Electrophysiological Correlates of Racial In-group Bias in Observing Nonverbal Social Encounters

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Abstract

■ Despite evidence identifying the role of group membership in social cognition, the neural mechanisms associated with the perception and evaluation of nonverbal behaviors displayed by in-group versus out-group members remain unclear. Here, 42 white participants underwent electroencephalographic recording while observing social encounters involving dynamic displays of nonverbal behaviors by racial in-group and out-group avatar characters. Dynamic behaviors included approach and avoidance poses and expressions, followed by the participants' ratings of the avatars displaying them. Behaviorally, participants showed longer RTs when evaluating in-group approach behavior compared with other behaviors, possibly suggesting increased interest and attention devoted to processing positive social encounters with their in-group members. Analyses of ERPs revealed differential sensitivity of the N450 and late positivity components to social cues, with the former showing initial sensitivity to the presence of a humanoid avatar character at the beginning of social encounters and the latter showing sensitivity to dynamic nonverbal behaviors displayed by the avatars. Moreover, time–frequency analysis of electroencephalography data also identified suppression of beta-range power linked to the observation of dynamic nonverbal behaviors. Notably, the magnitude of these responses was modulated by the degree of behavioral racial in-group bias. This suggests that differential neural sensitivity to nonverbal cues while observing social encounters is associated with subsequent in-group bias manifested in the evaluation of such encounters. Collectively, these findings shed light on the mechanisms of racial in-group bias in social cognition and have implications for understanding factors related to successful interactions with individuals from diverse racial backgrounds. ■

INTRODUCTION

Information conveyed by a variety of nonverbal behaviors (e.g., body language) plays a pivotal role in making inferences about others' mental states during social interactions (Dolcos, Sung, Argo, Flor-Henry, & Dolcos, 2012; Murphy, 2012; Hari & Kujala, 2009). Perception and recognition of nonverbal social cues, however, are not determined solely by the perceiver's familiarity with such cues themselves but are oftentimes influenced by the context in which they are embedded and processed by the perceiver (Kret & de Gelder, 2010). For instance, available evidence suggests that nonverbal behaviors can be differentially processed depending on whether or not they are displayed by those who belong to the same social group as the perceiver (i.e., in-group vs. out-group). Nonverbal behaviors displayed by in-group members tend to be decoded with higher accuracy compared with those displayed by out-group members (Adams et al., 2010; Elfenbein & Ambady, 2002), suggesting that in-group nonverbal behaviors are associated with increased familiarity and reduced uncertainty (Dovidio & Gluszek, 2012).

Despite recent evidence identifying the neural correlates of processing in-group and out-group information in a wide variety of tasks (for reviews, see Amodio, 2014; Amodio, Bartholow, & Ito, 2014; Cikara & Van Bavel, 2014; Molenberghs, 2013; Kubota, Banaji, & Phelps, 2012), little is known about the neural mechanisms associated with observing different kinds of nonverbal behaviors displayed by in-group versus out-group members in a defined social context. Furthermore, although human social cognition is thought to involve a set of complex processes that gradually unfold over time (Adolphs, 2001), forming impressions of other individuals can happen very quickly, within hundreds of milliseconds (Willis & Todorov, 2006; Bartholow, Fabiani, Gratton, & Bettencourt, 2001). Categorization of others into one's in-groups versus out-groups is also known to happen very quickly (Zarate & Smith, 1990) and effortlessly (Fiske, 1993). Therefore, brain imaging techniques with high temporal resolution, such as EEG and ERPs, would be particularly helpful in clarifying the temporal dynamics of neural responses associated with the effect of group membership on nonverbal perception and evaluation.

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Using a novel experimental paradigm closely mimicking the observation of people's social encounters in real-life situations (Katsumi & Dolcos, 2018; Katsumi, Kim, Sung, Dolcos, & Dolcos, 2017; Dolcos et al., 2012), this study examined the electrophysiological correlates of observing and evaluating nonverbal social encounters in a business setting.

Available evidence identifies the role of several ERP components in social cognitive processes in different task contexts, some of which also show modulations by in-group versus out-group information (e.g., Amodio et al., 2014; Hehman, Volpert, & Simons, 2014; Amoruso et al., 2013; Ito & Bartholow, 2009). In earlier time windows, ERP components such as P200/N200, which are generally implicated in attentional deployment (Luck & Hillyard, 1994), have been associated with early perception and categorization of group membership (Ito & Tomelleri, 2017; Kubota & Ito, 2007, 2017; Willadsen-Jensen & Ito, 2006, 2015; Senholzi & Ito, 2013; Dickter & Kittel, 2012; Amodio, 2010; Dickter & Bartholow, 2007; Correll, Urland, & Ito, 2006; Ito & Urland, 2003, 2005). In one study, greater N200 responses to in-group than to out-group faces were also associated with RT differences in categorizing these stimuli, thus suggesting a link between this ERP component and facilitated attention to in-group members (Dickter & Bartholow, 2007). In slightly later time windows, ERPs such as the N400/N450 have been associated with the observation of actions, particularly reflecting the extent to which certain actions are expected versus unexpected in a given (social) context (Amoruso et al., 2013). Modulation of N400/N450 amplitudes in the context of action observation might indicate difficulty in understanding others' behavior or in integrating the incoming social information with previous knowledge (Proverbio & Riva, 2009). Moreover, N400 has also been linked to stereotype accessibility, with larger responses typically being elicited by associations of certain groups and characteristics that are incongruent with the perceiver's expectations (Hehman et al., 2014). In even later time windows, ERPs including the late positivity (LP) have been associated with processing of social information such as biological motion (Proverbio, Ornaghi, & Gabaro, 2018; Orlandi, Zani, & Proverbio, 2017; Muñoz & Martín-Loeches, 2015; Proverbio, Crotti, Manfredi, Adorni, & Zani, 2012; Proverbio, Riva, & Zani, 2009), as well as with emotion processing[1] (Dolcos & Cabeza, 2002; Schupp et al., 2000). Larger LP responses were identified during the viewing of dynamic compared with static actions in pictorial stimuli, possibly reflecting an increased effort to process visual kinematic information (Proverbio et al., 2009). Moreover, the amplitude of LP was associated with the amount of information conveyed by videos depicting human bodily movements, thus suggesting a role of this ERP component in higher order integration of such information (Orlandi et al., 2017). In addition, other studies have also demonstrated a link between LP responses and the violation of expectancy in social

contexts (Van Duynslaeger, Van Overwalle, & Verstraeten, 2007; Bartholow, Pearson, Gratton, & Fabiani, 2003; Bartholow et al., 2001; Osterhout, Bersick, & Mclaughlin, 1997).

Aside from ERPs, recent EEG studies of social cognition also have begun to examine event-related changes in oscillatory dynamics in a variety of tasks (e.g., van Noordt, White, Wu, Mayes, & Crowley, 2015; Quandt & Marshall, 2014; Rossi, Parada, Kolchinsky, & Puce, 2014). The ERP approach provides important information about the time course of neural responses related to particular events of interest. However, ERPs as a result of averaging over a larger number of trials only reflect phase-locked activity and do not usually represent changes in oscillatory EEG activity that are event-related yet non-phase-locked (Bastiaansen, Mazaheri, & Jensen, 2012). A common technique to examine EEG activity in both time and frequency domains is the event-related spectral perturbation (ERSP; Makeig, Debener, Onton, & Delorme, 2004), which reflects changes in mean power across the EEG frequency spectra relative to baseline that are associated with stimulus presentation or response execution. Power changes in different EEG frequency bands have been described in numerous tasks and conditions, including those related to various social cognitive processes. For instance, modulations of oscillatory EEG activity in the alpha (mu) and beta ranges have been associated with processing of biological motion (Zarka et al., 2014; Oberman, Pineda, & Ramachandran, 2007; Järveläinen, Schürmann, & Hari, 2004), social interactions with virtual characters (Knyazev, Slobodskoj-Plusnin, Bocharov, & Pylkova, 2013), discrimination of emotional expressions and familiarity in faces (Güntekin & Basar, 2007), as well as with observation of actions performed by racial in-group versus out-group members (Gutsell & Inzlicht, 2010).

Several issues remain unclear regarding the role of group membership in the neural correlates of nonverbal perception and impression formation. First, much of the prior work examining the neural correlates of in-group/out-group processing has largely used static pictures depicting faces in isolation, particularly in the context of social categorization. In real-life situations, however, inference of others' mental states is oftentimes based on more comprehensive evaluations of nonverbal behaviors through both facial and bodily expressions (Katsumi et al., 2017; Van den Stock, Hortensius, Sinke, Goebel, & de Gelder, 2015; Dolcos et al., 2012). Second, although a few previous studies have identified dissociable neural responses associated with observing dynamic gestures displayed by in-group versus out-group members (e.g., Gutsell & Inzlicht, 2010), these studies often lacked a well-defined social context in which these cues were embedded and processed by the perceiver. Clarification of these issues is important to reach a better understanding of the neural correlates of in-group versus out-group processing with increased ecological validity.

In our recent investigation using functional MRI, we examined the neural mechanisms associated with the role of racial group membership in observing and evaluating nonverbal social encounters (Katsumi & Dolcos, 2018). Specifically, we found that observing racial in-group members displaying dynamic body language indicating positive intentions (i.e., "approach behavior") was associated with increased activity in the medial pFC, which in turn was associated with the more positive evaluations of in-group approach behavior (Katsumi & Dolcos, 2018). Moreover, compared with out-group approach behavior, evaluating in-group approach behavior was also associated with longer RTs, possibly suggesting increased attention and interest devoted to processing such information (Im et al., 2017; Brown, Bradley, & Lang, 2006). However, because of the sluggish temporal resolution of hemodynamic responses, it remains unclear how fast the neural responses associated with such in-group bias might be detectable during the observation of social encounters and how they might influence subsequent evaluations of such encounters. To address this issue, the current study utilized EEG techniques to clarify the neural mechanisms associated with observing social encounters with racial in-group and out-group avatar characters displaying different types of whole-body nonverbal behaviors. By capitalizing on brain imaging tools with high temporal resolution, this study sought to characterize neural indices of complex social-cognitive processes as they unfold over time while perceivers view social encounters.

Based on previous studies using similar experimental paradigms (Katsumi & Dolcos, 2018; Katsumi et al., 2017; Dolcos et al., 2012), this study aimed to clarify the neurobehavioral indices of observing racial in-group and out-group social encounters, focusing on both ERP responses and oscillatory EEG activity, and their relations to behavioral evaluations of such encounters. Informed by the available evidence reviewed above, we tested the following hypotheses. First, regarding the behavioral effects, (1) we expected to replicate the positive impact of approach behavior on the evaluation of social encounters (Katsumi et al., 2017; Dolcos et al., 2012), as well as the in-group bias as indexed by differences in RTs linked to the evaluation of social encounters involving in-group members displaying approach behavior (Katsumi & Dolcos, 2018). Regarding the ERP effects, (2) we expected to observe modulations of ERP components linked to earlier attentional and/or later evaluative processes, such as N200, N400/N450, and LP (Hehman et al., 2014; Amoruso et al., 2013; Ito & Bartholow, 2009; Proverbio et al., 2009), at the onset of different events during social encounters. In particular, given available evidence identifying modulations of N200 and N400/N450 in the context of social categorization (Hehman et al., 2014; Dickter & Bartholow, 2007), we expected that modulations of these ERP components would be observed at the beginning of social encounters. Moreover, given the sensitivity of LP to dynamic versus static actions (Orlandi et al., 2017; Proverbio et al., 2009),

modulation of the LP effect was expected at the onset of more elaborated nonverbal cues displayed during social encounters. In addition, we also explored the possibility that (3) oscillatory EEG activity would be modulated by the observation of social encounters involving different types of behavior, particularly within the alpha and beta ranges previously linked to action observation (Zarka et al., 2014; Gutsell & Inzlicht, 2010; Oberman et al., 2007; Järveläinen et al., 2004). Finally, we also explored the possibility that (4) behavioral in-group bias would modulate ERP/ERSP responses linked to observing different events within social encounters. Specifically, participants who exhibit stronger in-group bias behaviorally might also show greater differentiation between in-group versus out-group processing at the neural level, as previously reported (Molenberghs, Halász, Mattingley, Vanman, & Cunnington, 2013; Gutsell & Inzlicht, 2010; Ito, Thompson, & Cacioppo, 2004).

METHODS

Participants

Forty-seven young adults (M_{age} = 20.93 years, SD_{age} = 3.69 years; 24 women) participated in the study. Sample size was determined using an independent sample based on a desired power of .8 and an alpha of .05 to ensure sufficient statistical power for analyses of basic effects as well as those of participant subgroups (see also Katsumi et al., 2017). All participants were native English speakers, identified their race as white, and had no history of neurological or psychiatric disorders. The experimental protocol was approved by the University of Illinois institutional review board, and all participants provided written informed consent and received either course credit or payment for their participation. Data from five participants (three women, two men) were excluded due to technical issues related to EEG and/or behavioral data acquisition, leaving the final sample of 42 participants (21 women) for data analyses.

Experimental Design

Stimuli in this study were identical to those used in the previous investigations employing similar experimental paradigms (Katsumi & Dolcos, 2018; Katsumi et al., 2017), which were generated in Poser 7.0 (poser.smithmicro.com/poser.html) and presented using the CIGAL software (Voyvodic, 1999). The task consisted of a series of 10-sec whole-body animated movies illustrating nonverbal guest–host interactions in a business setting (Figure 1). Participants viewed the guest being greeted by a host (social interaction condition) or a cardboard cutout of a host (control/no social interaction condition). In the social interaction condition, the host displayed nonverbal behaviors that either encouraged (approach condition) or discouraged (avoidance condition) further social interaction. Specifically, the hosts in the approach condition stepped toward the guest while displaying open postures and

Figure 1. Diagram of the task. EEG data were recorded while participants viewed movies of guest–host interactions, in which hosts displayed dynamic nonverbal behaviors that either encourage (approach: open posture, smiling face; top row) or discourage (avoidance: closed posture, frowning face; middle row) further social interaction. A control/no social interaction condition, in which the host characters were replaced with a cardboard cutout depicting their whole body, was also included (bottom row). All trials were followed by participants' ratings of the host characters on competence as business representatives and their own interest in doing business with them. Time (in milliseconds) denoted in parentheses above specifies the onset of each event relative to that of each movie. Figure adapted from Katsumi and Dolcos (2018).
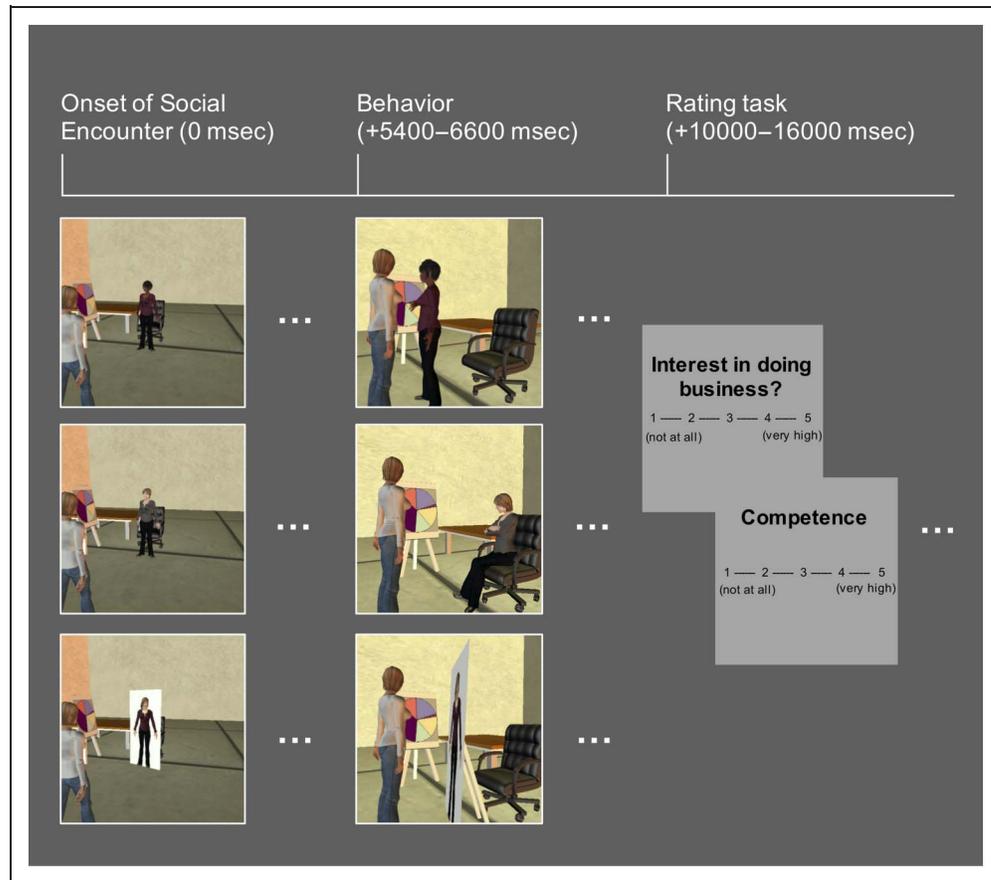
smiling faces, whereas the hosts in the avoidance condition stepped away from the guest while displaying closed postures and frowning faces (Sung et al., 2011). Within each condition, in half of the trials, social interaction was preceded by a handshake initiated by the host as part of the greeting protocol, and the order of trials with and without a handshake was counterbalanced across participants. The manipulation of handshake was only included to maintain consistency with prior studies and hence will not be the focus of this report. In the control/no social interaction condition, the host was depicted on a cardboard cutout, thus mimicking real-life contexts in which the human presence is replaced by similar cardboard images (e.g., of popular people or an organization's employees, such as those posted in stores or banks). It should be noted that there were no overall differences in the objective motion between the social interaction and control condition movies nor within the dynamic (approach vs. avoidance) conditions. This was due to the fact that movies in the control/no social interaction condition involved increased panning, which seemingly contributed to changes in luminance as much as biological motion observed in the dynamic conditions (see also Dolcos et al., 2012).

Host race was manipulated following previous studies using similar procedures (Krämer et al., 2013; Stepanova & Strube, 2009) by applying unique facial characteristics and skin tones representing particular racial groups. In-

group hosts represented white individuals, whereas outgroup hosts represented three non-white racial/ethnic groups: East Asian, South Asian, and black, in proportions similar to the representation of these racial/ethnic groups in the local student population (i.e., 50% white, 18.75% East Asian, 18.75% South Asian, 12.5% black). Host race was validated by an independent sample of participants ($n = 115$), who rated the host's race in each movie using 10-point scales (1 = *Definitely not white*, 10 = *Definitely white*). These participants provided their ratings of host race after they had completed the main evaluation task to avoid task contamination. Results of this validation showed that in-group/white stimuli were significantly more likely to be perceived as white ($M = 8.51, SD = 1.13$) compared with out-group/non-white stimuli ($M = 3.10, SD = 1.25; p < .001$), thus confirming our successful manipulation of hosts' race.

In-group and out-group hosts consisted of equal proportions of female and male characters. Guest gender was also manipulated to have equal proportions of female and male characters, which also allowed manipulation of perspective taking in observing social encounters (Dolcos et al., 2012). This manipulation was also not the focus of the present investigation, and thus, all analyses reported herein were performed without considering this manipulation. Each movie was followed by rating screens, which prompted participants to provide the following ratings, using 5-point scales (1 = *Not at all*, 5 = *Very high*): business competence of the

host ("Competence") and their own interest in doing business with the host ("Interest in doing business"). Each rating screen was displayed for 2 sec, and the order of the ratings was counterbalanced across trials. Both the ratings and the associated RTs were recorded.

Procedure

Upon providing written informed consent, participants were seated in front of a standard LCD monitor where all stimuli were presented during the task. Participants were told that the study examined the effect of first impressions formed in brief social interactions on the subsequent decision to further engage in business relations. Participants were instructed to use the whole rating scale and to give their ratings based on the observed social encounters, as well as to make their responses as quickly and accurately as possible using a computer keyboard. Participants completed eight runs of 20 trials each for a total of 160 trials and were assigned different run orders. Following our previous investigations (Katsumi & Dolcos, 2018; Katsumi et al., 2017), there were 128 trials in the approach and avoidance conditions (64 in each) and 32 in the control condition, consisting of equal numbers of in-group and out-group trials. The trials within each run were pseudorandomized, so that no more than three trials of the same kind were presented consecutively.

Behavioral Data Analysis

Behavioral ratings and RTs were analyzed by a series of repeated-measures ANOVA using the following variables as factors: Behavior (approach, avoidance, control) and Host Race (in-group, out-group).

EEG Data Acquisition, Preprocessing, and Analysis

EEG data were recorded for the entire duration of the task at a sampling rate of 2048 Hz using a 64-channel electrode cap, as well as three EOG electrodes, with a BioSemi ActiveTwo System and the ActiView software (BioSemi BV). EOG channels were located at the outer canthi of the left and right eyes and below the right eye. Data were processed using the EEGLAB software package (Delorme & Makeig, 2004) and the SASICA toolbox (Chaumon, Bishop, & Busch, 2015). First, the EEG data were imported to EEGLAB in which they were preprocessed by re-referencing to Fz (Nolan, Whelan, & Reilly, 2010; subsequently average-referenced before data analyses—see below), down-sampling to 256 Hz, low-pass finite impulse response filtering at 30 Hz, high-pass finite impulse response filtering at 0.1 Hz, and epoching each trial using a window of 1000 msec pretrial onset to 17,000 msec posttrial onset. Importantly, EEG data were segmented into 17,000 msec epochs only for data cleaning purposes (to retain all events of each trial; Urigüen & Garcia-Zapirain, 2015; Jung et al., 2000). Analyses of ERPs

and ERSPs were performed on much shorter data segments as typically done in other ERP/ERSP studies (see below).

Second, artifact rejection and correction were performed based on multiple criteria in the following order: (1) Noisy EEG channels were rejected using a normalized kurtosis criterion of three standard deviations; (2) noisy epochs were removed using extreme value criteria of ±500 μV for any EEG channel, followed by probability criteria of six standard deviations for single channels and two standard deviations for all EEG channels; (3) independent component analysis was used to decompose the EEG channel data, and SASICA was used to semi-automatically identify and remove independent components capturing artifacts based on statistical properties of these components as well as visual confirmation. Specifically, the following measures were examined to identify artifactual independent components: autocorrelation (with a lag threshold of 20 msec), focal topography, correlation with vertical and horizontal EOG signals, spatial and temporal signal features likely attributable to eye blinks (high temporal kurtosis, larger absolute mean inverse weights at frontal than posterior electrodes, the same sign on left/right portions of the electrode cap, and higher signal variance at frontal than posterior scalp regions; Mognon, Jovicich, Bruzzone, & Buiatti, 2011) as well as spatial kurtosis, power spectrum slope, the Hurst exponent, and the median gradient of component time courses (with a threshold of three standard deviations; Nolan et al., 2010). The components identified as artifactual were subsequently visually inspected following the guidelines described in Chaumon et al. (2015). Notably, such an artifact rejection/correction procedure involving examination of various data features was particularly desirable in the current experimental design in which each data epoch contained multiple events of interest. It is possible that data cleaning based on stricter and/or fewer criteria leads to loss of epochs in which not all events are affected by artifacts. Across participants, the average number of channels rejected (and subsequently interpolated) was 6.83 (SD = 2.09), whereas the average rate of epochs rejected was 7.76% (SD = 5.81), which is consistent with the recommended range (Delorme, Sejnowski, & Makeig, 2007).

Third, following previous studies examining nonverbal social cognition targeting similar ERP components (e.g., Bailey & Kelly, 2017; Kröger et al., 2014; Schmitz, Scheel, Rigon, Gross, & Blechert, 2012; Wangelin, Bradley, Kastner, & Lang, 2012; Righart & de Gelder, 2008), the data were re-referenced to an average reference, and the reference selected during data import to EEGLAB (Fz) was added back to the data. Rejected channels were then interpolated. Finally, epochs for each event of interest were extracted for each participant and entered into an EEGLAB STUDY for group-level analyses. In the present report, we focused our analyses on EEG data time-locked to the beginning of social encounters and nonverbal behaviors displayed by the host. At the onset of social

encounters, EEG data were segmented into 2200-msec epochs, with a 1000-msec prestimulus window (with the baseline defined from −1000 to −500 msec) and a 1200-msec poststimulus window. At the onset of behavior, EEG data were segmented into 1700-msec epochs, with a 500-msec prestimulus baseline and a 1200-msec poststimulus window.

ERP Analysis

ERPs were identified at peak electrode locations based on visual inspection of the scalp topography within time windows around each event of interest. This procedure identified possible modulations of N450 (450–550 msec poststimulus) at the onset of social encounters over frontal sites (F1, F2) and of the LP (300–1100 msec poststimulus) at the onset of behavior over central sites (Cz). We focused on the frontal and central electrode sites given available evidence identified in previous studies of action observation (Orlandi et al., 2017; Amoruso et al., 2013; Proverbio et al., 2009). For each ERP component, a repeated-measures ANOVA was performed on the mean amplitude with the following factors as independent variables: Behavior (approach, avoidance, or control at the onset of behavior; social interaction or control/no social interaction at the onset of social encounters) and Host Race (in-group, out-group). Post hoc t tests were performed to further examine significant ANOVA effects. The alpha level was set at $p < .05$ for all random-effects analyses of ERPs.

ERSP Analysis

Time–frequency decomposition of the EEG data was performed in EEGLAB to compare ERSPs between the experimental conditions of interest. This analysis focused on the onset of social encounters and of the behavior displayed by the host. Specifically, data epochs were 2200 msec in length (1000 msec prestimulus, 1200 msec poststimulus) relative to the onset of each event. These 2200-msec epochs were convolved with Morlet wavelets to generate a time–frequency spectrogram over a time span of −790 to 991 msec. The present analysis focused on a frequency window from 8 to 30 Hz, given available evidence identifying modulations of EEG oscillations in the alpha (8–15 Hz) and beta (16–30 Hz) range by social information (Zarka et al., 2014; Knyazev et al., 2013; Güntekin & Basar, 2007; Oberman et al., 2007). The decomposition included three cycles at the lowest frequency and increased by a factor of 0.5–5.625 at the highest frequency, with a sliding window length of 418 msec. For each condition, an ERSP image was generated to show mean changes in spectral power (in dB) for alpha and beta bands relative to the baseline period from −790 to −504 msec preceding the stimulus onset (Hanslmayr et al., 2011). Statistical analyses were conducted using paired-sample t tests and ANOVAs to examine differences in ERSP at the onset of social encounters

and behavior, respectively. To correct for multiple comparisons across a large number of time and frequency points, results were thresholded at $p < .05$ corrected for the false discovery rate (Benjamini & Hochberg, 1995). Upon identification of significant ANOVA effects on ERSPs, post hoc t tests were performed targeting only the area of the spectrogram showing these omnibus effects.

Analysis of the Effect of In-group Bias on ERPs/ERSPs

Upon identification of racial in-group bias based on differences in RTs (see Behavioral Results section below), a possible role of in-group bias in modulating ERP/ERSP effects was also explored. Specifically, we employed a median split to categorize participants into either a high- or low-bias group, depending on whether their mean RT differences for evaluating business interest for racial in-group versus out-group approach behaviors were slower or faster than the median RT at the whole-sample level, respectively. This procedure yielded two subgroups with an equal number of participants. Analyses of differences between participant subgroups have been reported in previous investigations from our group using similar experimental paradigms (based on comparable sample sizes; Katsumi et al., 2017) as well as by others (e.g., Hehman et al., 2014; Molenberghs et al., 2013; Shin & Bartholow, 2013). Importantly, the two bias groups in the present sample did not significantly differ in the distribution of sex, $\chi^2(1) = 0.095, p = .758$; age, $t(40) = 0.77, p = .443$; and the number of trials/epochs included in data analyses, $t(40) = 0.88, p = .384$, thus suggesting that the observed differences are not driven by individual variations in these variables. Furthermore, to assess the specificity of the observed effects to differences in racial in-groups, we performed the same analyses of behavioral and ERP data but by defining in-groups versus out-groups based on the congruency between the sex of participants and that of the host avatars.

The effect of in-group bias on ERPs/ERSPs was then examined at two levels. First, for each dependent variable of interest (i.e., N450, LP, beta power), a Behavior × Host Race × Bias Group (high vs. low) mixed ANOVA was performed to investigate the extent to which in-group bias modulates these neural responses. Second, a series of correlation analyses were performed between ERP/ERSPs and behavioral measures (ratings, RTs) separately for the high- versus low-bias groups to examine whether the link between neural and behavioral responses to particular events was differentially modulated by the degree of in-group bias. Given that the LP effect was observed during a wider time window from 300 to 1100 msec at the basic level (see Figure 4), we additionally examined the LP effect by extracting the mean amplitude from a more focused window from ~850 to 900 msec, which was informed by an independent analysis of ERSPs identifying significant differences between approach and avoidance behaviors within the beta range (see Figure 7).

RESULTS

Behavioral Results

Descriptive statistics of the ratings and RTs across conditions and participant subgroups are summarized in Table 1. First, we predicted that approach behavior would have a positive impact on the evaluation of social encounters in general (Katsumi & Dolcos, 2018; Dolcos et al., 2012) and would also be related to behavioral in-group bias as manifest in RTs in particular (Katsumi & Dolcos, 2018). Our behavioral results confirmed this hypothesis. Specifically, a Behavior × Host Race ANOVA yielded a significant main effect of Behavior: $F(2, 82) = 130.07$, $p < .001$, $\eta_p^2 = .760$. Overall, the mean competence and interest ratings combined were highest for social encounters involving approach behavior display of the host ($M = 3.63$, $SD = 0.51$), followed by avoidance behavior ($M = 2.66$, $SD = 0.55$), and then by the control condition ($M = 1.79$, $SD = 0.64$; all $ts > 7.25$, $ps < .001$). In addition, regarding the interest ratings, results also confirmed a significant interaction between Behavior × Host Race in RTs for the interest ratings: $F(2, 82) = 23.43$, $p < .001$, $\eta_p^2 = .364$. This interaction effect was driven in particular by significantly slower RTs associated with the interest ratings for the in-group approach compared with out-group approach condition, $t(41) = 7.20$, $p < .001$. RTs for the in-group control condition were also faster than those for the out-group control condition, $t(41) = 2.74$, $p = .009$, whereas RTs for the in-group and out-group avoidance conditions did not significantly differ, $t(41) = 0.29$, $p = .773$. Within the in-group conditions, RTs associated with the interest ratings for the approach condition were significantly slower than those for the avoidance and control conditions ($ts > 5.85$, $ps < .001$). Importantly, such differences in RTs by group membership were not observed when in-groups and out-groups were defined based on the match between participants' and hosts' sex, suggesting that these effects are specific to evaluating racial in-group versus out-group members. Taken together, these findings provide support to the previous findings regarding the positive impact of approach behavior on the evaluation of social encounters. Moreover, the current results are also consistent with evidence regarding racial

Table 1. Descriptive Statistics for the Behavioral Ratings and RTs: Means (SDs)

	Approach		Avoidance		Control	
	InG	OutG	InG	OutG	InG	OutG
Interest Ratings						
High-bias group (n = 21)	3.41 (0.60)	3.51 (0.62)	2.56 (0.56)	2.56 (0.58)	1.74 (0.57)	1.88 (0.66)
Low-bias group (n = 21)	3.54 (0.53)	3.61 (0.57)	2.45 (0.63)	2.49 (0.63)	1.69 (0.69)	1.77 (0.66)
Competence Ratings						
High-bias group (n = 21)	3.71 (0.55)	3.82 (0.48)	2.88 (0.49)	2.91 (0.52)	1.83 (0.69)	1.86 (0.71)
Low-bias group (n = 21)	3.67 (0.47)	3.75 (0.46)	2.68 (0.62)	2.73 (0.62)	1.80 (0.67)	1.74 (0.70)
Interests RTs						
High-bias group (n = 21)	1128.88 (160.61)	954.59 (153.07)	969.88 (188.07)	973.36 (196.35)	950.34 (46.42)	998.39 (206.88)
Low-bias group (n = 21)	1099.88 (269.83)	1064.06 (256.00)	1035.16 (266.33)	1039.16 (255.37)	1012.35 (253.55)	1086.28 (303.94)
Competence RTs						
High-bias group (n = 21)	943.95 (154.37)	950.91 (124.34)	982.47 (168.80)	964.61 (148.52)	935.89 (251.76)	939.53 (208.83)
Low-bias group (n = 21)	979.85 (269.16)	1017.54 (92.00)	1038.53 (233.01)	1049.56 (271.09)	970.31 (264.29)	958.54 (270.62)

InG = In-group; OutG = Out-group.

in-group bias in the context of business interactions, particularly driven by RT differences between in-group and out-group members displaying approach behavior. This suggests that longer RTs for in-group than out-group approach behaviors may reflect greater interest in evaluating in-group members conveying positive intentions.

ERP Results (1): Basic and Bias-related Effects on N450 Responses at the Onset of Social Encounters

Second, we predicted that modulations of ERP components such as N200 and N400/N450 related to social categorization would be observed at the onset of social encounters, whereas those of LP would be observed at the onset of more elaborated nonverbal cues during social encounters. Partially confirming this hypothesis, ERP analysis identified a set of ERP components whose amplitude was modulated at the onsets of different events of interest: an N450 effect at the onset of social encounters and an LP effect at the onset of the host's behavior. Of note, further confirming our hypothesis that these ERP components are modulated by in-group bias, our results showed both effects of basic manipulations and of the degree of behavioral in-group bias as determined by RTs, thus also confirming our fourth hypothesis. These effects are reported in turn below.

Basic Effects of Social Encounters on N450

A Behavior × Host Race ANOVA targeting ERPs at the onset of social encounters showed a significant main effect of Behavior, $F(1, 41) = 6.93$, $p = .012$, $\eta_p^2 = .352$. Specifically, the average N450 amplitude over frontal sites in response to observing the beginning of social encounters involving a cardboard display of the host ($M = -5.08$, $SD = 3.86$) was significantly greater than in response to observing the beginning of social encounters involving the actual host ($M = -4.12$, $SD = 2.58$; Figure 2). No other significant effects were identified from this ANOVA.

Effects of In-group Bias on N450

A Behavior × Host Race × Bias Group ANOVA identified a significant main effect of Bias Group, $F(1, 40) = 5.72$, $p = .022$, $\eta_p^2 = .125$, but no significant interaction effects involving this factor. Overall, the mean N450 amplitude was significantly larger (more negative) in the high-bias ($M = -4.21$, $SD = 2.46$) than in the low-bias groups ($M = -2.53$, $SD = 2.06$). Notably, although an interaction between Behavior × Bias Group was not statistically significant, a comparison of the mean N450 amplitude between control and social interaction conditions within each bias group revealed that the N450 effect was present in the high-bias group, $t(20) = 2.68, p = .011$, but not in the low-bias group ($t[20] = 0.89, p = .383$; Figure 3). Consistent with this ANOVA effect, brain–behavior correlation analyses revealed that behavioral in-group bias (i.e., difference in RTs between in-group vs. out-group approach behaviors) was overall negatively associated with the mean N450 amplitude for both control, $r(40) = -.299, p = .054$, and social interaction, $r(40) = -.388, p = .011$, conditions.
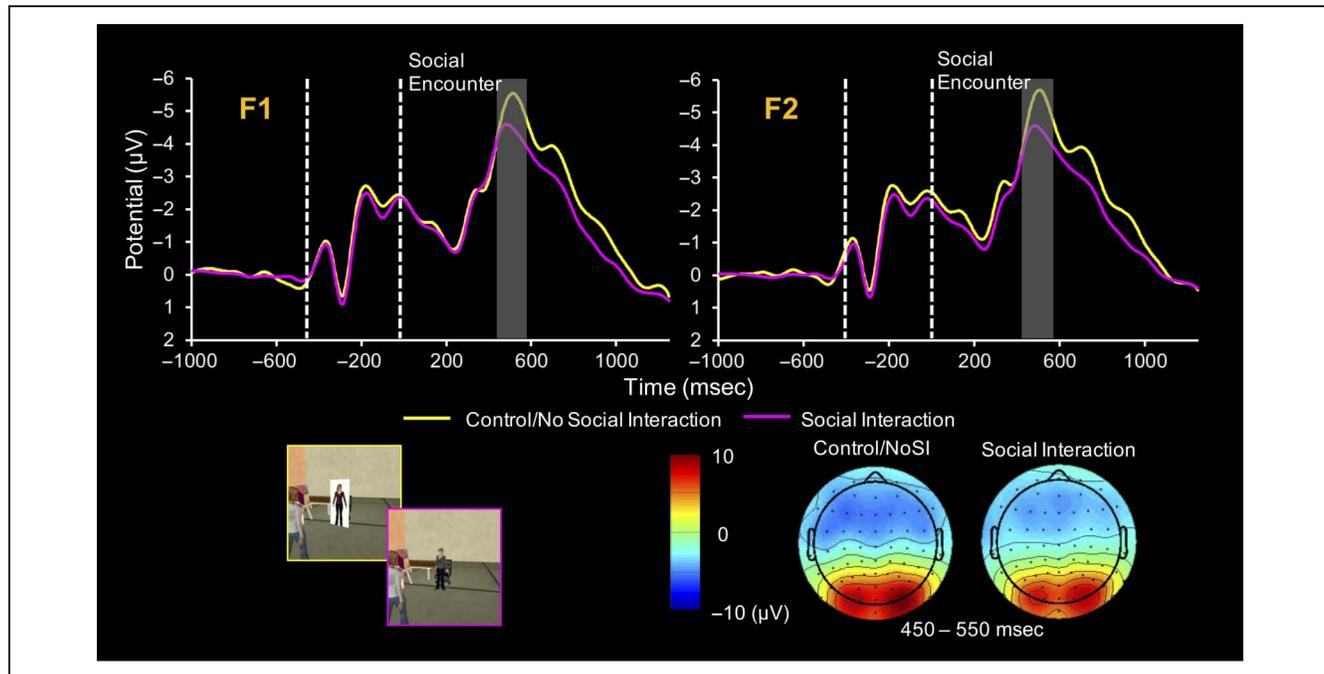
Figure 2. N450 responses linked to observing the beginning of social encounters. ERP results showed greater N450 responses for observing social encounters involving a cardboard display of the host compared with those involving the actual host, at frontal electrode sites and within a time window of 450–550 msec poststimulus (shaded in gray). The dashed lines indicate the beginning of the trials and the onset of social encounters, respectively; see also the Methods section. The data were down-sampled with a resampling factor of 15 for display purposes.
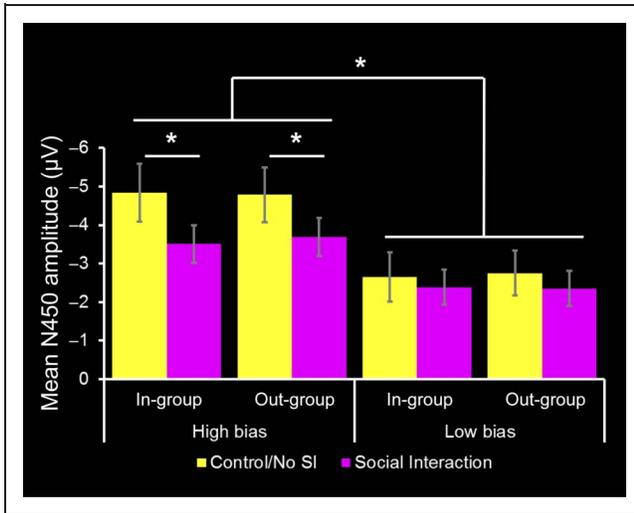
Figure 3. Effect of in-group bias on the N450 amplitude. Comparisons of the mean N450 amplitude between participants with relatively high- versus low in-group bias (as defined by differences in RTs for evaluating in-group vs. out-group approach behaviors) revealed that differences in N450 responses observed for social encounters involving cardboard versus dynamic displays of the host were uniquely significant in the former group. Error bars denote the *SEM*. *p < .05.

Similar to the behavioral results, these significant effects of in-group bias were identified only when the high- versus low-bias groups were defined on the basis of race and not of sex.

ERP Results (2): Basic and Bias-related Effects on LP Responses at the Onset of Nonverbal Behaviors Displayed by the Host

Basic Effects of Host Behavior on LP

A Behavior × Host Race ANOVA targeting ERPs at the onset of behavior showed a significant main effect of Behavior, $F(2, 80) = 22.25$, $p < .001$, $\eta_p^2 = .381$. Specifically, consistent with prior work on biological motion and action observation (Proverbio et al., 2009), the average LP amplitude over central electrode sites in response to observing approach ($M = 1.77$, $SD = 2.10$) and avoidance behaviors ($M = 1.51$, $SD = 2.25$) were significantly greater than in response to observing the control condition ($M = -0.26$, $SD = 1.63$): approach versus control: $t(41) = 5.46$, $p < .001$; avoidance versus control: $t(41) = 4.22$, $p < .001$ (Figure 4). Although the mean LP amplitude did not significantly differ between observing approach and avoidance behaviors at a general level, $t(41) = 0.82$, $p = .209$, the mean LP amplitude was significantly greater for observing approach ($M = 1.70$, $SD = 2.11$) than avoidance behaviors ($M = 1.22$, $SD = 1.83$) within the in-group condition, $t(41) = 2.06$, $p = .046$, whereas the corresponding difference was not significant within the out-group condition, $t(41) = 0.58$, $p = .566$.

Effects of In-group Bias on LP

A Behavior × Host Race × Bias Group ANOVA did not reveal a significant main effect of Bias Group, $F(1, 40) = 1.89$,
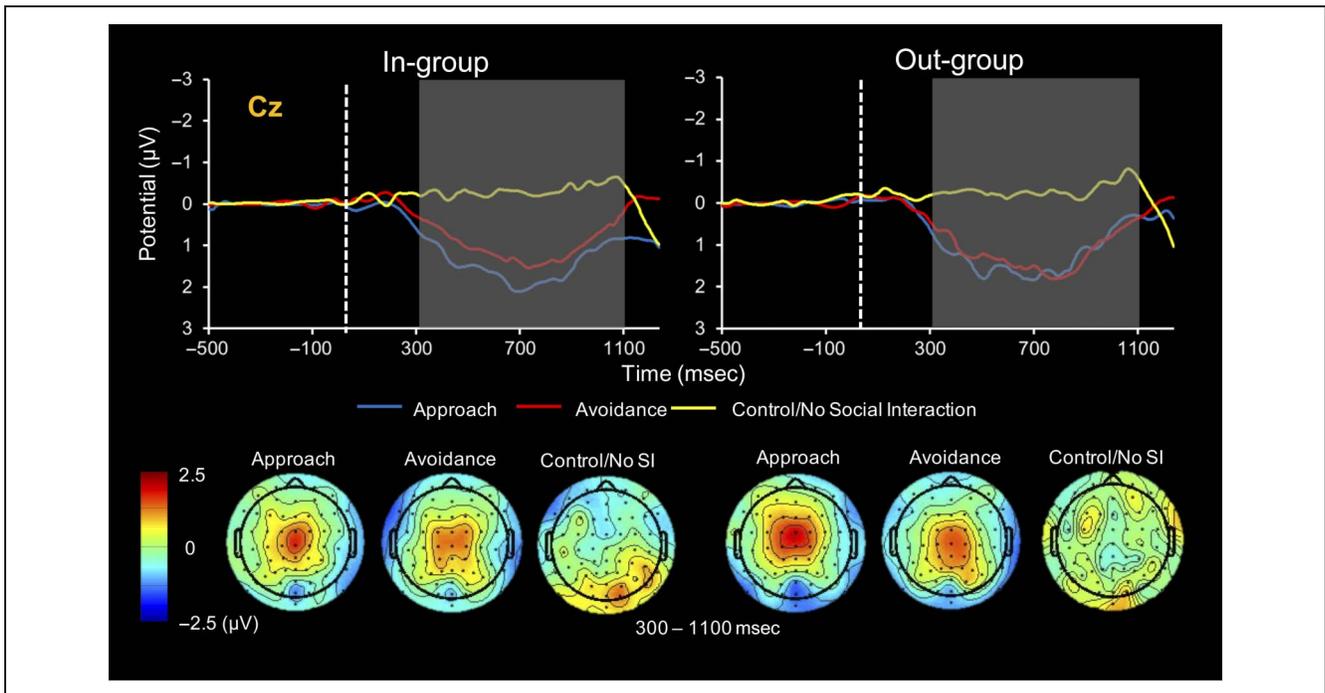
Figure 4. LP responses linked to observing nonverbal behaviors displayed by the host. ERP results showed greater LP responses for observing dynamic nonverbal behaviors displayed by in-group and out-group hosts compared with the control condition, at central electrode sites and within a time window of 300–1100 msec poststimulus (shaded in gray). The dashed line indicates the onset of approach and avoidance behaviors displayed by the host and of the control condition in the movies. The data were down-sampled with a resampling factor of 15 for display purposes.

Figure 5. Effect of in-group bias on the LP amplitude. Differences in the mean LP amplitude between the in-group approach and control conditions were positively associated with the interest ratings for the in-group approach condition. Interestingly, this pattern of correlation was observed only among the high-bias group evaluating in-group members. The LP amplitude was extracted from a window (~850–900 msec), where significant differences in beta power were observed between approach and avoidance behaviors (Figure 7, bottom right).
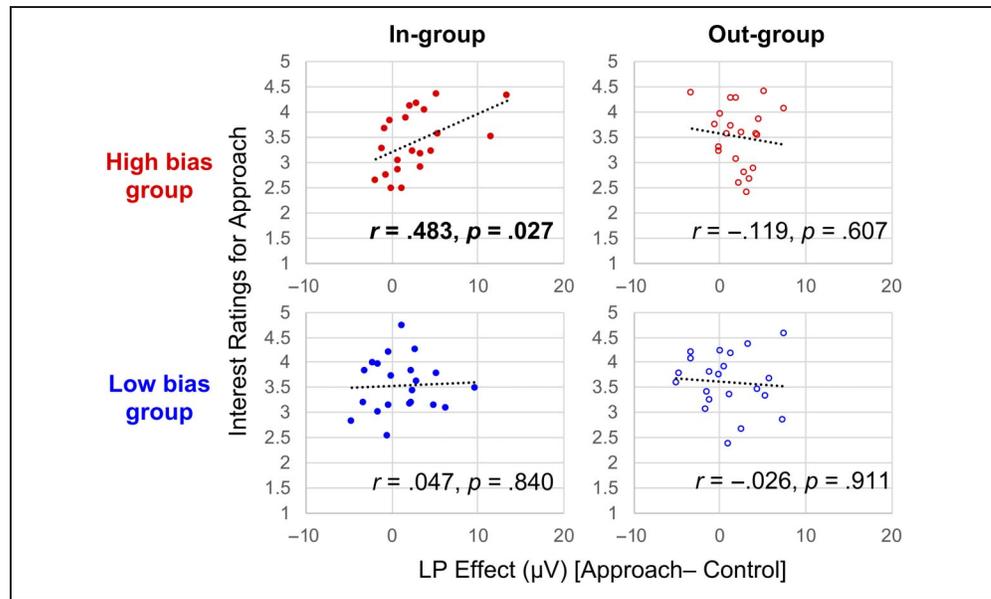
$p = .177$, $\eta_p^2 = .045$, nor any significant interaction effects involving this factor. However, brain–behavior correlation analyses identified a significant relation between the LP amplitude and behavioral ratings, which was unique to the high-bias group evaluating in-group members. Specifically, in the high-bias group, differences in the LP amplitude between the in-group approach versus control conditions were positively associated with the interest ratings for in-group members displaying approach behavior, $r(19) = .483$, $p = .027$. That is, those participants who showed greater LP responses to observing in-group approach behavior also subsequently rated in-group members displaying such behavior more positively. However, this link between LP and behavior was not identified with respect to the evaluation of out-group members or in the low-bias group (Figure 5).

ERP Results (3): Link between N450 and LP Responses

To clarify possible associations between the N450 and LP effects (at the onset of social encounters and social behaviors, respectively) linked to in-group biases, correlation analyses were performed across all participants. For each participant and for each ERP component, the difference in the mean amplitude between social interaction and control conditions was first calculated separately for in-group and out-group trials. These analyses identified a significant negative relation between the N450 and LP responses for in-group trials, $r(40) = -.361$, $p = .018$, but not for out-group trials, $r(40) = -.050$, $p = .753$ (Figure 6). That is, those participants who showed greater N450 response to a cardboard display of the in-group host at the beginning of social encounters subsequently showed attenuated LP response linked to the observation of dynamic nonverbal behaviors displayed by the in-group host.

Taken together, these ERP results demonstrate that ERP components such as N450 and LP are modulated by different types of social information, with the former showing initial sensitivity to human presence at the beginning of social encounters and the latter showing sensitivity to processing different types of nonverbal behaviors displayed by the host. Furthermore, the current results also suggest that

Figure 6. Correlations between N450 and LP amplitudes. Across participants, the amplitude of N450 (difference between the social interaction and control conditions) measured at the onset of social encounters was negatively associated with that of LP (difference between the social interaction and control conditions) measured at the onset of the host's behavior. This relation was observed uniquely in in-group trials.
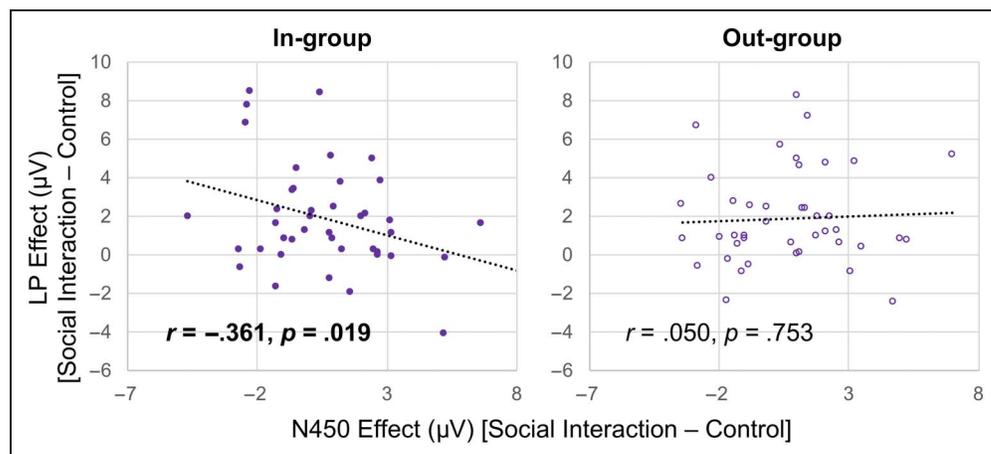
behavioral in-group bias defined based on RT differences significantly modulates neural responses detectable earlier in time during the observation of social encounters.

ERSP Results: Basic and Bias-related Effects on Alpha and Beta Power at the Onset of Nonverbal Behaviors Displayed by the Host

Regarding ERSP results, we explored the possibility that oscillatory EEG activity would be modulated by the observation of social encounters involving different types of behavior. Consistent with this idea, analyses of oscillatory EEG activity revealed significant modulations of alpha and beta power linked to the observation of dynamic nonverbal behaviors. Importantly, similar to our ERP results, beta power was also influenced by the degree of behavioral in-group bias, thus providing support to our fourth hypothesis.

Basic Effects of Host Behavior on Beta/Alpha Power

At the onset of social encounters, a paired-sample *t* test comparing ERSPs between the social interaction versus control conditions did not reveal significant differences. At the onset of behavior, a one-way ANOVA identified

significant differences in ERSPs within the beta range (~15–25 Hz) as well as in the alpha range (~8–15 Hz) linked to observing different types of behavior displayed by the host. Post hoc *t* tests revealed that observing approach and avoidance behaviors were associated with greater suppression in the beta frequency range from ~700 to 990 msec poststimulus compared with the control condition. Interestingly, beta suppression was also greater for observing approach than avoidance behaviors at ~850 msec poststimulus (Figure 7). Moreover, there was also greater alpha power for observing dynamic nonverbal behaviors compared with the control host display from 0 to ~250 msec poststimulus.

Effects of In-group Bias on Beta Power

Finally, to examine the effect of in-group bias on beta power, the mean ERSP value was computed for each condition in each group within the area of the spectrogram showing a main effect of behavior at ~15–25 Hz from 700 to 990 msec (see Figure 7, bottom). A Behavior × Host Race × Bias Group ANOVA on mean beta power did not reveal a significant main effect of Bias Group, $F(1, 40) = 0.20$, $p = .660$, $\eta_p^2 = .005$, nor any significant interaction effects involving this factor. However, similar to the LP
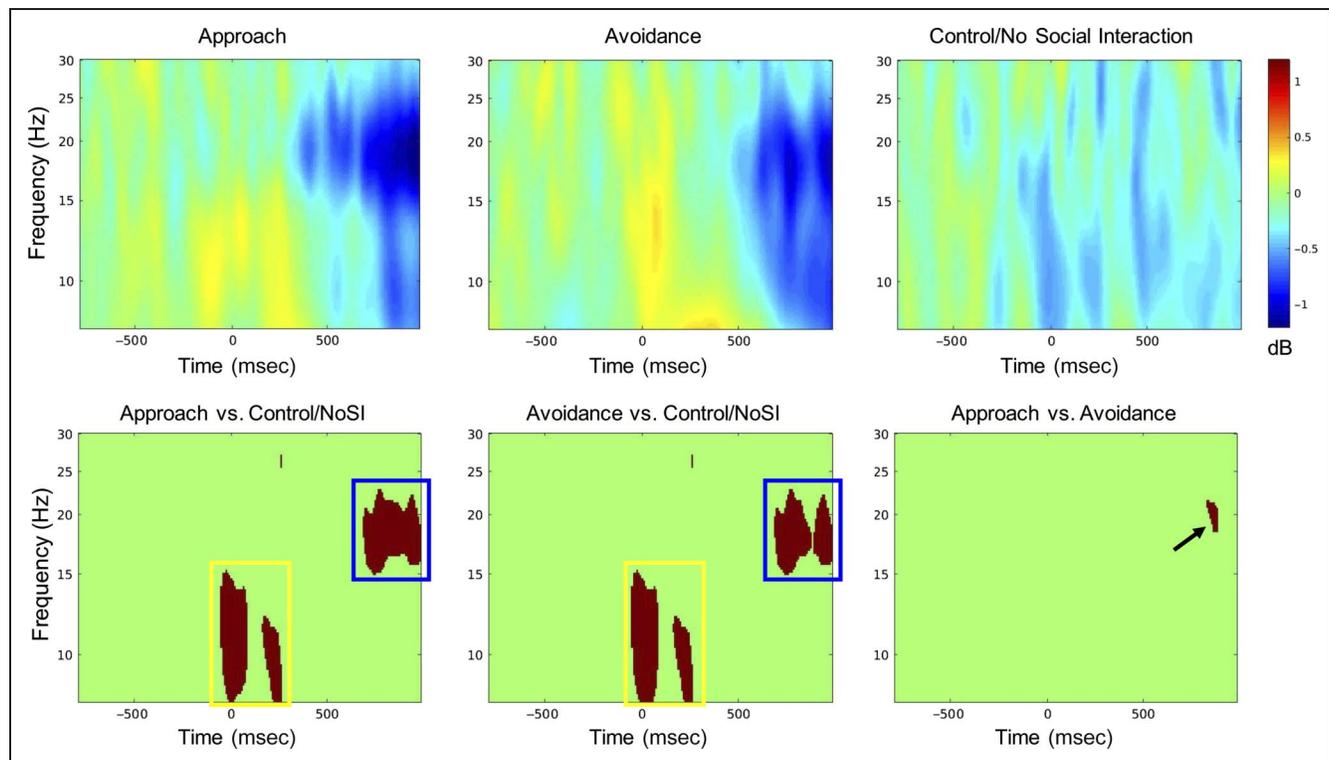
Figure 7. Differential alpha and beta power by observing nonverbal behaviors. Observing dynamic approach and avoidance behaviors displayed by the host was associated with suppression of beta power (at 700–990 msec; blue rectangles) and a transient increase in alpha power (at 0–250 msec; yellow rectangles) compared with the control condition. Additionally, greater suppression of beta power was also observed for observing approach compared with avoidance behaviors at ~850 msec poststimulus (black arrow). The dark red areas in the spectrogram in the bottom row represent significant pairwise differences between the experimental conditions (uncorrected $p < .05$, two-tailed), which also showed a significant main effect of behavior in a one-way ANOVA (FDR-corrected $p < .05$).

Figure 8. Effect of in-group bias on beta power. Differences in mean beta power between the in-group approach and control conditions were positively associated with RTs for evaluating the interest ratings for the approach condition. Interestingly, this pattern of correlation was significantly observed only among the high-bias group evaluating in-group members.
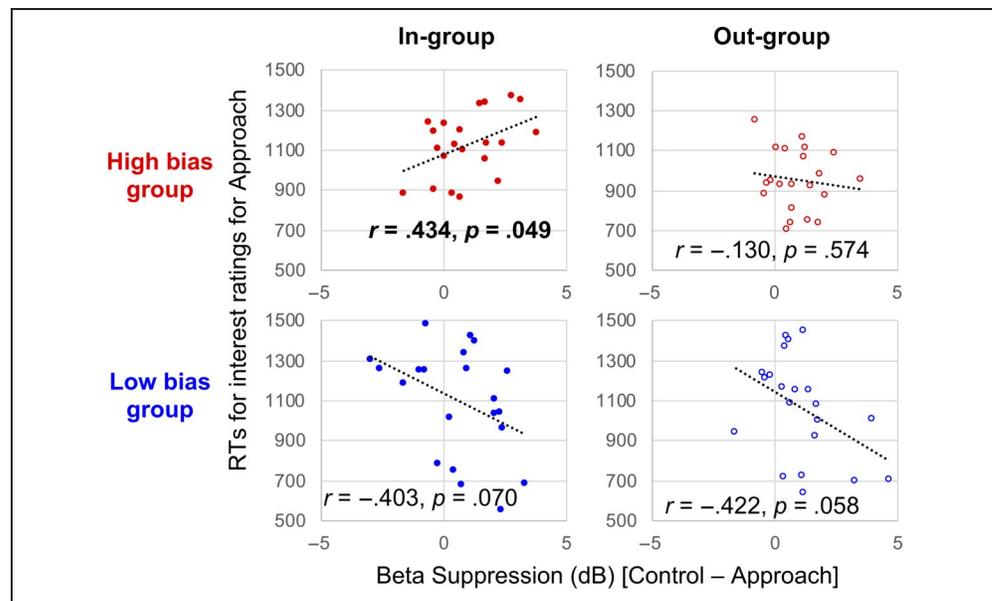
effect above, brain–behavior correlation analyses identified a significant relationship between beta power and RTs, which was unique to the high-bias group evaluating in-group members. Specifically, in the high-bias group, differences in beta power between the in-group approach versus control conditions were positively associated with RTs associated with evaluating the interest ratings for in-group members displaying approach behavior, $r(19) = .434$, $p = .049$. Namely, those participants who showed greater suppression of beta power linked to observing in-group approach behavior also subsequently showed slower RTs for evaluating in-group members displaying such behavior. However, this link between beta power and behavior was not identified with respect to the evaluation of out-group members or in the low-bias group (Figure 8).

Overall, these findings show that observation of dynamic nonverbal behaviors is associated with changes in oscillatory EEG activity in the alpha and beta band ranges. Beta power at the onset of approach behavior displayed by in-group members also seems to be associated with the subsequent evaluation of social encounters involving such behavior.

DISCUSSION

Using EEG/ERP techniques, this study sheds light on the temporal dynamics of the neural mechanisms associated with the observation and evaluation of nonverbal social encounters with racial in-group and out-group members. Complementing the previous study examining similar issues using fMRI (Katsumi & Dolcos, 2018), the present results extend the available evidence by demonstrating how group membership influences processing of various social cues presented at different points in time during social encounters and how it affects subsequent

evaluations of these encounters. The main findings will be discussed in turn below.

Behavioral Results

Our behavioral results replicated previous findings using similar experimental paradigms (Katsumi & Dolcos, 2018; Katsumi et al., 2017; Dolcos et al., 2012) and identified the positive impact of approach behavior on ratings, in general, and of in-group approach behavior on RTs, in particular. Consistent with the available evidence, observation of expressive dynamic gestures signaling approaching intentions was associated with higher ratings of business competence and interest compared with those signaling avoidance intentions. This result confirms the powerful role of subtle nonverbal cues in affecting evaluative judgments in a business setting. Also consistent with our previous finding (Katsumi & Dolcos, 2018), we identified significant differences in RTs for evaluating social encounters with in-group versus out-group members, which were driven by longer RTs for in-group than out-group approach behaviors. Longer RTs for in-group than out-group approach behaviors may reflect greater interest in in-group members seemingly conveying positive intentions. This is consistent with previous evidence showing that participants spent more time viewing pictures of racial in-group than out-group members displaying pleasant intentions, whereas they did not show such difference by group membership in viewing unpleasant pictures (Brown et al., 2006). The same behavioral analysis based on categorizing in-group versus out-group members by sex did not reveal significant effects. This suggests that the observed in-group bias defined on the basis of RT differences in the evaluation of approach behavior is specific to racial characteristics and not another social category. Importantly, as discussed below, both behavioral ratings and RTs showed covariation

with electrophysiological measures linked to the observation of different nonverbal behaviors across participants. This suggests that racial in-group bias in nonverbal perception and evaluation also manifests as a function of individual variation in neural responses.

Effects on N450 Responses at the Onset of Social Encounters

Basic Effects of Social Encounters on N450

ERP analysis identified modulation of N450 responses at the onset of social encounters, with larger N450 amplitudes associated with the observation of encounters involving a cardboard representation of the host compared with the actual host. In the linguistic domain, the N400 has been established as a robust electrophysiological marker of semantic processing, the amplitude of which is typically sensitive to semantic congruity, expectancy, and word frequency, among others (reviewed in Kutas & Federmeier, 2011). However, emerging evidence suggests that modulation of N400/N450 responses can be identified in a variety of task contexts, including those involving the observation of action-related stimuli (most typically over frontal electrode sites; Amoruso et al., 2013). For instance, previous studies using video clips of people engaging in everyday activities found that observing actions with semantically anomalous endings (e.g., combing one's hair with a toothbrush) elicited greater N400-like responses compared with observing actions with anticipated endings (Reid & Striano, 2008; see also Wu & Coulson, 2005). This evidence has led to the idea that the N400/N450 effect observed in the context of action-related paradigms might reflect difficulty in understanding others' behavior in a given context or in integrating the incoming social information with the perceiver's previous knowledge (Proverbio & Riva, 2009).

These findings raise the possibility that the N450 effect observed in this study reflects participants' expectation and preference for the host's behavior in business interactions. Based on their previous experience, people might expect by default and hence prefer business encounters involving interactions with the "real" host. Seeing a cardboard representation of the host at the beginning of social encounters, therefore, might deviate from this a priori expectation, possibly resulting in larger N450 responses. This view is also supported by our behavioral results identifying the lowest ratings of business competence and interest for the control condition involving a cardboard display of the host, suggesting that the absence of dynamic body language confers the most negative impact on impression formation, possibly due to the violation of expectation regarding business interactions.

Intriguingly, there is also evidence suggesting a link between LP responses and social expectancy violation (Van Duynslaeger et al., 2007; Bartholow et al., 2001, 2003; Osterhout et al., 1997). In this study, however, no modulation of LP-like components was identified at the onset of social encounters. Available evidence suggests that LP/P300 and N400/N450 might be sensitive to different types of expectancy violations in social contexts. Specifically, LP/P300 has been more closely linked to evaluative incongruence (e.g., a mismatch between the valence of a category and a subsequent target stimulus), whereas N400/N450 has been associated with an increased effort in integrating inconsistent behaviors with one's person schema (Baetens, Van der Cruyssen, Achtziger, Vandekerckhove, & Van Overwalle, 2011; Herring, Taylor, White, & Crites, 2011). Therefore, it is possible that the current experimental design tapped more into the latter type of expectancy violation, resulting in the modulation of N450 responses. More research is needed to further our understanding of the type of violations or conditions that modulates LP/P300 versus N400/N450.

Effects of In-group Bias on N450

This study identified evidence demonstrating that behavioral racial in-group bias based on differences in RTs for evaluating approach behaviors is associated with modulation of ERPs occurring earlier in time during the observation of social encounters. Regarding the N450, differential N450 responses between the control/no social interaction and social interaction conditions were driven uniquely by those participants who exhibited greater in-group bias. The link between N400/N450 and behavior has been identified in previous studies of social cognition. For instance, greater N400 responses elicited by stereotypically incongruent versus congruent information about black individuals was correlated with more negative explicit attitudes toward them (Hehman et al., 2014). In addition, greater frontal N400 reactivity elicited in the context of a social norm violation task was related to higher scores on attitudinal measures associated with the strength of social norms (Mu, Kitayama, Han, & Gelfand, 2015). Significant differences in the N450 amplitude only in the high-bias group suggest that those participants who exhibit greater racial in-group bias might also show stronger expectations and preferences about social encounters at a more general level. This idea is supported by available evidence showing that indices of in-group favoritism (e.g., racial, ethnic) are significantly associated with concerns over the adherence to and maintenance of social norms in general (Lewis & Bates, 2014; Sibley & Duckitt, 2008).

Effects on LP Responses at the Onset of Nonverbal Behaviors Displayed by the Host

Basic Effects of Host Behavior on LP

At the onset of the host's behavior, ERP analysis identified modulation of sustained LP responses peaking at ~750 msec poststimulus over central electrode sites, with

larger LP amplitudes associated with the observation of dynamic (approach and avoidance) behaviors compared with a cardboard display of the host. This is overall consistent with previous ERP studies identifying differences in the amplitude of LP in similar time windows between dynamic and static displays of facial/bodily expressions (Orlandi et al., 2017; Recio, Sommer, & Schacht, 2011; Proverbio et al., 2009). For instance, greater LP responses were identified while viewing pictorial stimuli depicting dynamic versus static human actions, possibly reflecting an increased effort to process visual kinematic information (Proverbio et al., 2009). Using EEG source reconstruction techniques, these authors identified as possible generators of this LP effect several regions that are part of the action observation network, including the lateral temporo-occipital cortices (extrastriate body area, extending into the STS, fusiform gyrus), (pre)motor cortex, cingulate gyrus, and lateral pFC. Indeed, many of these regions were also identified as showing significantly greater activity for observing dynamic nonverbal behaviors versus a cardboard display of the host (Katsumi & Dolcos, 2018). Therefore, one possibility is that greater LP responses identified in the current study are associated with increased involvement of the action observation network while processing dynamic nonverbal behaviors during social encounters.

In the context of overall similar LP responses linked to the observation of in-group and out-group social encounters, our ERP analysis also identified significant differences in the LP amplitude in observing approach versus avoidance behaviors displayed by in-group but not out-group members. This suggests that not only does the magnitude of LP responses reflect processing of dynamic nonverbal behaviors in general, but it also might be a neural marker of in-group bias during action observation by showing sensitivity to the valence of such behaviors. Of note, this effect is also consistent with the present behavioral results identifying significantly slower RTs associated with the interest ratings for approach than for avoidance behavior displayed by in-group hosts, whereas RTs did not differentiate within the out-group conditions.

Effects of In-group Bias on LP

Greater LP responses for observing approach behavior (compared with a cardboard display of the host) were associated with the more positive evaluation of interest for such behavior, but only within the high-bias group evaluating in-group members. Overall, this is consistent with the results of brain–behavior covariation analyses we reported in our previous investigation with similar experimental designs (Katsumi & Dolcos, 2018), in which activity in the medial pFC for observing in-group approach behavior (compared with a cardboard host display/control condition) was positively associated with the interest ratings for this condition. Similar to the N450,

previous studies have shown that the amplitude of positive deflections observed over similar scalp locations and time windows during a picture evaluation task was associated with subjective ratings of arousal (Cuthbert et al., 2000). Furthermore, other studies examining LP responses during face processing tasks have revealed that the LP amplitude for observing racial in-group faces was positively associated with scores on an explicit measure of racial prejudice (Ito et al., 2004). The present results are overall consistent with these findings regarding the role of this ERP component in processing of socioemotional stimuli and further provide evidence for the LP's sensitivity to in-group approach behavior.

Link between N450 and LP Responses

Follow-up correlation analyses revealed that, although observed at different points in time during social encounters, the amplitudes of the two ERP components discussed thus far (N450 and LP) were significantly associated with one another, uniquely in the context of social encounters with in-group members. Specifically, our results revealed that those participants who showed greater N450 response to a cardboard display of the in-group host at the beginning of social encounters subsequently showed attenuated LP response while observing dynamic nonverbal behaviors displayed by the in-group host. When observing social encounters, particularly those with unknown others, the perceiver needs to continuously process and keep track of incoming information to accurately infer the target's intentions. In this context, integration of social information acquired at different points in time might have a facilitating effect on subsequent processing and evaluations of the target/host. Therefore, one possibility is that the significant relationship between N450 and LP amplitudes uniquely identified with respect to in-group processing in this study indexes the involvement of interactive mechanisms that facilitate processing of social information.

Consistent with this idea, available evidence on the neural mechanisms of action observation points to the existence of a distinct network of brain regions subserving these processes. Previous studies of action-related N400/N450 using source reconstruction techniques have identified the potential origins of these ERP components in regions including the superior temporal (BA 20/BA 21), lateral parietal (BA 39), cingulate, and premotor areas (BA 6), among others (Proverbio, Riva, & Zani, 2010; van Elk, van Schie, & Bekkering, 2010). Notably, these regions partially overlap with those identified as the possible generators of the LP effect linked to observation of dynamic actions, as discussed above (Proverbio et al., 2009). These results are also overall consistent with available fMRI evidence also identifying the role of these regions in action observation (Yang, Rosenblau, Keifer, & Pelphrey, 2015; Van Overwalle & Baetens, 2009). One possibility is that the significant relation between N450 and LP responses reflects the continuous engagement of a broader

neural system subserving ongoing monitoring of others' actions, potentially relevant for inferring their intentions. Interestingly, neural in-group bias has been previously observed as modulation of activity in this action observation network (Katsumi & Dolcos, 2018; Molenberghs et al., 2013). The present results extend this evidence by identifying similar effects of group membership on electrophysiological responses associated with observing social encounters. Future studies should further examine the link between these ERP components by employing experimental designs better suited for other analyses (e.g., intraparticipant correlation), which can provide evidence complementary to the interparticipant analysis as carried out in the present work (Bridwell et al., 2018).

Effects on Alpha and Beta Power at the Onset of Nonverbal Behaviors Displayed by the Host

Basic Effects of Host Behavior on Beta/Alpha Power

Complementing the LP effect discussed above, ERSP analysis identified significant modulations of oscillatory EEG activity associated with the observation of approach and avoidance behaviors relative to a cardboard display of the host. Specifically, observing dynamic nonverbal behaviors was associated with greater suppression of power in the beta range from ~700 to 990 msec poststimulus over central electrode sites. This result is overall consistent with previous studies identifying similar changes in beta power during the observation of simple everyday actions such as hand movements and walking (Pozzo et al., 2017; Zarka et al., 2014; Darvas, Rao, & Murias, 2013). Available evidence suggests that the attenuation of EEG activity in the alpha and beta ranges during action observation may reflect increased activity within the sensorimotor cortices (reviewed in Cheyne, 2013; Pineda, 2005). Therefore, one possibility is that beta suppression identified during the observation of dynamic behaviors is associated with greater sensorimotor representations (thus enhanced processing) of such behaviors displayed by the host during social interactions.

In addition, suppression of beta power at ~20 Hz was greater for observing approach than for avoidance behaviors, although this effect was confined to a much smaller area within the time–frequency space. Previous fMRI investigations of social cognition found that regions such as the posterior STS and amygdala showed increased activity when observing social interactions involving approach/ affiliative behaviors than to those involving avoidant ones (Dolcos et al., 2012; Kujala, Carlson, & Hari, 2012). The current results expand this evidence and demonstrate that suppression of beta power over central sites might be a neural marker sensitive not only to dynamic gestures in general but also to specific nonverbal cues conveying positive intentions. This finding also builds upon existing evidence and shows that beta suppression is associated with the observation of complex nonverbal cues displayed in a defined social context.

Furthermore, this study also identified a transient increase in alpha power (~8–15 Hz) for observing dynamic nonverbal behaviors compared with a cardboard display of the host. Similar patterns of power changes in the alpha band have been reported in recent studies of action observation (Aridan, Ossmy, Buaron, Reznik, & Mukamel, 2018; Girges, Wright, Spencer, & O'Brien, 2014; Zarka et al., 2014). These differences were characterized by greater alpha power for upright versus inverted facial motion (Girges et al., 2014) or normal versus uncoordinated body movements (Zarka et al., 2014). Therefore, one possibility is that transient changes in alpha power index the extent to which a certain stimulus to be processed is expected (and thus preferred) in a given context. This view is consistent with the interpretation of the N450 effect discussed earlier, where significant differences were also observed between the control/no social interaction versus social interaction conditions.

Effects of In-group Bias on Beta Power

Similar to the LP effect, greater beta suppression for observing approach behavior was found to be associated with longer RTs for evaluating the interest for such behavior, but only within the high-bias group evaluating in-group members. As with ERPs, indices of beta suppression over central electrode sites during action observation and execution have been shown to predict the accuracy of mental inference based on faces and bodies (Perry et al., 2017). Extending this evidence, the current results demonstrate that suppression of oscillatory EEG activity within the beta frequency range is reliably associated with the behavioral evaluation of social encounters, but specifically among those with high in-group bias evaluating in-group approach behaviors. To the extent that beta suppression might index greater sensorimotor representations of the observed actions (Cheyne, 2013), one possibility is that observing in-group members' behavior conveying positive intentions involves direct encoding at the neural level to a greater degree, which exerts stronger influences on evaluative judgments.

Critically, the present findings have implications for gaining better understanding of the factors relevant for successful interactions with individuals from diverse social backgrounds. Our results demonstrate that greater behavioral in-group bias is associated with enhanced modulations of electrophysiological activity linked to observing different nonverbal cues earlier during social encounters. This suggests that observation of subtle nonverbal behaviors exerts rapid and powerful influences over subsequent social decision-making processes, and this effect is particularly pronounced among individuals favoring their racial in-group members in their evaluations. One key factor, then, for successful social interaction might be to accurately infer and understand others' intentions through nonverbal communication in context, without being biased by group membership. For instance,

when interacting with individuals from different cultures (i.e., cultural out-group members), deviations in nonverbal expressions relative to what is most typically expected from one's own culture (e.g., the absence of a handshake or bow when interacting with members of Western or East Asian cultures, respectively) might lead him or her to interpret them as a sign of disrespect, displeasure, or distrust. In this context, it is important to be aware that rules for nonverbal expressions may vary considerably from one culture to another (Matsumoto & Hwang, 2012; Safdar et al., 2009; Matsumoto, 2006). Therefore, successfully understanding others' intentions in interracial, cultural, or ethnic interactions require knowledge of variations in nonverbal communication and the flexibility to interpret the meaning of nonverbal behaviors in different social contexts, without relying heavily on schemas shaped by previous in-group interactions. By better understanding the neural mechanisms associated with group bias in nonverbal perception and evaluation, we can use these indices as targets for novel neurobehavioral training or intervention programs to reduce unwanted bias toward or against particular social groups (Molenberghs & Louis, 2018).

Limitations

The following limitations associated with this study should be acknowledged. First, increased ecological validity allowed by our dynamic stimuli, similar in length to those employed in previous EEG studies (e.g., Gutsell & Inzlicht, 2010, 2012), can also come at a cost, because observing continuous social encounters for several seconds can increase the likelihood of artifacts related to eye movements and other muscle activity. It is important to note, however, that this study used independent component analysis to extract and remove artifacts from the data by identifying EEG activity associated with EOG signal, muscle activity, and bad channels based on its spatial and temporal features (Chaumon et al., 2015; Mognon et al., 2011; Nolan et al., 2010). Therefore, it is unlikely that significant differences observed between the experimental conditions and groups in the current study were driven by signal artifacts. Nevertheless, future studies should try to minimize the source of such artifacts.

Second, because our dynamic movie stimuli depicted social encounters involving multiple events occurring one after another, some conditions (e.g., control) had relatively smaller numbers of trials. This was necessary to limit the length of the experiment and to have the overall task structure consistent with that of our previous fMRI investigation (Katsumi & Dolcos, 2018), which facilitated comparison and integration of results across studies. Although these numbers are consistent with guidelines from the ERP literature (e.g., Rietdijk, Franken, & Thurik, 2014; Moran, Jendrusina, & Moser, 2013) and with previous ERP studies of social interaction (e.g., Leng, Zhu,

Ge, Qian, & Zhang, 2018), it is ideal to employ larger number of trials to increase power and ensure replicability.

Third, although the racial in-group bias as determined by RT differences was significantly related to ERP/ERSP responses observed in this study, it is not clear from the current data whether different indices of in-group favoritism would show similar associations. Notably, our analyses defining in-groups versus out-groups on the basis of sex did not yield significant effects as observed in our main analysis, suggesting that these effects are specific to evaluating racial in-group versus out-group members. Future work should further examine the potential role of in-group bias in various domains (e.g., at the trait level; Lewis & Bates, 2010) to clarify the extent to which neural responses might be modulated by in-group bias observed in specific social contexts versus at a more general level. In addition, although justified by our power analyses based on an independent sample (Katsumi et al., 2017), results of our brain–behavior correlations based on participant subgroups should be interpreted with caution given their exploratory nature in relatively small (sub)samples (Yarkoni, 2009). It is also important to note that the current sample had relatively homogeneous demographic characteristics, consisting of college-aged healthy young adults residing in the midwestern United States. Therefore, it remains unclear to what extent the present findings regarding racial in-group bias would be similarly observed in different racial, cultural, ethnic, or age groups. To address these important issues, future research should aim to replicate the between-group effects identified in this study with larger and more demographically diverse samples. Finally, although our analytical approach is consistent with those of the previous investigations examining similar issues, it has been suggested that multilevel modeling approaches might confer advantages over traditional ANOVA for analyzing psychophysiological data (Volpert-Esmond, Merkle, Levsen, Ito, & Bartholow, 2018; Martin, Karcher, Bartholow, Siegle, & Kerns, 2017; Kristjansson, Kircher, & Webb, 2007). Therefore, it would be of interest for future studies to consider employing such techniques, which might help identify meaningful effects based on similar experimental designs with possibly increased statistical power.

Conclusions

Collectively, the present investigation makes novel contributions to the literatures on electrophysiological correlates of nonverbal social cognition and group processes. Extending the available evidence, this study sheds light on the temporal dynamics of neural mechanisms associated with the observation and evaluation of social encounters in a defined social context. Replicating previous behavioral findings, this study identified evidence for in-group bias driven by the evaluation of in-group approach behavior. ERP results showed that ERP components typically implicated in social cognition (N450 and LP) were

sensitive to nonverbal behaviors displayed by the host and to participants' in-group bias. Specifically, social encounters involving a cardboard host display was associated with larger N450 responses compared with those involving dynamic behaviors displayed by the host, possibly related to participants' unfulfilled expectations about typical social encounters. Observing dynamic nonverbal behaviors was also associated with greater LP responses and suppression of beta oscillations compared with control stimuli, thus suggesting increased engagement of sensorimotor activity while viewing social encounters involving display of nonverbal behaviors. Of note, these neural responses showed modulations by the degree of racial in-group bias, thus demonstrating a link between behavioral group bias and neural sensitivity to various social cues during social encounters. These findings advance our understanding of the neural mechanisms associated with observing and evaluating nonverbal social cues by pointing to detectable temporal indices linked to real-time processing of social information and by showing how such processes are modulated by racial in-group bias. This novel evidence has important implications for clarifying the temporal dynamics of information processing in social interactions, particularly in the context of encounters with individuals from diverse racial backgrounds.

Acknowledgments

Note

1. It is important to note that, in the domain of emotion processing, this ERP component is commonly referred to as the late positive potential, which has been associated with processing of motivationally significant stimuli such as emotionally arousing pictures (Hajcak, MacNamara, & Olvet, 2010; Dolcos & Cabeza, 2002; Cuthbert, Schupp, Bradley, Birbaumer, &

Lang, 2000; Schupp et al., 2000). However, to keep consistency with previous studies examining social cognition (e.g., the Proverbio studies cited above), we will refer to this ERP component as the LP in this report.

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