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Unravelling competitors' brain-and-body correlates. The two-persons social neuroscience approach to study competition

Michela Balconi [1,2] - **Laura Angioletti** [1,2]

[1] *International Research Center for Cognitive Applied Neuroscience (IrcCAN), Catholic University of the Sacred Heart, Milan, Italy*

[2] *Research Unit in Affective and Social Neuroscience, Department of Psychology, Catholic University of the Sacred Heart, Milan, Italy*

DOI: https://dx.doi.org/10.7358/neur-2021-029-bal2 laura.angioletti1@unicatt.it

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ABSTRACT

Competition refers to a condition for which an individual or a group strive to gain or win something by defeating or establishing superiority over others. It follows that, unlike cooperation, the gain of one foresees the loss of the other. Most accounts have focused on the individual and social cognitive mechanisms featuring cooperative/competitive behavior, however, a fascinating question regards the neurophysiological correlates of competitive social phenomenon. What happens at a neural and peripheral level in the brain-and-body system of two people engaged in a competitive dynamic? The combination of multiple neuroscientific techniques adopted to unveil the individual and social complexity of competition leads us discussing a more recent and promising paradigm in neuroscience, the hyperscanning. In the social neuroscience field, hyperscanning allowed shifting from a single-person to a two-persons perspective and can open new opportunities to study interpersonal brain-and-body connectivity during competitive social interactions in increasingly ecological contexts.

Keywords: competition; cooperation; social neuroscience; social brain; hyperscanning

1. AT THE BEGINNING, THERE WAS THE SOCIAL BRAIN…

The social brain, as common background of both competitive and cooperative brain, constitutes the starting point of this theoretical discussion. From a neurophysiological perspective, the notion of "social brain" refers to a circumscribed collection of regions and networks in the brain specifically devoted to social cognition. But why we developed a social brain? And, what the social brain does?

The social brain hypothesis was proposed as an explanation for the fact that primates have abnormally large brains for their body size compared to all other vertebrates. Primates evolved and developed expanded brains to manage their unique complex social systems. So, it is the social brain that permits us to connect and relate with other individuals. Firstly, it helps us "to read the intentions" of the person we are interacting with. Furthermore, it helps us to predict others' behavior and, as with all the interplays with the others (individual or agent), we can perform better if we can anticipate what awaits us.

The better we are able to predict what somebody is aiming to do following, the more effective our interplay with that person will be. Hence, it can be argued that the main function of the social brain is to facilitate individuals in anticipating the intentions of other during social exchanges. The nature of these predictions could also be unconscious and automatic and not only conscious and pondered. Frith (2007) mentioned the classical Pavlovian conditioning as an example of a social learning process that allows us to anticipate what will happen after a conditioned stimulus. Such basic conditioning has social relevance if the conditioned stimulus is social, like a facial expression (e.g., the mom displays a joyful expression before providing food to her child). So, it might be argued that the ability to make predictions about people's actions on the basis of their mental states is the most relevant feature of the social brain (Frith, 2007).

The assumption is that mental states are at the basis of the behavior, so the knowledge that one person has intentions, and has been called "having a theory of mind". And the ability of "mentalizing" consists in the automatic process thanks to which we can "read" others' intentions and mental states. There are various diverse sorts of "mental conditions" that can influence our behavior. For example, there are long-term dispositions related to the trustworthiness of a person or beliefs about the world. There are transient emotions like joy and anger. There are needs and desires, like thirst, which orient specific goal-directed behaviors. Finally, there is the intention to communicate with others and the related skill to recognize that certain conducts are communicative.

Thus, the social brain is at the basis and supports the higher-level processes involved in social cognition, it helps us to predict others' behavior even by mirroring others' cognitive, emotional and behavioral reactions. Previous research found that during social interpersonal interactions people can significantly influence and shape each other's emotional states and behaviors: the roots of such mechanisms lie in basic resonance skills which allow to perceive, mimic, and symmetrically understand others' feelings, actions and intentions, as suggested, for example, by simulation and emotional contagion theories (Gallese et al., 2004).

Interestingly, a recent approach highlighted that, when these mirroring mechanisms occur, people involved in the social interaction become implicitly coupled by means of different behavioral, neural, and psychophysiological measures. Some examples can be found in the alignment of behavior (Konvalinka et al., 2010), posture, neural activity, and psychophysiological measures (Giuliano et al., 2016), which can provide an interesting and formalized method to explore the relations between neurophysiological, physiological, affective, and behavioral processes. In fact, although neurophysiology was typically viewed as an intrapersonal process in previous research on social linkage, the central and peripheral responses of two people interacting together can often display substantial correlation during a significant interpersonal exchange.

1.1 An evolutionary neurophysiological perspective to explain social brain

The evidence of the inclusion of the amygdala, orbital frontal cortex, and temporal cortex as major components of the social brain network came primarily from animal studies.

Subsequently, there have been two considerable inclusions to the list of social brain regions, thanks to the discover of neuroimaging for the study of social brain in human volunteers. First, the medial prefrontal cortex and the adjacent paracingulate cortex have been reliably found to be active in research where participants must think about mental states. Second, the mirror system was found in primates and humans' brain and supports the sharing of others' experiences (Rizzolatti & Craighero, 2004).

Previously Frith (2007) briefly reviewed the evidence on the mirror system and the four specific brain regions considered to have a role in social cognition: (i) the amygdala, (ii) the temporal poles, (iii) the posterior superior temporal sulcus (pSTS) and the adjacent temporo-parietal junction (TPJ), and (iv) the medial prefrontal cortex (MPFC) and the adjacent anterior cingulate cortex (ACC). Moreover, he depicted the precise roles of these cortical and subcortical systems and considered to what extent their functions are particularly social. To sum up, the amygdala has a role in social interactions because its activity is elicited by the expression of the emotion on a face (e.g., fear; trustworthiness), and by the process of association of value (positive or negative) to stimuli (LeDoux, 2000). In contrast, temporal lobes are convergence zones for semantic memory and for knowledge on how to adapt to a social script. Thirdly, pSTS and TPJ are respectively responsible for predicting movement trajectories, and perspective-taking; while, lastly, MPFC and ACC paracingulate cortex are activated by i) mentalizing situations, real-time social interactions (or even their simple observation), ii) conditions on which the person must answer to questions on other person's attitude and disposition, iii) self-perception tasks (Mitchell et al., 2005).

Altogether these aspects reflect the complexity of brain structures that are involved in social interactions and suggest the possibility (or better the need) to analyse the relationship between more than one social agent at the same time by a neuroscientific perspective.

1.2 Neurophysiology of competitive and cooperative behaviours

The evidence on the specific neurophysiology of competitive and cooperative behaviour came mainly from neuroscientific studies. Both these two conditions require an engaging social interaction and were demonstrated to activate the anterior insula, an important paralimbic structure linked to two aspects, that is the sense of agency and the attribution of actions to the self, on one hand, and the autonomic arousal, on the other hand (Pace-Schott et al., 2019). Therefore, both competition and cooperation are likely to elicit social and motivational states of the participants that draw into arousal mechanisms (Decety et al., 2004).

1.2.1 Competition

Starting from competition, the strong increase in the prefrontal cortex (PFC) activity – mainly in the mPFC - observed during competitive tasks might mirror higher executive processing demands (Decety et al., 2004). Particularly, it was illustrated that the processing load related to competitive social dynamics is linked to enhanced PFC activation, as indicated by electrophysiological (EEG) and hemodynamic measures (by functional Near Infrared Spectroscopy, fNIRS), respectively showing alpha power decrease and increase blood oxygenation, compared to the other examined brain regions (Balconi & Vanutelli, 2016, 2017a). As such, competition imposed a higher cognitive load.

This significant higher responsiveness of the PFC was principally detected when subjects were notified on their efficient interaction (during the feedback condition, experimentally manipulated) and specifically for positive feedback (vs negative or pre-feedback condition), suggesting a central role of PFC in the case of a positive self-perception (i.e., "to be a good performer") within a social situation where the competition is relevant and stressful. This "improved brain effect" was also accompanied by a considerable incremented cognitive and behavioural performance (decreased error rates -ER- and reaction times -RTs-) in our previous studies (Balconi & Vanutelli, 2016, 2017a).

The intrinsic relationship between behavior and social representation in competitive settings might highlight the plausibility of considering the reciprocal influence of the PFC and self- perception, and of the PFC and the cognitive task, as they may be conceived as two sides of the same coin. That is, a sort of "circular effect" may be adduced: on one hand, the social significance of the performance for the social hierarchy appears to be highly relevant in balancing the subjects' performance across the task (with a consistent and parallel increasing of social ranking perception and subjective performance), that is modulated by the prefrontal areas which could support the social perception process (accurate self-knowledge and self-improvement). On the other hand, the proposed increment in cognitive results may influence the self-perception of ranking position, with evident gains for the subjective representation of social status. Also, in this second case, the PFC may support the reciprocal relationship between cognitive performance and social representation, reinforcing the "social value" of the PFC (Marsh et al., 2009).

Besides, right inferior parietal activation was found and interpreted as processing the distinction between self and other (Decety, 2004). Moreover, both dorsolateral (DLPFC) and ventrolateral (VLPFC) cortices have proven to be involved during ranking considerations (Balconi & Pagani, 2014). The activity of these brain areas during social interactions that implicate perception of social performance is likely to be associated with higher-level top-down processes over, for example, affective responses when considering social ranking. Such mechanisms are meant to manage appropriate behavioral responses when considering social status. As already suggested by previous evidence, these neural circuits could be recruited to trigger socio-emotional responses and behavioral inhibition related to dominance and submission (Marsh et al., 2009).

Secondly, a higher inter-brain homologous response was found for couples in competition after the feedback condition in a previous fNIRS study (Balconi & Vanutelli, 2017a). Specifically, when participants were artificially notified and perceived to have performed better, a homologous and similar brain response was produced in the two brains, with higher coherent PFC activity within the couple. Despite the task was competitive, the self-perceived efficacy produced a sort of "glue" between the two brains, orienting the subjects in the same direction and perhaps inducing towards a similar strategy running in parallel. The present results provide initial evidence for the hypothesis of a significant inter-brain effect during competitive tasks and offer suggestions for future studies examining the extent to which the competition in two brains is selectively related to a better cognitive joint performance for the two inter-agents (Balconi & Vanutelli, 2017a).

However in a later study, was found a gradual decrease of inter-brain functional EEG connectivity in prefrontal areas over the time for dyads competing, specifically in a post-feedback compared to control condition (Balconi & Vanutelli, 2018b). This effect was mainly consistent for delta frequency band, previously linked to high-arousal and emotionally-connoted stimuli and deeper emotional engagement (Balconi & Pozzoli, 2005; Knyazev et al., 2009) and theta band, connoting strategic control and conflict monitoring (Cristofori et al., 2013), suggesting that the specific modulation of theta and delta activities might be connected to the motivational and attentional value of ongoing competitive social dynamics and processing of relevant social-affective cues. In fact, just the emotional and motivational components can diverge in competitive conditions. It should be noted that a previous EEG-fNIRS study showed that a clear hemispheric lateralization effect during competitive conditions, with left lateralized cortical network within the PFC in concomitance to positive feedback was shown for high-BAS (high Behavioral Activation System scale) subjects (Balconi & Vanutelli, 2016). Also, high-BAS displayed improved behavioural performance (low RT and ER) than low-BAS. The left hemispheric effect was demonstrated to be the prominent results able to explain both hemodynamic and cortical EEG modulations. The fact that this cortical "unbalance" in favour of the left hemisphere in response to positive reinforcing conditions, like competition finalized to reach a higher social position, was also accompanied by superior performance and an increased social efficacy during ranking attribution, may suggest an underlying link between the left cortical activity, the external social ranking representation, and the competitive behavior. The specific cortical localization may suggest the consistent over-activation of the left cortical system and an attendant predominance of this brain area in managing subjects' cognitive behaviour when they perceived to be better performers. To support this interpretation, past studies demonstrated that high social power perception is indeed related to greater left frontal brain activity compared to low social power (Boksem et al., 2012).

On the other hand, a significant prefrontal brain lateralization effect was present during competitive dynamics, with the right hemisphere being more engaged with respect to the left one in post-feedback condition (Balconi & Vanutelli, 2017a). This result may be understood taking into consideration the social role of PFC and the lateralized effect observed in previous studies

(Balconi et al., 2012), that may relate the increased right hemisphere responsiveness to a noteworthy raise of more negative and avoidance emotions toward the competitor, linked to the competitive condition. As already detailed, the right hemisphere is supporting the aversive circumstances where the subjects are required to manage the conflictual and potential divergent goals (Balconi et al., 2012). Therefore, the individualistic and competitive aims at the task may induce a sort of a ‘‘negative echo’’ for the subjects, with a significant increase of more withdrawal attitudes. Consequently, PFC activity results to be involved in the processing of emotional behaviour which involves the competitive dynamic (Chiao et al., 2008).

Nonetheless, to deeply comprehend the present apparently counterintuitive discussion, it is necessary to refer to a crucial and ampler construct, that is the role of a personality component defined as “approach attitude”, measured by BAS explained above. In fact, it has been previously suggested that the left frontal cortical asymmetry is associated to approach motivations and with dominance tendency and, therefore, to BAS construct (Davidson, 1992). Specifically, it was shown that, based on resting intracortical activity during social threat, participants with higher resting activation in the left vs. right DLPFC cortex exhibited more adaptive, dominant, and approach-oriented responses (Koslow et al., 2013). In general, the relevance of the BAS construct may also be related to these three levels of explanation, that are integrated with each other: the sense of self-efficacy; the sensitivity to the reinforcing conditions and rewarding aspects; the dominance trait.

These results suggest that social status may not be a static and “universally valid” phenomenon; rather, the perception of our own ranking and social power, particularly during conditions of competition with others, might be directly and strongly related to personality approach-related components. This is in line with previous studies (Demaree, 2005), which reported that those individuals with a higher-BAS were more likely to relate to the dominant and “proactive” character in circumstances which were shown to elicit a positive effect, whilst those with a higher BIS sensitivity were more inclined to relate to a submissive and passive character. However, so far the relationship between personality components and the emotional effects of competition on brain activity, taking into consideration the role of emotions on the cortical response (and on inter-brains responsiveness) when it responds to social situations as competition of cooperation, have been deepened by few studies. For this reason, to determine this reciprocal relationship, future investigations should better examine the distinct effect of emotions and competition on the cortical reactivity.

1.2.2 Cooperation

Regarding the neurophysiology of cooperation, when people cooperate brain regions associated with pleasure and reward such as the ventral striatum and caudate nucleus are activated (Cacioppo & Cacioppo, 2020; Rilling et al., 2002). Because reciprocity evolved as the tendency to pay back in kind, the tendency is for cooperation to carry social benefits (e.g., cooperative responses) and competition to carry social costs (Cacioppo & Cacioppo, 2020).

In Decety and colleagues (2004) neuroimaging study, cooperative actions recruited left anterior frontal cortex and orbitofrontal areas suggested to have a fundamental role in making behavioral choices, particularly in incompletely specified or unpredictable situations. These results were compatible with a previous neuroimaging study that investigated social interactions by means of the iterated Prisoner's Dilemma Game (Rilling et al., 2002). Both authors interpreted such result starting from evolutionary and developmental psychology and stressed the highly rewarding effect of cooperation and a sort of merging of the two partners.

In the field of rhythm, music and motor synchronization some previous studies used rhythmic synchronization to assess the capacity to cooperate with each other. Lindenberger and colleagues (2009) found that, when playing a short melody together, dyads of guitarists showed increased phase synchronized theta and delta oscillations. The authors suggested that coordinated behaviors are characterized by inter-brain oscillatory coherence (Lindenberger et al., 2009). Also, since the reported rhythms were all in the lower frequency range, it is possible that the similarities in sensorimotor feedback could have enhanced between-brain synchronization. To disambiguate this issue the same team (Sänger et al., 2012) later used a similar but advanced paradigm with a more complex piece of music such that the two members of the couple would have different roles, a leader, and a follower. The paradigm reduced similarities in movement, proprioception, and perception. Results extended previous data and attributed between-brain phase coherence to musical coordination periods. Also, since the effects were larger at frontal and central sites, it was proposed that the on-line representation of one's own and others' actions and their combination into a joint, coupled model, may help to support Interpersonal Action Coordination (IAC).

Analogously, another study by Yun and colleagues (2012) used a leader-follower task to demonstrate the presence of implicit motor synchronization when interacting with another human. Seated face to face, a leader had to perform hand movements and another player had to imitate them at their best. Finally, both participants were asked to freeze. The behavioral results highlighted that the two mates implicitly synchronized their movements, mainly during the final phase that followed imitation. EEG results showed higher phase synchronization following the imitation phase within theta and beta frequency bands over the inferior frontal gyrus, anterior cingulate, parahippocampal gyrus, and post-central gyrus. Such results were considered as an improved coupling between the two cognitive representations.

Similarly, a previous study used a video feedback system and asked subjects to imitate the other's hands movement. The researchers found higher inter-brain phase synchronization within mu, beta, and gamma cerebral rhythms in the right centro-parietal areas of the two brains during behavioral synchrony (Dumas et al., 2010). Also, a work by Kawasaki and collaborators (2013) explored the presence of inter-brain correlation during speech rhythm synchronization. Results showed that speech rhythms were more easily synchronized in the joint condition with respect to the individual condition where subjects performed the same task within a computerized session. Moreover, increased synchronized theta/alpha amplitudes were found in the same temporal and lateral-parietal regions known to be associated with social cognition, such as comprehending others' intentions, affects, and actions (Adolphs, 1999).

Lastly, in Cui and colleagues' work (2016) dyads of participants were asked to press two keys either simultaneously (to obtain synchronized action in cooperative condition), or as fast as possible to obtain a better result than their partner during the competitive condition. The participants showed increased inter-brain synchronization in the right superior frontal areas during cooperation, but not competition: such result emerged because of the necessity to model others' behavior during a cooperative task. It should also be considered that the increase in cortico-cortical communication was high and significant, and involved heightened responses between all non-motor areas with strategy planning regions (such as prefrontal areas). This increase of neural connectivity patterns (associated to physiological linkage and interpersonal tuning) when participants are involved in cooperative dynamics is perhaps one of the most interesting neural evidence reported by a large corpus of previous studies (for further evidence and understanding, see: Astolfi et al., 2011; Balconi et al., 2017a, 2017b, 2019, 2020; Balconi & Salati, 2017; Balconi & Vanutelli, 2018b; Venturella et al., 2017).

2. HOW TO STUDY COMPETITION FROM A NEUROSCIENTIFIC PERSPECTIVE: PARADIGMS AND MEASURES

2.1 Neuroscientific methods

Because of its specific features, fNIRS has been extensively used within the field of social neuroscience, ranging from the study of cognition, towards more complex emotional and interpersonal mechanisms. Considering social neuroscience as a potential field of application, in fact, the main strength features of fNIRS include its portability and low sensitivity to body movements, its safety of use and the chance to integrate it with other neuroscientific measures, making it suitable for monitoring cortical hemodynamics in a variety of experimental and ecological conditions, specifically in interactive tasks.

To get more in detail, fNIRS allows a better temporal resolution recording but has a lower spatial resolution than fMRI; on the other hand, it has a higher tolerance to motion artifact and it gives the chance to monitor O2Hb and not only HHb, as provided by fMRI. It is also suitable for long-time continuous monitoring, and it is more participant friendly than fMRI, given that all participants are eligible for its application, of all ages, without particular exclusion criteria. These advantages are specifically useful for ecological tasks, mainly because it is not easy to reproduce real-life situations within an fMRI or a PET scanner. These contexts introduce many requirements about spontaneous movement, sounds, experimental timing, etc. This way, the task becomes very unlikely and there is the risk of unreliable behaviors and responses by the subjects. This is particularly important when considering the ecological validity of an experiment and data disclosure.

Indeed, a new research perspective tried to maximize the abovementioned fNIRS advantage towards the implementation of ecological conditions related to some constructs coming from a social/affective neuroscientific perspective, involving competition and cooperation in human interactions. Therefore, fNIRS can be proposed in all respects as a good alternative candidate to explore and understand competitive neural dynamics, from a human-to-human (H2H), towards a brain-to-brain (B2B) approach in real-time and in an ecological setting. fNIRS has already been used in hyperscanning studies for exploring the mechanisms and dynamics of competition (Balconi & Vanutelli, 2016, 2017a).

Event-Related Potential (ERP) technique was previously exploited in this context: a large late positive complex ERP response (700-1200 ms) was found in social competitive conditions compared to neutral ones (Zeng et al., 2013), but also P300 amplitude was previously found to be influenced by competitive (vs cooperative) conditions (Cui et al., 2016), and a more prominent Late Positive Potential (LPP) amplitude occurred when the participants processed the face of a highest-rank player (Breton et al., 2014).

To find out how the type of social interaction affects linkage, which is the concordance between the neural biological signals of agents involved, in a recent EEG study pair of participants played a turn-based computer game in which the level of competition was systematically varied between cooperation and competition (Spapé et al., 2013). In this study, increased beta and gamma EEG frequency bands power was observed in the central and parietal sites, especially when the participants played competitively against each other (both at the individual and the interpersonal level) and thus were associated to social competition (Spapé et al., 2013).

As detailed above, EEG-hyperscanning method was used to deepen competition tendency in healthy subjects and found a hemispheric effect in favor of the brain left side as characteristic of the competitive behavior, showing an imbalance for high-BAS in comparison to low-BAS individuals in the case of a rewarding context (Balconi & Vanutelli, 2016). Moreover, functional EEG connectivity analyses showed a reduction of inter-brain functional connectivity (primarily involving bilateral prefrontal areas) for slower EEG frequency bands (delta and theta); while, correlation analyses highlighted a significant association between cognitive performance and inter-brain connectivity measures (Balconi & Vanutelli, 2018a, 2018b, 2018c).

Also, psychophysiological autonomic measures (skin conductance, heart rate, blood pressure, skin temperature) have been used taking into account specifically the modulation in arousal. Indeed, arousal is considered a fundamental feature of behavior and it is defined as the neurophysiological basis underlying all the processes in the human organism, with a specific role for emotional behavior. In particular, electrodermal activity (EDA) is considered a valid and sensitive indicator responding to the smallest variation in phasic arousal, which is the behavioral response to specific stimulus emotional valence (Balconi et al., 2012).

Interestingly, Adam and colleagues (2015) measured bidders' skin conductance response (SCR) and heart rate (HR) as objective proxies for their arousal and immediate emotions, respectively, in auctions with different social competition conditions. They showed the highest arousal responses when participants were competing, versus the absence of social competition, specifically with other human bidders (vs computers). This result not only highlighted the specific effect of competition on autonomic indices, but also the relevance of knowledge to be engaged in a human interaction for bidders to feel the urge to beat the competitors. This lays the foundation for the application of paradigms that take into account real human interactions in experimental conditions. In this regard, following studies started to adopt autonomic indices to measure competition during hyperscanning paradigm, and they found increased Skin conductance Level (SCL), SCR and HR suggesting higher arousal conditions in dyads concurrently with an increased behavioral performance during a joint competitive interactive task (Vanutelli et al., 2018). Moreover, in this study inter-subject analysis, revealed increased physiological linkage was observed after the positive feedback, resulting in heightened SCR and HR synchronization.

Lastly, physiological responses were also exploited in exploring sport competitions, such as basketball, martial arts, and stressful competitive conditions more broadly.

2.2 Recent evidence by using a multi-measures approach

To explore the role of behavioural, peripheral and neural components in competition, in a series of recent experimental paradigms we employed a new task which is able to artificially induce competition and frustration during an interpersonal game, by presenting specific feedback to the members of the dyads (Balconi & Pagani, 2014; Balconi & Vanutelli, 2017a, 2017b, 2018a, 2018b, 2018c).

Participants were required to play a game and asked to perform as their best in a way to defeat their competitor. During the game, which was a sustained attention task that required the recognition of target stimuli among non-targets, participants were continuously informed about their performance and, halfway, they received more general feedback assessing their performance level, in order to favour competitive mental representations. Then, the instructions encouraged them to try to perform better or to keep going like that in the second phase of the experiment. Of course, both the trial and the general feedback were artificially manipulated, giving the possibility to employ this task both for competitive and for cooperative conditions. This procedure was designed to guarantee the perfect synchronization of agents' activities. After each experimental block, the subjects received artificial feedback according to the competitive/cooperative version of the task, in the form of two arrows at the top (better performance/high cooperation score); a dash (comparable/average performance); or two arrows at the bottom (worse performance/low cooperation score). In its competitive version, the task intended to discourage the formation of an emotional bond in the dyads and promote competitive mechanisms. (Figure 1)

To gather the complexity of the phenomenon, together with neural (electrophysiological and hemodynamic), physiological (electrodermal and cardiovascular indices), behavioural parameters, subjective measures (approach and avoidance attitudes) were also acquired by administering the BIS/BAS questionnaire (Carver & White, 1994). The adoption of this task allowed us to perform different order of analysis for gather insights on neural, physiological, behavioural and personality correlates of cooperative and competitive behaviour in each dyad. Later in the article, we will discuss the methods of analysis developed and applied to study the competitive phenomenon, which foresee an increasing level of complexity (from a single person perspective to two-persons perspective).

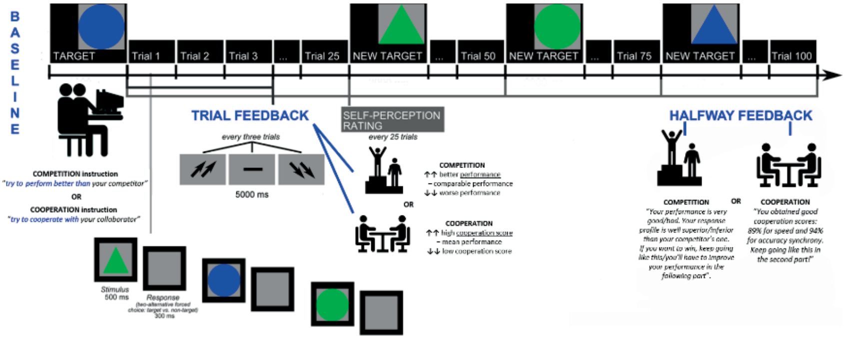

Figure 1. Experimental procedure which represents setting, task structure instructions and feedback (trial and halfway) set for the competitive and cooperative version of the task (retrieved and modified from Balconi and Vanutelli, 2017a)

Following this methodological approach, other recent applied research (Adam et al., 2015) integrated self-report measures in physiological protocols and developed an assessment three concrete constructs related to emotional processes in competitive contexts: the desire to win, the fear of losing and the "competitive arousal", which stems from the thrill of beating competitors. The application of multi-method research designs proves to be a possible solution to effectively grasp the cognitive and emotional assumptions and effects of competition at the neurophysiological, psychophysiological, behavioural and self-report level.

2.3 The social approach: the interaction investigated by hyperscanning

As detailed above, neuroscience can offer an ample range of techniques and paradigms to be applied to research on competition. The simultaneous EEG recordings of several brains have recently opened a new field, called *Hyperscanning*. It is a recent paradigm in neuroscience which consists in the simultaneous recording of the cerebral activity of two or more subjects involved in interactive tasks (Balconi & Vanutelli, 2017a). This measure allows for exploring interpersonal brain mechanisms generated by social interactions. Previous studies showed that the mutual adaptation of two interactive brains results in brain synchrony, and cooperative tasks are one of the best examples of possible applications of such technique. Accordingly, these mechanisms cannot be captured by conventional single-subject recordings (Balconi & Vanutelli, 2017b). Taking into account these methodological considerations, *hyperscanning* technique could be useful to highlight the neural synchronization of two interactive participants during joint activities like cooperation and competition. In Figure 1, the experimental interactive task previously described in section 2.2. is represented, during which hyperscanning technique was adopted in our previous studies on competition and cooperation.

3. FROM A SINGLE PERSON TO TWO-PERSON PERSPECTIVE IN SOCIAL NEUROSCIENCE: INTRA-BRAIN AND INTER-BRAIN FUNCTIONAL CONNECTIVITY

Although the abovementioned studies significantly improved the neuroscientific research assessing competitive/cooperative dynamics, the main advantage of an ecological setting for this topic lies in the opportunity to move from a simple analysis about each subject's neural response during joint actions and its association with the behavioral output, towards more complex computations (Babiloni & Astolfi, 2012). In detail, it is possible to investigate if and how one's brain activity is related to that of another interacting partner simultaneously recorded (synchrony analysis).

The present section was aimed at illustrating the use of neuroscientific tools in the social/affective neuroscientific research seeking to explore interpersonal dynamics considering a brain-to-brain approach. Moving from a single person to a second-person approach, more complex analyses have been discussed regarding concurrent, joint neurophysiological data, for both time and frequency domain procedures. We believe that it should be important for upcoming work to frame and interpret the meaning of the presence of such "hyperlinks" by adopting evidence-based theoretical models to understand and explain the co-modulation of the neural parameters. The potentiality of EEG-, fNIRS-, autonomic- based hyperscanning techniques should anyhow be better framed in future studies translating competition in H2H to B2B interactions.

However, as already suggested by Crivelli and Balconi (2017), in the attempt to address such research questions, important concerns have been raised in relation to the best statistical approach to calculate specific indices expressing the strength of such a relationship. Accordingly, a variety of methods have been implemented to analyze and interpret concurrent data and calculate inter-brain synchrony, or functional connectivity. More specifically, this can be defined as the relation between the neural activities coming from different brain areas or, in our case, from the brain areas of different, separated, brains. Making a step back to the definition of interpersonal coordination, it can be described as the extent to which the interaction's behaviors are non-random, coordinated in both timing and form. Thus, when dealing with the neurophysiological data underlying such joint behaviors, the passage of time is of main interest. Indeed, when calculating inter-brain connectivity, the main goal is to establish the presence of consistency in the time course of two (or more) time series (Crivelli & Balconi, 2017). Such synchrony is assessed with different techniques according to the methodology (i.e., time-domain and frequency-domain analyses; for a description see Angioletti et al., 2019).

4. FUTURE CHALLENGES. WHAT ARE THE NEW PATHS FOR STUDYING COMPETITIVE BEHAVIOR IN THE NEUROSCIENTIFIC FIELD?

In this last paragraph, a brief overview of examples of protocols realized thanks to the hyperscanning approach will be described. Specifically, the study of competition using hyperscanning has been partially deepened in the following fields: basic research on empathy, emotions (Balconi & Vanutelli, 2017a), and game theory (Astolfi et al., 2011). However, evidence from recent studies suggests that competitive dynamics could also be explored in other contexts.

Recently, prosocial behavior was shown to increase perceived self-efficacy, perception of cognitive abilities and social interactions in social neuroscience studies. Therefore, we implemented a multimethod EEG-fNIRS hyperscanning paradigm to explore the effect of gift donation on a cooperation task (Balconi et al., 2020). Similar basic research could be developed even in optics of competitive behaviour for exploring in-depth emotional consequences of competition.

In the field of rhythm, music and motor synchronization some previous studies used rhythmic synchronization to assess the capacity to cooperate with each other by adopting a leader-follower task. A recent finger-tapping experiment adopted an asymmetrical pattern between two members in leader-follower dynamics (Konvalinka et al., 2014): it was demonstrated that it is possible to differentiate roles based on the modulation of frontal alpha-suppression, being this latter prominent in leaders than followers. It has been hypothesized that leaders probably allocated more resources to self-processing to monitor their own rhythm, while followers should monitor the output of their partner.

Similarly, the new-born field of neuromanagement suggests interesting ecological food for thought for studies on competition. With this regard, hyperscanning allowed us to explore real-time communication between manager and employee and observe points of success or fractures. Three main studies can be addressed in this field.

The first one consists of a pilot study where leaders and employees discussed topics related to the company, to the workgroup, and their own personal change (Venturella et al., 2017). Couples' neural and autonomic responses were observed exploring neurophysiological brain and body synchronization as an index of interpersonal tuning. A greater neural electrophysiological response was detected for leaders, compared to employees, specifically during the discussion of personal change and company mission, data that was interpreted as index of a relevant attitude to act and approach emerging issues, and proposing solutions on the basis of personal expertise and involvement. Moreover, during the discussion of personal change topic, in which participants were asked to describe past episodes in which they were directly engaged in managing a situation directed towards company improvement, leaders adopting an authoritative style showed higher autonomic activity (HR) as a marker of increased arousal, compared to leaders adopting a cooperative style.

In this study, a general stronger emotional activation was shown by the employees, with the increasing of SCL values, independently from the leadership style of the manager, perhaps due to the unusual situation. Nevertheless, SCR showed increased arousal when the employee had to face an authoritative leader and his unidirectional communication style, especially when the employee's personal change topic is treated. Conversely, employees that had to face a more participative leader, showed greater SCR values when the leader gets involved in employee's change process (Venturella et al., 2017).

Leader's involvement may have succeeded in qualifying the employees' genuine response. In this way it becomes possible that the leader transmits his readiness to act to the employee, encouraging his positive change and accordingly the company well-being. While a sustained long-term level of arousal (increased SCR) may lead to a loop of physiological and psychological distress. This is in line with previous research showing charismatic and transformational leadership is also associated with low levels of staff stress, conversely the authoritarian leadership correlates with high levels of staff stress (De Hoogh & Den Hartog, 2008).

Thus, if leaders with higher emotional intelligence can also empathize more effectively with the emotion of employees and express more emotionally appropriate interactions and reactions; what could be the consequences of competitive behaviors in leadership? Or better, what are the neural markers highlighting competition and achievable success in leaders and managers? And from a relationship perspective, what are the effects of this behaviour on employees?

In this regard, the second study deepened the specific features of employing a cooperative or authoritative style in leadership, analysing if and how this style could be associated with different dyadic engagement (Balconi et al., 2019). Thirdly, the effect of the presence of unidirectional *vs* reciprocal feedback (provided only by the leader or by leader and employee), as well as the assignment of a quantitative or just a qualitative assessment during a job interview was recently explored (Balconi et al., 2019). These studies are just an example of a large body of research exploring how to manage leadership in cooperative and competitive terms in ecological contexts (Balconi & Salati, 2017). We strongly believe the study of competition might find a space in these complex contexts related to management and leadership, perhaps even considering competition effect at the intragroup and intergroup level by employing modern ecological multi-hyperscanning.

But this will be the second part of the story.

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