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Exploring the neuropsychological basis of behavioral contagion during learning about another agent's social preferences: Evidence from an ERP study

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Social contagion is a pervasive phenomenon and an important social influence that involves the rapid dissemination (propagation) of behaviors, attitudes, emotions, or ideas from one person to another, often without conscious reflection or rational thought. This phenomenon is closely related to conformity, by which a person changes his/her original ideas and attitude and imitates certain behavior of others. Although some behavioral research has been carried out on contagion and conformity, there is very little neuropsychological understanding of these phenomena. Existing research on social influence and conformity has predominantly focused on tasks like mental rotation or rating tasks involving facial expressions, with fewer studies exploring risk preferences and temporal discounting. However, there is a notable gap in the literature when it comes to examining social influence and conformity using other-regarding preference models derived from heterodox economics. To address this research gap, the present study investigates the neuropsychological underpinnings of social contagion by utilizing event-related potentials (ERPs) recorded while subjects engage in mini-dictator games. The behavioral analysis revealed that contagion had an impact on the participants' preferences, leading to a change in their choices. We observed a P300 component in the midline and right posterior during the time window of 200-350 ms after stimulus onset, which showed a significant increase in mean amplitude when participants observed others' behavior, compared to when they made decisions based on their own preferences. Moreover, the lack of late positive potential in the time window of 500-650 ms suggests that the presence of P300 may indicate difficulty in making decisions. In summary, by analyzing both behavioral and ERP data, this study may provide a more comprehensive understanding of the cognitive and neural processes that drive conformity and contagion behavior. Our analysis has the potential to inform policymakers in developing effective interventions for promoting positive social behaviors and reducing negative ones.

Key words: contagion, Fehr-Schmidt model, dictator game, event-related potentials, decision difficulty, P300

INTRODUCTION

Gaining a comprehensive understanding of how people behave, and make decisions within a society is a highly complex process. The social phenomena emerging within human societies can be described as non-linear, dynamic, unpredictable, and multi-dimensional (Richardson & Marsh, 2014). The COVID-19 pandemic is a prime example of how human societies are embedded within complex systems, and how individuals face complex situations. To identify appropriate solutions to such complex issues, interdisciplinary approaches, and collaboration among researchers from various disciplines are essential. Social influence is an example of such complexity as our decision-making processes are heavily shaped by social interaction, which is an integral part of our daily lives. Conformity and contagion are two types of social influence that promote the mim-

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icry of beliefs, feelings, values, and behaviors with the opinions of others, and as such, they play a significant role in shaping most social behaviors (Levy, 2008; Xie et al., 2016; Wang & Busemeyer, 2021; Zheng et al., 2021). People often make these forms of decisions when unsure about their choices or having doubts about which alternative to choose as well as to avoid potential sanctions for deviating from established norms (Carpenter, 2004). In fact, imitation extends beyond human beings and animals; it also manifests in the realm of medical science. Recent studies have revealed a fascinating phenomenon in the context of brain cancer cells, specifically glioblastoma. These malignant cells have demonstrated an exceptional ability to mimic normal brain cells, thereby conferring resistance to conventional therapeutic interventions (Kim et al., 2024).

Although throughout this paper, we use the terms 'conformity' and 'contagion' and even 'herding' interchangeably, it is important to note that, there exist both similarities and differences between these concepts. This interchangeable usage enables us to highlight the broader phenomenon of social influence, where individuals' behaviors and attitudes are shaped by the influence of others. Both conformity and contagion involve changes in a person's behavior as a result of external influences and are characterized by conflict (Weiß et al., 2024). However, contagion differs from conformity in that individuals initially experience internal conflict, which is reduced or resolved through the influence of others. In contrast, conformity begins with harmony, and external influence creates conflict that must be resolved by the conformer (Wheeler, 1996).

In this paper, it is crucial to address two key points. Firstly, it is important to highlight that social contagion is a dynamic process that can manifest through both direct interaction and observational learning which is rooted in Bandura's social learning theory. Secondly, a significant finding to consider is that individual differences have been consistently shown to predict the degree of social conformity, thereby shedding light on the heterogeneous nature of conformity among individuals (Klucharev et al., 2009; Campbell-Meiklejohn et al., 2010; Nook & Zaki, 2015; Nook et al., 2016; Kim et al., 2021). Overall, conformity and social contagion are interconnected social processes influencing human behavior and decision-making.

Various social and economic situations encountered in daily life can be classified as conformity behavior, such as engaging in healthy habits like going to the gym or having a healthy diet (Nook & Zaki, 2015), political voting, and fashion trends (Xie et al., 2016). Prosocial behavior, such as generosity, cooperation, and donation, is more likely to be emulated among peers (Dimant, 2019; Yu et al., 2021). Similarly, individuals' likelihood of performing antisocial behavior, such as stealing, dishonesty, and cheating, may increase if they observe their peers acting in such a manner (Gino et al., 2009; Falk & Ichino, 2015; Dimant, 2019; Yu et al., 2021).

In the section that follows, we will briefly discuss some of the most relevant studies that deal with conformity from different perspectives.

Literature review and hypotheses formulation

Given the complexity of social influence, it is impossible for a single perspective to fully explain conformity behavior. Thus, researchers from various fields including psychology, sociology, anthropology, economics, and more recently neuroscience, have studied this phenomenon over the years, resulting in a multitude of perspectives and approaches to understanding conformity (Asch, 1951; Baumeister, 1982; Bond & Smith, 1996; Chein, Jansen, Korbee & Bruijn, 2019; Deutsch & Gerard, 1955; Duell, Hooen, McCormick, Prinstein & Telzar, 2021; Goeree & Yariv, 2015; Janes & Olson, 2000; Klucharev, Hytonen, Rijpkema, Smidts & Fernandez, 2009; Muzafer Sherif, 1935; Xu, Becker, Kendrick, 2019).

The history of the study dates back to 1759. In his book "Theory of Moral Sentiments, "Adam Smith, proposed that conformity could be described as "herding" behavior, which is considered as a type of "mechanical imitation" and a form of "unconscious social contagion" (Song et al., 2022). Sociologists in the nineteenth century were aware that social pressures may influence opinions, beliefs, and actions (Packer, 2012). "Social somnambulism" is the term used by psychologists like Gustave Le Bon and Gabriel Tarde to explain imitation as a collective hypnosis (Rook, 2006). Conformity research was extensively investigated between the 1930s and 1950s, and many experiments were conducted to demonstrate its importance. Psychologist Sherif (1935) conducted a classic study on conformity based on perceptual processes. He utilized the autokinetic optical illusion by asking group members to judge the illusory movement of a stationary projected image and determined whether it could influence the opinions of others. He found that in an ambiguous situation, a naive person conformed to the opinion of the confederates (stooges). Asch's (1952) 'Line Judgment Task' is another influential study that examines conformity. Participants were tasked with matching the length of a line segment to a comparison line. Asch's measurements showed that, in many cases, subjects showed conformity to obviously incorrect answers and followed the overruling majority. American sociologist Phillips (1974) studied imitative suicides and claimed that suicide rates generally increase when excessive suicidal behavior is observed only in the geographical region that receives media attention. This condition is known as the 'Werther effect'.

Early economists such as Thorstein Veblen, George Katona, and John Maynard Keynes pioneered the use of socio-psychological factors that drive human decision-making, especially in stock markets (Baddeley, 2017; Deldoost, 2022). Keynes used the term 'contagious animal spirits' to refer to the noneconomic motives of people's irrational behavior that can sway the markets. In his book 'The General Theory of Employment, Interest, and Money' (1936), he devoted substantial attention to the sociological and psychological forces of herding behavior that occur in times of uncertainty (Baddeley, 2010; Chen & Chen, 2020).

Traditionally, two types of conformity are recognized. The first is normative conformity, which is often less conscious (Baddeley, 2018). This type of conformity involves conforming to social norms in order to avoid sanctions for deviating from those norms (Carpenter, 2004).

The second type is informational conformity, which occurs when individuals leverage information acquired from others. This typically happens when a person lacks knowledge and seeks to align their beliefs with someone who possesses more accurate information, driven by the desire to be correct.

The rapid development of interdisciplinary research has led neuroscientists to focus on the neurobiological and neurochemical basis of social conformity. Neuroscience techniques such as EEG and ERP allow us to directly observe brain electrical activities and gain a more detailed understanding of the rapid changes in cognitive processes underlying conformity and contagion behavior. This provides a more objective and precise measurement, in contrast to traditional behavioral science methods that often rely on indirect measurements. For instance, Suzuki et al. (2016) used a model-based analysis of behavioral and fMRI data to demonstrate that contagion influences both behavioral and neural responses, and can alter individuals' risk preferences through observation and learning about another agent's behavior. Garvert et al. (2015) conducted an experiment to investigate the impact of learning about another agent's preferences on subjective intertemporal choice preferences. They found that, after observing and learning a partner's choices, subjects' own discount rate can be biased toward the partner's direction. The fMRI data showed that plasticity is caused by learning another's value in the medial prefrontal cortex. Additionally, plasticity predicts the extent to which one's preferences shift toward the behavior of others.

Time-locked EEG activity or ERP is an excellent method for observing sensory and cognitive processes by capturing the brain's electrical activities on the order of milliseconds. (Fabiani et al., 2000; Amodio et al., 2014; Xie et al., 2016). The most famous and commonly studied ERP waveforms that are associated with social and higher cognitive processes are the N200, P300 and LPP waveforms. In response to repetitive stimuli, the N200 deflection typically peaks around 200-350 ms after the stimulus onset (Folstein & Petten, 2008; Luck, 2012; Zhang et al., 2019). Some scholars have argued that the N200 is sensitive to effects related to cognitive conflict, error monitoring, and response inhibition, which are generated in the anterior cingulate cortex. Additionally, the amplitude of the N200 is positively correlated with levels of response conflict (Folstein & Petten, 2008; Nieuwenhuis & Yeung, 2003; Zhang et al., 2019). When we make decisions, the P300 waveform is induced. It is thought to reflect how we evaluate and categorize stimuli, and its amplitude is negatively correlated with the difficulty of decision-making (Cutmore & Muckert, 1998; Vallesi & Stuss, 2010). Chen et al. (2010a) used ERP to investigate how consumer herding behavior in online book buying is related to neural and psychological factors. Behavioral data showed that there is greater herding of decisions when customer reviews are consistent. A positive correlation was found between the herding rate and the amplitude of the LPP component, which is sensitive to the detection of categorical differences. Zhang et al. (2019) found that, compared to herding choices, anti-conformity choices caused an increased N2 amplitude (i.e., more negative), indicating that participants might have been experiencing more decision conflict. In contrast, herding choices enhanced the amplitude of the LPP component. This suggests that when subjects stay with the majority, they may have a greater sense of decision confidence and better evaluation categorization before making final decisions.

To the best of our knowledge, little is known about the comprehensive understanding of the neuropsychological mechanisms that underlie contagion and conformity in the existing literature. This research gap highlights the need to investigate the cognitive and neural processes involved. To date, the majority of experiments exploring into social influence and conformity have predominantly focused on tasks such as mental rotation or rating tasks (Berns et al., 2005; Shestakova et al., 2013; Simonsen et al., 2014; Chen et al., 2023) involving facial expressions, as well as on behavioral economics tasks like risk preferences or intertemporal choice (Garvert et al., 2015; Suzuki et al., 2016). However, there has been limited investigation into the effects of social influence and conformity using behavioral game experiments within neuroscience domains. Moreover, only a few studies have explored the application of other-regarding preference models derived from heterodox economics, where individuals' decisions not only impact their own payoffs but also influence the payoffs of others. Consequently, there is a notable gap in the literature regarding the examination of social influence and conformity through the lens of these heterodox economic models, which provide a more comprehensive understanding of social decision-making dynamics.

Additionally, a neuropsychological measure, event-related potentials (ERPs), is also employed to investigate the neural and cognitive bases of social influence and the role of imitation in humans. The findings of this study will fill a crucial gap in the literature, by shedding light on how individuals align their attitudes, and behaviors with others. Furthermore, this paper opens several avenues for future research, providing insights for designing effective strategies and interventions in fostering desirable social outcomes.

Hypotheses regarding behavior and event-related potentials

In this study, we explore both behavioral and neural mechanisms underpinning imitation and conformity, focusing on two extensively researched ERP components within the context of decision-making: the P300 and LPP. As manipulation may influence decision-making when subjects observe others' behavior, we hypothesize that when subjects observe the behavior of others, the degree of similarity between the subjects' behavior and the behavior of the observed will be greater after manipulation than before manipulation, indicating the occurrence of contagion (H1).

From an electrophysiological point of view, the presence of the P300 and LPP components may support decision-making theories such as categorization theory, while the absence of LPP may provide evidence for the conflict theory hypothesis. Previous research (Chen et al., 2010a) has shown that category similarities can enhance the amplitude of both the P300 and LPP components. Building on this finding, we propose the following hypothesis:

H2: Individuals who conform, similar to the effects of category similarities, will show higher LPP and P300 amplitudes compared to those who do not conform. This hypothesis is based on the theory that social conformity is associated with increased attention to social cues and heightened cognitive processing, which may be similar to the effects of category similarities on these brain components. If confirmed, this finding could provide further evidence for the notion that social conformity and category similarities may share similar neural mechanisms.

The amplitude of LPP or P300 is inversely related to the difficulty of decisions (Azizian et al., 2006; Chen et al., 2010a). This means that as the difficulty of a decision increases, the amplitude of LPP or P300 decreases. We can formulate the following hypothesis:

H3: Individuals who exhibit conformist behavior, similar to the effects of decision difficulty, will exhibit greater amplitudes of either P300 or LPP compared to those who do not conform.

This hypothesis is based on the theory that social conformity is associated with reduced decision-making effort and cognitive load. If confirmed, this finding would provide further evidence for the relationship between decision difficulty and brain activity, and extend our understanding of the neural mechanisms underlying social conformity.

METHODS

Participants

An a-priori power analysis was conducted using G*Power to determine the necessary sample size (Faul et al., 2009). In accordance with the literature (Clayson et al., 2019), which is commonly used in similar research designs to determine sample size, statistical power, and effect size, a minimum of 26 participants was required for a power of 0.80, with α set at 0.05, and an effect size of 0.6.

Thirty healthy students from SBU University voluntarily participated in this ERP experiment in a single one-hour session for a compensation of 100 K toman (approximately 5 dollars). The subjects ranged in age from 18 to 30 years (M age=25 years, SD=4.71). The informed consent forms were signed by all participants before the study began. They were all right-handed, had no history of nervous or mental diseases/psychiatric illness, and had no history of brain injuries. Additionally, they had normal vision and hearing. Due to excessive head and ocular movements during data acquisition, two participants were excluded from the analysis. As a result, the final sample comprised 28 participants (8 female). The experiment was carried out following the guidelines of Helsinki Declaration. The ethical aspects of the experiment were evaluated and approved by the ethical review board of the Institute for Cognitive Science Studies, with a reference number of IR.UT.IRICSS.REC.1400.34.

Prior to conducting the main experiment, a series of trial tests were performed to ensure a smooth and effective research process. These trial tests focused on clarifying instructions, refining buttons and questions, and ensuring their clarity for participants.

Materials

The entire experimental task consisted of three sessions or phases and was conducted under no time pressure conditions (Fig. 1A, 1B). The 66 trials of the binary mini-dictator games are displayed in Fig. 1C. The list of all mini-dictator games can be found in supplementary materials. In the first session, the subject acted as a dictator and was repeatedly asked to decide how to allocate a finite set of experimental currency (ECUs) between themselves and other person (Fig. 1D). This session is referred to as the self-trials session and is represented by orange. In the second session, participants only observed the proposals made by the confederates (observe session) which is depicted with blue. As in previous studies (Klucharev et al., 2009; Campbell-Meiklejohn et al., 2010; Zaki et al., 2011; Garvert et al., 2015; Suzuki et al., 2016), participants were told that the choices they observed were made by a subject in a previous experiment. In actuality, however, computer algorithms were designed to generate observer's choices. Subsequently, participants were asked to estimate and rate their confidence level between 0 and 100% regarding which options the previous participant had chosen, and then were given correct response feedback. Prediction trials were used to confirm that participants learned the observer's behavioral preferences and tendencies. Session 3 involved both self-trials and observe trials, and the order of presentation for the trials in each game was randomized. The purpose of the experiment and the manipulation approach were initially not explained to the participants. However, to ensure transparency and ethical conduct, a debriefing session was conducted as an integral part of the research process. During this session, the researchers provided a comprehensive explanation of the goal and purpose of the study to the participants.

We conducted a repeated mini-dictator game as a means of measuring the social preferences of subjects, using the Fehr-Schmidt (FS) model, which is a widely-used in heterodox economics. The model can be formally represented as follows:

$$U_i = M_i - \alpha_i \max[(M_j - M_i), 0] - \beta_i \max[(M_i - M_j), 0] \quad i \neq j$$

In this model, represents the individual's own utility, denotes their own monetary payoff, and represents the monetary payoff of another individual. The model includes two parameters that reflect the subject's feelings of envy (disutility from being behind) and guilt (disutility from being ahead). We estimated the regression described by equation (1) in order to extract these parameters from the task data. Using the calculated parameters of the FS model from phase one, the algorithm will present participants with appropriate op-

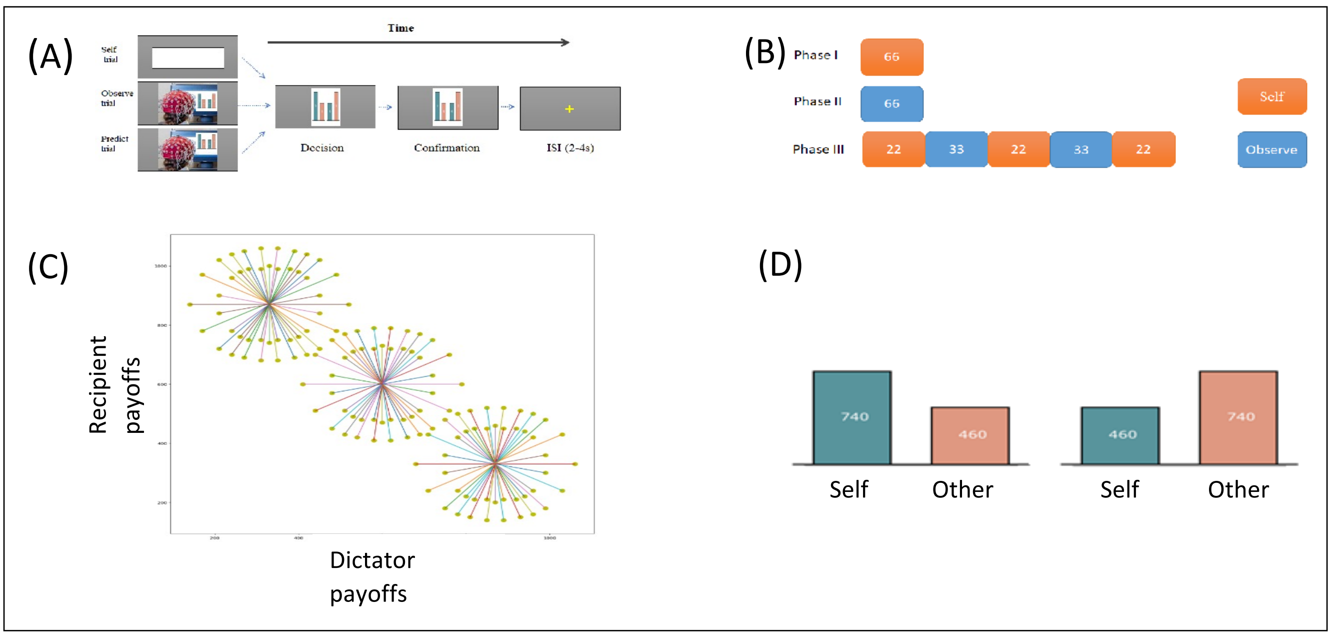

Fig. 1. Schematic illustration of the time course of stimulus presentation in the games task (A). Overall schedule in a block-wise manner. Trials in each block are indicated by white digits (B). All allocations in different inequality space (C). An example of dictator's decision. A binary allocation menu (D).

tions based on the choices of others during phase two, with the intention of manipulating their decisions. For a comprehensive understanding of the behavioral model, please refer to the supplemental experimental procedures, which contains additional details in the form of MATLAB code.

Procedure

To minimize distraction, the experiment was conducted in a shielded room with low lighting levels. Participants were seated on comfortable couches in front of 19-inch computer monitor. Prior to experiment, a brief explanation of the experiment instructions was given to the subjects. They were instructed to avoid blinking or moving their body as much as possible while keeping their eyes fixed on monitor approximately 75 cm away from them.

At the start of the experiment, participants were asked to carefully read a set of instructions displayed on the computer screen, which were previously explained by the experimenter. They were then instructed to compare the two options and choose one of them using the mouse buttons (left or right), while the EEG signals were recorded simultaneously. As mentioned earlier, the stimuli were displayed on the monitor screen without any time pressure, and the interstimulus interval was approximately 2000 ms. The stimulus sequence is shown in Fig. 1A. To avoid becoming fatigued, participants were given the option to rest or press the space button to continue.

Electroencephalogram recording and analysis

For this experiment, continuous EEG data was recorded from the scalp using a 64-channel Ag/AgCl electrode cap. The recording was performed using the amplifier designed by Liv Intelligent Technology Ltd Co., (website: www.lliivv.com/). The EEG data recording was performed by sampling frequency of 250 Hz and the impedance of all recording sites was less than 5 kΩ throughout the experiment. Prior to the stimuli presentation, 4 min of resting state EEG data (2 min in eyes-closed and two minutes in eyes-open conditions) were recorded as well. The electrodes placed behind the ears were used to measure the average activities, and the presentation and recording systems were synchronized by sending trigger markers on the parallel port. The open-source software EEGlab, ERPlab in MATLAB (Version 2019b; MathWorks Inc., Natick, MA) is used for the pre-processing of the collected data. The cutoff frequency of the bandpass filter was 1-40 Hz to reduce residual high-frequency artifacts in the waveforms. Signals are often corrupted by eye-related artifact like blinking and eye movement or muscle potentials that generate large amplitude peaks that need to be eliminated. Independent component analysis (ICA) which is a general and practical tool for removing oculomotor artifacts. For each EEG channel, ERP signals were segmented at intervals of 200 ms before stimuli onset to 600 ms after onset. ERPs were averaged separately for each channel and experimental condition.

Behavioral results

The conformity rate is the proportion of subjects who made conformity decisions according to observed choices. Fig. 2 (left panel) displays the similarity of subjects' decisions in session 1 and session 3 with confederate.

The horizontal axis represents the number of similarities between the subject's decisions and the confederate in session 1, while the vertical axis represents the number of decision similarities in session 3. If contagion occurred, we would expect to see more trials located above the 45-degree line. The graph and statistical test indicate that the phenomenon of contagion occurred for a significant number of participants. We conducted a paired t-test was performed to analyze the similarity of subjects' decisions in phase 1 and phase 3 with those of the confederate. The results revealed a significant difference between the two phases: participants exhibited higher similarity with the confederate in phase 3 compared to phase 1 ($t=-4.35$, $p<0.001$). These findings provide support for H1, which predicted that the phenomenon of contagion would occur.

Table 1 displays the mean response times (RTs) for the behavioral data, which represent the time it took participants to make decisions from the moment each stimulus was presented in the experiment.

As Table 1 shows, the response times (RTs) were significantly shorter in phase 3 compared to phase 1 ($t=3.83$, $p<0.001$). Moreover, the mean RTs for the contagion group in phase 3 (2.75 ms) were slightly shorter than for non-contagion (2.77 ms). However, a t-test revealed no significant difference between RTs for contagion and not contagion ($t=-0.04$, $p=0.9$).

Table 1. Phase 1 / phase 3 mean response times.

Condition	RTs	SD
Phase1	4.16	2.06
Phase 3	2.76	0.96

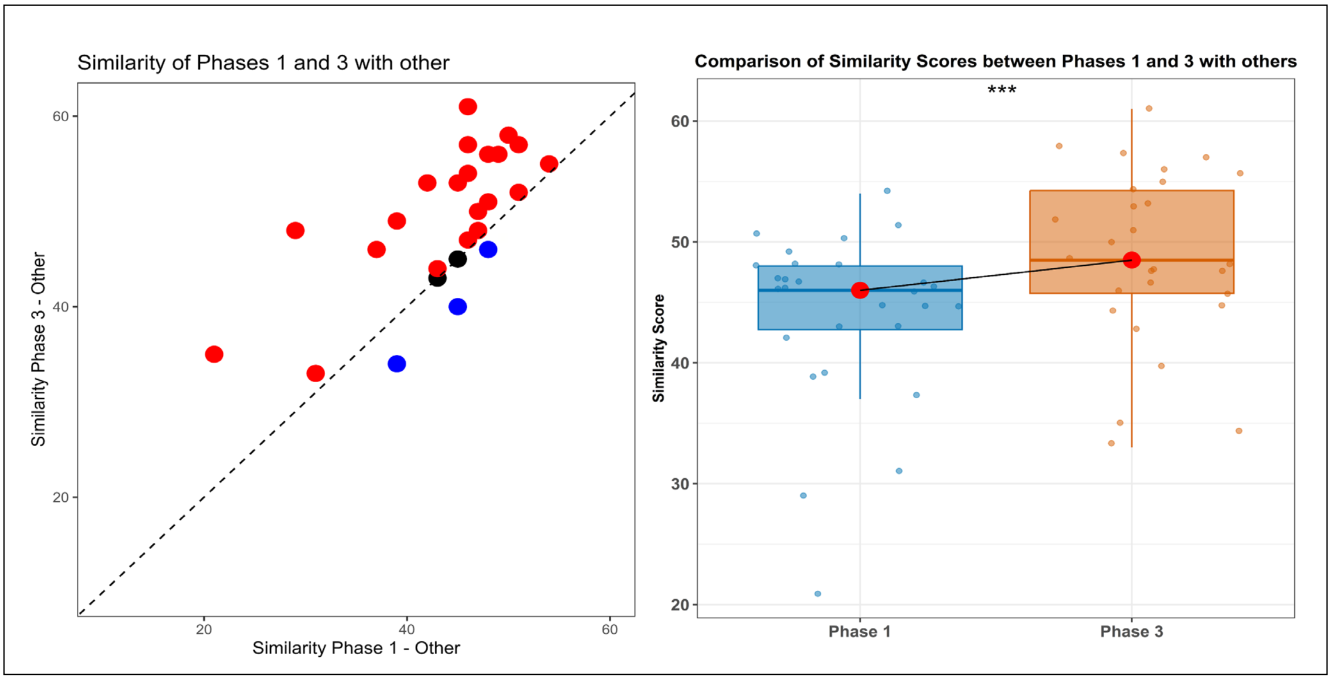

Fig. 2. Similarity of subjects' decisions in phase 1 and phase 3 with the confederate.

RESULTS

ERP results

The effects of three factors (predictors) were analyzed – 64 channels ×2 (phases: phase 1 and phase 3) and ×2 (contagion: exposed to contagion and non-exposed to contagion) – on the amplitude of a dependent variable in two different windows: 200-350, and 500-650 within subjects in R software.

P300

For the time window of 200 to 350 ms, within participants repeated measure three-way ANOVA revealed significant effects of three factors (Contagion, Phase, and Channel) on ERP amplitudes, as well as significant interactions between the factors. The ANOVA results reported in Table 2 revealed a significant contagion effect ($F_{(1,27)}$=32.258, p<0.001). This suggests that mean P300 amplitudes vary between conditions with and without contagion. Meanwhile, we also found a significant phase effect ($F_{(1,27)}$=75.978, p<0.001), indicating that ERP amplitudes differed across phases.

Table 2. Three-way ANOVA results.

Source	d.f	Sum Sq	Mean Sq	F value	Pr(>F)
Contagion	1	0.158	0.1583	32.258	1.47e-08 ***
Phase	1	0.373	0.3729	75.978	< 2e-16 ***
Channel	63	4.549	0.0722	14.711	< 2e-16 ***
Contagion: Phase	1	0.288	0.2885	58.771	2.31e-14 ***
Contagion: Channel	63	0.066	0.0011	0.215	1
Phase: Channel	63	0.109	0.0017	0.351	1
Contagion: Phase: Channel	63	0.062	0.0010	0.200	1

Also, the main effect of the channel was significant ($F_{(63,1727)}$=14.711, p<0.001). This implies that ERP amplitudes differ across various electrode locations. The data also revealed significant interaction effects between contagion and phase ($F_{(1,27)}$=58.771, p<0.001), suggesting that the effect of contagion on ERP amplitudes depends on the phase of the experiment. However, the interaction effect between contagion and channel showed not significant ($F_{(63,1727)}$=0.215, p=1), indicating that the effect of contagion on ERP amplitudes does not depend on the electrode location. Similarly, the interaction between phase and channel was not significant ($F_{(63,1727)}$=0.351, p=1), indicating that the effect of phase on ERP amplitudes does not depend on the electrode location. Finally, the interaction effect between contagion, phase, and channel was insignificant ($F_{(63,1727)}$=0.200, p=1). In summary, the results suggest that phase, contagion, and channel all have significant effects on ERP amplitudes. In addition, contagion's effect on ERP amplitudes depends on the experiment phase.

LPP

The ANOVA results showed that the 'channel' variable was not significant ($F_{(63,3328)}$=1.27, p=0.077) in the time windows of 500 to 650 ms. As a result, we did not observe LPP (late positive potential) components in this time window. As mentioned earlier, the P300 and LPP components of the ERP are sensitive to various cognitive processes, including category similarity and decision difficulty. Therefore, if only one of these components is observed (e.g., only P300 or only LPP), it's possible that its amplitude may be more closely related to decision difficulty rather than category similarity.

Differences waves from not contagion minus contagion in different phases

From the 200 to 350 ms time window, we segmented the brain into nine regions of interest (ROIs) following the approach used in previous research (Chen et al., 2010b). ERP differences between the two experimental conditions were then analyzed and compared for each ROI and electrode separately.

Table 3 shows the results of the statistical analysis. Three regions were found to be significant; however, after conducting *post hoc* analyses, two regions of interest (ROIs) – midline posterior and right posterior – withstood the false discovery rate (FDR) correction test, indicating that these differences were statistically significant at the adjusted alpha level. Specifically, the *p*-value for the right posterior ROI was less than 0.01. There are moderates to large effect sizes for Cohen's d and Hedges' g in the regions with significant *p*-values, suggesting that these differences are meaningful and not simply by chance. The effect sizes are generally smaller for the non-significant regions, indicating that the groups do not differ as much. Fig. 3, 4 show the grand averaged difference ERP waveforms for contagion and not-contagion in different phases in midline posterior and right posterior respectively. The scalp map distribution of the grand average difference potential between contagion and non-contagion differences is presented in Fig. 5, along with the corresponding *p*-values.

This topo plot supports the notion that the temporo-parietal and parieto-occipital regions of the brain play a crucial role in processing information, particularly with respect to conformity and other regarding information.

Table 3. Results of statistical analysis for ROI differences.

ROI	t-value	p-value	Cohen's d	Hedges' g
Left frontal (FP1, F3, F7, FC3, FT7)	1.56	0.128	0.33	Small
Midline frontal (FPZ, FZ, FCZ)	1.58	0.125	0.33	Small
Right frontal (FP2, F4, F8, FC4, FT8)	2.02	0.052	0.61	Medium
Left central (C3, T7)	0.96	0.345	0.20	Small
Midline central (CZ)	1.10	0.280	0.24	Small
Right central (C4, T8)	1.28	0.211	0.30	Small
Left posterior (CP3, TP7, P3, P7, O1)	2.37	0.025*	0.66	Medium
Midline posterior (CPZ, PZ, OZ)	2.43	0.0219*	0.67	Medium
Right posterior (CP4, TP8, P4, P8, O2)	2.95	0.006**	0.87	Large

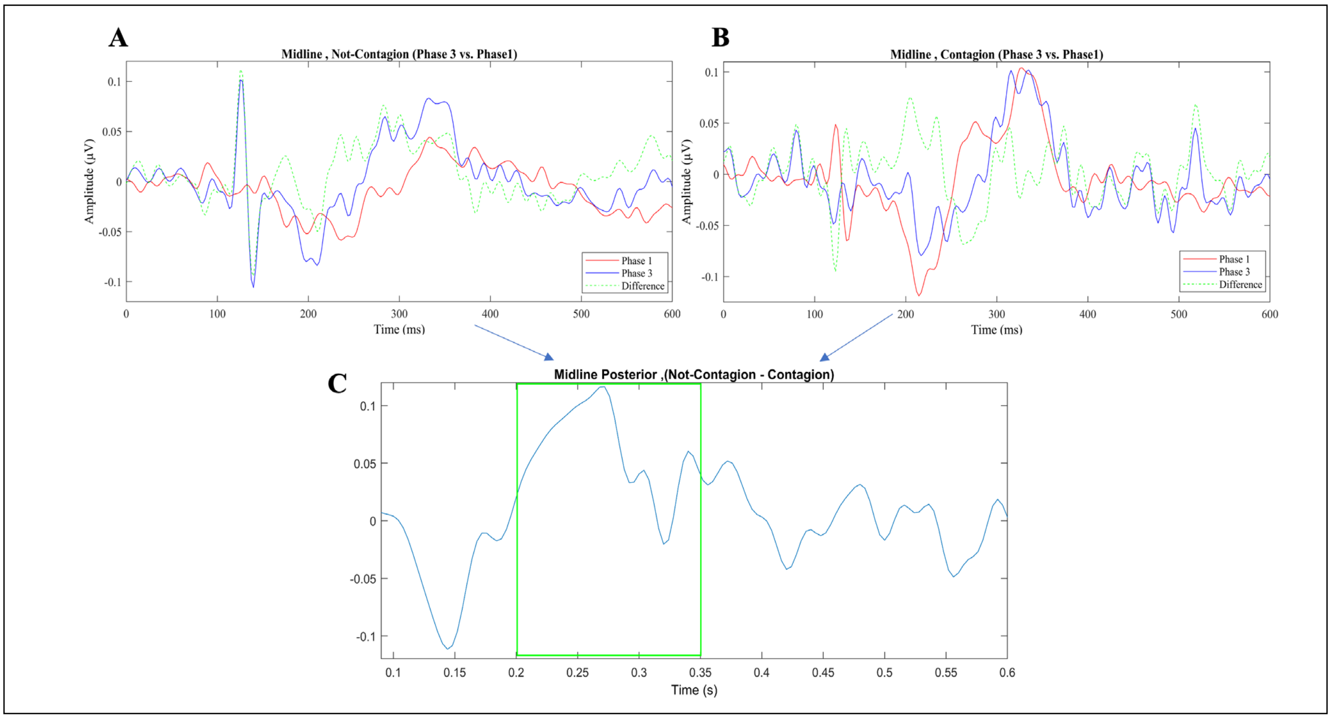

Fig. 3. Grand-averaged waveform of P300 in the midline posterior region for contagion and not contagion in phase 1 and phase 3 (panels A and B, respectively). Panel C shows the difference waveform of not-contagion and contagion in the midline poster.

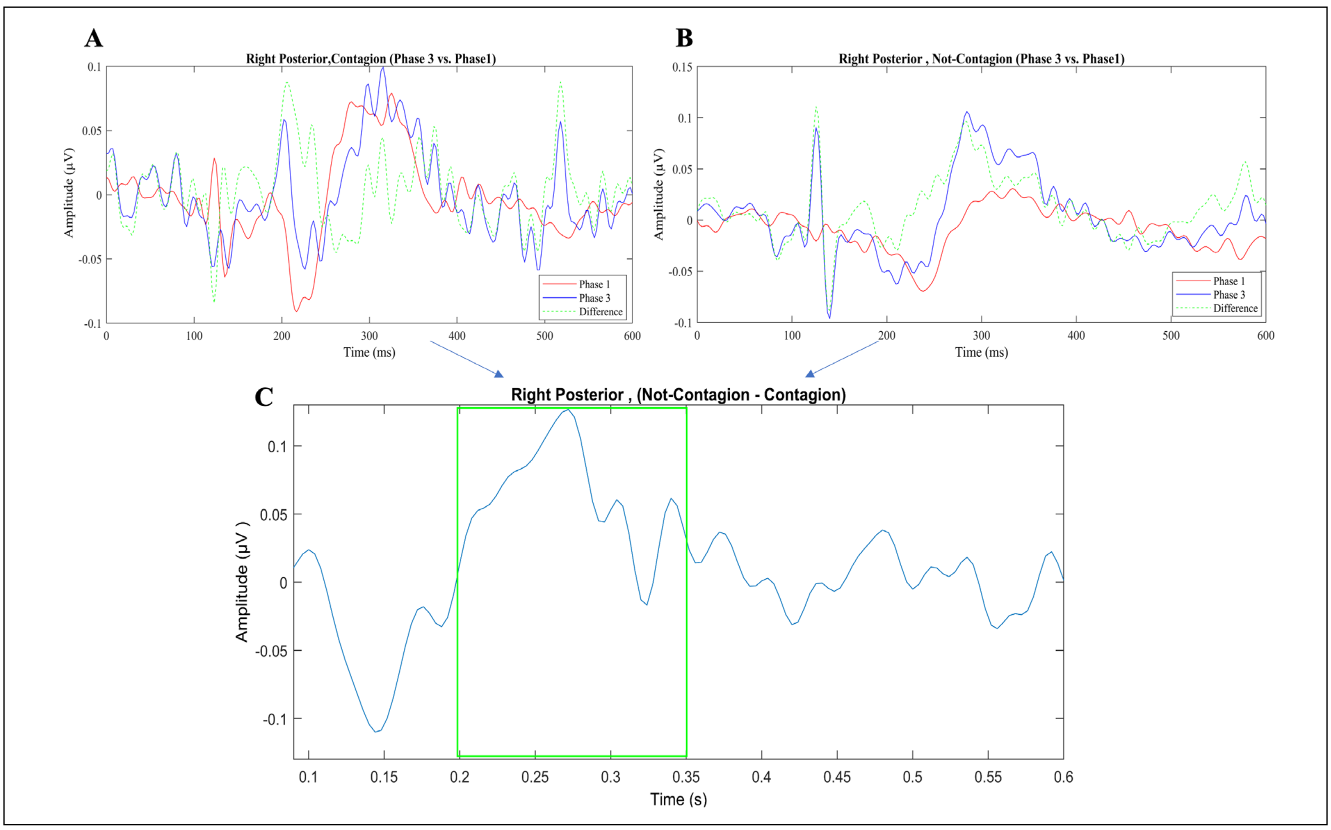

Fig. 4. Grand-averaged waveform of P300 in the right posterior region contagion and not contagion in phase 1 and phase 3 (panels A and B, respectively). Panel C shows the difference in the waveform of not-contagion and contagion in the right posterior.

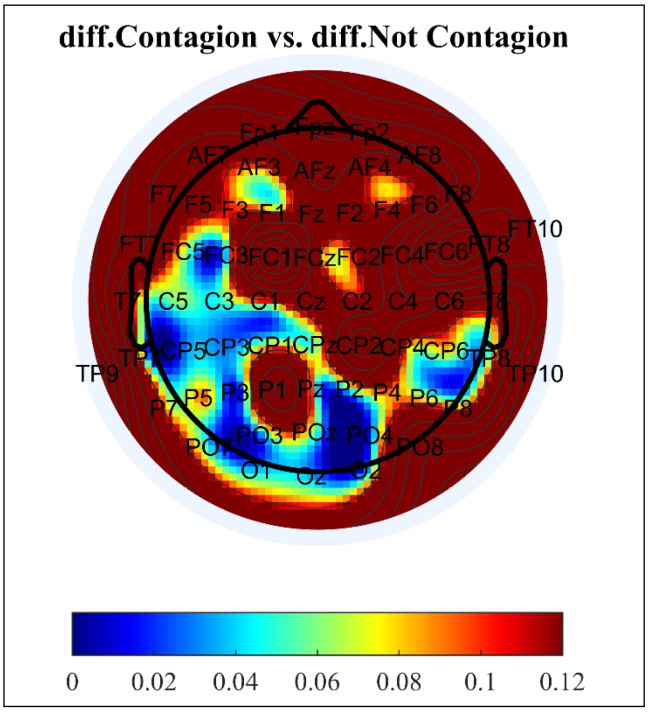

Fig. 5. The *p*-value topographic distribution of grand average difference potentials between 200 and 350 ms.

At the same time, the differences in ERP between the left hemisphere (FP1, F3, F7, FC3, FT7, C3, T7, CP3, TP7, P3, P7, O1), and right hemispheres (FP2, F4, F8, FC4, FT8, C4, T8, CP4, TP8, P4, P8, O2) were analyzed. The results showed that the P300 response in the right hemisphere was significantly larger than in the left hemisphere, with a t-value of 2.20 and a *p*-value of 0.03.

Also, as seen in Fig. 6 the mean amplitude across the all subjects and electrodes in right, left and midline posterior between 200 and 350 ms for phase 3 (Mphase3=0.03, SD=0.042) was larger than phase 1 (Mphase1= 0.01, SD=0.044).

Overall, the contagion and conformity conditions elicited a P300 that was distributed in the midline posterior and right posterior regions, with a significantly larger amplitude observed over the right hemisphere electrode sites. These results provide support for hypothesis 3, which pertains to the effect of decision difficulty on amplitude, rather than to the effect of category similarity, since both components (i.e., P300 and LPP) must be observed to address this issue.

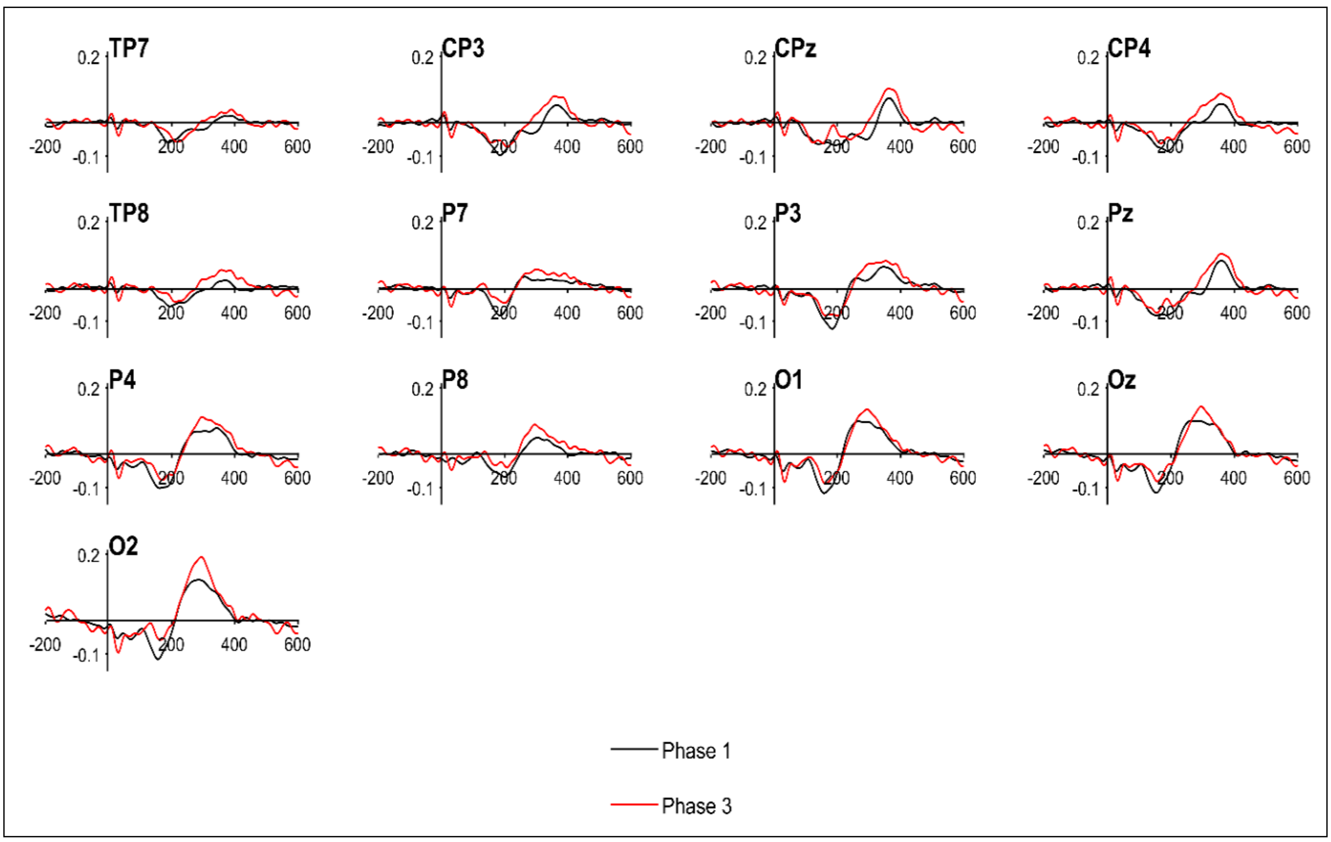

Fig. 6. ERP waveform across all subjects in selected electrodes.

Group differences in neuropsychological measures

To determine whether individuals' behavioral changes are manifested in brain activity, we conducted a Spearman correlation between amplitude and reaction time in ERP data, both across all subjects and among those who experienced contagion. Mean event-related potential (ERP) amplitude differences were calculated between phase 3 and phase 1 within the significant regions of interest (ROIs) during the time interval of 200-350 ms. Additionally, differences in reaction time between phase 3 and phase 1 were also computed. As we can see from Fig. 7A a significant inverse relationship was observed between the two variables, suggesting that as amplitude increase, reaction time decrease. This negative correlation was stronger among individuals who conformed (rho=–0.58, p=0.02) than the correlation coefficient for all subjects (rho=–0.35, p=0.03). Thus, the correlation between amplitude and reaction time is more pronounced in individuals who had higher levels of conformity (Fig. 7B). However, an inverse relationship between the two variables was not observed in the not conformed subject (rho=–0.15, p=0.3) (Fig. 7C).

Fig. 7. Scatterplots showing the correlation between difference in RT and the difference in mean ERP amplitude. The fitting regression line is shown in black, and the 95% confidence interval for the line is shown in gray shading.

DISCUSSION

The current study aimed to investigate how individuals are influenced by the decisions of others and to investigate the neural and behavioral mechanisms underlying this contagion effect.

The outcomes of our behavior experiment have replicated the classical behavioral pattern commonly seen in social conformity studies; individuals' initial decisions can be modified as a result of observation of others' behavior (Chen et al., 2010a, 2010b; Zhang et al., 2019). Our first hypothesis, which proposed that individuals would be affected by behavioral contagion, was supported. The reasons for this behavioral change could include factors such as limited information, low self-confidence, and social pressure to conform. In essence, people have the propensity to believe in and maintain consistent with the majority of others' beliefs (Deutsch & Gerard, 1955; Chen et al., 2010a; Gao et al., 2017; Zhang et al., 2019).

Behaviorally, in line with previous studies (Chen et al., 2010a, 2010b), we found that the mean RTs in phase 3 were significantly shorter than in the initial phase. The fact is that, the reduced reaction time observed in phase 3 can be attributed to various factors, including familiarity with the environment, and / or learning from observing the choices of others. As participants became more familiar with the task and learned from the behavior of others, they likely developed a faster decision-making process, leading to a decrease in reaction times.

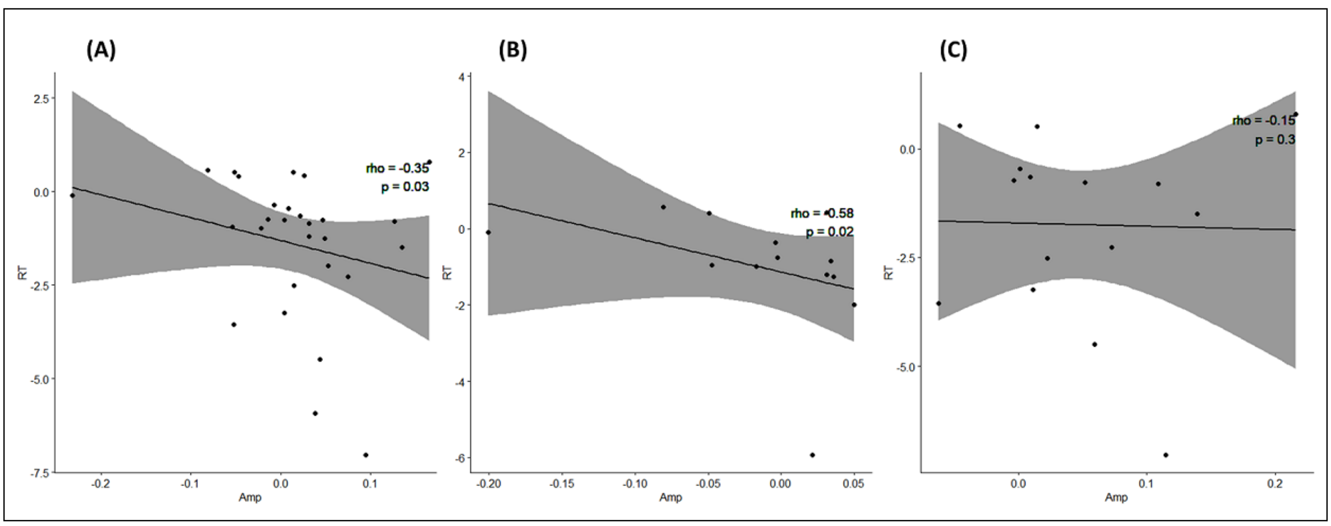

Fig. 7. Scatterplots showing the correlation between difference in RT and the difference in mean ERP amplitude. The fitting regression line is shown in black, and the 95% confidence interval for the line is shown in gray shading. Results for (A) all subjects; (B) conformed subjects; (C) subjects who did not conform.

In addition, the results of the analysis revealed that participants who exhibited higher levels of conformity demonstrated significantly smaller differences in reaction time between phases 1 and 3, compared to those who did not conform. This suggests that participants who aligned their decisions with the observees may have had less difficulty in making decisions and did not require more time to process decision-making conflicts.

The ERP results indicated that in phase 3, participants who shifted their choices toward the observees' choices exhibited a larger P300 amplitude compared to other participants. P300 is an established neural marker of core information processing in the brain (Palmer et al., 1994; Pierguidi et al., 2019; Xie et al., 2016) and its amplitude has been shown to be negatively related to the difficulty of decision-making tasks (Vallesi, 2011) so in phase 3, participants who aligned their decisions with the observees they had less difficulty in making decisions compared to those who did not align their decisions.

The third hypothesis posited that individuals who aligned the behavior to match others, will exhibit either larger LPP or P300 amplitude like the effect of decision difficulty reported in previous studies (Palmer et al., 1994; Cutmore & Muckert, 1998; Finnigan et al., 2002). This finding suggests that the absences of LPP response may be more closely related to decision difficulty rather than category similarity. However, the absence of a significant LPP component in the time windows 500-650 ms could potentially be attributed to the experimental design or influenced by the relatively small sample size and insufficient number of trials.

We divided the brain into nine regions of interest (ROIs) and calculated amplitude differences between phase 1 and phase 3 in the time window of 200-350 ms for participants who displayed higher conformity *versus* those who did not. We found that two out of the nine ROIs showed significant amplitude differences, suggesting neural activation patterns associated with behavioral contagion.

Moreover, our findings indicate a significant difference in P300 amplitude between right hemisphere and left hemisphere. Specifically, the P300 amplitude was found significant in the right hemisphere. There may be a differential involvement of hemispheric processing in behavioral contagion. The topo plot offers compelling evidence regarding the functional importance of the temporo-parietal and parieto-occipital brain regions in the processing of information associated with conformity and other regarding information. The parieto-occipital region has been implicated in processing both self-relevant and other-relevant information (Padmanabhan et al., 2017). The right temporoparietal junction (rTPJ) has been identified as having a distinct role in understanding the beliefs of others (Spreng & Andrews-Hanna, 2015). It is actively involved in processing social information, such as making inferences about the intentions and beliefs of individuals (Tso et al., 2018). Furthermore, studies (Peng et al., 2021) have indicated that the rTPJ also influences emotional mimicry based on group membership.

Although some researchers have reported the activation of the frontal lobe in conformity tasks, the results of our research are in line with the findings of Berns et al. (2005). They reported that conformity is associated with activation in visual cortical and parietal regions, while the frontal lobes showed no significant activity. This discrepancy may be attributed to differences in the experimental paradigms and stimuli employed across studies. They suggested that changes in participants' initial judgments during conformity tasks could be attributed to low-level perception rather than higher-level attentional processes. Our findings support this notion and highlight the importance of visual and parietal regions in the neural mechanisms of conformity. The involvement of these regions suggests that participants may rely on visual information processing and basic perceptual mechanisms to align their judgments with those of others, rather than engaging executive processes associated with the frontal lobes.

We also found a correlation between the difference in RT values and the difference in mean ERP amplitudes before and after the manipulation for a significant ROI within the time windows of 200-350 ms. We can interpret the results as follows: when subjects conform or experience a contagious effect, they tend to have lower reaction time and higher amplitude in their ERP data (Chen et al., 2010a, 2010b). The negative correlation between amplitude and reaction time differences could be attributed to the neural mechanisms involved in the cognitive processes of conforming or experiencing a contagious effect. This interpretation is supported by the finding that ERP amplitude, which serves as a neural measure, exhibits a significantly larger magnitude within the significant ROI for the group displaying higher conformity compared to the group displaying lower conformity. Conversely, reaction time differences, a behavioral measure, is shorter in the higher conformity group, suggesting a potential inverse relationship between the two variables and indicating the presence of a shared underlying neural process.

Our study is subject to several limitations that may impact the generalizability of our findings. Firstly, the relatively small sample size and unequal gender distribution could potentially influence the statistical power analysis. Additionally, the imbalanced gender distribution introduces the possibility of biased results. To enhance the reliability and robustness of our findings, we recommend conducting future studies with a larger sample size and ensuring equal gender representation.

Experimental research on social preferences has commonly involved student participants. However, it is important to consider the limitations associated with this sample. Recent research by Epper et al. (2024) has demonstrated differences in the distribution of social preferences between students and the general population. These differences are likely influenced by factors such as age and education. Additionally, conformity tendencies can be influenced by various personality factors, including age, gender, and cultural differences (Deldoost, 2022). Studies have indicated that an individual's age significantly affects their susceptibility to social conformity. In particular, individuals in early and late adulthood tend to be more easily influenced compared to those in middle age (Visser & Krosnick, 1998; Wijenayake et al., 2021). Considering these factors, it is important to acknowledge that our study's sample consisted solely of students, which may limit the generalizability of our findings. Future research should aim to include participants from diverse backgrounds to gain a more comprehensive understanding of social preferences and decision-making behavior.

While our study applied EEG to measure neural activity, future investigations could incorporate other neuroimaging techniques, such as fMRI, allowing for a more detailed examination of the brain region-specific and providing insight to deepen our understanding of the neural processes underlying contagion and social influence.

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