Individual Alpha Frequency Predicts Perceived Visuotactile Simultaneity

Daniele Migliorati1,2, Filippo Zappasodi1, Mauro Gianni Perrucci1, Brunella Donno1, Georg Northoff3, Vincenzo Romei4, and Marcello Costantini1

Abstract

Temporal encoding is a key feature in multisensory processing that leads to the integration versus segregation of perceived events over time. Whether or not two events presented at different offsets are perceived as simultaneous varies widely across the general population. Such tolerance to temporal delays is known as the temporal binding window (TBW). It has recently suggested that individual oscillatory alpha frequency (IAF) peak may represent the electrophysiological correlate of TBW, with IAF also showing a wide variability in the general population (8–12 Hz). In our work, we directly tested this hypothesis by measuring each individual’s TBW during a visuotactile simultaneity judgment task while concurrently recording their electrophysiological activity. We found that the individual’s TBW significantly correlated with their left parietal IAF, such that faster IAF accounted for narrower TBW. Furthermore, we found that higher prestimulus alpha power measured over the same left parietal regions accounted for more veridical responses of non-simultaneity, which may be explained either by accuracy in perceptual simultaneity or, alternatively, in line with recent proposals by a shift in response bias from more conservative (high alpha power) to more liberal (low alpha power). We propose that the length of an alpha cycle constrains the temporal resolution within which perceptual processes take place.

INTRODUCTION

We live in a complex environment that requires the constant integration of multiple stimuli coming from different sensory sources (Stein, Stanford, & Rowland, 2014). In such a multisensory environment, it is crucial to determine whether multiple sensory events belong to the same external cause. A key element that allows us to achieve this is the encoding of temporal relationships between events. However, the encoding of temporal features of multisensory stimuli could be affected by several factors, leading to a fallacious reconstruction of the external environment. Drawing from the physical limitations of our perceptual systems (we can see only a small portion of the light spectrum or hear very few sound frequencies), there are many sources of variability that affect the temporal properties of multimodal stimuli. Some examples include the varying transmission speeds at which different sensory information travel through the air (Chen & Vroomen, 2013; Keetels & Vroomen, 2012; Vroomen & Keetels, 2010; Spence & Squire, 2003), the different durations of sensory transduction timing (sound waves take less time than that required for the chemical transduction of light in the retina; King & Palmer, 1985), or even cognitive biases (Grabot, Kösem, Azizi, & van Wassenhove, 2017; Grabot & van Wassenhove, 2017; Samaha, Iemi, & Postle, 2017). Because of these disparities, the human brain needs a window of tolerance to bind stimuli together (Bao et al., 2015) in order for them to be assigned to the same or to a separate external event. Cognitive neuroscientists have alluded to this temporal tolerance (sensitivity) by adopting different, but for the most part, mutually exchangeable descriptions. The most common descriptions used are temporal window of integration (Massaro, Cohen, & Smeele, 1996), subjective simultaneity window (Arikan, van Kemenade, Straube, Harris, & Kircher, 2017), and temporal binding window (TBW; Powers, Hillock-Dunn, & Wallace, 2016; Simon & Wallace, 2016). We will refer to the latter description thereof. The TBW does not correspond to an all-or-none phenomenon, rigidly splitting between synchronous and asynchronous perception (Burr, Silva, Cicchini, Banks, & Morrone, 2009). Rather, its width depends on stimulus complexity (Stevenson & Wallace, 2013), with narrower TBWs for simple stimuli (e.g., flash and beeps) and wider TBWs for speech stimuli (e.g., McGurk effect; McGurk & Macdonald, 1976). The width of the TBW depends also on the cognitive load required to accomplish the task (van Wassenhove, 2013; Soto-Faraco & Alsuis, 2007). For instance, Soto-Faraco and Alsuis (2007) showed that the correct judgment of stimulus order can be made while still perceiving illusory
percepts during the McGurk effect. This suggests that temporal resolution in perception reflects the cognitive load behind the type of judgment required by the participants (i.e., speech processing requires slower operation than detecting the correct order of the stimuli). Furthermore, it suggests that the efficiency of multisensory integration is independent of its temporal resolution and represents a different computational need (Noel, Modi, Wallace, & Van der Stoep, 2018). However, when participants are simply and explicitly requested to judge the simultaneity of a multisensory event, observers make a probabilistic judgment about the nature of the stimulus pair. The main aim of our work is to understand the neural signature of such probabilistic judgment.

Recently, most of the attention has been focused on the analysis of the prestimulus ongoing oscillatory activity (Ronconi, Oosterhof, Bonmassar, & Melcher 2017). Particularly, research has focused on alpha oscillations (8–12 Hz) because it is thought that they reflect the momentary state of cortex excitability that can best account for by the way information is processed. Evidence for the pivotal role of ongoing alpha oscillations in parsing sensory information comes from visual perception studies (Dugué, Marque, & VanRullen, 2011; Busch, Dubois, & VanRullen, 2009; Mathewson, Gratton, Fabiani, Beck, & Ro, 2009; Romei, Gross, & Thut, 2010; Romei et al., 2008; Hebb, 1949) showing how ongoing phase and alpha power predict accuracy in visual perception. Several unsensory and multisensory illusions have been found to be very short-lived, falling within a period of around 100 msec (Yuan, Li, Liu, Yuan, & Huang, 2016; Lange, Oostenveld, & Fries, 2011; van Eijk, Kohlrausch, Juola, & van de Par, 2008), corresponding, on average, to the mean duration of an alpha cycle (Cecere, Rees, & Romei, 2015). In this respect, there is evidence suggesting a link between the duration of an individual alpha cycle (individual alpha frequency [IAF]), namely, the frequency in the alpha range with the greatest power, Bazanov & Vernon, 2014) and visual temporal sensitivity of individuals (Wutz, Melcher, & Samaha, 2018; Minami & Amano, 2017; Samaha & Postle, 2015; Coffin & Ganz, 1977). The main result emerging from these studies is that faster alpha frequencies are associated with enhanced temporal sensitivity in the visual domain. Similarly, IAF also seems relevant to understand multisensory interactions. For instance, Cecere et al. (2015) found that the faster the individual alpha cycle, as indexed by the IAF, the narrower the window of illusion in the double flash illusion (DFI; Shams, Kamitani, & Shimojo, 2000; Bowen, Mallow, & Harder, 1987). Furthermore, they demonstrated that, by experimentally speeding up or slowing down IAF, they could shrink or enlarge the window of illusion, respectively. In addition, they found that alpha amplitude across participants predicted the individual’s overall susceptibility to the illusion, in the sense that lower alpha amplitude leads to enhanced proneness to the illusion, akin to Lange, Keil, Schnitzler, van Dijk, and Weisz (2014).

So far, the temporal resolution of TBW across individuals has been investigated within the visual and auditory domains in the DFI (Cecere et al., 2015) and the temporal order judgment task (Grabot et al., 2017). Here, we want to extend previous observations to different sensory modalities (visual and tactile) and task (simultaneous judgment [SJ] task). Specifically, we tested whether IAF can account for interindividual variability in the temporal resolution when participants have to judge whether a visual and tactile stimulus has been presented simultaneously or not. Moreover, we tested whether alpha power could predict for more or less veridical responses within participants.

METHODS

Participants

Twenty-two healthy individuals took part in the study (10 men, mean age = 22.7 years, SD = 1.8, range = 21–27 years) at the Institute for Advanced Biomedical Technologics, Chieti, Italy. All participants had self-reported normal hearing and vision, and none had any personal or close family history of neurological or psychiatric disorders, by self-report. The study was approved by the local ethics committee, and participants gave their informed consent before taking part in the study. At the end of the session, the participants received monetary compensation.

Apparatus and Stimuli

Visual stimuli consisted of a red light-emitting diode (with a 0.5-cm diameter) fitted on the top edge of a foam cube, with a luminous flux of 0.48 lm, placed in front of the participants and lasting for 30 msec. For tactile stimuli, we used a constant current electrical stimulator (DST7A; Digitimer), with the electrode placed on the index finger of the left hand. The luminosity of the visual stimulus was kept constant while tactile stimuli were delivered at 150% of the individual’s sensory threshold to ensure a clear tactile perception. Participants held the foam cube with their left hand, receiving both stimulation close in space to each other to ensure that no spatial incongruity could influence task execution.

Experimental Session

The whole experimental protocol was divided into two separate sessions, administered back-to-back on the same day, with a 15-min break between them. During the first session, participants underwent the behavioral SJ task used to estimate the TBW. This session was performed before the EEG recording. The behavioral session lasted around 20 min. Once the behavioral session was completed, participants were prepared for the EEG recording. After the preparation, participants underwent four blocks of the SJ task with individualized temporal
delays while recording brain activity with EEG. The whole experimental session lasted around 3 hr, with some time variance due to EEG montage timing.

**Task and Procedure**

*Behavioral SJ Task and Estimation of the TBW*

Each trial started with the presentation of either a visual or a tactile stimulus followed, after a variable delay, by the stimulus in the other sensory modality. The SOAs between the two stimuli were ±500, ±400, ±300, ±200, ±150, ±100, ±50, and ±25 msec. Negative SOAs indicate a trial in which the visual stimulus was presented first, whereas positive SOAs indicate a trial in which the tactile stimulus was presented first. A total of 16 intervals were used, with 28 trials per interval, for a total of 448 trials, divided in two equal blocks. The intertrial interval ranged randomly between 2000 and 3500 msec. The presentation of the stimulus pairs was pseudorandomized. Participants gave their responses with the right hand using a standard computer keyboard. They were instructed to use “b” and “m” to express their judgment. The response assignment was counterbalanced across participants. To determine the TBW, we first calculated a rate of perceived synchrony for each SOA, as the percentage of trials in which the participants reported that the presentation was synchronous. The observed distribution of responses was fitted to two sigmoid functions, one for the negative and one for positive SOAs. The sigmoid function was defined by the equation

\[ 1 + \left( \exp\left(a \times (x-b)\right) \right) \]

where \( a \) and \( b \) represent free parameters—the slope and the inflection point of the curve, respectively (Farrer, Valentin, & Hupé, 2013). The estimated SOA corresponding to the inflection point of each fitted distribution was taken as a measure of temporal sensitivity. Doing so, we obtained a value of temporal sensitivity for both visual-leading (left side, TBW\(_{\text{left}}\)) and tactile-leading (right side, TBW\(_{\text{right}}\)) stimulus pairs (Figure 1).

**Determining Individualized SOAs for the EEG SJ Task**

For each participant, the critical SOAs for visual-leading and tactile-leading sequences in which they misperceived nonsimultaneity as simultaneity on 50% of trials were calculated using data from the behavioral session described above.

Specifically, two critical SOAs were calculated by using the values corresponding to the 50% of the psychometric functions obtained in the behavioral session, one for visual-leading sequences ("Vis–Threshold" condition) and one for tactile-leading sequences ("Tact–Threshold" condition). Moreover, we calculated four additional SOAs by subtracting and adding 50 msec from each individual threshold interval. Hence, in the EEG experiment, we included six SOAs that were individually determined: three SOAs for visual-leading sequences (Vis–Threshold + 50 msec, Vis–Threshold + 50 msec), three SOAs for tactile-leading sequences (Tact–Threshold + 50 msec, Tact–Threshold + 50 msec). Each condition was presented 108 times, for a total of 648 trials, evenly distributed across four blocks. The trial structure was the same as in the behavioral session, except for the SOAs (described above) and intertrial interval, ranging from 3500 to 5000.
**EEG Recording and Preprocessing**

We used a 64 electrodes cap (model BrainCap, BrainAmp MR Plus amplifier, Brain Products), placed in accordance with the 10–20 international system. We used two electrooculographic channels, placed over the right and left temple, to monitor eye movements and for offline artifacts rejection. The reference electrode was positioned in correspondence of the FCz electrode, between electrodes Fz and Cz. The ground electrode was placed between electrodes Fpz and Fz. The impedance was measured before each block and was kept below 10 kΩ. All the data were processed using EEGLAB (Delorme & Makeig, 2004) software in MATLAB. We acquired online data at 5 kHz (band-pass filtered from 0.016 to 250 Hz), and then, the data were down-sampled at 250 Hz. Data were offline filtered between 1 and 30 Hz for the current analyses. Data were epoched between ±2000 msec around the first stimulus onset. We detected and removed noisy channels using a threshold with a probability at 5% (pop_rejchan). We then computed independent component analysis using the FastICA algorithm (Hyvärinen & Oja, 2000) to identify and reject noise, ocular, cardiac, and muscular artifacts. At this point, we interpolated the rejected channels. Finally, the EEG signal was re-referenced against a common average reference.

**Data Analysis**

*Individual Alpha Frequency*

For the calculation of the IAF, we cut all of the prestimulus epochs from −2000 to 0 msec in respect to the first stimulus onset. Then, we computed the power spectrum density for all the electrodes using the Welch estimation method (windowing: Hamming, window length: 2 sec, overlap: 50%), dividing the signal in the four classical EEG bands (delta: 1–4 Hz, theta: 4–7 Hz, alpha: 7–13 Hz, beta: 13–30 Hz), with a frequency resolution of 0.49 Hz. We then extracted the IAF defined as the discrete frequency with the highest power magnitude within the alpha range (Klimesch, 1997; see Bazanova & Vernon, 2014, for an extensive review of IAF). To test for the hypothesis that IAF predicts individuals’ TBWs, we computed Pearson correlation between IAF expressed in milliseconds for an extensive review of IAF). To test for the alpha range (Klimesch, 1997; see Bazanova & Vernon, 2014; Kaiser, 2005, for similar approaches). To account for normal distribution, data were transformed into decibel scale (10 × log10 [µV]).

*Prestimulus Alpha Amplitude*

The power around the individual alpha peak frequency was computed from the EEG signal preceding the stimulus pairs. This was done to test for the hypothesis that accuracy (veridical response) in synchronous perception can be explained by prestimulus alpha amplitude. To do so, we aggregated visual- and tactile-leading trials. We used this approach because the threshold SOA used during the EEG session did not differ significantly from each other (paired sample t test with 1000 sample bootstrap correction), t(1, 17) = −0.946, p = .35, CI [−308.27, 117.38]. Prestimulus alpha power was extracted by using a single-trial Morlet wavelet using the EEGLAB ERSP tool. We ran the analysis for the whole trial epoch, starting from −2000 to +2000 relative to the first stimulus onset, with a minimum number of 3 cycles and an increasing factor of 0.8. This resulted in a frequency range from 3 to 125 Hz. We analyzed a time window ranging from −500 and −140 msec (Samaha, Gossseries, & Postle, 2017; Slagter, Prinssen, Reteig, & Mazaheri, 2016; Leonardelli et al., 2015; Walz et al., 2015; Ai & Ro, 2014; Keil, Müller, Hartmann, & Weisz, 2014; Keil, Müller, Ihssen, & Weisz, 2012; Mathewson et al., 2009; Romei et al., 2008) to avoid effects of poststimulus activity smearing backward on prestimulus data, due to the sliding window method used (Iemi, Chaumon, Crouzet, & Busch, 2017). For each participant, we calculated the complex modulus (magnitude) on each time point of the time window analyzed only for the frequencies corresponding to ±2 Hz around the IAF peak for each electrode, in all the trials. Subsequently, at the individual level, we computed the average of alpha power for the entire time window. Hence, for each participant, we estimated a prestimulus alpha power value for SJ and one for non-SJ. These data were entered in the statistical analysis (see Bazanova & Vernon, 2014; Kaiser, 2005, for similar approaches). To account for normal distribution, data were transformed into decibel scale (10 × log10 [µV]). To investigate the role of prestimulus alpha power on responses, we compared prestimulus alpha power preceding simultaneous and nonsimultaneous responses with a paired sample t test (two-tailed). To correct for multiple comparisons, a nonparametric cluster-based permutation test (Maris & Oostenveld, 2007) was performed using FieldTrip toolbox in MATLAB (Oostenveld et al., 2011). The parameters were the same as those used in the correlation analysis.
RESULTS

Behavioral SJ
All participants completed the behavioral SJ task. All data fitted the sigmoid model (TBWleft $R^2 = .98$, SD = .05, range = .79–.99; TBWright $R^2 = .97$, SD = .05, range = .77–.99; see Figure 2 and Table 1). However, we excluded four participants from all the subsequent analyses because they never reached at least 80% of perceived simultaneity. For the visual-leading sequences, the mean value of the TBW (i.e., right TBW) was 169 msec (SD = 37). For the tactile-leading sequences, the mean value of the TBW (i.e., left TBW) was 176 msec (SD = 42).

SJ Results during EEG Recording
As explained in the Determining Individualized SOAs for the EEG SJ Task section, we used stimuli with a SOA corresponding to the 50% of the individual TBW calculated from the behavioral session. For the visual-leading sequences, the mean value of the temporal threshold was 150 msec (SD = 39). For the tactile-leading sequences, the mean value of the temporal threshold was 153 msec (SD = 29). Visual-leading and tactile-leading temporal thresholds did not differ from each other (paired sample $t$ test with 1000 bootstrap correction), $t(1, 17) = -0.555$, $p = .58$, CI $[-14.05, 7.44]$.

To ascertain that our participants had a complete chance-level perception of simultaneity across all conditions, we tested their performance during the EEG task. The comparison showed no differences between the perception of simultaneity and a chance-level performance (one sample $t$ test with 10,000 bootstrap correction against 0.5), $t(1, 17) = 0.393$, $p = .699$, CI $[-0.042, 0.062]$. Participants reported simultaneity in the 51.1% (SD = 24%) of the trials (see Figure 3).

EEG Results

Individual Alpha Frequency
The nonparametric cluster-based permutation test revealed a significant positive correlation between IAF and TBWleft ($t = 13.71$, $p = .005$; see Figure 4) in a left parietal cluster including CP1 ($r = .66$, $p < .01$), CP3 ($r = .62$, $p < .01$), P1 ($r = .52$, $p = .02$), P3 ($r = .44$, $p = .06$), and PO3 ($r = .55$, $p = .02$). The same analysis on the TBWright revealed a positive correlation between IAF and TBWright in a similar left parietal cluster, including CP1 ($r = .50$, $p = .03$) and CP3 ($r = .55$, $p = .01$); however, it did not survive correction for multiple comparisons (cluster-based permutation; $t = 4.93$, $p = .22$; see Figure 4).

Prestimulus Alpha Power
We performed a nonparametric cluster-based permutation test on the power of prestimulus alpha band between the two judgments (simultaneous vs. nonsimultaneous). The
analysis was significant ($t = 9.67, p = .015$; see Figure 5), owing to higher alpha power before non-SJ compared with SJ. The significant cluster was located over the left centro-parietal electrodes (C5, CP3, CP5, P3, TP7; see Figure 5).

**DISCUSSION**

We investigated the relationship between prestimulus electrophysiological activity and subsequent perception of simultaneity, and the electrophysiological underpinnings of temporal sensitivity to visuotactile stimuli, by employing an SJ task.

We found that whether visuotactile stimuli are perceived as simultaneous depends on the overall level of the left centroparietal oscillatory alpha activity. Specifically, we found that higher alpha power leads to more veridical responses (i.e., nonsimultaneity), relative to low alpha power, which is instead related to the nonveridical perception of simultaneity. Importantly, when investigating the neural underpinning of temporal sensitivity (as measured using the TBW), we found it to be positively correlated with the individual alpha peak frequency recorded from centroparietal electrodes, in that the faster the oscillations within the alpha range, the narrower the TBW (i.e., higher temporal resolution). The positive correlation between IAF and temporal resolution can be explained by endorsing the idea that alpha frequency represents the actual currency of perceptual sampling (Cecere et al., 2015; Samaha & Postle, 2015). The effect of alpha power on simultaneity judgments could be framed either in the context of the excitability account of alpha predicting accuracy (Klimesch, Sauseng, & Hanslmayr, 2007) or alternatively coding for confidence in perceptual judgment (e.g., Samaha, Iemi, et al., 2017).
Figure 4. Correlation map. (A) Top section: topography of $t$ values of correlation analysis between TBW$_{left}$ and IAF around left occipitoparietal electrodes. Electrodes included in the cluster are highlighted with red circles. Bottom section: scatter plot of the correlation between IAF over left occipitoparietal and TBW$_{left}$. (B) Top section: topography of $t$ values of correlation analysis between TBW$_{right}$ and IAF around left parietal electrodes. Electrodes included in the cluster are highlighted with red circles. Bottom section: scatter plot of the correlation between IAF over left parietal and TBW$_{right}$.

Figure 5. Topoplot alpha power. (A) Scalp distribution of individual alpha power resulting from the contrast between non-SJ and SJ. (B) Statistical map of $t$ values resulting from the nonparametric cluster-based permutation test. (C) Electrodes included in the cluster showing a significant difference between judgments (C5, CP3, CP5, P5, TP7) are highlighted.
showed that temporal sensitivity to multisensory stimuli is encoded in the individual duration of an alpha cycle. These results suggest that neural oscillatory activity in alpha frequency is at the core of interindividual differences regarding sensory processing in the time domain, expanding on previous findings on unimodal visual perception (Samaha & Postle, 2015). Among the evidence initially pointing to a role of alpha oscillatory activity in temporal organization of paired stimuli is a study by Gho and Varela (1989). They showed that if two flashes are presented within an alpha cycle, they are interpreted as occurring simultaneously; conversely, if they are presented in two different alpha cycles, they are reported as occurring in succession (but see VanRullen & Koch, 2003). Therefore, according to accumulating evidence, the duration of an alpha cycle would represent the actual currency of perceptual sampling, which defines temporal sensitivity. The current pattern of results provides relevant insight to the significant impact that task instructions may have on the way that the same stimulus is processed. Indeed, the SJ task as used in our current study, strictly requires evaluating the perceived simultaneity of two stimuli, therefore specifically tapping into time sensitive processes.

Other temporal tasks, such as the temporal order judgment task, may require additional resources or strategies, including cognitive bias or expectancy of which sensory stimulus will be presented first (Matthews, Welch, Achtan, Fenton, & FitzGerald, 2016; Van Der Burg, Olivers, Bronkhorst, & Theeuwes, 2008; Mitrani, Shekerdjiski, & Yakimoff, 1986; Allan, 1975). Hence, SJ is likely to purely reflect the participants’ temporal sensitivity without interference of additional process regarding stimulus modality or priority evaluation.

That said, a possible role of attention can be argued, given that prestimulus alpha oscillations reflect attentional processes (van Ede, de Lange, Jensen, & Maris, 2011; Thut, Nietzel, Brandt, & Pascual-Leone, 2006), indexing the momentary inhibition of irrelevant information (Händel, Haarmeier, & Jensen, 2011). However, we have not actively manipulated attentional dimensions, such as load, spatial location, and so forth, and no obvious attentional modulation could be observed in line with the previous reports suggesting that judging simultaneity of suprathreshold clear stimuli seems not to be affected by attentional modulation such as prior entry (Yates & Nicholls, 2011) or the Posner effect (Donohue, Green, & Woldorff, 2015).

Accumulating evidence support the idea that ongoing neural oscillations can be part of the mechanisms that enable multisensory integration. For instance, Lakatos, Chen, O’Connel, Mills, and Schroeder (2007) recorded single neuron activity in the primary auditory cortex of the monkey’s brain induced by audio–tactile stimuli. The authors showed how the tactile stimulus can “reset” the phase of ongoing oscillations in the auditory cortex (Northoff, 2013). This phase resetting can produce two different effects: If the auditory stimulus arrives during a high excitability phase, the co-occurring tactile stimulation can produce an enhancement of the neural response in the primary auditory cortex; on the contrary, if the auditory stimulus arrives in a low excitability phase, the co-occurring tactile stimulation would be suppressed. Similar observations have been made in humans, in that a simple sound can reset occipitoparietal alpha band oscillatory activity (Mercier et al., 2013; Romei, Gross, & Thut, 2012). Klimesch et al. (2007) propose the idea that alpha EEG activity could reflect the rhythmic oscillation inhibitory system. It is known that neurons can have a tonic or a phasic activity. The tonic activity can be “rhythmically interrupted” and turned into phasic by the action of inhibitory neurons (Klimesch et al., 2007). Neurons also have their own excitability level (Mele, Leal, & Duarte, 2016): A single cell can be more resistant to inhibition if its level of excitability is high, meaning that it needs stronger signals to change its pattern of activation. Given that alpha band can be an inhibitory oscillation, Klimesch and colleagues affirm that if alpha power is high, it may be possible that more neurons can fire synchronously. Interestingly, neurochemical evidence supports these findings by showing that GABA and glutamate systems, which shape ongoing oscillatory activity, predict individual differences in multisensory processing (Balz et al., 2016). The increase of inhibition does not lead to a reduction of firing rate, but rather to a more precise temporal activity. It is possible that this mechanism creates a temporal constraint of ongoing oscillation, providing a strict time window for neurons to fire (Fries, 2005). For this reason, we can speculate that if alpha power is high, the temporal structure and temporal pattern of activity of prestimulus activity will also be high. Therefore, the increase of temporal dynamic can be responsible for the correct detection. In other words, if there is an increase of alpha power before the judgment, it may be possible that such higher accuracy may depend on the fact that the two stimuli fall in a more time organized “window” of activity, thus leading to a correct judgment. The concept that temporal organization of neural signal is a fundamental aspect in multisensory integration is not entirely new, in fact recently, Ferri et al. (2017) showed how the temporal structure of BOLD activity (as indexed by the power law exponent) in primary auditory cortex predicts the width of the audio–tactile TBW. In particular, stronger resting-state long-range temporal correlations, indexed by a larger power law exponent, robustly predicted narrower audio–tactile TBW.

The Multifaceted Dimension of Oscillatory Activity in the Brain: Optimizing Sensory Integration

A relevant aspect of our findings is that prestimulus alpha power can predict the participants’ judgment of simultaneity. Indeed, our experimental setting enabled us to study differences in subjective perception of simultaneity when the physical stimulation was kept constant across participants.
According to a more recent proposal, alpha power would not account for visual discrimination per se, but rather to a perceptual bias in visual discrimination confidence (Benwell et al., 2017; Samaha, Iemi, et al., 2017). Recent research has shown that this might be the case. For instance, Limbach and Corballis (2016) performed a signal detection theory analysis of detection performance as a function of alpha power. They observed that participants adopted a more conservative criterion when alpha power was high. Similarly, Iemi and colleagues found a relationship between alpha power and response criterion (Iemi et al., 2017). Moreover, higher alpha power seems to lead to more conservative perceptual bias coding for the nonsynchronous perceptual outcome (Iemi & Busch, 2018; Benwell et al., 2017; Samaha, Iemi, et al., 2017). This might come from the accumulated perceptual experience during the task in which a higher occurrence of nonsimultaneous stimuli is observed. Under these circumstances, higher alpha power will anchor perceptual bias toward the conservative choice of nonsimultaneous occurrence, whereas low alpha power will be anchored to the more liberal perceptual bias that visual and tactile stimuli have been simultaneously presented.

Conclusion

Our data support the idea that two main features of ongoing oscillations, power and frequency, contribute respectively to the perception of synchrony during a simultaneity judgment task and define windows providing the temporal frame of visuotactile perceptual sampling. According to Bao et al. (2015), the synchronization of information onto different temporal windows must be the key to an adaptive perception of the world (Northoff & Huang, 2017). This mechanism accomplishes the process of dividing the continuous stream of information into discrete temporal units, which are defined by the length of each individual alpha cycle.

Acknowledgments

V. R. was supported by the BIAL Foundation (grant 204/18).

Reprint requests should be sent to Migliorati Daniele, Laboratory of Neuropsychology and Cognitive Neuroscience, Department of Neuroscience, Imaging and Clinical Sciences, and Institute for Advanced Biomedical Technologies, University G. d’Annunzio, Chieti, Italy, or via e-mail: daniele.migliorati88@gmail.com or Costantini Marcello, Laboratory of Neuropsychology and Cognitive Neuroscience, Department of Psychological, Health and Territorial Sciences, and Institute for Advanced Biomedical Technologies, “G. d’Annunzio” University of Chieti-Pescara, Chieti, Italy, or via email: marcello.costantini@unich.it.

REFERENCES


