-related) as covariates. The ANCOVAs indicated a significant effect of change in N2ac amplitude in time window 1 on change in correct responses ($F_{(1,44)} = 4.631$, $p = 0.037$, $\eta_p^2 = 0.10$), with greater increases in cue-N2ac amplitudes being associated with lesser decline in performance after the switch. Moreover, there was an interaction of age and cue-N2ac amplitude ($F_{(1,44)} = 4.595$, $p = 0.038$, $\eta_p^2 = 0.10$). No effects were found for changes in N2ac amplitude in time window 2 (target) or age, nor an interaction of age and target-N2ac amplitude (all $F\langle$ 0.148; all $p\rangle$ .05). Neither were there any effects of change in alpha power lateralization (all $F\langle$ 2.523; all $p\rangle$ .05).

This pattern of results was confirmed by correlation analyses, in which the relationships between the decline in performance and changes in N2ac amplitude in time windows 1 and 2 were

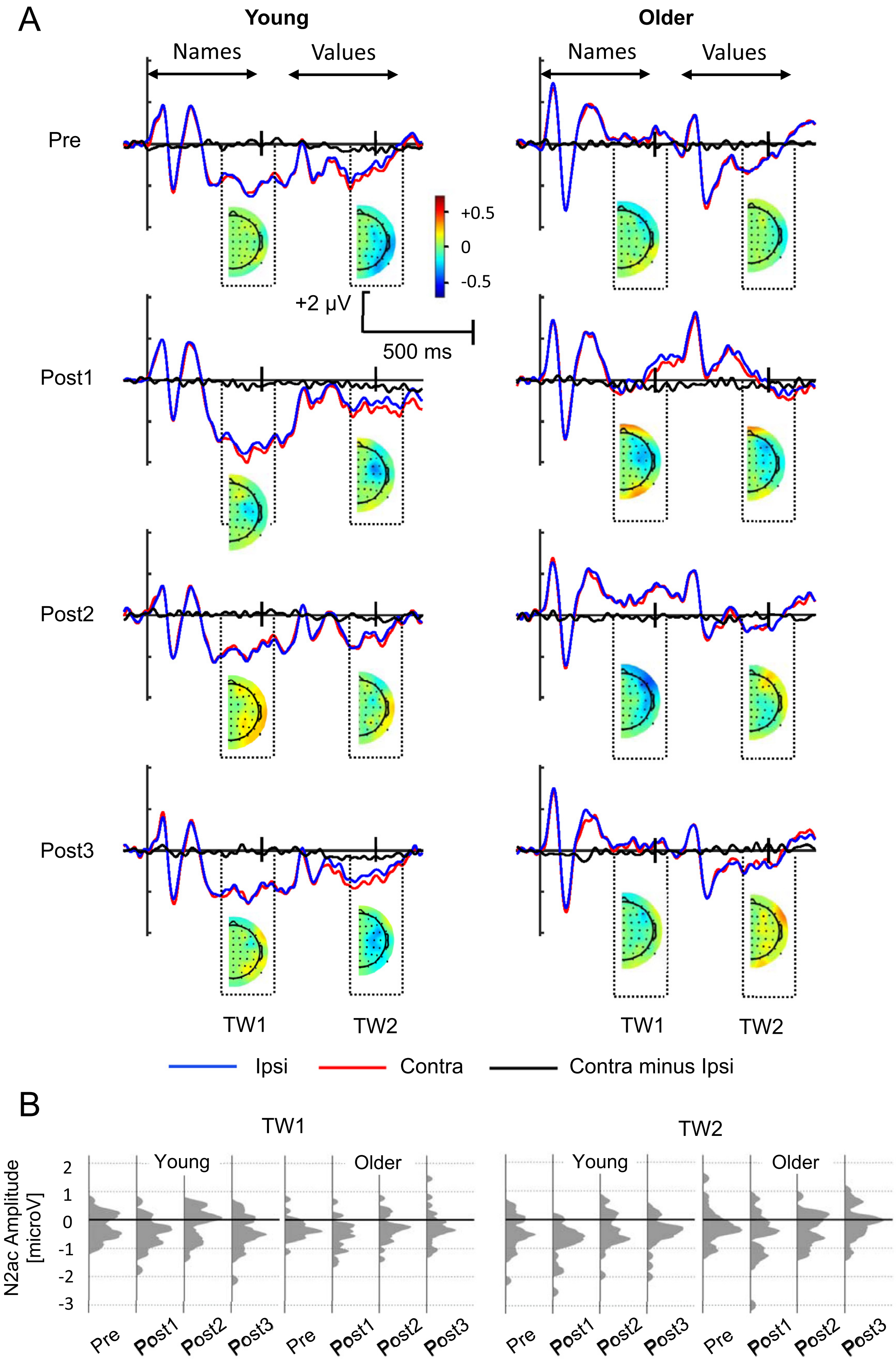

Fig. 2. (A) Grand-average ERPs. ERPs averaged across FC3/4 and C3/4 electrodes are plotted as a function of time relative to the onset of the company names and values for Pre, Post1, Post2, and Post3 sequences, and for young and older participants. Contralateral and ipsilateral portions of the signal (relative to the location of the target company) as well as the resulting difference wave (contralateral minus ipsilateral) are displayed, time windows for analyses of the N2ac amplitudes related to company Names (*cue*-related processing in time window TW1) and company Values (*target*-related processing in time window TW2) are marked. In addition, the respective scalp topographies, based on subtraction of contralateral minus ipsilateral values, are depicted. Contra- and ipsilaterality refer to the (trial-based) current target location, such that the polarity is the same for Pre and Post sequences. (B) Beanplots indicating the distribution of N2ac amplitudes measured in TW1 and TW2 for Pre, Post1, Post2, and Post3 sequences, and for young and older participants.

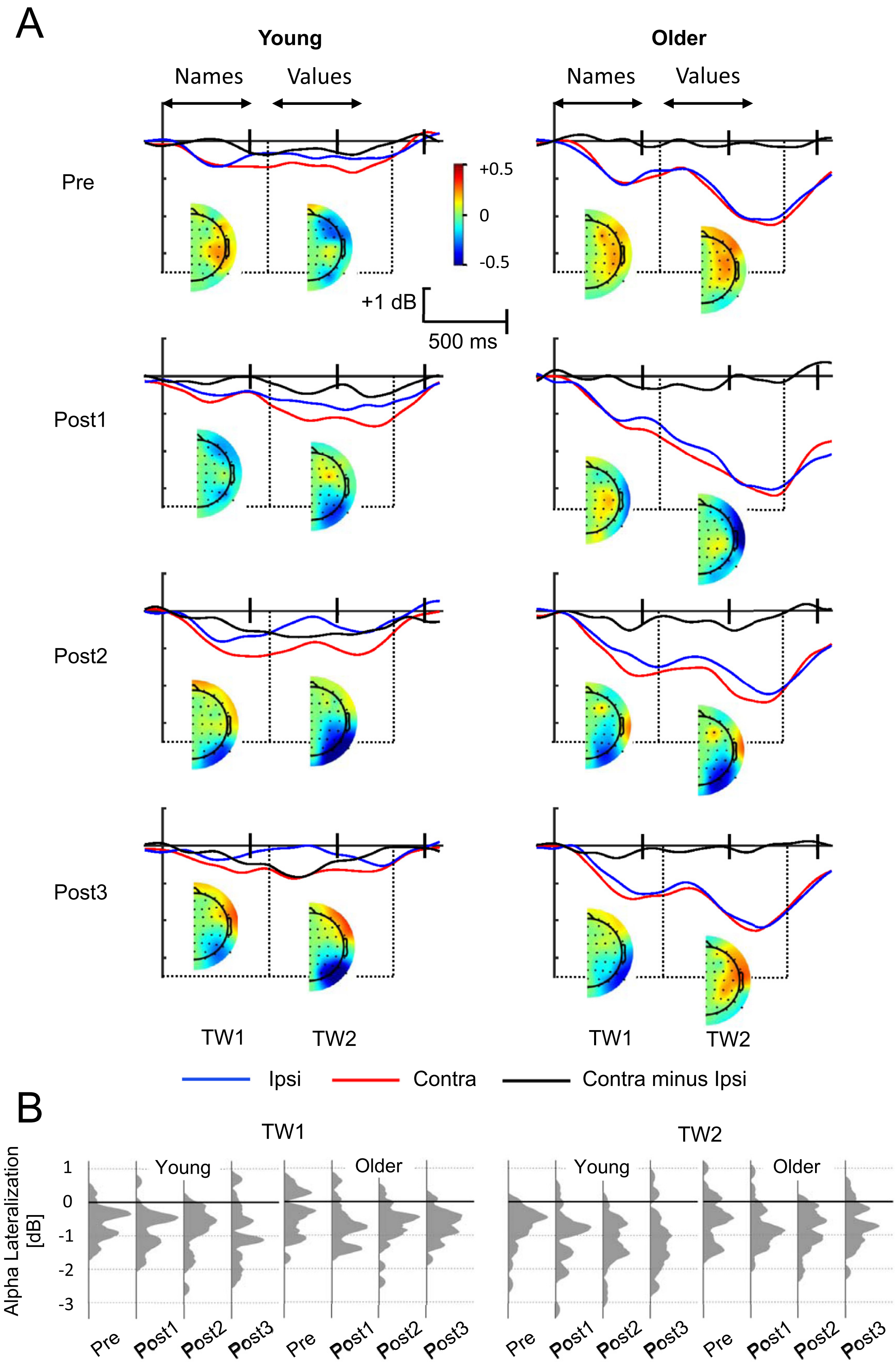

Fig. 3. (A) Alpha power. Alpha power at parieto-occipital clusters of electrodes (P3/4, P7/8, PO3/4, PO7/8, O1/2) plotted as a function of time relative to the onset of the company names and values for Pre, Post1, Post2, and Post3 sequences, and for young and older participants. Contralateral and ipsilateral portions of the signal (relative to the location of the target company) as well as the resulting difference wave (contralateral minus ipsilateral) are displayed, time windows for analyses of alpha power suppression and lateralization related to company Names (*cue*-related processing in time window TW1) and company Values (*target*-related processing in time window TW2) are marked. In addition, the respective scalp topographies, based on subtraction of contralateral minus ipsilateral power values, are depicted. Contra- and ipsilaterality refer to the (trial-based) current target location, such that the polarity is the same for Pre and Post sequences. (B) Beanplots indicating the distribution of Alpha power lateralizations measured in TW1 and TW2 for Pre, Post1, Post2, and Post3 sequences, and for young and older participants.

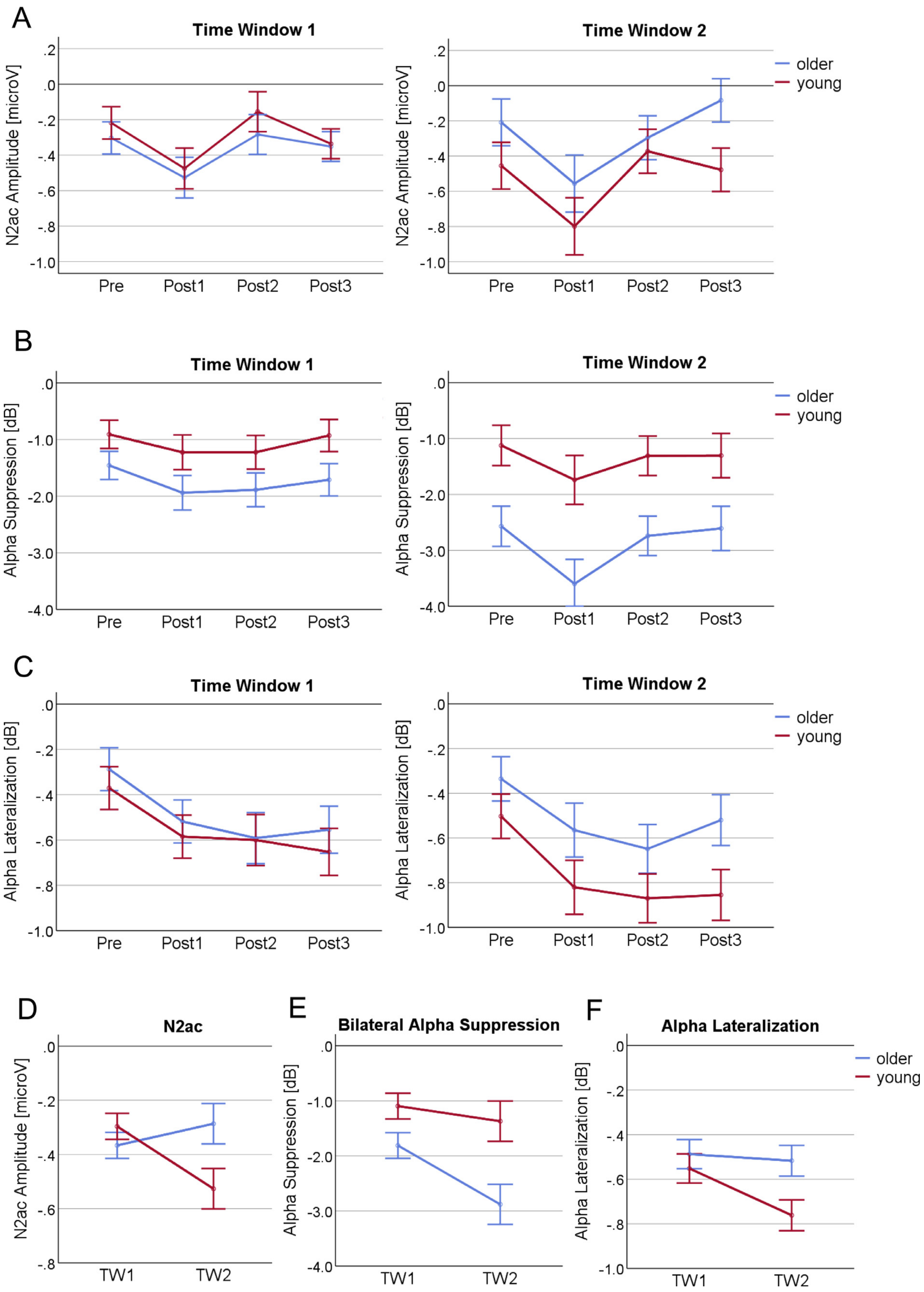

Fig. 4. N2ac amplitudes (A), alpha power suppression (B), and alpha power lateralization (C) for Pre, Post1, Post2, and Post3 sequences, shown for young and older participants, as well as averaged across sequences (D-F), shown for time windows 1 (*cue*-related processing of company name, TW1) and 2 (*target*-related processing of company value, TW2). Error bars are standard errors across participants ($N = 22$).

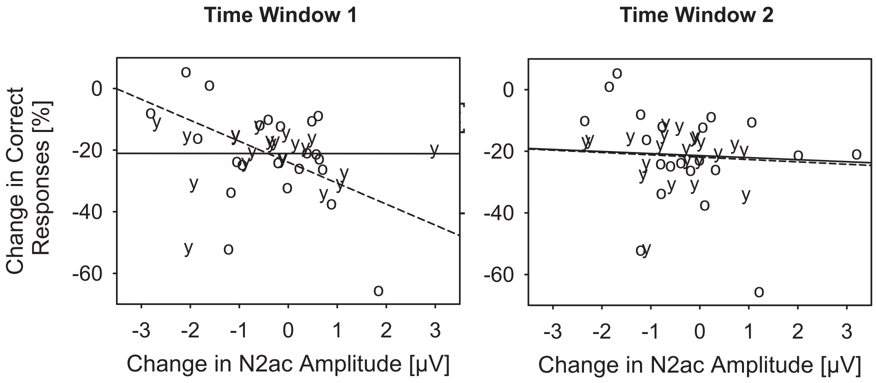

Fig. 5. Relationships between changes in N2ac amplitudes and changes in percentages of correct responses (Pre- vs. Post1 sequences) for younger (y) and older (o) participants for time windows 1 (company name) and 2 (company value) together with regression lines (dotted: younger; solid: older).

explored, separately for younger and older participants. These revealed a significant correlation in time window 1 only for the older group ($r = -0.478$; $p = .049$; Bonferroni-Holm-corrected p-values), but not the younger group ($r = -0.002$; $p = .994$), and no significant correlations for time window 2 (older: $r = -0.091$; younger: $r = -0.063$; both $p > .05$; Fig. 5).

4. Discussion

In the present study, we explored lateral shifts of attention after spatial switches of a target talker in a simulated cocktail-party situation in younger and older adults. N2ac amplitude and alpha power lateralization were used as electrophysiological correlates of lateralized auditory spatial attention. A speech comprehension task was employed in which pairs of words were presented, with the first serving as a cue to the position of the second, task-relevant one. Thus, it was possible to distinguish between the cortical response to the cue triggering the auditory search for the target after a switch had occurred, and the response to the target stimulus triggering the answer to the task. As in our previous studies (e.g., Getzmann et al., 2015a, 2017), the performance in speech comprehension (as operationalized by the rate of correct answers) declined immediately after a switch of the target talker across the participants' hemispace and returned back to the pre-switch level in the trials thereafter. At the same time, N2ac and alpha power lateralization increased, as well as the non-lateralized alpha power suppression. The analyses indicated a number of specific results that are discussed in detail in the following.

4.1. N2ac increase following target switch

The N2ac amplitude increased immediately after a switch, but faded quickly back to the pre-switch level afterwards, in Post 2 and Post 3 sequences. Assuming the N2ac to be a correlate of the allocation of selective attention to a target stimulus among multiple concurring stimuli (Gamble and Luck, 2011), this temporal pattern appears plausible, given that after a switch a re-orienting of spatial auditory attention is required. Thus, the N2ac appears to reflect a dynamic process that comes into play when auditory search is required rather than when attention is sustained at a target located within the same hemisphere. In line with that assumption, the N2ac is usually observed in highly dynamic scenarios, in which the target position typically changes from trial to trial (e.g., Gamble and Luck, 2011; Gamble and Woldorff, 2015; Lewald et al., 2016). The scenario employed in the present study, with the target being presented at a constant location for a number of trials, is more closely related to real-life listening situations, in which we typically listen to the same talker (at the same location) for at least a while before someone else takes their turn to talk.

Interestingly, there was a relationship between the increase in N2ac amplitude and the decrease in performance after a switch: A more pronounced N2ac increase was associated with a less pronounced decrease in the rate of correct responses. This relationship is in line with previous findings, in which greater N2ac amplitudes were related to overall better performance in sound localization in multi-talker environment (Lewald et al., 2016). Moreover, using linear mixed modeling, it has only recently been demonstrated that the N2ac amplitude significantly predicts accuracy in multi-talker sound localization (Klatt et al., 2020b), suggesting that more efficient attentional filtering and selection of information during auditory search (indicated by increased N2ac amplitudes) was associated with a better localization performance. Here we show, besides sound localization, the same appears to be true for speech comprehension in a dynamic listening scenario. Accordingly, using an auditory search paradigm with either a target localization or a (non-spatial) target detection task, it has been shown that the N2ac occurred in both task settings (Klatt et al., 2018b), indicating the significance of rapid focusing of attention onto a target position for both spatial and non-spatial sound processing.

Regarding the present talker switch paradigm, the results appear plausible, given that more effective shifting of attention toward the relevant hemispace should be associated with a better managing of that switch, resulting in a reduced decline in performance. However, this association was only found for the N2ac to the company names, but not in response to the company values. In the present paradigm, the target company name (i.e., the cue) indicated the position of the upcoming task-relevant company value (i.e., the target). Thus, the increase in cue-N2ac (and not in target-N2ac) was related to the switch-related change in performance, suggesting that the initial re-orienting of attention onto a new target location determined the efficiency of the subsequent attentional selection of the target information.

However, the association of cue-N2ac and performance was only evident in the older, but not the younger adults. One possible interpretation may be that between-subjects differences in the abilities to quickly shift attention were more strongly associated with a decline in performance in the older than in the younger group. In this regard, it should be noted that while there was no overall age difference in the mean amplitudes of cue-N2ac, the variation within the group of older participants appeared to be much higher than within the younger group (cf. Fig. 5). Age differences in N2ac amplitudes have not yet been studied systematically; even results of the more extensively studied visual counterpart of the N2ac, the N2pc, are rather contradictive (e.g., Lorenzo-López et al., 2008; Wascher et al., 2012; Mertes et al., 2017). Here, age differences in mean amplitude were only found for the target-N2ac, which was greater in the younger, than the older group, suggesting an age-related reduction of attentional focusing onto the target, but not the cue stimulus. Thus, the sustained attentional processing of the task-relevant information, but not to the initial auditory search itself seems to be impaired.

In line with the latter finding, no age differences in N2ac have been found in a recent study (Klatt et al., 2020b), in which a similar auditory search design was used, but only one sound stimulus per trial (instead of pairs of temporarily separated samples) was presented. Therefore, it rather resembled the cue-stimulus used here. It should further be noted that the ERP responses to the speech stimuli in general differed profoundly between the two age groups (as analyzed in the original study, Getzmann et al., 2015a). This is especially true for the analysis window of the cue-N2ac, where the younger group showed a pronounced (non-lateralized) negativity that was nearly absent in the older group (cf. Fig. 2A). This reduction in N2 which has already been observed (e.g., Schiff et al., 2008; Getzmann et al., 2015b; Stothart and Kazanina, 2016) is usually interpreted as reflecting declines in inhibition of concurrent (speech) stimuli, quite in line with the inhibitory deficit hypothesis, assuming that age-related deficits in performance are closely linked to a decline in the ability to inhibit the processing of irrelevant information (Hasher and Zacks, 1988; Guerreiro et al., 2010). Despite of this obvious reduction in N2 in the older group, it is striking that at least the cue-N2ac did not differ between the two groups. In other words: While inhibition and cognitive control in general are prone to age-related declines, the initial re-orienting of attention in auditory search as required here after switches in talker locations appears to be preserved, at least with respect to those processes reflected by the N2ac. On the other hand, it should also be noted that the N2ac is a relatively small ERP and that possibly much more participants have to be tested than done here to reliably assess differences between younger and older adults. In this respect, the current findings should be regarded as preliminary.

4.2. Alpha power suppression and lateralization

A bilateral suppression of alpha power clearly emerged following the onsets of the company names and values, with maximum amplitudes peaking about 400 ms after the names and about 440 ms after the values. This modulation of alpha oscillations is similar to a previous study, in which the temporal structure of alpha power modulations was in close synchrony with the rate of dichotically presented verbal stimuli (Wöstmann et al., 2016). Also, the delay of alpha power modulation by several hundred ms relative to the onset of sound is in line with the literature (e.g., Obleser and Weisz, 2012; Wöstmann et al., 2015). Alpha-band oscillations in general are closely linked to attentional processes, in particular to the suppression and selection of information (Klimesch, 2012). Consistently, modulations of alpha power have been shown to play an important role for the selection and inhibition of speech stimuli in challenging listening situations (for review, Strauß et al., 2014). Recent evidence from a MEG study using neurofeedback indicates that alpha suppression is in fact causally involved in modulating attention rather than being a mere byproduct of attention (Bagherzadeh et al., 2020). Thus, the present temporal pattern of the ERSP responses demonstrates the dynamic modulation of auditory attention in response to rhythmic speech input, with the deployment of attention being closely linked to the occurrence of the stimuli. Moreover, the fact that the alpha suppression was increased after a change in target talker location had occurred indicates that extra attentional resources were allocated to manage the switch of attention. Accordingly, decreases in alpha power have been associated with stimulus processing (rather than 'idling'; Pfurtscheller et al., 1994), increased memory load (Krause et al., 2000), and greater information processing demands in general (Griffiths et al., 2019), suggesting that alpha power can be interpreted as a measure of cognitive effort (Dimitrijevic et al., 2019). Similar to the N2ac, the increase in alpha suppression following a switch in target location faded away once the target location remained stable in subsequent trials. This temporal pattern of bilateral alpha dynamics was especially pronounced in response to the company values (i.e., the target stimuli), indicating that more attentional resources were allocated to the processing of the task-relevant target than to the cue that merely indicated the location of the target.

In the older group, across all sequence types (Pre-switch, Post1, Post2, Post3), but in particular in response to the company values, alpha suppression was larger than in the younger group. A possible interpretation of this effect is that older participants invested more cognitive resources to perform the task, especially when processing the task-relevant target information. This pattern is in line with the decline-compensation hypothesis (Wingfield and Grossman, 2006), which claims that older people try to compensate for age-related declines in primary functions like basic hearing abilities and deficits in speech understanding by increased mental effort. Accordingly, there was an overall worse performance of the older group in the present study, but this was not related to changes of talker location across the hemispace.

In addition to the alpha power suppression independent from target position, the lateralization of alpha power was also modulated following a cross-hemispace switch in target talker location, with the alpha lateralization being significantly increased after a switch in target location. This increase in lateralization appeared to be more sustained than the bilateral (non-lateralized) alpha suppression, as it was longer lasting, and still significant in Post 3 sequences, that is, long after the switch. This modulation of alpha lateralization is also different from the increase in N2ac, which quickly faded away after the switch. Alpha power lateralization in general is assumed to reflect the top-down controlled voluntary allocation of attention (Ikkai et al., 2016; Thut et al., 2006) and has frequently been observed in auditory task requiring spatial attention (e.g., Kerlin et al., 2010; Tune et al., 2018, Wöstmann et al., 2016). In particular, the present demonstration of a "homing in" of spatial attention toward the hemispace of the target information following a switch corroborates the findings of a recent study, in which a switch of parieto-occipital alpha power lateralization after a shift of the direction of attention across the listener's hemispace could be shown even at a more fine-grained level of spatial resolution (Deng et al., 2020). The present findings are also in line with a recent spatial-cuing study, demonstrating that alpha power lateralization was well pronounced following a cue indicating an upcoming target location. During the presentation of the target stimulus, however, alpha lateralization was practically absent when additional (non-spatial) cue information had been provided. This suggests that after top-down selection of a target location spatial attention becomes less important to filter out relevant information out of a mixture of competing sounds (Bonacci et al., 2020).

Independently of whether a switch in talker location occurred or not, alpha lateralization to the company values was stronger in younger than in older participants, while the two age groups did not differ in alpha lateralization relative to the company names. It is still a matter of debate to what extent alpha lateralization is preserved or diminished in older adults. Spatial-cueing studies focussing on visual anticipatory attention showed mixed results (e.g., Hong et al., 2015; Leenders et al., 2018; Mok et al., 2016; van der Waal et al., 2017), while two studies in the auditory modality suggested preserved alpha lateralization in older adults when anticipating an upcoming (lateralized) stimulus (Heideman et al., 2018; Tune et al., 2018). It should be noted, however, that the present experimental design is fundamentally different from a „classical“ cueing paradigm, in which the attention is shifted in anticipation of a target that has been indicated by a (usually centrally presented) pre-cue. Instead, our cue (the company name) was presented at the very same location as the target (the company value) and triggered the auditory search for the new target position after a switch occurred. The target, on the other hand, contained the task-relevant (non-spatial) information. The present pattern of results therefore suggests an age-related reduction in speech content-related attentional processing of the company value at the anticipated lateralized position. This observation is in line with the results of a previous study, indicating that younger adults were able to focus lateralized attention more efficiently to the task-relevant target than the older ones (Dahl et al., 2019). On the other hand, preserved alpha lateralization to the cue suggests that older adults activated the oscillatory mechanisms for searching for the relevant target hemispace to the same degree as their younger counterparts. In line with this conclusion, a recent study using an auditory search paradigm, in which alpha power lateralization following a sound array containing a lateral target stimulus was investigated, did not find differences between younger and older listeners (Klatt et al., 2020b). Interestingly, in a cued working memory task using arrays of lateralized visual stimuli, a quite similar pattern of alpha lateralization was found, with preserved alpha lateralization in anticipation of the upcoming lateralized memory array, but reduced alpha lateralization in older adults during the task-relevant retention processes following the stimulus display (Leenders et al., 2018).

No relationship between increases in alpha lateralization and the switch-related decline in performance was found, neither for the cue- nor target-related alpha lateralization. This observation is in line with a recent study (Klatt et al., 2020b), in which alpha lateralization following a lateralized target stimulus was not associated with accuracy in sound-in-noise localization; in contrast, N2ac amplitudes significantly predicted accuracy. That is, greater N2ac amplitudes were related to better performance. This was true for both younger and older age groups who showed a comparable pattern of neural activity. Consistent with this previous study, the present results again suggest that N2ac and alpha lateralization reflect distinct aspects of attentional orienting.

5. Conclusion

In summary, we found that both N2ac amplitudes as well as the magnitude of alpha lateralization increased following a cross-hemispace switch in target location. This emphasizes their involvement in handling dynamically changing sound environments and their role in shifts of spatial attention, rather than sustained spatial attention at a given location. The differences in the temporal evolvement of changes in the magnitude of lateralization as well as the differences in their association with behavioral performance demonstrate that N2ac and alpha lateralization reflect distinct attentional processes. While cue-related increases in N2ac amplitude were associated with pre- to post-switch declines in behavioral performances of older adults, there was no association between alpha lateralization and behavioral outcomes in neither age group. We pose that the N2ac is primarily associated with the initial auditory search and focusing of attention onto the relevant target position, whereas alpha lateralization is presumably associated with the following in-depth attentional processing of the stimulus in preparation of a response. Age-related differences in those lateralized measures suggest that rather than the initial re-orienting of attention following a target-location switch, the following attentional processing may be impaired in older adults.

Declaration of Competing Interest

All authors disclose no actual or potential conflicts of interest including any financial, personal, or other relationships with other people or organizations that could inappropriately influence (bias) their work.

CRediT authorship contribution statement

Stephan Getzmann: Visualization, Data curation, Formal analysis, Writing - original draft, Writing - review & editing. **Laura-Isabelle Klatt:** Formal analysis, Writing - original draft, Writing - review & editing. **Daniel Schneider:** Formal analysis, Writing - original draft, Writing - review & editing. **Alexandra Begau:** Formal analysis, Writing - review & editing. **Edmund Wascher:** Formal analysis, Writing - review & editing.

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