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Language and Motor Processing in Reading and Typing: Insights from Beta-Frequency Band Power Modulations

Michele Scaltritti^{1,2}, Caterina Suitner², Francesca Peressotti²

1 Dipartimento di Psicologia e Scienze Cognitive, Università degli Studi di Trento, Corso Bettini 84, 38068 – Rovereto (TN), Italy. e mail: michele.scaltritti@unitn.it

2 Dipartimento di Psicologia dello Sviluppo e della Socializzazione, Università degli Studi di Padova, Via Venezia 8, 35131 – Padova (PD). Italy. e mail: caterina.suitner@unipd.it; francesca.peressotti@unipd.it

Author Note

Correspondence concerning the article should be addressed to: Michele Scaltritti, Dipartimento di Psicologia e Scienze Cognitive, Università degli Studi di Trento, Corso Bettini 84, 38068 – Rovereto (TN), Italy. e mail: michele.scaltritti@unitn.it

Abstract

Power modulations of the EEG activity within the beta-frequency band were investigated across silent-reading and copy-typing tasks featuring emotionally negative and neutral words in order to clarify the interplay between language and motor processing. In reading, a single desynchronization surfaced 200-600 ms after target presentation, with a stronger power-decrease in lower beta frequencies for neutral compared to negative words. The typing task revealed two distinct desynchronizations. A first one surfaced within spatio-temporal coordinates closely resembling those of the desynchronization observed in the reading task, thus pointing towards a common origin at the level of linguistic processing of the input word stimuli. Additionally, a second motor-related desynchronization surfaced during the typed response, from 700 to 2000 ms after stimulus onset. Here, words' emotional connotation affected the higher beta band. The comparison between tasks thus suggests that different beta desynchronizations reflect distinct EEG landmarks for language and motor processing. Further, the effect of emotional connotation on the motor-related desynchronization of the typing task suggests that language processing can propagate its influence onto the stage of motor response execution, pointing against a serial flow of information from language onto motor processing.

Keywords: EEG; language production; motor control; beta-frequency band

1. Introduction

Electroencephalographic (EEG) activity in the beta-frequency band (13 – 30 Hz) has been traditionally associated with motor processing (e.g., Pfurtscheller & Lopes da Silva, 1999). The typical pattern consists of a reduction in power (desynchronization) during motor programming and response execution, followed by a post-movement power increase (synchronization) (Kivalik, Zaepffel, Brovelli, Mackay, & Riehle, 2013). Recent research, however, provides evidence for the involvement of beta oscillations across a variety of cognitive functions (Engel & Fries, 2010; Spitzer & Haegens, 2017), including different aspects of language processing such as grammatical (Davidson & Indefrey, 2007; Bastiaansen, Magyari, & Hagoort, 2010) and semantic processing (Luo, Zhang, Feng, & Zhou, 2010; for a review, Weiss & Mueller, 2012), with a focus on action semantics (e.g., Klepp, Niccolai, Buccino, Schnitzler, Biermann-Ruben, 2015; van Elk, Schie, Zwaan, and Bekkering 2010). Extant evidence supports the notion of this dual nature of beta-frequency oscillations in language. For example, power decreases in beta oscillations occurring before speech onset within a picture naming task are modulated by the semantic context provided by a preceding sentence (Piai, Roelofs, Rommers, & Maris, 2015; see also Piai, Roelofs, & Maris, 2014). Intriguingly, these modulations can be linked to different neural structures involved in conceptual processing, memory retrieval, and motor response implementation (Piai et al., 2015; see also Piai, Rommers, & Knight, 2018). Power modulations in the beta-frequency band thus capture both language and motor processing, possibly offering a window into the flow of information across these two major components of language production.

As noted by several researchers in the fields of spoken/written word production and reading aloud (e.g., Hicock, 2012; 2014; Kandel & Perret, 2015; Mousikou & Rastle, 2015; Weingarten, Nottbusch, & Will, 2004), cognitive-linguistic processes and those related to the implementation of the corresponding motor responses have been investigated by separate research traditions. Possibly, this division stems from the assumption that motor-response implementation can start only after linguistic processing has terminated (e.g. Levelt, Roelofs, & Meyer, 1999; Meyer & Levelt, 2000).

This discrete transition from linguistic onto motor processes seems to hold even within models that otherwise posit a continuous, cascaded flow of information between linguistic representational levels (e.g. Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001; McClelland, 1979). However, behavioral evidence seems to contradict this staged architecture by showing the influence of higher-level cognitive processes on motor responses within language production tasks (e.g., Fink, Oppenheim, & Goldrick, 2018; Gahl, 2008; Goldrick et al., 2019; Roux, McKeef, Grosjacques, Afonso, & Kandel, 2013; Scaltritti, Arfè, Torrence, & Peressotti, 2016; but see Damian, 2003; Pinet, Ziegler, & Alario, 2016), extending the cascaded and interactive architecture to encompass stages of response execution as well (e.g., Goldrick et al., 2019).

The neurophysiological underpinnings of the potentially continuous stream of information mapping linguistic processing onto motor response implementation have remained more elusive. The issue has received renewed interest through the investigation of typing tasks. As typed responses are produced with the hands, this allows a close scrutiny of the cortical dynamics related to motor-response programming and execution, without the excessive contamination of the EEG signal by motor-artifacts associated with spoken responses. Extant evidence based on event-related potentials (ERPs) is consistent with the separation of language processing and motor response execution within discrete processing stages. For example, Scaltritti, Pinet, Longcamp, and Alario, (2017) used a semantic priming paradigm with typed responses and, despite reliable effects both in terms of reaction times (RTs) and N400, found no semantic priming effects on ERPs capturing motor-response preparation. Pinet, Dubarry, and Alario (2016) explored semantic interference effect generated when typing the name of multiple exemplars of the same semantic category (e.g., animals) across trials (Brown, 1981; Howard, Nickels, Coltheart, & Cole-Virtue, 2006). Again, no semantic effect was found in EEG indexes related to motor processing.

Very interestingly, however, in their work Pinet, Dubarry and Alario (2016) provided a detailed description of power modulations of the beta-frequency band during a typed production task (see also Pinet, Hamamè, Longcamp, Vidal, & Alario, 2015). The authors highlighted two

separate decreases of beta power (event-related desynchronizations, ERD). A first ERD surfaces after stimulus onset and is followed, before the beginning of the response (i.e., before the pressing of the first keystroke) by a transient event-related synchronization (ERS). Around the time of the onset of the motor response, a second more prolonged ERD surfaces and lasts for the whole duration of response execution, followed by a final ERS arguably related to the typical beta-band rebound after response termination (see Kivalik et al., 2013). The left-lateralization of the first ERD lead Pinet, Dubarry and Alario (2016) to speculate a link with language processing, whereas the second bilateral ERD would be more related with motor processing. This evidence thus provides a framework to explore the unfolding and the potential relationships between language and motor-processing exploiting beta-band ERDs.

The aim of our current research is twofold. Our first goal was to more closely investigate the two-ERDs pattern reported by Pinet and colleagues (2016) and, in particular, to further address the possibility that the two ERDs provide distinct EEG landmarks of language and motor processing. In our experiment, this was done by comparing beta-band power modulations within a silent reading task with those elicited by a copy-typing task. Language-related ERDs should be present in both tasks, arguably with similar spatio-temporal coordinates. Differently, any motor-related ERD should be present only in the typing task, where an actual motor response is performed. Additionally, we aimed to explore the transition between language and motor-processing by tracking the effect of a linguistic manipulation across the beta power modulations of the two tasks. To reach this second goal, we exploited the emotional connotation of words. Compared to other potential manipulations of the linguistic stimuli, in fact, emotional connotation provides detectable signatures within oscillatory-power modulations.

In the time-frequency domain, several studies investigated the effects of emotional connotation for a wide variety of stimuli (for a review, Güntekin & Başar, 2014), seemingly converging on the involvement of oscillations in the beta-frequency band (particularly in the lower range) when processing emotional visual stimuli such as images (e.g., Schubring & Schupp, 2019;

Güntekin & Başar, 2010), and faces (e.g., Güntekin & Başar, 2007; Cooper, Simpson, Till, Simmons, & Puzzo, 2013). With respect to word stimuli, the electrophysiological dynamics underlying the processing of emotive stimuli have been extensively investigated in the time-domain (for a review, Citron, 2012) revealing the involvement of early (200 – 300 ms) ERP components, such as the Early Posterior Negativity (EPN), related to the attentional capture exerted by emotional words during lexical access, as well as later effects (500 – 800 ms) on the Late Positive Complex (LPC), reflecting more controlled and explicit processing of emotional content (Citron, 2012). Focusing instead on oscillatory dynamics, within a magnetoencephalographic (MEG) study investigating silent reading, Hirata and colleagues (2007) highlighted a decreased oscillatory power in beta frequencies over anterior cingulate cortex and left inferior (IFG) and middle frontal gyrus (MFG) for both negative and positive words with respect to neutral ones. Differences as a function of valence were detected selectively for the prefrontal cortex in terms of different lateralization of the ERDs. Further, Putman, Arias-Garcia, Pantazi, and van Schie (2012) showed an increase in delta-beta power coupling for participants who showed less interference from the negative emotional connotation of distracter words compared to neutral ones in a variant of the Stroop task. Differently, in case of incidental reading during a color discrimination task, Wang and Bastiaansen (2014) found that both positive and negative emotional connotation of words modulated alpha-ERD, pointing towards an attentional capture from emotionally connotated linguistic stimuli.

For the purpose of our experiment, what is relevant is that a variable of the linguistic input stimulus, such as its emotional connotation, can be clearly tracked at the level of time-frequency modulations, potentially within a frequency band that has proved to be sensitive to both language- and motor-related processes. This allows to track the course of the effect across distinct processing stages indexed by distinct beta ERDs. Specifically, if the processing of the linguistic input and the implementation of the corresponding motor-response unfold within separate serial processing-stages, the emotional connotation should modulate beta power only for the first, early desynchronization, and in a similar way in the reading and in the typing task. Otherwise, if direct

interaction can occur between linguistic and motor stages, the effect of emotional connotation may surface even in the second motor-related ERD.

In summary, our experiment directly compared a silent reading and a copy-typing task within the same participants, in an effort to track and compare the beta-power modulations across the two, thus shedding light on their functional interpretation. Additionally, we manipulated the emotional connotation of the words, with the aim to trigger a modulation of beta power driven by the processing of the input linguistic stimulus and track its time-course across language and motor stages of processing as indexed by beta ERDs. In order to reduce the number of comparisons, we focused on the contrast between emotionally negative and emotionally neutral words, given the similar effects yielded by negative and positive emotional words within language-related cortical areas (Hirata et al., 2007), as well as in terms of overall effects within less spatially selective signals offered by the EEG (Wang & Bastiaansen, 2014). Further, we focused our analyses on the beta-frequency band, partitioned into 2 subranges (low: 13 – 20 Hz; high: 21 – 30 Hz), in order to gain sensitivity with respect to the effects of emotional connotation, which seem to be mostly reflected into the lower beta-frequency band (e.g., Csukly, Farkas, Marosi, Szabò, 2016). Additionally, some features of the motor-related beta-band oscillations, such as the post-movement beta-band rebound, can be more clearly detected on the higher end of this frequency band (Pfurtscheller, Woerz, Supp, & Lopes da Silva, 2003). We also report more exploratory analyses of the alpha/mu band (8 – 12 Hz). On the one side, these latter frequencies have also been related to motor processing (e.g., Babiloni et al., 2002; Pfurtscheller, 2003; Pineda, 2005) and may therefore provide additional insights on the issues at stake. On the other, at least for EEG studies, power modulations of the alpha-band have been linked with the processing of the emotional connotation of words (Wang & Bastiaansen, 2014). As the dynamics of low-beta activity tend to parallel those of the alpha-frequency band, particularly in the sensorimotor domain (Spitzer & Haegens, 2017), we felt it was important to provide a differential description and to ascertain the specificity of any beta-related modulation.

2. Method

2.1 Participants

Twenty-four right-handed, Italian native-speakers were recruited (8 females and 16 males, $M_{age} = 24.25$, $SD_{age} = 2.31$). Three participants of the original sample were replaced, either due to poor signal quality or to an excessive number of errors in the typing task (35% of the trials). Handedness was assessed using the Edinburgh Handedness Inventory (Oldfield, 1971). Participants' mean handedness score was 89.33 ($SD = 12.40$, range 60 - 100), and all of them could be classified as right-handed. Typing skills were assessed via a test (modeled after Pinet et al., 2015) administered a few days before the experiment. Participants could take part in the experimental phase only if they were able to type fluently without looking at the keyboard and using all (or most of) their fingers with a consistent finger-to-keystroke mapping. Participants received all the information about the procedure before the typing test, and provided written informed consent once they registered to the typing test. Participation was compensated with 10€ per hour. All the procedures received approval from the Ethical Committee for Psychological Research of The University of Padova.

2.2 Stimuli

Stimuli were selected from the Italian adaptation (Montefinese, Ambrosini, Fairfield, Mammarella, 2014) of the Affective Norms for English Words database (ANEW; Bradley & Lang, 1999). Words within the database were categorized as *negative* if their affective valence score (range 1–9) was below 3, and as *neutral* if their affective valence score was between 4 and 7. We then selected two sets of 100 words each, one composed of negative words, the other of neutral words. For each of the two sets, half of the words had the first letter typed with the right hand (R), and the other half with the left hand (L). As motor-related beta ERDs tend to be larger over sites contralateral to the effector, this was done to avoid introducing any spurious lateralization at the time of response onset (first keystroke). Neutral and Negative words differed in terms of affective

valence, $F(1, 196) = 1587.37, p < .001$, and arousal, $F(1, 196) = 172.34, p < .001$, while being comparable across a series of psycholinguistic variables (see Table 1).

Table 1. *Variables controlled across Negative and Neutral words.*

Variables	Negative		Neutral	
	R	L	R	L
No. letters	7.02 (1.75)	7.36 (1.41)	7.2 (1.87)	7.58 (1.76)
Frequency (log)	3.49 (1.48)	3.68 (1.16)	3.69 (1.1)	3.53 (1.49)
Orthographic N.	3.46 (4.48)	2.48 (2.37)	3.74 (4.26)	3.1 (3.61)
Familiarity	5.65 (1.06)	5.47 (1.08)	5.84 (0.82)	5.7 (0.57)
Imageability	6.55 (0.95)	6.48 (0.98)	6.41 (1.32)	6.75 (1.06)
Concreteness	5.8 (1.32)	5.83 (1.34)	5.65 (1.64)	6.24 (1.41)
Valence	2.13 (0.42)	2.11 (0.38)	5.76 (0.85)	5.66 (0.76)
Arousal	6.55 (0.72)	6.42 (0.67)	5.23 (0.77)	5.18 (0.59)
No. opposite keystrokes	3.52 (1.33)	3.18 (1.27)	3.62 (1.52)	3.28 (1.40)

Note. No. letters = number of letters; Orthographic N. = orthographic neighborhood size; No. opposite keystrokes = number of keystrokes produced with the opposite hand with respect to the one used to type the first one. R = words in which the first keystroke was typed with the right-hand; L = words in which the first keystroke was typed with the left-hand. Mean values are reported. Standard deviations are reported within parentheses. All variables were retrieved from the Montefinese et al. (2014) database.

Specifically, ANOVAs conducted on each control variable considering Stimulus Type (Negative vs. Neutral) and Response Hand (Right vs. Left) as factors failed to highlight any significant main effect or interaction (all $F_s < 2.23$, all $p_s > .10$). To ensure that the two sets of

items were further comparable in terms of recruitment of the left vs. right hand not just in the first keystrokes, but during the whole typed responses, care was taken in controlling the number of keystrokes typed with the opposite hand with respect to the one used for the first one. Negative and Neutral words were comparable across this dimension ($t < 1$). This was true even when limiting the analysis to the second and third keystrokes ($t < 1$), which exert a noticeable influence on EEG indexes of motor-preparation surfacing at the time of response onset (Scaltritti, Alario, & Longcamp, 2018).

Items were divided into 2 subsets for counterbalancing purposes. Each subset contained 50 negative (25 L, 25 R) and 50 neutral words (25 L, 25 R). The ANOVAs conducted on the different control and experimental variables failed to highlight any significant difference between subsets (all $F_s < 1.6$, all $p_s > .3$), as well as any significant interaction between subsets and Stimulus Type/Response Hand (all $F_s < 1.79$, all $p_s > .18$). Six additional words were selected to serve as practice trials, and 10 as fillers (see the section Experimental Task).

2.3 Apparatus and procedure

2.3.1 Typing test. Participants sat in front of a computer screen and a computer keyboard and were asked to copy three texts (635, 709, and 621 characters spaces included). Each text was first displayed on the screen so that participants could read it and familiarize with its contents. Afterwards, each text was presented in three separate parts. Participants were asked to copy-type each part and to press the enter-key to move onto the next one. The typed text was shown below the written text. Within each text, typing speed was calculated by dividing the number of correctly-typed words by the time elapsing between the first and the last keystroke. Accuracy was indexed with the percentage of words containing no errors nor edits. Participants typed on average 56 words per minute ($SD = 8.85$, range 45 - 74), with an accuracy of .88 ($SD = 0.05$, range .79 - .96). The procedure was programmed and administered via the Presentation Software (NeuroBehavioral Systems) and typed responses were collected using a highspeed DirectIN Keyboard PCB v2010 (Empirisoft) granting a 1 millisecond accuracy in the recording of keystrokes' timing.

2.3.2 Experimental task. Participants sat in an armchair in front of a computer screen (~ 60 cm) and a keyboard. As for the typing test, the experimental procedure and behavioral data acquisition were controlled using the Presentation software and using the keyboard described above. Participants were first asked to complete a questionnaire collecting demographic information, the Edinburgh Handedness Inventory (Oldfield, 1971), and questions regarding the typing habits. After installation of the EEG cap, they were given time to familiarize with the keyboard, and then the experimental procedure began.

The experiment included 2 tasks within separate sequential blocks: The Reading and the Typing tasks. In the Reading task, participants sat with their arms and their backs resting on the armchair and were instructed to silently read the written words displayed on the screen. They were further instructed about the presence of catch-trials. In these trials (10, randomly presented among the sequence of experimental trials) they were instructed to reach the keyboard placed in front of them to type the last word they read, and then go back to the former posture. Catch trials were used to keep participants engaged. Each catch trial was followed by a filler trial, to avoid any movement-related contamination due to the changing posture. In the Typing task, participants sat with their hands resting on the keyboard, and were instructed to copy-type each word. Written instructions were presented on the screen at the beginning of each task, followed by 10 practice trials. For both the Reading and the Typing tasks, participants were prompted to take short self-terminated breaks, if needed, every 20 trials. Practice, filler, and catch trials were all excluded from any analysis.

Within both tasks, each trial started with a fixation cross (+) displayed at the center of the screen for 2000 ms. Word-stimuli appeared immediately after, and remained on the screen for 4000 ms. In the Typing task, typed responses were echoed below the word stimuli. For the catch trials of the Reading task, the trial structure was the same as for experimental trials, except for the fact that the sentence “Type the last word you have read” (in Italian) was displayed at the center of the screen instead of a word. Participants responses for catch trials appeared on the screen, below the prompt-sentence. Trials were separated by a blank screen lasting 2000 ms. All the written stimuli

appeared in black (RGB 0, 0, 0) on a grey background (RGB 210, 210, 210) and were displayed in Times New Roman font (26-point size). The assignment of the two subsets of items (see the section Stimuli) to each task, as well as the order of the two tasks, were counterbalanced across participants. Within each task, stimuli were presented in random order. Half of the participants were presented with 12 different random sequences of stimuli. The other half were presented with these sequences in their reverse order. The experiment lasted approximately 40 minutes (excluding the installation of the EEG cap).

2.4 EEG recording and processing

The EEG was acquired from 60 active electrodes placed in standard 10–20 locations on an elastic ActiCap (Brain Products), referenced to the left-earlobe (Fp1, Fp2, AF7, AF3, AF4, AF8, F7, F5, F3, F1, FZ, F2, F4, F6, F8, FT7, FC5, FC3, FC1, FC2, FC4, FC6, FT8, T7, C5, C3, C1, CZ, C2, C4, C6, T8, TP7, CP5, CP3, CP1, CPZ, CP2, CP4, CP6, TP8, P7, P5, P3, P1, PZ, P2, P4, P6, P8, PO9, PO7, PO3, POZ, PO4, PO8, PO10, O1, OZ, O2). Three electrodes were placed next to the outer canthi and below the left eye to serve as electro-oculograms (EOGs), and one electrode was positioned on the right-earlobe for offline re-referencing. Impedance at each electrode site was maintained below 20 K Ω . EEG and EOG signals were amplified and digitized with a 500 Hz sampling rate (filters: .01 – 100 Hz). Analyses were performed using the MATLAB toolboxes EEGLAB (Delorme & Makeig, 2004), ERPLAB (Lopez-Calderon & Luck, 2014), and FieldTrip (Oostenveld, Fries, Maris, & Schoffelen, 2011).

Data were re-referenced offline to the average of both earlobes. Continuous data were then band-pass filtered (Order 2 Butterworth filters) between 0.1 and 70 Hz, and notch filtered at 50 Hz. Epochs going from 2000 ms before stimulus onset to 4000 ms after stimulus onset were extracted. Noisy electrodes were interpolated via spherical interpolation and a first artifact rejection was performed to remove epochs contaminated by excessive noise. Afterwards, ICA was computed (algorithm: AMICA; Palmer, Makeig, Kreutz-Delgado, & Rao, 2008) and components corresponding to blinks were removed. A second artifact rejection was conducted in order to

exclude the remaining noisy epochs. Finally, a -200 to 0 pre-stimulus baseline was applied (by subtraction). Only correct trials were included in the following analyses. Responses were considered correct when they fulfilled all the 3 following conditions: a) the first two letters were typed correctly, b) the backspace was not used (no editing), and c) the final response did not include more than 1 typographical error (addition, omission, substitution, transposition).

The time-frequency representation was computed via 7-cycles Morlet wavelet sliding at 10 ms steps from -2000 to 3500 ms in each epoch (0-padded to a length of 8 seconds to obtain integer frequency values) and at each frequency between 6 and 35 Hz. Power values were averaged within participants and separately within the 4 conditions yielded by the combination of the two experimental factors of Task and Emotional Connotation. For analyses in the time domain, shorter epochs were extracted going from -200 ms to 1200 ms around stimulus onset. Event-related potentials (ERPs) were computed by averaging epochs by conditions within each participant. Resulting ERPs were further low-pass filtered at 30 Hz (Order 2 Butterworth).

2.5 Statistical analyses

For both ERPs and time-frequency analyses we used nonparametric cluster-based permutation tests. To compare any two conditions, a series of paired t-tests was conducted, one for each time-point within each channel. The t-values surpassing a predefined threshold ($p < .05$) were selected and grouped into clusters on the basis of temporal and spatial adjacency (minimum 2 neighboring electrodes). Cluster-level statistics were computed by summing the t-values within the clusters. Cluster p-values were then computed with respect to a null distribution of the t-values obtained via permutations ($N = 1500$) by randomly reassigning samples across conditions. In this framework, the cluster p-value is represented by the proportion of permutations featuring a larger test-statistics compared to the observed one (Groppe, Urbach, & Kutas, 2011; Maris & Oostenveld, 2008), with a two-tailed alpha level determined at $p = .025$. For the analyses of the interaction between Stimulus Type (Negative vs. Neutral) and Task (Reading vs. Typing), average differences between Negative and Neutral conditions (normalized by their sum) were separately computed

within the Reading and the Typing tasks and submitted to the same test described above. Statistical analyses in the time-frequency domain were conducted on three different frequency bands, averaging power values within each band (alpha/mu, 8-12 Hz; low beta, 13-20 Hz; high beta, 21-30 Hz).

3. Results

3.1 Behavioral Data

Behavioral analyses were conducted just for the Typing task. Linear mixed models were used for chronometric measures of correct responses (reaction time, mean interkeystroke interval, response duration), whereas generalized mixed models were used for accuracy (library lme4, Bates, Maechler, Bolker, & Walker, 2015) via the R software (R Core Team, 2015). By-participants and by-item random intercepts were included in the models. The effect of Stimulus Type (Neutral vs. Negative) was assessed via log-likelihood tests comparing the model including the fixed effect under examination against a null model featuring just the random effects. There were no significant effects across all the three measures (all χ^2 s > 0.89, all ps > .34). A summary of the behavioral results is offered in Table 2.

Table 2. *Summary of the behavioral results.*

Measures	Negative	Neutral
Accuracy	.89 ± .02	.90 ± .02
Reaction time	644 ± 9.52	651 ± 10.06
Mean interkeystroke interval	174 ± 3.61	173 ± 3.74
Response duration	1717 ± 18	1747 ± 19

Note. Mean and standard error for behavioral measures of the typing performance. Reaction times reflect the time elapsing from the onset of the word stimuli until the time of the first keystroke. Mean interkeystroke intervals reflect the average time between different keystrokes. Response

durations reflect the time elapsing from the onset of the word stimulus until the last keystroke. All the chronometric measures are expressed in ms.

3.2 ERPs

Statistical analyses included all the electrodes and all the samples from stimulus onset until 1200 ms afterwards. Despite the lack of any significant interaction between the factors Stimulus Type and Task (all $ps > .68$), we separately report the effect of Stimulus Type within each Task, in order to facilitate comparisons with previous reports that mostly focused on reading (for a review, see Citron, 2012). Results are summarized in Figure 1.

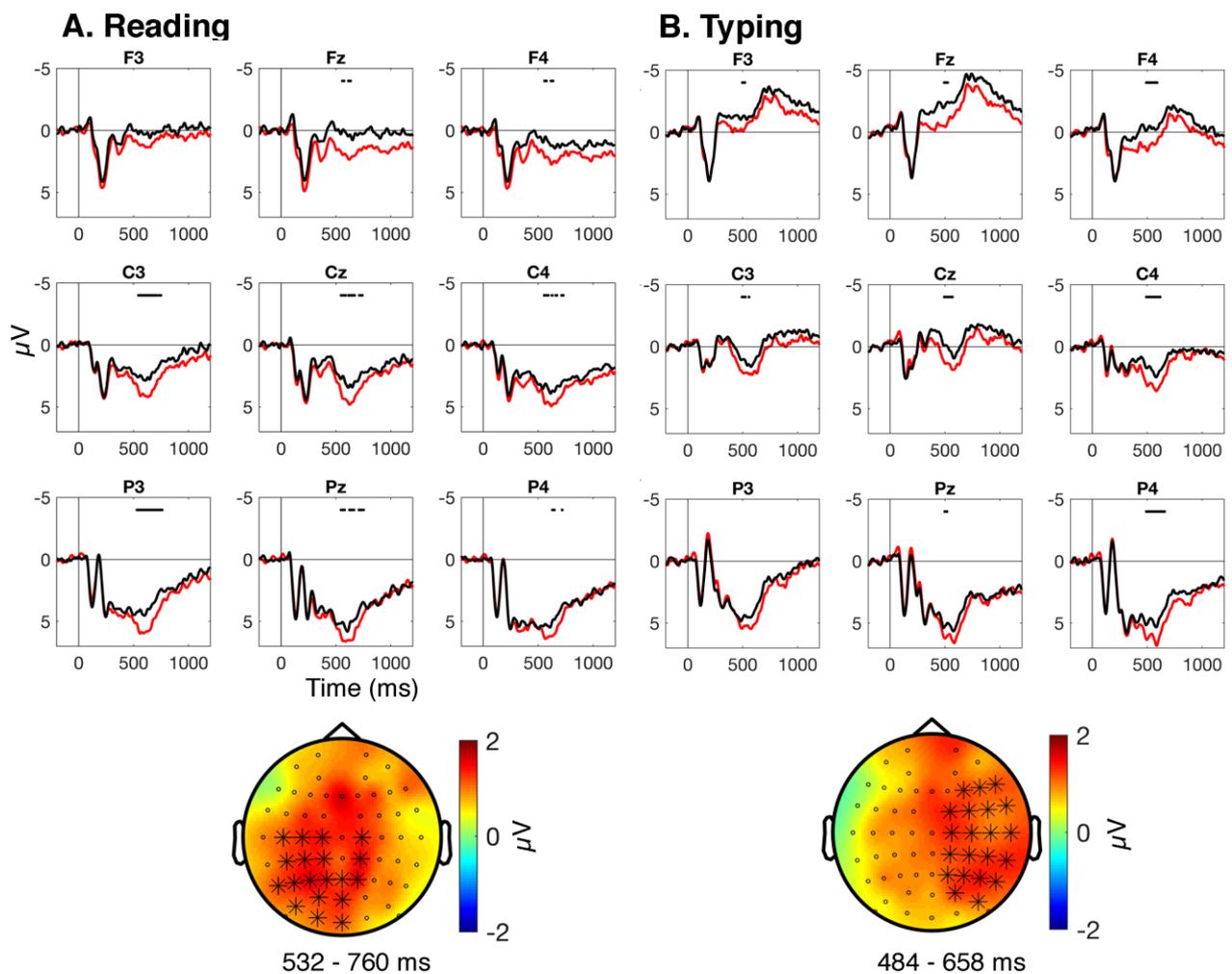


Figure 1. ERPs for Neutral (black) and Negative words (red) in the Reading (A) and in the Typing (B) tasks. The horizontal bars on ERP plots mark those samples involved in the cluster capturing the significant difference between the two conditions. Topographies show the effect the effect of Emotional Connotation (Negative – Neutral) for the time-windows indicated below, and corresponding to the temporal extension of the cluster capturing the difference. Electrodes that

were part of the cluster for more than 50% of the samples within the time-interval are highlighted ()*.

In the Reading task, the significant difference between Negative and Neutral words was captured by a positive cluster ($p = .024$) surfacing in a time-window between ~630 – 760 ms with a rather broad spatial distribution. Similarly, the effect of Stimulus Type in Typing was captured by a broadly distributed positive cluster ($p = .021$) in a time-window going from ~ 460 to 560 ms. These results are in line with the traditional larger late posterior positivity complex (LPC) often reported when comparing words differing across the emotional valence dimension (Citron, 2012).

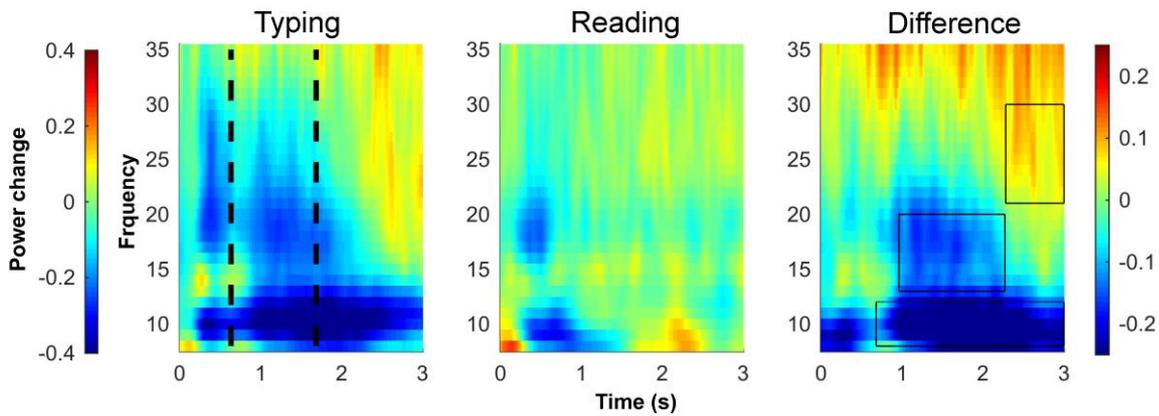
3.3 Alpha/mu and beta band power

The alpha/mu band displayed a prolonged ERD in the Typing task, surfacing roughly 200 ms after stimulus onset and propagating to the whole epoch duration. Differently, in the Reading task the alpha/mu ERD appeared to be more transient, with a return to baseline power values ~ 600 ms after stimulus onset. With respect to low and high beta-power modulations, in the Typing task we detected two distinct ERDs. An early ERD was present in the interval between 200-600 ms after stimulus onset, whereas a second ERD unfolded later on (roughly from 700 until 2000 ms after stimulus onset), during motor response execution. This second ERD was followed by an ERS (beta rebound) involving mostly the higher beta band towards the end of the epoch, after motor response had terminated (Figure 2). Whereas the second ERD and the rebound were exclusive features of the typing task, a pattern similar to the first beta-power ERD was detected also in the reading task, within comparable spatial, temporal, and frequency coordinates.

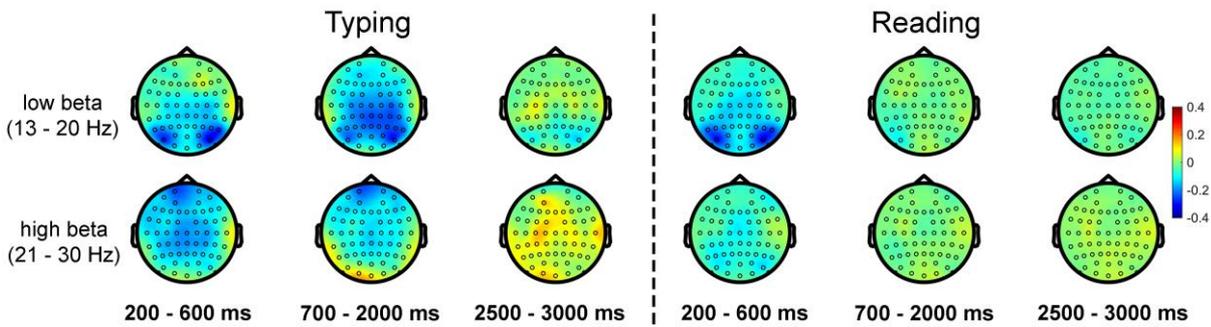
Statistical analyses encompassed the whole set of electrodes, from stimulus onset to 3000 ms afterwards. The main effect of Stimulus Type failed to reveal any significant effect in any of the frequency bands (all $ps > .083$). The main effect of Task (Typing vs. Reading), on the other hand, highlighted significant differences across all the bands. Specifically, in the mu/alpha band (8 – 12 Hz), a significant negative cluster ($p < .001$) surfaced at ~ 680 ms after stimulus onset and spread to

the whole epoch duration. The cluster initially focuses on more posterior sites, and spreads to more anterior channels, including frontal ones, later on in the epoch. Arguably, this pattern captures both the posterior alpha suppression determined by the appearance of new visual stimuli in the typing task (the participants typed response echoed on the screen) and the frontal mu desynchronization related to the motor response. A significant difference was found also in the lower beta band (13 – 20 Hz), with a negative cluster ($p = .009$) spreading in a time-window between ~960 and 2270 ms, mostly on parietal and posterior electrodes, with a slight bias towards the right hemisphere. Finally, a significant difference was found also with respect to the high beta band (21 – 30 Hz), with a positive cluster ($p = .001$) surfacing from ~ 2280 ms until the end of the epoch over fronto-central and parietal sites and possibly capturing the beta band rebound typically found at the end of motor response execution. Results for the comparisons between tasks are summarized in Figure 2.

A: Time frequency representations



B: Topographies of the beta ERDs/ERSs



C: Topographies of the clusters

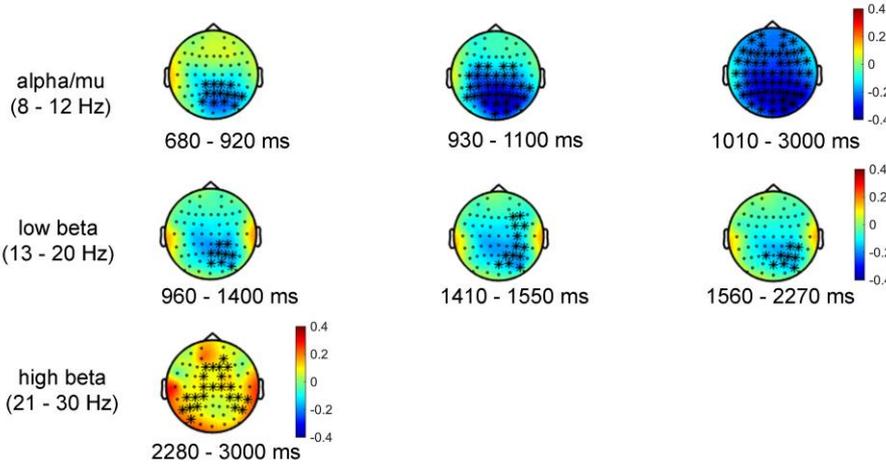


Figure 2. Alpha/mu and beta power differences between tasks. A: time-frequency power representations for the two tasks with respect to a pre-stimulus baseline going from -800 to -500 ms. Dashed vertical lines represent the median RT and the median latency of the final keystrokes in the Typing task. The difference spectrum reflects the subtraction between power in the Typing task and in the Reading task normalized by their sums. The contoured areas reflect time/frequencies coordinates of the clusters capturing the significant differences between tasks. Time-frequency power spectra were obtained by averaging activity for the electrodes FC3, FC1, FC2, FC4, C3, C1,

Cz, C2, C4, CP3, CP1, CPz, CP2, CP4, P3, P1, Pz, P2, P4. B: Topographies of the low (first row) and high (second row) beta ERDs/ERSs for the reported time-windows (indicated below each topography) within each task (Typing and Reading). C: Topographies of the clusters found when comparing the two tasks. Each topography reports the difference between Typing and Reading (normalized by their sum) in the corresponding frequency band (on the left) and time-interval (below). Electrodes that were part of the cluster for more than 50% of the samples within the time-interval are highlighted ().*

The interaction between Stimulus Type (Negative vs. Neutral) and Task (Typing vs. Reading) failed to reach conventional significance in the alpha/mu band (all clusters' $p > .079$). Within the lower beta band, the interaction was significant, with a negative cluster ($p = .013$) surfacing in the time window between ~250 ms and 460 ms after stimulus onset on fronto-central, central, and parietal sites. In the higher beta band, the analysis of the interaction revealed a negative cluster approaching conventional significance ($p = .049$), surfacing in a time range between ~1790 - 1920 ms, mostly involving central and parietal sites. Follow-up comparisons between Negative and Neutral conditions were conducted separately within each task. In reading, a significant positive cluster ($p = .001$) was found in the low beta band, in a time-window between ~250 and 470 ms., with a rather wide scalp distribution mostly focused on fronto-central sites in the right hemisphere. No effect was detected in higher beta frequencies (all $p > .13$). For the lower beta frequencies in the Typing task, a negative cluster involving posterior sites approached conventional significance ($p = .044$) within a latency range between 660 and 810 ms. Importantly, we observed a significant negative cluster in the higher beta frequencies ($p = .023$), in the latency range between ~ 1780 and 1900 ms. with a centro-parietal distribution. Results for the interaction and for the within-task effect of Stimulus Type are presented in Figure 3.

A: Topographies of the clusters for the interaction



B: Time frequency representations

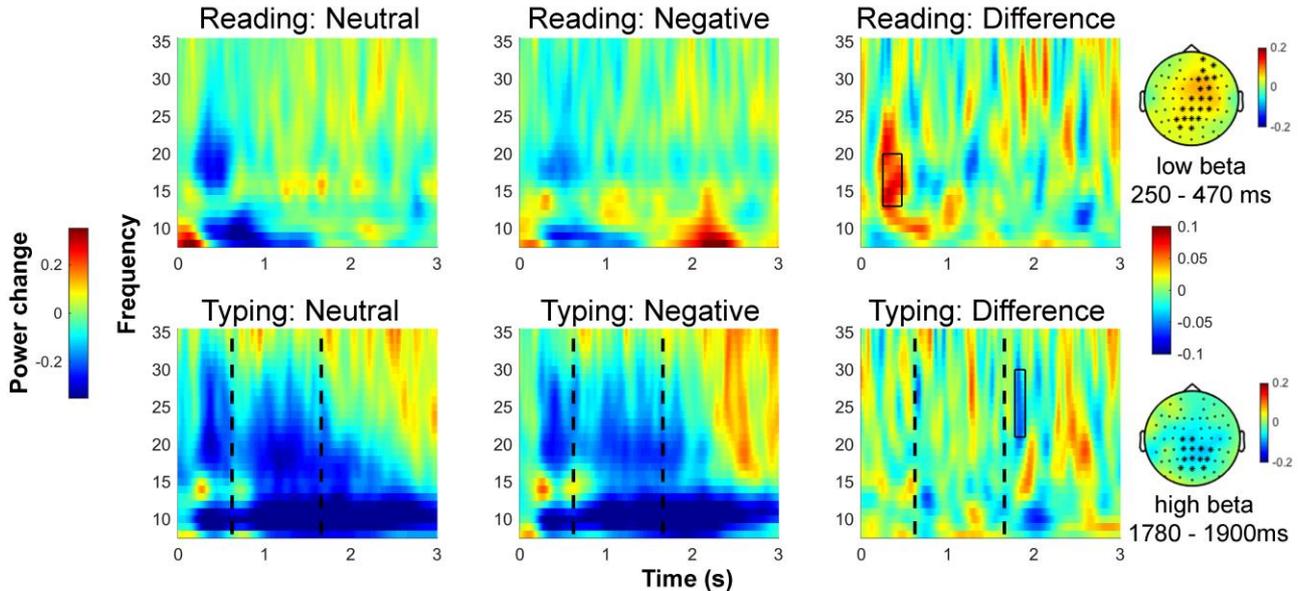


Figure 3. Time-frequency power as a function of Stimulus Type (Negative vs Neutral) within tasks. *A: Topographies of the clusters found when assessing the Interaction between Stimulus Type and Task. Each topography reports the difference between Typing and Reading with respect to the effect of Stimulus Type (difference between Negative and Neutral, normalized by their sum) in the corresponding frequency band and time-interval. Electrodes that were part of the cluster for more than 50% of the samples within the time-interval are highlighted (*). B: Time-frequency power representations as a function of Task and Stimulus Type with respect to a pre-stimulus baseline going from -800 to -500 ms. Dashed vertical lines represent the median RT and the median latency of the final keystroke in the Typing task. The difference spectrum reflects the subtraction between power elicited by Negative and Neutral Stimuli, normalized by their sums. The contoured areas reflect time/frequencies coordinates of the clusters capturing the significant differences between Stimulus Types. Time-frequency power spectra were obtained by averaging activity for the electrodes FC1, FC2, C1, Cz, C2, CP1, CPz, CP2, P1, Pz, and P2. The topographies display the difference between Negative and Neutral stimuli (normalized by their sum) for the power of the frequency band in the interval reported below. Electrodes that were part of the cluster for more than 50% of the samples within the time-interval are highlighted (*).*

4. General Discussion

We measured beta-frequency band power modulations across two linguistic tasks, reading and typing, in an effort to (a) distinguish language- and motor-related beta-power modulations and (b) track the unfolding of a linguistic manipulation across stages of input linguistic processing and output motor processes. The functional characterization of the beta ERDs was elucidated by comparing the reading and the typing tasks. An earlier ERD surfaced within similar spatio-temporal coordinates across both silent-reading and copy-typing, pointing towards task-invariant stages of linguistic-processing triggered by the word stimuli. A second ERD surfaced solely in typing during the typed response, suggesting a selective association with motor-response processing. Within this functional characterization, the results further revealed a pattern that challenges a discrete view in which linguistic and motor processing are strictly separated within serial stages.

Specifically, for the typing task the emotional connotation of words affects the late beta ERD surfacing during the typed response. At least under the conditions examined by the experiment, it thus seems that language processing can propagate its influence onto the phase of motor-response execution. This result suggests that continuous and interactive processing is not limited to linguistic stages. Instead, it may involve later stages of motor-response execution as well. Consistently, motor implementation can be affected by lexical and semantic features of input linguistic stimuli. Whereas this view has received substantial support from behavioral data (e.g., Goldrick et al., 2019), the neurophysiological underpinnings of these long-range interactions remain elusive. The present experiment provides initial insights, suggesting that oscillatory dynamics in the beta-frequency band may capture part of this continuous processing stream.

Previous studies using typing to investigate the transition from language onto motor processes, focused on ERPs related to motor-programming of hand movements, and found no influence from higher-order lexical-semantic processing on these indexes (e.g., Scaltritti et al., 2017; see also Pinet, Dubarry, & Alario, 2016). The present experiment suggests that this sort of long-range interactions, instead of modulating the earlier programming phase, involves the actual

execution of the motor-response. The timing of the effect of emotional connotation, in fact, seems to fall within temporal coordinates clearly beyond response onset. Importantly, models of action performance (e.g., Glover, 2004) distinguish between a pre-movement planning phase, where motor programs for goal-directed actions are retrieved and selected, and an online control system, which monitors the execution of the motor-response online during its unfolding (for review, Eliot, Helsen, & Chua, 2001). For typing, behavioral evidence suggests that orthographic representations can play a role during response execution by supporting the online control of the typed response (Scaltritti et al. 2016). The current experiment further suggests that action control interacts also with higher-order information related to the meaning of the words and, in this case, their emotional connotation. This would represent a peculiarity of linguistic tasks, as the online control systems is generally sensitive to a more restricted set of parameters compared to the planning phase, during which higher-order cognitive information are more relevant (Glover, 2004).

Albeit the processing of emotional connotation involves a major component of language processing such as the access to semantic information, it is important to point out that the effect we report on the motor-related beta ERD may specifically result from the involvement of affective processes and related emotion-action links. The relationships between emotion and action, in fact, hinges upon fundamental avoidance/approach behaviors as well as on more specific action-schemas involved in the expression of emotionally charged internal states, yielding detectable activation of the motor cortex even when abstract emotive words are displayed (Moseley, Carota, Hauk, Mohr, & Pulvermüller, 2012). More research is needed to ascertain whether other higher order linguistic manipulations related to lexical-semantic processing (e.g., imageability, animacy) could also influence motor-response execution.

This research provides additional insights with respect to the role of beta-ERDs in language. The replication of the two-ERDs pattern originally outlined by Pinet, Dubarry, and Alario (2016) is noteworthy, given the use of different stimuli (words vs pictures) and tasks (copy-typing vs typed picture-naming), and points towards a generalizability of the functional characterization of distinct

beta ERDs, which may represent electrophysiological landmarks for language and motor processing across a variety of conditions. In particular, the early “linguistic” ERD reliably surfaces across multiple linguistic tasks (silent-reading, copy-typing, typed picture-naming) as long as participants purposefully attend to lexical-semantic dimensions of the stimuli, whereas oscillatory power in the beta-frequency range is significantly reduced when reading is incidental (Delal et al., 2009). The language-related beta ERD thus seems to index a deeper processing of the linguistic information within the stimuli, independently from task specificities and stimulus format.

Further, in our Reading task emotional connotation yielded an attenuated ERD for negative compared to neutral words. Two considerations suggest that this effect may index the explicit processing of emotional connotation, rather than a more automatic attentional capture by emotive contents. First, the ERPs analyses revealed a clear effect on the LPC, and no effect at the level of EPN, suggesting that controlled processing is mainly concerned in the context of our experiment. Second, Wang and Bastiaansen (2014) highlighted that increased allocation of attention towards emotive words are reflected in sustained alpha suppression, whereas beta-frequencies are relatively spared. The different outcomes can be promptly linked to the differences in task requirements. Whereas in Wang and Bastiaansen (2014) reading occurred incidentally, in our experiment participants were explicitly required to read and pay attention to every word they saw. Under these latter conditions any potential influence related to attentional capture should be reduced. The sensitivity of the early beta ERD to emotional connotation may thus reflect controlled processing of emotional connotation when reading for content. This would corroborate the notion that the early beta-ERD indexes purposeful access to higher-order semantic information.

An important discrepancy between our data and extant literature should be noted as well. In our case, negative stimuli yielded a reduced beta-ERD in silent-reading, whereas previous reports (Hirata et al., 2007) indicate an increased beta-frequency suppression. Inconsistencies in the direction of the effects are not new for emotive stimuli, with studies reporting an increase of beta oscillatory power for negative compared to neutral stimuli, and others highlighting the opposite

pattern (for a review, see Schubring & Schupp, 2019). Most recently, the field has started to systematically address these ambiguities, by exploring potential underlying factors, such as difference in task requirements or in baseline activity due to varying inter-trial intervals (Schubring & Schupp, 2019). The differences between our study and the one from Hirata and colleagues (2007) involves many parameters that are potentially relevant. The two experiments, in fact, use different inter-trial intervals (4s here, 3s in Hirata et al., 2007), different scripts (alphabetical vs Kanji), and consider different neurophysiological signals (EEG vs MEG). Admittedly, we do not know which of these parameters, or which combination of parameters, can account for the discrepancy.

In general, it is challenging to map the direction of power modulations within beta-frequency band and corresponding differences in cognitive terms. For example, even when limiting our scope to the motor domain, there is no clear correspondence between the strength of beta ERDs and the amount of sensorimotor activation (e.g., Stancák, Riml, Pfurtscheller, 1997; Stancák, Feige, Lücking, Kristeva-Feige, 2000; Pistohl, Schulze-Bonhage, Aertsen, Mehring, Ball, 2012; as reviewed in Kilavik et al., 2013). It is worth mentioning, however, that at least in the time-domain our manipulation of the emotional connotation yielded prototypical results, with an increased LPC for negative words compared to neutral ones (see Citron, 2012).

Finally, we would like to acknowledge some limitations. The effect of emotional connotation in typing occurred in a time-window beyond the median offset time of the motor response (i.e., after the median latency of the final keystroke). Albeit temporal smoothing inherent to time-frequency decomposition and a cautious interpretation of the spatio-temporal features of clusters both warrant against drawing strong interpretations of the timing of the effect, this result may suggest that the influence of emotional connotation on motor-response processing is limited to a subset of slower trials. However, this subset does not correspond to a few outliers, as roughly 41% of the responses were still being typed within (or beyond) the temporal window of the cluster capturing the effect of emotional connotation in typing. Another possibility is that the effect reflects a post-response access to the semantic and affective content of the typed word. Albeit our data are

not able to rule out this possibility, it is worth noticing that the effect of emotional connotation on the second ERD in typing is different to the one detected in the first ERD of the reading task. In fact, it affects a different range of frequencies (high beta) and in the opposite direction (increased rather than reduced ERD for negative words), corroborating the interpretation of the effect in terms of a modulation of motor processing rather than as an access to semantic/affective information.

We also need to highlight the lack of any effect of emotional connotation during the first “linguistic” ERD of the typing task. We cannot exclude that the effect may have been obscured by an overlapping beta-band suppression related to motor preparation occurring before response onset (Kivalik et al., 2013) and insensitive to higher-order linguistic information. In case, this also suggests that the first beta ERD in typing does not capture solely language processing, but a mixture of language processing and motor programming. Interestingly, the two classes of processes (linguistic vs motor) may be differentially represented within distinct ranges of the beta frequency band. With respect to the first beta-ERD, in fact, reading and typing display a striking similarity within the low-beta range (13-20 Hz), whereas a stronger ERD seems to surface in typing at the level of high-beta frequencies (21 – 30 Hz), possibly related to motor programming of the upcoming response (Figure 2, panel B). However, as the statistical analyses do not provide strong evidence for this between-task differentiation, additional research seems needed to conclusively tease apart language and motor-related contributions to the first ERD in typing, for example by delaying the motor response or by manipulating factors related to motor-response preparation.

4.1 Conclusions

In conclusion, beta-band power modulations seem able to capture both language and motor processing across reading and typing tasks. The comparison between the two tasks suggests that language and motor processing are separately captured by two temporally ordered ERDs. The examination of an effect driven by the processing of the linguistic stimuli across these two electrophysiological landmarks provides evidence for a potential influence of language processing

on motor-response execution, thus supporting the notion of long-range interactions between linguistic and motor stages of processing.

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References

- Babiloni, C., Babiloni, F., Carducci, F., Cincotti, F., Coccozza, G., Del Percio, C., ... & Rossini, P.M. (2002). Human cortical electroencephalography (EEG) rhythms during the observation of simple aimless movements: a high-resolution EEG study. *NeuroImage*, *17*(2), 559-572.
- Bastiaansen, M., Magyari, L., & Hagoort, P. (2010). Syntactic unification operations are reflected in oscillatory dynamics during on-line sentence comprehension. *Journal of Cognitive Neuroscience*, *22*(7), 1333-1347.
- Bates, D., Mächler, M., Bolker, B., & Walker, S. (2015). Fitting linear mixed-effects models using lme4. *Journal of Statistical Software*, *67*, 1-48.
- Bradley, M. M., & Lang, P. J. (1999). *Affective norms for English words (ANEW): Instruction manual and affective ratings* (Vol. 30, No. 1, pp. 25-36). Technical report C-1, the center for research in psychophysiology, University of Florida.
- Brown, A.S. (1981). Inhibition in cued retrieval. *Journal of Experimental Psychology: Human Learning and Memory*, *7*(3), 204-215.
- Citron, F. M. (2012). Neural correlates of written emotion word processing: a review of recent electrophysiological and hemodynamic neuroimaging studies. *Brain and Language*, *122*(3), 211-226.
- Coltheart, M., Rastle, K., Perry, C., Langdon, R., & Ziegler, J. (2001). DRC: A dual route cascaded model of visual word recognition and reading aloud. *Psychological Review*, *108*, 204–256.
- Coombes, S. A., Cauraugh, J. H., & Janelle, C. M. (2007). Emotional state and initiating cue alter central and peripheral motor processes. *Emotion*, *7*(2), 275.
- Cooper, N. R., Simpson, A., Till, A., Simmons, K., & Puzzo, I. (2013). Beta event-related desynchronization as an index of individual differences in processing human facial

- expression: further investigations of autistic traits in typically developing adults. *Frontiers in Human Neuroscience*, 7, 159.
- Csukly, G., Farkas, K., Marosi, C., & Szabó, Á. (2016). Deficits in low beta desynchronization reflect impaired emotional processing in schizophrenia. *Schizophrenia Research*, 171(1-3), 207-214.
- Dalal, S. S., Baillet, S., Adam, C., Ducorps, A., Schwartz, D., Jerbi, K., ... & Lachaux, J. P. (2009). Simultaneous MEG and intracranial EEG recordings during attentive reading. *Neuroimage*, 45, 1289-1304.
- Damian, M. F. (2003). Articulatory duration in single-word speech production. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 29, 416–431
- Davidson, D. J., & Indefrey, P. (2007). An inverse relation between event-related and time–frequency violation responses in sentence processing. *Brain Research*, 1158, 81-92.
- Delorme, A., & Makeig, S. (2004). EEGLAB: An open source toolbox for analysis of single-trial EEG dynamics including independent component analysis. *Journal of Neuroscience Methods*, 134(1), 9–21.
- Elliott, D., Helsen, W. F., & Chua, R. (2001). A century later: Woodworth's (1899) two-component model of goal-directed aiming. *Psychological Bulletin*, 127, 342.
- Engel, A. K., & Fries, P. (2010). Beta-band oscillations—signaling the status quo? *Current Opinion in Neurobiology*, 20(2), 156–65.
- Fink, A., Oppenheim, G.M., Goldrick, M. (2018). Interactions between lexical access and articulation. *Language, Cognition and Neuroscience*, 33, 12-24.
- Gahl, S. (2008). Time and thyme are not homophones: The effect of lemma frequency on word durations in spontaneous speech. *Language*, 84, 474–496.
- Glover, S. (2004). Separate visual representations in the planning and control of action. *Behavioral and Brain Sciences*, 27, 3-24.
- Goldrick, M., McClain, R., Cibelli, E., Adi, Y., Gustafson, E., Moers, C., & Keshet, J. (2019). The influence of lexical selection disruptions on articulation. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 45, 1107-1141.
- Groppe, D. M., Urbach, T. P., & Kutas, M. (2011). Mass univariate analysis of event-related brain potentials/fields I: A critical tutorial review. *Psychophysiology*, 48(12), 1711-1725.
- Güntekin, B., & Başar, E. (2007). Emotional face expressions are differentiated with brain oscillations. *International Journal of Psychophysiology*, 64, 91-100.
- Güntekin, B., & Başar, E. (2010). Event-related beta oscillations are affected by emotional eliciting stimuli. *Neuroscience Letters*, 483, 173-178.

- Güntekin, B., & Başar, E. (2014). A review of brain oscillations in perception of faces and emotional pictures. *Neuropsychologia*, *58*, 33-51.
- Hickok, G. (2012). Computational neuroanatomy of speech production. *Nature Reviews Neuroscience*, *13*, 135–145.
- Hickok, G. (2014). The architecture of speech production and the role of the phoneme in speech processing. *Language, Cognition and Neuroscience*, *29*, 2–20.
- Hirata, M., Koreeda, S., Sakihara, K., Kato, A., Yoshimine, T., & Yorifuji, S. (2007). Effects of the emotional connotations in words on the frontal areas—a spatially filtered MEG study. *NeuroImage*, *35*(1), 420-429.
- Howard, D., Nickels, L., Coltheart, M., & Cole-Virtue, J. (2006). Cumulative semantic inhibition in picture naming: Experimental and computational studies. *Cognition*, *100*(3), 464-482.
- Kandel, S., & Perret, C. (2015). How does the interaction between spelling and motor processes build up during writing acquisition? *Cognition*, *136*, 325–336
- Kilavik, B. E., Zaepffel, M., Brovelli, A., MacKay, W. A., & Riehle, A. (2013). The ups and downs of beta oscillations in sensorimotor cortex. *Experimental Neurology*, *245*, 15-26.
- Klepp, A., Nicolai, V., Buccino, G., Schnitzler, A., & Biermann-Ruben, K. (2015). Language–motor interference reflected in MEG beta oscillations. *NeuroImage*, *109*, 438-448.
- Levelt, W. J. M., Roelofs, A., & Meyer, A. S. (1999). A theory of lexical access in speech production. *Behavioral & Brain Sciences*, *22*, 1–75.
- Lopez-Calderon, J., & Luck, S. J. (2014). ERPLAB: An open-source toolbox for the analysis of event-related potentials. *Frontiers in Human Neuroscience*, *8*, 213
- Luo, Y., Zhang, Y., Feng, X., & Zhou, X. (2010). Electroencephalogram oscillations differentiate semantic and prosodic processes during sentence reading. *Neuroscience*, *169*(2), 654-664.
- Maris, E., & Oostenveld, R. (2007). Nonparametric statistical testing of EEG- and MEG-data. *Journal of Neuroscience Methods*, *164*, 177–190.
- McClelland, J. L. (1979). On the time relations of mental processes: An examination of systems of processes in cascade. *Psychological Review*, *86*, 287–330.
- Meyer, A. S., & Levelt, W. J. M. (2000). Word for word: Multiple lexical access in speech production. *European Journal of Cognitive Psychology*, *12*, 433–452.
- Montefinese, M., Ambrosini, E., Fairfield, B., & Mammarella, N. (2014). The adaptation of the affective norms for English words (ANEW) for Italian. *Behavior Research Methods*, *46*(3), 887-903.
- Moseley, R., Carota, F., Hauk, O, Mohr, B., & Pulvermüller, F. A role for the motor system in binding abstract emotional meaning. *Cerebral Cortex*, *22*, 1634-1647.

- Mousikou, P., & Rastle, K. (2015). Lexical frequency effects on articulation: A comparison of picture naming and Reading aloud. *Frontiers in Psychology*, 6, 31.
- Oldfield, R. C. (1971). The assessment and analysis of handedness: the Edinburgh inventory. *Neuropsychologia*, 9(1), 97-113.
- Oostenveld, R., Fries, P., Maris, E., & Schoffelen, J. M. (2011). FieldTrip: Open source software for advanced analysis of MEG, EEG, and invasive electrophysiological data. *Computational Intelligence and Neuroscience*, 156869. doi: 10.1155/2011/156869
- Palmer, J. A., Makeig, S., Kreutz-Delgado, K., & Rao, B. D. (2008). Newton method for the ICA mixture model. In *Proceedings of the 33rd IEEE international conference on acoustics and signal processing (ICASSP 2008)*, (pp. 1805–1808). Las Vegas, NV
- Pfurtscheller, G. (2003). Induced oscillations in the alpha band: functional meaning. *Epilepsia*, 44, 2-8.
- Pfurtscheller, G., & Lopes da Silva, F.H. (1999). Event-related EEG/MEG synchronization and desynchronization: basic principles. *Clinical Neurophysiology*, 110(11), 1842-1857.
- Pfurtscheller, G., Woertz, M., Supp, G., & Lopes da Silva, F. H. (2003). Early onset of post-movement beta electroencephalogram synchronization in the supplementary motor area during self-paced finger movement in man. *Neuroscience Letters*, 339, 111-114.
- Piai, V., Roelofs, A., & Maris, E. (2014). Oscillatory brain responses in spoken word production reflect lexical frequency and sentential constraint. *Neuropsychologia*, 53, 146-156.
- Piai, V., Roelofs, A., Rommers, J., & Maris, E. (2015). Beta oscillations reflect memory and motor aspects of spoken word production. *Human Brain Mapping*, 36, 2767-2780.
- Piai, V., Rommers, J., & Knight, R. T. (2018). Lesion evidence for a critical role of left posterior but not frontal areas in alpha-beta power decreases during context - driven word production. *European Journal of Neuroscience*, 48, 2622-2629.
- Pineda, J. A. (2005). The functional significance of mu rhythms: translating “seeing” and “hearing” into “doing”. *Brain research reviews*, 50(1), 57-68.
- Pinet, S., Dubarry, A. S., & Alario, F. X. (2016). Response retrieval and motor planning during typing. *Brain and language*, 159, 74-83.
- Pinet, S., Hamamé, C. M., Longcamp, M., Vidal, F., & Alario, F. X. (2015). Response planning in word typing: Evidence for inhibition. *Psychophysiology*, 52(4), 524-531.
- Pinet, S., Ziegler, J., & Alario, F.-X. (2016). Typing is writing: Linguistic properties modulate typing execution. *Psychonomic Bulletin & Review*, 23, 1898-1906.
- Pistohl, T., Schulze-Bonhage, A., Aertsen, A., Mehring, C., & Ball, T. (2012). Decoding natural grasp types from human ECoG. *Neuroimage*, 59(1), 248-260.

- Putman, P., Arias-Garcia, E., Pantazi, I., & van Schie, C. (2012). Emotional Stroop interference for threatening words is related to reduced EEG delta–beta coupling and low attentional control. *International Journal of Psychophysiology*, *84*, 194-200.
- R Core Team (2015). *R: A language and environment for statistical computing*. Vienna, Austria: R Foundation for Statistical Computing. <http://www.R-project.org/>
- Roux, J.-S., McKeef, T. J., Grosjacques, G., Afonso, O., & Kandel, S. (2013). The interaction between central and peripheral processes in handwriting production. *Cognition*, *127*, 235–241.
- Scaltritti, M., Alario, F. X., & Longcamp, M. (2018). The scope of planning serial actions during typing. *Journal of Cognitive Neuroscience*, *30*, 1620-1629.
- Scaltritti, M., Arfè, B., Torrence, M., & Peressotti, F. (2016). Typing pictures: Linguistic processing cascades into finger movements. *Cognition*, *156*, 16-29.
- Scaltritti, M., Pinet, S., Longcamp, M., & Alario, F. X. (2017). On the functional relationship between language and motor processing in typewriting: an EEG study. *Language, Cognition and Neuroscience*, *32*(9), 1086-1101.
- Schubring, D., & Schupp, H. T. (2019). Affective picture processing: Alpha-and lower beta-band desynchronization reflects emotional arousal. *Psychophysiology*, e13386.
- Spitzer, B., & Haegens, S. (2017). Beyond the status quo: A role for beta oscillations in endogenous content (re) activation. *Eneuro*, *4*, ENEURO.0170
- Stančák Jr, A., Riml, A., & Pfurtscheller, G. (1997). The effects of external load on movement-related changes of the sensorimotor EEG rhythms. *Electroencephalography and Clinical Neurophysiology*, *102*(6), 495-504.
- Stančák Jr, A., Feige, B., Lücking, C. H., & Kristeva-Feige, R. (2000). Oscillatory cortical activity and movement-related potentials in proximal and distal movements. *Clinical Neurophysiology*, *111*(4), 636-650.
- van Elk, M., van Schie, H. T., Zwaan, R. A., & Bekkering, H. (2010). The functional role of motor activation in language processing: motor cortical oscillations support lexical-semantic retrieval. *NeuroImage*, *50*(2), 665-677.
- Wang, L., & Bastiaansen, M. (2014). Oscillatory brain dynamics associated with the automatic processing of emotion in words. *Brain and Language*, *137*, 120-129.
- Weingarten, R., Nottbusch, G., & Will, U. (2004). Morphemes, syllables and graphemes in written word production. In T. Pechman & C. Habel (Eds.), *Multidisciplinary approaches to language production* (pp. 529–572). Berlin, NY: Mouton de Gruyter.

Weiss, S., & Mueller, H. M. (2012). “Too many betas do not spoil the broth”: The role of beta brain oscillations in language processing. *Frontiers in Psychology, 3*, 201. doi: 10.3389/fpsyg.2012.00201