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The effect of acoustic feedback in an auditory Posner paradigm: delay effect and bias in ERP

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Abstract

A 'delay effect' occurs when a subject hears the sound of his own voice that is delayed by few milliseconds. This abnormal feedback induces difficulties in the articulation of language. This study aims to investigate ERP modulation during an auditory Posner paradigm an auditory delay effect (DAF) training. Main ERPs results highlighted delayed latencies and greater amplitudes after DAF. This can indicate how auditory feedback systems affect motor and auditory attentional early processes, by altering not only the task itself in language performance, but also producing a delayed bias in ERP components. So, if the acoustic feedback is naturally presented without delayed latency (NDAF), subjects will have no difficulty in producing verbal language and no ERP bias. If the stimulus is presented as DAF, subjects will present difficulties in articulating language, and will show ERP bias, in particular in frontoparietal, in temporoparietal, and in parietal ROI. This highlights the momentary interruption of an automatic process.

Keywords: attentional bias; delay effect; stuttering; altered auditory feedback; auditory Posner task

1. Introduction

The language production system is sensitive not only to the surrounding environment, but also to the auditory feedback in relation to subject's own voice output. A 'delay', in auditory feedback, is defined as the division of a signal in separate components, one of which is delayed, and then reintroduced into the original signal.

Over time, three mechanisms involved in language monitoring have been identified: kinesthetic and proprioceptive feedback from changes in the muscle and sensory apparatus, both involved in speaking and listening; the auditory feedback transmitted through the bony structures of our organism, in particular the bones of the head; the auditory feedback transmitted by the speaker to his receptive apparatus (Yates, 1963).

The absence of one of these mechanisms underlying the monitoring capacity, however, does not compromise linguistic production in an absolutistic manner; the latter, in fact, appears strongly interconnected with the acoustic conditions in which the speaker is located, which would be able to regulate automatically the production. To define better the acoustic-environmental condition, we can explain that the speaker use the sound localization mechanism to modulated his voice. Specifically, the human auditory system uses several cues to improve linguistic production, for example time- and intensity-differences between both ears, spectral information, timing analysis, correlation analysis, and matching of motor pattern (Howell & Archer, 1984). Starting from this point just described, it emerges that the production processes travel in parallel, but in different pathways compared to 'language understanding'. For example, in an ecological system, the auditory feedback is a strong help that allows speech articulation and production (Hagoort & Levelt, 2009; Levelt, 2000). In subjects with a healthy auditory and articular system, the speech production is about 15 speech articulation each second (Gaskell, 2012). Furthermore, the 'ecological' speech movements are planned to follow auditory trajectories (Guenther & Hickok, 2015; Siegel, Pick, & Garber, 1984).

An effective and functional self-monitoring can, however, be compromised if the feedback coming to our auditory system is altered; for example, in an experimental setting, by applying a delayed time of a few milliseconds on such feedback, evident articulation difficulties emerge (Invitto, Faggiano, Sammarco, De Luca, & De Paolis, 2016; Van Borsel, Drummond, & de Britto Pereira, 2010).

According to the latest behavioural measures, there are no difficulties in healthy and adult subjects when feedback is delayed by 50 ms, since fluency is equivalent to when feedback is natural; instead, there are evident alterations in the same subjects of linguistic production when the feedback is delayed by 200 ms, to the point of comparing the fluency difficulties encountered to the difficulties of those affected by stuttering (Stuart, Kalinowski, Rastatter, & Lynch, 2002). The alteration or cancellation of auditory feedback (as in the case of some people with hearing problems) can introduce distortions in linguistic production. Several previous studies have shown that the introduction of altered auditory feedback (AAF, Altered Auditory Feedback) has led subjects to apply different modulation formulas in linguistic production (Howell, 1990). In fact, subjects modulate the voice level when they listen to noise or hear their own speech amplified: increasing voice in noise condition and decreasing voice when the speech is amplified (Howell, 1990). A condition commonly used in the AAF studies is that of DAF (Delayed Auditory Feedback), which brings alterations of different degrees in the fluency of linguistic production, in terms of volume, production time, pitch, and speech rate. The distortion presented is related to several factors, including, for example, the delay time used during the study, but also the individual susceptibility of the subject to the DAF. For example, the introduction of a DAF appears to have opposite, compensatory effects on individuals suffering of stuttering (Andrews, Howie, Dozsa, & Guitar, 1982; Lincoln, Packman, & Onslow, 2006). In these subjects, a DAF can normalize speech production, probably because the subjects have a distractor that diverts the speakers from the feedback of their own stuttering fluency speech. As for the delay times, according to different studies, a delay of 50 ms or less, although detected by the subject, produces an alteration in the fluency of very limited language (Black, 1951); on the contrary, a critical and maximal interference was detected with a delay condition around 200 ms (Takaso, Eisner, Wise, & Scott, 2010). In a recent study, the cerebral and behavioural variable response that the subjects present in the face of a DAF has been deepened (Agnew, McGettigan, Banks, & Scott, 2018). At the end of the study it was found, among the various results, that the use of different delay times (specifically 50 ms and 200 ms) leads to the use of different neural strategies for language modulation, with an activation of neural patterns partially different: under a 200 ms delay was associated with activity in ventral sensorimotor cortices, whereas ability to produce normal sounding speech under a 50ms delay was associated with left inferior frontal gyrus activity (Agnew et al., 2018). Moreover, in the type of response to the DAF, considerable variability was detected both within subjects (Burke, 1975) and between subjects (Yates, 1963).

Despite the various factors of variability described above, in neurobiological terms, the recent literature is in agreement that in most conditions of DAF there is a greater bilateral activation of the superior temporal and inferior parietal cortex (Fu et al., 2006; Hashimoto & Sakai, 2003a; Takaso et al., 2010). Recent literature suggested that increasing speech rate engages central mechanisms of movement programming and attentional control via cortico-cerebellar loops more than sensory feedback systems, resulting in less DAF induced speech errors (Agnew et al., 2018). In particular seems that left hemisphere is more susceptible to DAF and this could be due to the necessity to control attentional processes during the task. Furthermore, Borden et al., showed an irregular peripheral activity, measured through electromyography (EMG), during DAF condition (Borden, 1979). This could be interpreted as a correlation between motor output and auditory feedback pathways and strongly suggests a role of attentional mechanism underlying delay process. Anyway, fMRI research result showed and increased arousal in prefrontal (Cohen, Botvinick, & Carter, 2000) and parietal areas (Agnew et al., 2018). We can hypothesize that, under an effect that slows not only the motor components, but also those articulatory and automatic components, the basic attentive processes also suffer a slowdown bias, which could manifest itself with the involvement of slow and non-synchronous attention times at the presentation of the task. We choose to investigate this bias through ERP technique, that has better temporal resolution respect to fMRI and is the most suitable technique to analyse changes in attentional processes (Hillyard & Anllo-Vento, 1998; Woodman, 2010). Following this hypothesis, the aim of this study was to investigate through an auditory Posner paradigm (Posner, 1980), basic auditory attentional components due to the administration of a different vocal training for two groups: an experimental group with a 200ms DAF placed in the headphones in relation to one's voice and a group control with feedback without any DAF (NDAF). In order to detect differences between the two conditions, phonetic analyses were performed on the vocal recordings performed during the vocal training and the analysis of the ERP components (i.e, N2 and P3) detected by the EEG recordings performed during the auditory Posner paradigm. In particular, N2 is a component elicited even under the influence of cognitive control, related to strategic monitoring and control of motor responses (Folstein & Van Petten, 2008) and P3 is a component that easily is modulated in Posner paradigm and is related with the difficulty of the task (Kok, 2001).

2. Method

2.1 Participants

20 subjects, university students, were recruited for the experiment (Mean Age=28.6 years; s.d.=3). All subjects were normo-listeners and did not report

any history related to previous neurological disorders. All participants have previously signed an informed consent drawn up according to the Helsinki declaration.

2.2 Experimental procedure

All participants underwent a voice recording audio training followed by an auditory Posner task. The conditions relating to the vocal training have been differentiated according to the subject's belonging to the NDAF or to the DAF group.

2.3 Voice recording audio training

The vocal training was divided into two different procedures. In both conditions the subject's voice was recorded through the use of the Nuendo software while he was asked in order:

1. Name and surname;
2. Place of residence;
3. Employment;
4. Reading of Manzoni's poetry "Il 5 Maggio";
5. Recite a text of subject's choice (poetry or song);

The choice of poetry (point 4) and subsequent spontaneous acting (point 5) was due to the fact that the subject could experiment the reading of a poem belonging to the scholastic background of the subject (the poem "Il 5 Maggio" is enclosed in Italian school programmes of secondary education) and the reading or free acting of a text chosen by the subject, free from scholastic conditioning.

In the delayed condition, the subject voice was recorded and administrated through the headphones with a delay of 200ms (i.e, multimedia file Il 5 Maggio_Delay). In the no-delay condition the voice was recorded and administrated in real time (i.e, multimedia file Il 5 Maggio_No_Delay).

The subjects in the experimental group were given both conditions in sequence, while the subjects belonging to the control group were administered only the condition without delay. Subsequently, the phonetic analysis of the vocal recordings was performed with the aid of the PRAAT acoustic analysis software (software dedicated to the acoustic analysis of the voice)(de Jong & Wempe, 2009; Styler, 2013).

2.4 Auditory Posner task

The Auditory Posner task was generated and administered with through the E-prime 2.0 software. Following the vocal training of audio recording, the subjects were sitting in front of the computer screen with headphones on their ears. At the beginning of the task, the subjects displayed the instructions related to the Posner on the screen. A mono-aural pure tone pip (1,000 Hz), presented unilaterally, was administrated both as the cue (250 ms) and as the target. Cue-target asynchrony was either 100 or 600 ms. The spatial relationship between cue and target defined two conditions: valid target and invalid target. The congruence between cue and target lateralization was randomized, giving rise to two different conditions: valid target (located on the same side of the cue, 40% of cases) and invalid target (located on the opposite side of the cue, 40% of cases). The remaining 20% of cases consisted in the presentation of the cue without any target to follow (Fernandez-Duque & Posner, 1997; Posner, 1980). The task of the subjects was to press any key on the keyboard only when the target was valid. During the Auditory Posner task, an EEG recording was performed.

3. Results

3.1 Phonetic analysis of vocal recordings

The recording of the vocal test of the two conditions (DAF-NDAF), allowed to carry out two types of analysis, with the PRAAT software, of the audio recordings of the subjects (see Figure 1):

- a first analysis centered on a sample of word of the Ode "5 Maggio";
- a second analysis of the first 4 verses of the same Ode.

In the first analysis, the words of the first 4 verses considered to be more significant than the speech frequency were taken in the recordings with delay effect:

“Ei fù. Siccome im/mo/bi/le,
dato il mor/tal /sos/pi/ro,
stette la spo/glia/ im/me/mo/re
orba di tanto spi/ro”.

For each word considered, the average pitch, intensity and duration were analysed in the recordings with the effect of the delay and in the recordings without effect for each subject, also the parameter "speech rate" was considered, definable as the number of syllables present in the word / time of the production of the word itself.

Figure 1. Example of a spectrogram of DAF condition and NDAF Condition

3.2 ERP Recording and Components Analysis

EEG signals were recorded from a 16 channels amplifier (Brain Products V-Amp) mounted in an electrode cap according to the International 10‑20-system. We used the Brain Vision Recorder recording software and the Brain Vision Analyzer (Brain Products GmbH) analysis software. Electrode impedance was kept below 10 kΩ. The EEG recording sampling rate was 500 Hz. Electrodes were referenced online to the FCz. One electrode was placed at the outer canthus of the left eye and used to monitor eye movements. Trials contaminated by eye movements, amplifier conditioning, or other artefacts were rejected. The signal was filtered offline (0.01‑35 Hz, 8 dB) and the threshold for artefact rejection was set at > |125| μV. Ocular rejection was performed through independent component analysis (ICA). ERP epochs included a 100-ms pre-stimulus baseline period and a 500-ms post-stimulus segment. Separate averages were calculated for each Stimulus segmentation (cue, congruent target, incongruent target). Peaks detection were applied according to ERP latency detected in grand average. ERP components were labelled N2 and P3 (Luck, 2014).

Through the use of the SPSS @IBM SPSS Statistics software, the amplitude and latency of the ERPs N2 and P3 components of the Target Congruent condition were analysed.

A repetitive ANOVA was performed on the widths of the N2 with Laterality (3 levels: left, center, right) and Electrodes (5 ROI: Fp, F, C, P, O) as a within-subject factor and Group (2 levels) as a between-subject factor (alpha = 0.05). The Greenhouse-Geisser correction was applied where necessary (the original degrees of freedom are reported). For post-hoc tests, least-significant difference (LSD) comparisons were performed.

The same ANOVA measure repeated were performed for the P3 both in amplitude and in latency.

3.3 Acoustic Results of vocal recordings

From the vocal recordings in DAF and NDAF, it is clear how the subjects change the vocal expression, while answering the same questions and requests.

In the images we can notice that, during the vocal recordings with the effect of the delay, the subjects not only lengthen the duration of the syllables clearly, but use a monotonal vocal tone, as well as increase the vocal volume as to overwhelm the effect and in some cases, there is a speeding up of the quantity of words emitted, in an attempt not to be overwhelmed by the effect reproduced in the headphones. A statistical comparison was carried out between the recordings made with the effect of the delay and those without the effect, to verify that there was a significant difference due to the effect itself (shown in Table 1).

Table 1. Average values for each word during control condition and Delay condition

No Delay	Pitch (Hz)	Intensity (Db)	Duration (sec.)	Speech Rate
Immobile	127,23	64,81*	0,65*	6*
Mortal	132,61	63,33*	0,42*	5*
Sospiro	124,6	60,68*	0,66*	5*
Spoglia	133,09	64,32*	0,36*	6*
Immemore	123,12	62,78*	0,6*	7*
Spiro	115,76	60,93*	0,45*	5*

Delay	Pitch (Hz)	Intensity (Db)	Duration (sec.)	Speech Rate
Immobile	129,99	68,7*	0,93*	5*
Mortal	142,57	68,17*	0,50*	4*
Sospiro	136,5	66,09*	0,87*	4*
Spoglia	138,87	70,89*	0,59*	4*
Immemore	133,83	69,13*	0,8*	5*
Spiro	121,86	65,45*	0,61*	4*

*t Test <0.05

From the analyses performed with the Student t-Test between the "immobile" Pitch of DAF and the "immobile" Pitch of the NDAF, no significance emerged (t> 0.05) and so for all the other words considered.

On the contrary, significance emerged for intensity, duration and speech rate; through the analysis, it can be seen how with the delay effect, the subject tends to pronounce a lower number of syllables in greater time and the duration of the vocal emission of the words, increases in the recordings with the delay effect.

It is concluded that, since there is significance for the duration t-test and the speech rate t-test (t <0.05), for all the words considered, there is a difference between the words emitted with the delay effect and without this effect, i.e. the words emitted with the delay effect, have a longer duration than the words emitted without this effect (t <0.05) and for the speech rate it has been observed that for the utterance of the same words, use them on average more time for each syllable.

The analysis of the intensity produced significant results in the difference between the Delay and No Delay effect (t<0.05) in direction of a greater intensity in Delay condition. The second analysis was carried out on the first 4 verses of the Ode, Pitch max, Pitch min, Pitch max-min, Pitch mean and duration were analysed, the number of syllables per verse was considered, in order to calculate the speech rate.

“Ei/ fù/. Sic/co/me/ im/mo/bi/le/, (verse 1)
da/to /il/ mor/tal/ so/spi/ro/ , (verse 2)
stet/te/ la/ spo/glia/ im/me/mo/re/ (verse 3)
or/ba /di /tan/to /spi/ro/ (verse 4)

The t-test highlighted, in verse 1, significant differences between the two conditions, for the duration and speech rate with t <0.05, or the verse 1 emitted with the effect delay verse 1 emitted without such effect, and the number of syllables / s issued in the recordings made without the effect. For all the other parameters considered, no significance emerged (t> 0.05).

For verse 2, through the tense test with the effect of delay and recordings without effect, for duration, speech rate and difference between pitch and max pitch (t <0.05), as above written in verse 1. The parameter difference between the pitch and the minus the subtraction from the maximum. Pitch in the same sequence. For all the other parameters considered, no significance emerged (t> 0.05).

For verse 3, through the t-test with the effect of delay and recordings without effect, for duration, speech rate and average pitch with t <0.05, as written above in the verse 1. The mean pitch parameter is the mean of the Pitch 3. For all other parameters considered, significance (t> 0.05) has not emerged.

For verse 4, with the effect of delay and recordings without effect, for speech rate and average pitch with t <0.05 or in the recording with the effect delay fewer syllables are issued in a longer time than the recording of the same verse issued without this effect. For all the other parameters considered, significance did not emerge (t> 0.05).

Table 2. Average Value of Pitch Max (Hz), Min (Hz), Difference of Pitch (Hz), Duration (sec.) and Speech Rate of 4 verses analysed, in Delay condition vs Control Condition

No Delay	Pitch max (Hz)	Pitch min (Hz)	Difference Pitch max-min (Hz)	Average Pitch (Hz)	Duration (sec.)	Speech rate
Verse 1	180,95	101,24	79,72	137,34	1,6*	6*
Verse 2	155, 23	110,58	44,65*	130,54	1,58*	5*
Verse 3	169,4	111,25	58,14	128,3*	1,56*	6*
Verse 4	151,83	96,98	54,85	127,87*	1,24	6*

Delay	Pitch max (Hz)	Pitch min (Hz)	Difference Pitch max-min (Hz)	Average Pitch (Hz)	Duration (sec.)	Speech rate
Verse 1	202,57	105,54	97,03	141,23	2,48*	4*
Verse 2	174,7	92,96	81,736*	138,03	1,9*	4*
Verse 3	161,83	101,83	60	136,43*	2,25*	4*
Verse 4	169,4	108,41	61	135,51*	2,1	4*

* t Test <0.05

It can be concluded, therefore, that in the four verses analysed there is a substantial difference in the speed of speech, or the verses emitted with the delay effect have a longer duration than the verses issued without this effect. As a consequence, the effect produces a delay in the duration of the speech issue, probably due to a slowdown in language production and an increase in the time required for articulation.

3.4 ERP N2 Results

The repeated measures conducted on the amplitudes of the ANOVA have shown significance for two factors.

The first is the Laterality factor [F (2.32) = 3.155 p <0.05], in relation to which the right electrodes showed amplitudes significantly greater than the central and left ones.

The second is the Electrodes factor [F (4,64) = 9,931 p <0,05], from which it emerges from the post hoc that the occipital electrodes, in the DAF condition, showed greater amplitudes than all the other electrodes (see Figure 2), and that the parietal and parieto-temporal electrodes, in both conditions, have greater amplitudes with respect frontal localization.

ANOVA repeated measures conducted on latencies reported significance for interaction Laterality * Electrodes [F (8.128) = 2.973 p <0.05]. The results also report shorter latency in control condition compared to the delayed condition [F (1.16) = 5.580 p <0.05].

Specifically, in the first comparison, F4 (right frontoparietal) showed a delayed latency than F3 (left frontoparietal region) and Fz (frontocentral region) (see Figure 3). Pz showed delayed latency than P3 and P4 (parieto-temporal region). In the second comparison, there was a difference between Pz and Cz, where Pz has a lower latency (see Figure 4). Furthermore, in the right lobe, F4 has a lower latency than P4.

3.5 ERP P3 Results

The ANOVA measure repeated were performed for the P3 both in amplitude and in latency. No significance emerged due to group in amplitudes.

For the latency, significance has emerged for the Electrodes factor [F (4,64) = 13,146 p <0,05], in particular: the occipital have delayed latencies than all the other electrodes analysed; the parietals electrodes showed faster latencies of the occipital, latency equal to the central ones and greater latency of frontal and frontopolar (see Figure 3); the central electrodes have higher latencies than the frontal but equal to that of the frontopolar (and the parietal ones); the frontal localization presented faster latency than all the electrodes, except for the frontopolar; frontoparietal showed faster latency of parietal and occipital positions (Figure 5).

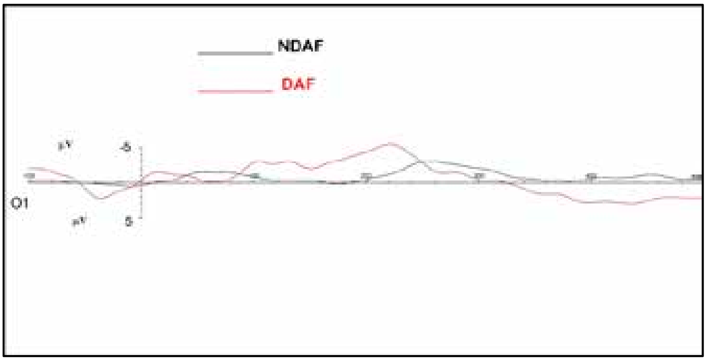

Figure 2. Matching ERP of O1 position (left occipital area): NDAF condition (black line) vs DAF condition (red line)

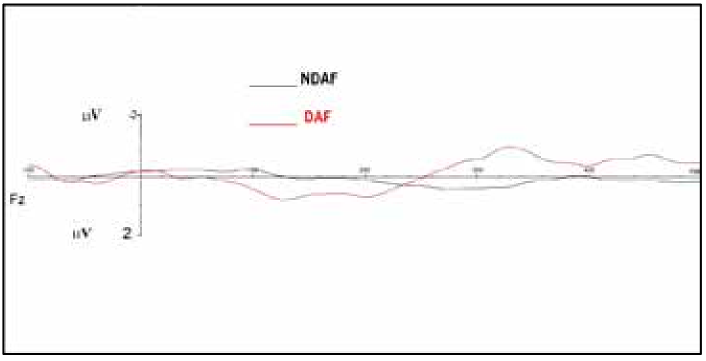

Figure 3. Matching ERP of Fz position (frontocentral area): NDAF condition (black line) vs DAF condition (red line)

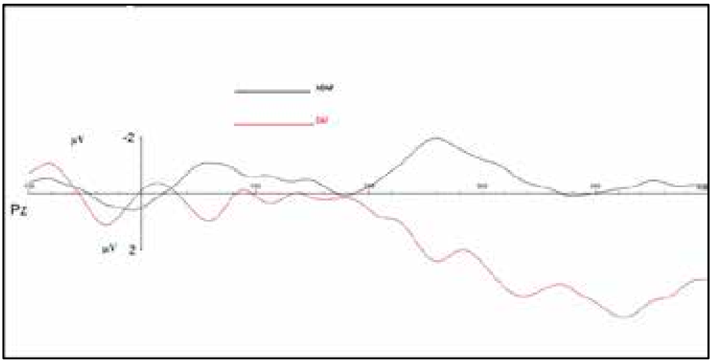

Figure 4. Matching ERP of Pz position (centroparietal area): NDAF condition (black line) vs DAF condition (red line)

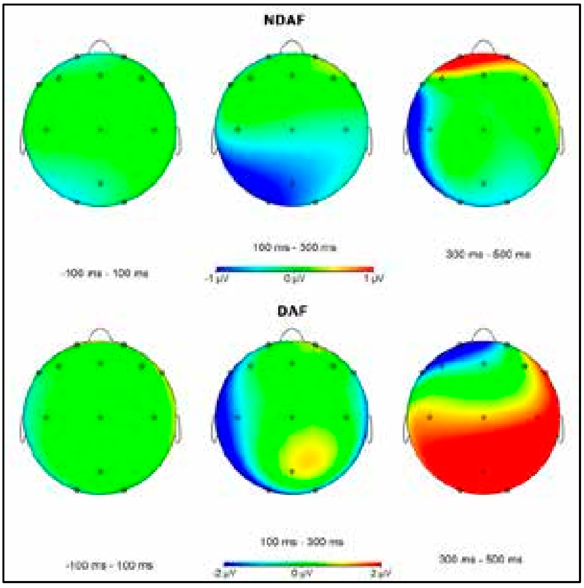

Figure 5. Mapping comparison of NDAF and DAF condition during three different time ranges (i.e, -100 ms - 100 ms; 100 ms - 300 ms; 300 ms - 500 ms); in particular the range between 100 ms - 300 ms corresponds to N2 ERP component and the range between 300 ms - 500 ms corresponds to P3 ERP component

4. Discussion

A 'delay effect' occurs when a subject hears the sound of its own voice that is delayed by few milliseconds. This feedback induces difficulties in the articulation of language. We analysed the effects on attention during training with natural and delayed auditory feedback. If the stimulus is naturally presented without delayed latency, subjects will have no difficulty in producing verbal language. If the stimulus is presented with a delayed acoustic feedback, subjects will present difficulties in articulating language, concentrating on what they are reading, or simply pronouncing their names and surnames (Van Borsel et al., 2010). This highlights the momentary interruption of an automatic process. After 7-10 minutes of delayed feedback, the subjects present habituation to the delay effect. This parameter adjusts the time between the introduction of the original signal and the reintroduction of the delayed signal. The results that emerged, highlighted the effective correlation between people's attentional capacity and the ability to monitor their linguistic production; in fact, the latter represents, if used effectively, a fundamental tool for the understanding the 'others' and the 'self'.

In this perspective, it emerges that the dynamism of the linguistic process characterizes not only the elaboration phase of the inputs but also that of the production of the different outputs, noting that the processes characterizing the different phases take place in parallel; the choice to analyse this process through the ERP has in fact allowed to highlight this characteristic of the linguistic process.

Furthermore, our results, taking into account the neural network that supports the self-monitoring of linguistic production (Christoffels, Formisano, & Schiller, 2007; Hashimoto & Sakai, 2003b), have corroborated what has already emerged in the literature about the role of the temporal and parietal areas within this network. The temporo-parietal areas, in fact, showed a marked slowdown in the latency of the components examined (N2 and P3) with reference to the experimental condition in which subjects were given delayed auditory feedback of 200 ms. If we consider hemispheric differences, in N2 we can see a greater amplitude in the right hemisphere. This could be related to the cross-modal nature of the task (both linguistic, attentional and acoustic) (Booth et al., 2002; Invitto et al., 2017).

Furthermore, in the DAF condition, we found greater amplitudes and delayed latency in parietal, frontal and occipital regions, specifically, the right frontoparietal, centroparietal, and temporoparietal region seems to be the more impaired during the DAF condition. The results of this early component are related to strategic monitoring and control of motor responses (Folstein & Van Petten, 2008) impaired, in our study, by the DAF condition (and this impairment is evident in behavioural result as well).

In P3 component, easily modulated in Posner paradigm by the difficulty of the task, we found delayed latencies in posterior localization (occipital and parietal); and we can observe an increasing in latency starting from frontal localization up to parietal and occipital localization. These results let us think of a pathway of connectivity that starts from attentional levels (i.e, frontal region) and arrives at posterior perceptual region (i.e, parietal and occipital regions). It is interesting to note how the global attentive aspect (right hemispheric preference) has a predominance with respect to the linguistic aspects (left hemispheric preference).

The actual alteration of these areas, in functional terms, could represented the momentary blackout of the automatic self-monitoring process and could be the evident results of the bias produced starting by attentive process up to cognitive processes. The resulting electrophysiological results are even more interesting and understandable if related to behavioural results, which have converged into a clear alteration of the verbal fluency of the subjects, as well as a clear increase in the tone of voice, grammatical errors and sometimes the formulation of neologisms.

Some inter-individual differences in the ability to compensate individuals with respect to the momentary black-out of the monitoring process have emerged from the behavioural point of view. These differences, in the literature, seem to be correlated in part with the ability of individuals to manipulate the tone of their own voice, partly with the kind of belonging, partly with age (Borden, 1979; Hain, Burnett, Larson, & Kiran, 2001; Howell & Powell, 1987). Future studies could, therefore, focus on the analysis of these behavioural differences, verifying if these can correlate with specific differences also from the neural point of view; a widening of the emerged results can indeed be particularly useful also in the clinical perspective, taking into account those situations in which the processes of linguistic elaboration and production are altered.

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