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Rejecting unfairness enhances the implicit sense of agency in the human brain

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Sense of agency (SoA) describes the feeling of control over one's actions and their consequences. One proposed index of implicit SoA is temporal compression, which refers to the phenomenon that voluntary actions and their outcomes are perceived as closer in time than they actually are. The present study measured temporal compression in the social norm violation situation. In two experiments participants joined in an Ultimatum game (UG), in which they were presented with offers that varied in fairness and they could choose to accept or reject the offers by pressing buttons. A neutral sound would occur after their choices in the UG and the participants had to estimate the time interval between their button pressing and the occurrence of the sound, and EEG signals were recorded during the task. Experiment 1 demonstrated that rejecting unfair offers decreased the perceived interval between action and outcome compared to accepting fair offers, suggesting a higher level of SoA after rejecting unfair offers. Experiment 2 replicated these results and further revealed an attenuated N1 in response to the sound following rejections of unfairness. Taken together, these results highlight the importance of social norms in affecting people's behaviors and agency experiences.

Keywords Sense of agency, Temporal compression, Fairness, Ultimatum game, Event-related potentials (ERPs)

Sense of agency (SoA) refers to the feeling that people feel control over their own actions and the following consequences. SoA is a pervasive and crucial aspect of human consciousness[1,2]. This subjective experience of agency generally tells us whether we are responsible for the consequences of our actions in daily life, thus SoA also plays a key role in human social life[3–6]. In the past decades, researchers have focused on unraveling the mechanisms underlying SoA[7–9]. More recently, there has been a growing interest in testing SoA during joint actions or in social contexts[10–13]. As social creatures, people usually have to interact and cooperate with others in many social aspects[14]. During social interactions, people often need to learn social norms which can enhance their ability to get al.ong with others. For instance, past research has demonstrated that children acquire notions of fairness from a rather early age[15]. When interacting with others, individuals often adhere to social norms, expecting smooth interactions. However, individuals may sometimes face norm violations or unexpected behavior from others. How do individuals regain control in such situations, and how do their responses to norm violations shape their agentive awareness and identity in social contexts? In the present study, we aimed to investigate the impact of individuals' action choices on the sense of agency in the context of norm violations.

According to traditional economic theories, in social interactions people typically behave in a rational way that can maximize their self-interests. However, during the last decades, experimental economics has congruously showed that agents do not only try to maximize their monetary gain. One example is the Ultimatum Game (UG). In the UG, two players decided to divide a certain amount of money. The first player, who plays the role of the proposer, comes up with a proposal to split the money between the two players. The second player, who acts as the role of the responder, decides either to accept or decline the proposed split. If the responder accepts the offer, the money will be divided following the division of the proposer. If, however, the responder rejects the offer suggested by the proposer, both parties earn nothing[16]. Classical economic theory argues that the recipient should accept every offer, since "few is better than nothing". However, empirical studies observed that the responders are willing to sacrifice their own monetary benefits to punish the unfair proposers[16–18].

Many models interpret the rejection of unfair offers that contradicts the rationality of human decision-making. One prominent suggestion is that people are motivated naturally by a sense of fairness and equality, and thus paying a price to create more fair outcomes would bring happiness[19,20]. Concerning the origin of the fairness preference, the reciprocity theory suggested that people care about the intention behind the offer and are willing to pay to punish unfair behaviors. The punishment will encourage fairness and cooperation at the

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group level or in future interactions[19], and this benefit may outweigh the cost to the responder[20]. Alternatively, the "wounded pride hypothesis" argued that rejecting unfair offers is an emotional response to a threat to the integrity or status of the recipient[21]. According to this view, the rejection of unfair offers in the UG is not a prosocial behavior toward maintaining fairness but a willing choice to avoid the imposition of an inferior status. Previous studies testing responders' decision makings in the UG usually focused on the origin of the fairness consideration, however little research, so far, has examined how the action choice in this dilemma situation influences people's subjective experiences, namely the sense of agency. Although previous research on the UG shows that social norms greatly influence behavior, it is still uncertain how people's sense of agency is affected during social interactions when these norms are violated. In the present research, we investigated this issue by examining how action choices in the UG affected the sense of agency.

Previous research tested the underlying mechanisms of agency experiences and proposed two influential accounts of SoA: the comparator model[22,23]and the cognitive reconstruction theory[24,25]. The former view is based on the computational theories of motor control. According to the comparator model, when one initiates a movement, a predicted effect is generated from an efference copy of the motor command and then this prediction is compared with the actual effect. A match results in an attenuation of the perceived effect and generates the experience of agency, while a mismatch causes a surprise and implies that external factors may have generated the effect[22]. The motor prediction theory posits that SoA reflects the degree of compatibility between predicted effects and real effects. In contrast, the cognitive reconstruction view suggests that SoA is a postdictive cognitive reconstruction rather than a predictive process, based on a match between prior thoughts and following action outcomes[24,26]. Recently, researchers argue that SoA reflects a combination of both internal sensory-motor signals and external cues (e.g., social context, emotion, and beliefs), and the weights of different cues may vary depending on the specific context[27]. However, other research also suggests that non-motor signals may influence the sense of agency through heuristic judgment rather than cue integration, and contextual cues can serve as heuristics sufficient to determine both implicit and explicit senses of agency[28].

In the present study, we used the temporal compression to measure the implicit SoA[29–31]. Temporal compression describes the phenomenon that voluntary actions and their outcomes are perceived as closer in time than they actually are. Previous studies consistently found that the magnitude of temporal compression reflects differences in SoA[29,31], suggesting it as a useful index for measure the SoA. This temporal compression effect was originally known as "intentional binding"[32]. Intentional binding was typically tested by comparing intentional actions with passive actions (e.g., actions triggered by external forces), and the binding effect was absent for passive actions[29,32]. In the present study, we compared the perceived duration of the action-effect interval between accepting fair offers and rejecting unfair ones in the UG. While temporal compression was often used to measure implicit SoA, more recent research has shown that the effect is not only linked to SoA but is also associated with causation and multisensory integration[33,34]. Thus, we used temporal compression instead of intentional binding as a more general term.

Recent research has shown that social contexts can modulate the implicit SoA - temporal compression, but the results are mixed. For instance, some studies found that the presence of others can reduce the temporal compression effect[10]. It was suggested that when interacting with others, mentalizing processes may interfere with task-related processing and increase the difficulty of action selection, thereby reducing participants' SoA[10]. On the other hand, a joint-action study found that interacting with a human counterpart, rather than a computer, led to increased action-effect monitoring, indicating an enhanced SoA for social cues[35]. It was suggested that social cues provide higher predictability for action-effects than physical objects. Based on previous literature, both motor and non-motor cues may affect the SoA in complex, interwoven ways within social contexts[36]. In those studies, emotions were often missing, which is rare in daily life since emotions are a common part of social interactions.

So far, little research has specifically examined the SoA in contexts of social norm violations. As shown by previous neuroscientific research on the UG, both cognitive and emotional processes are involved when responding to unfairness[17,18,20]. Unfair offers often cause feelings of anger, which may lead to impulsive actions. Moreover, although experiencing unfairness is negative, sanctioning norm violators can be rewarding, activating reward areas in the brain despite monetary loss[17,20]. As suggested by previous research on the relationship between emotion and implicit agency, negative emotions tend to reduce agency, while positive emotions tend to enhance it[36]. Thus, we assume that if anger causes participants to impulsively reject unfairness, regret may be induced over the action-outcome, leading to a reduced SoA. Alternatively, punishing norm violators may increase positive mood, for instance, helping to maintain the principle of fairness or rebuild pride, which may enhance the SoA.

As mentioned above, here we tested how social norms modulate people's actions and the implicit SoA in the UG. In Experiment 1, we measured the temporal compression combined with the UG paradigm. Previous studies on the UG have found that the source of the offer affects participants' choices. Specifically, participants are more likely to reject unfair offers from humans than from computers[16,17]. In this experiment, we explored whether the temporal compression would be influenced by the type of proposer in this experiment. Since we were also interested in the neural responses linked to the action-outcome processing, we conducted Experiment 2 in which we measured both temporal compression and ERPs related to the choice-outcome chain. Thus, we analyzed the ERPs which have been associated with the processing of the proposers' offers including the feedback-related negativity (FRN) P3, and effect related N1. The FRN is a negative ERP component and is usually largest at frontocentral sites. It peaks at around 200–400 ms after stimulus onset. Generally, a more negative FRN was found following unfair than following fair offers (e.g[37]). indicating the value of the offer and/or the prediction error of the responder. P3 is a positive ERP component and is often largest over central-parietal electrode sites. It typically occurs 300–500 ms after the stimulus onset. This component has been linked to the decision-makers' motivational state and the distribution of attentional resources used for value judgment and decision making[38,39]. Prior studies have found that P3 was more sensitive to positive feedback than to negative feedback[38], as well as to fair offers than unfair ones[37].

More importantly, we also measured the N1 component linked to the tone following participants' choices. There is well-documented evidence that the auditory-evoked N1 component is reduced in amplitude when participants listen to tones produced by their own voluntary actions, compared to when the tones were produced externally or when they passively listen to identical tones[40,41]. Thus, sensory attenuation is an important feature of self-produced action effects. Considering that people's sense of agency is strongly connected to sensory attenuation, sensory attenuation was also used to measure the implicit sense of agency[29].

In the current study, we predicted that the results would replicate previous findings: participants accept most fair offers and generally reject unfair ones. Additionally, participants would be more likely to reject unfair offers from humans than from computers. In line with previous neurophysiological studies, we expected to replicate the FRN and P300 effect in response to fair and unfair offers. Regarding temporal compression and N1, we proposed two hypotheses. First, unfair offers can provoke negative feelings and lead to impulsive actions, which may result in a feeling of losing control and subsequently reduce temporal compression and N1 attenuation compared to fair situations. Alternatively, rejecting unfairness may serve to maintain the principle of reciprocity and/or rebuild pride, inducing a more positive emotional state, which may lead to increased temporal compression and N1 attenuation. Regarding the type of proposers, we predicted that the modulation effect of fairness on temporal compression would be more pronounced for humans than for computers.

Experiment 1
Methods
Participants

Thirty-two volunteers (14 males, $M = 21.65$ years, $SD = 1.85$) were enrolled and were paid for their participation. All participants were right-handed, with normal or corrected to normal vision and no history of psychiatric or neurological disorders. Participants who did not follow instructions or who failed to generate action-effect intervals covarying monotonically with objective temporal interval would be deleted from analyses[42], and one participant was excluded from data analyses due to the failure of the experimental procedure during the experiment. During recruitment, the experimenter asked participants if they had any prior knowledge with economic experiments such as the Ultimatum Game or the Dictator Game (a variation of the UG). If participants knew any relevant information, they would not be allowed to join the experiment. After the experiment, participants were asked to write down their thoughts and feelings about the entire process. None reported doubting the reality of the experimental manipulations. The experiment was conducted with the approval of the Ethics Committee of Shenzhen University Psychology School and all procedures in this study were in accordance with the Helsinki declaration. Written informed consent was obtained from the participants after they received detailed information about the study.

The sample size was chosen to ensure sufficient power to detect the effect of fairness on temporal perception. A prior power analysis that was conducted using the G*Power software[43]showed that a sample size of 24 participants was required to achieve at least 80% statistical power for the current study analyses - a repeated measures (ANOVA) with a medium effect size $f = 0.25$ and alpha level $= 0.05$[44]. Thus, the sample size in the present study met the requirement.

Procedures

Once participants arrived at the laboratory, they read instructions about the goal of the experiment and got acquainted with the whole experimental procedure. They learned that they would be the responder deciding whether to accept or reject the proposed offers in a UG. Particularly, the participants were instructed that the offers were from either human beings or a computer. They were informed that the offers from other human participants were real but made before their arrival, and their responses would not affect subsequent offers. Participants also learned that at the end of the experiment, both the participant (responder) and the proposer would be paid according to the Participant's decisions. In fact, offers made by human partners had been predetermined, which guaranteed that all participants saw the same set (and a full range) of offers[18]. Half of these offers were relatively equal, i.e., dividing the 10 (RMB) fairly (5:5, 6:4), while the remaining half ones were divided unfairly (9:1, 8:2). Previous studies frequently use the 7:3 condition as a filler trial because this mid-value offer (7:3) increases the difficulty of decision-making related to fairness considerations and subsequent action choices[45]. Therefore, one offer of 7:3 was also added in the experiment to simulate human free behaviors but not included in the data analyses. The offers proposed by the computer were the same as those from humans that half of all offers were fair, and the remaining half were unfair. All offers were presented in a randomized order.

Practice phase.

In the practice phase, participants got familiar with the experimental procedure. First, Participants acted as responders in six trials of the UG. In each trial, participants saw an image of the sum of money (10 RMB) and another image of a computer making an Ultimatum offer. Next participant saw the offer (e.g., 'You get 1 (RMB), Ta gets 9 (RMB)', 'Ta' represents third-person pronouns - she/he/it - in the Chinese phonetic alphabets), then participants would respond to the offer by pressing a left or a right key ('accept' or 'reject'). After the response, participants saw the outcome based on their responses (e.g., 'You get 1, Ta gets 9', if the offer was accepted; or 'You get 0, Ta gets 0', if the offer was rejected). To counterbalance the mapping between the key position and the choice position, half participants accepted the offer by pressing the left key and another half received the offer by pressing the right key.

After the UG practice, participants were trained to differentiate between 100, 500, or 1000 ms (the endpoints and medium-point of the Visual Analogue Scale (VAS) employed in the time estimation task). In each trial, participants listened to two sounds separated by 100, 500, or 1000 msec, and they were asked to report if the time interval between the two sounds were 100, 500, or 1000 msec at the end of each trial. Participants saw feedback (correct or incorrect response) about their performance on the time interval estimation. After the time discrimination training, the UG and the time estimation task were combined, and participants completed the practice trials before the experimental procedure. In the last practice phase, participants responded to the offer from a computer, and after a random interval (100 ~ 1000 ms) an auditory stimulus was present, and participants were required to judge the temporal interval between their action and the action effect by moving the mouse pointer along the VAS from 0 ms to 1000 ms (with markers indicating 100 ms intervals see Fig. 1). And they were reminded that 1,000 ms is the equivalent of 1 s.

The experimental phase.

At the beginning of each trial, a fixation point was presented on the screen with a duration randomly varying between 1000 and 1500 ms and was followed by an image of the sum of the money. Next participants saw an image of the proposer (human or computer image) for 2 s. Then participants saw the offer, and they would respond to the offer by pressing a left or a right key to accept or reject the division, respectively. After their key press and a variable delay between 200 and 800 ms, a sound was delivered for 200 ms via headphones. The time interval between the movement (pressing keys) and effect (sound) varied randomly between 200, 500, and 800 ms. After hearing the sound and a variable interval (300 ~ 800 ms), participants estimated the time interval between the key press and the ensuing sound by moving the mouse pointer along the VAS from 100 ms to 1000 ms which was the same as the practice phase. They were told that the time interval would vary randomly from trial to trial, and the time range was between0 and 1,000 ms. Participants were also instructed to use all intervals between0 and 1,000, as accurately as possible, without confining their choice. There were 240 trials in the whole experiment with 60 trials per condition (20 trials at each action-tone interval, in random order). The experiment consisted of 4 blocks of 60 trials and participants could rest between blocks.

Results

Behavioral performance

We analyzed the acceptance rate (% of trials: The percentage of participants' acceptance for each condition) using ANOVA, with Fairness (fair, unfair) and Proposer (computer, human) as within-subject factors. The results revealed a main effect of fairness, $F(1, 30) = 419.77$, $p < .001$, $\eta_p^2 = 0.933$. The acceptance rate results replicated previous results in Ultimatum Game experiments: Participants accepted most relatively fair offers (95.30%) but rejected a large proportion of unfair offers (18.60%). Moreover, the two-way interaction of Fairness by Proposer was significant, $F(1, 30) = 6.54$, $p = .016$, $\eta_p^2 = 0.179$. Simple effect analysis showed that: Unfair offers proposed by humans were more frequently rejected (13.06%) than unfair offers generated by the computer (24.14%), $p = .027$, $d = 0.337$, indicating that participants had a stronger aversive response to unfair offers proposed by humans than to those generated by a computer. There was no difference between acceptance rates of fair offers

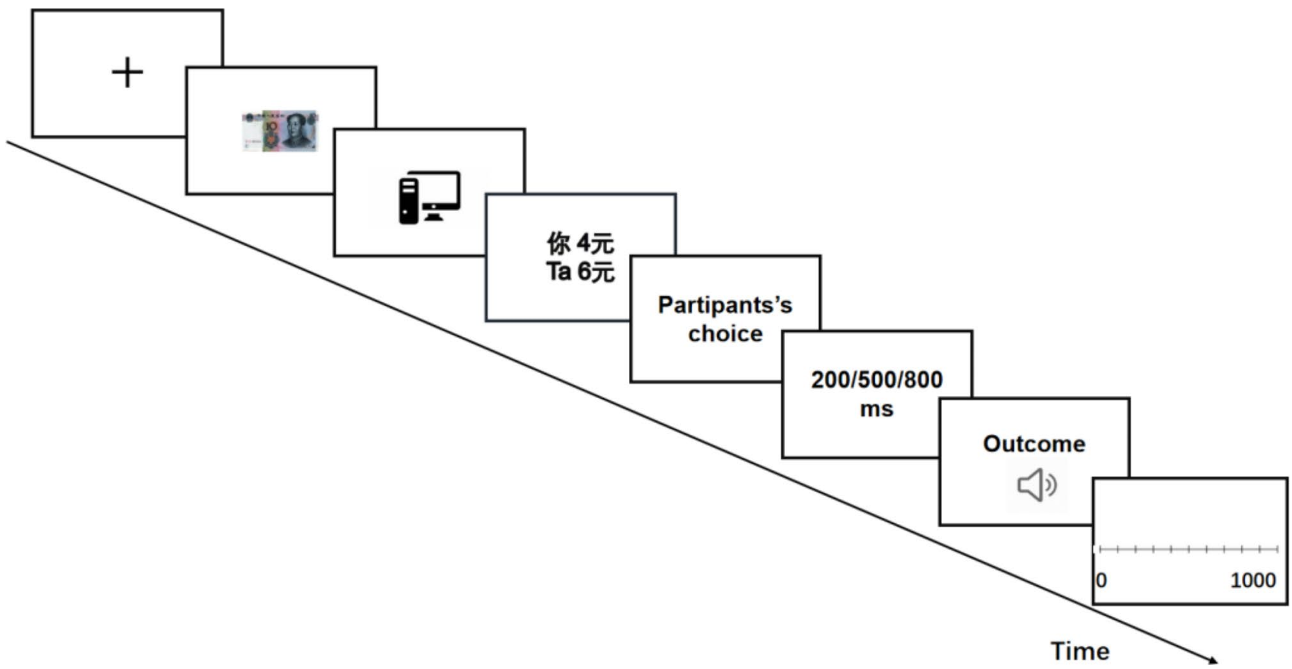

Fig. 1. Trial procedure of experiments 1 and 2. Participants were presented with fair and unfair offers proposed by computers or humans respectively (in experiment 2, the proposers only included humans), and they can either choose to accept or reject the offers by pressing the keys. After their responses, a sound would occur. The time interval between their response and the sound varied randomly (200, 500, or 800 ms). At the end of each trial, participants estimated the time interval between their action and the auditory stimulus on a visual scale.

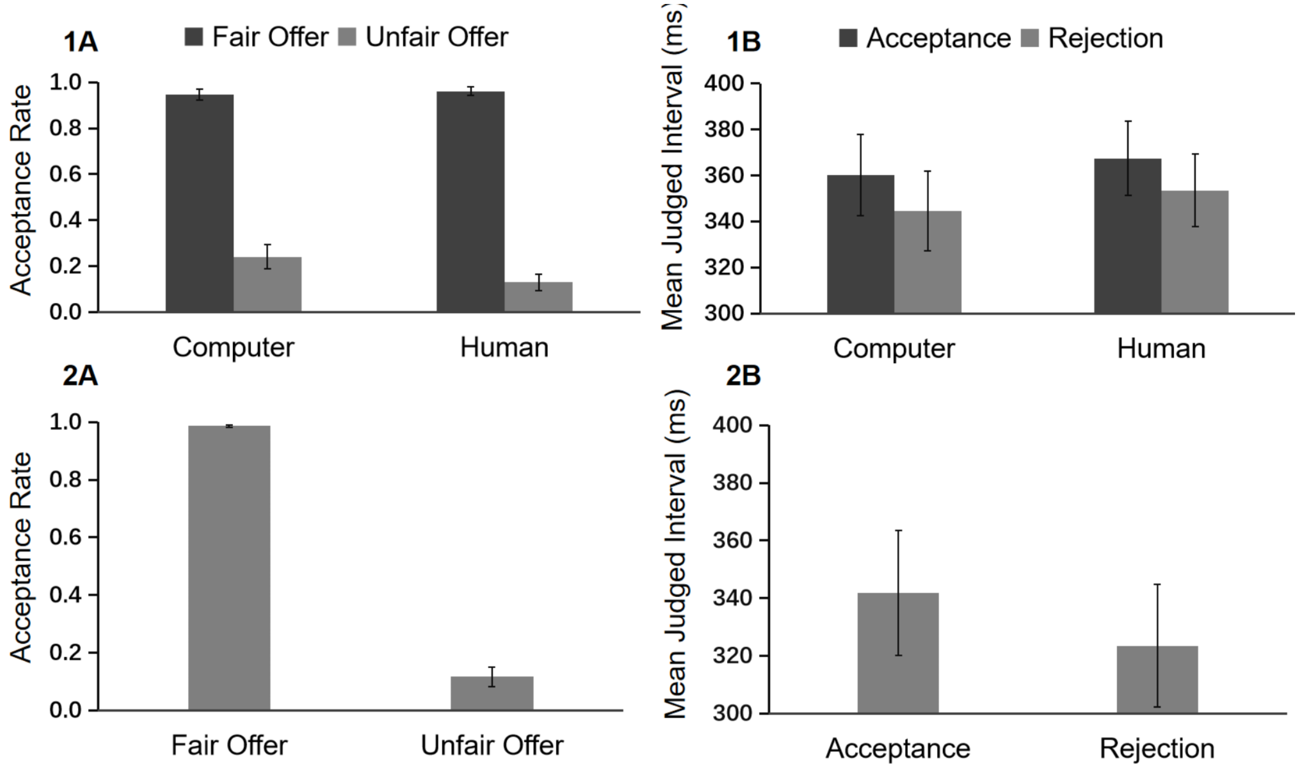

Fig. 2. (**1A**) Mean acceptance rates (%) of fair and unfair offers proposed by the computer and humans respectively in experiment 1. (**1B**) Time interval estimates (action-tone-interval) for accepting fair offers and rejecting unfair offers proposed by the computer and humans respectively in experiment (1) (**2A**) Mean acceptance rates (%) of fair and unfair offers proposed by humans in experiment (2) Error bars indicate the standard errors. (**2B**) Time interval estimates (action-tone-interval) for accepting fair offers and rejecting unfair offers proposed by humans in experiment 2.

proposed by humans (96.02%) and by the computer (94.57%), $p = .364$. The main effect of proposer was not significant, $F(1, 30) = 2.80$, $p = .105$, $\eta_p^2 = 0.085$.

Mean RTs analyses found that participants responded slower ($M = 1073.18$ ms, $SD = 471.00$) when reject unfair offers than when accept fair offers ($M = 929.33$ ms, $SD = 424.41$). t (30) = -5.746, $p < .001$, $d = 0.320$.

Temporal compression.

We analyzed the time interval estimates using ANOVA, with Response (acceptance, rejection) and Proposer (computer, human) as within-subject factors. Since we were interested in participants' ensuing decision to accept or reject the division, we focused on the comparison between the accepting responses of fair offers and the rejecting responses of unfair offers. The included trial counts for *human fairness accepted* ($M = 57.61$, $SD = 6.28$), *human unfairness rejected* ($M = 52.16$, $SD = 11.86$), *computer fairness accepted* ($M = 56.74$, $SD = 8.21$), and *computer unfairness rejected* ($M = 45.52$, $SD = 17.63$). There was an unbalanced number of accepted and rejected trials in each condition, which may compromise the statistical power of the analyses[46].

Results showed that the judged interval when rejecting unfair offers was significantly shorter than the judged interval when accepting fair offers ($M_{accept} = 363.76$ ms, $M_{reject} = 349.04$), $F(1, 30) = 6.766$, $p = .014$, $\eta_p^2 = 0.184$. The was no interaction effect between Proposer and Fairness, $F(1, 30) = 0.020$, $p = .888$, $\eta_p^2 = 0.001$. The human condition and computer condition exhibited similar time estimation for rejecting unfair offers and accepting fair offers. There effect of Proposer was not significant, $F(1, 30) = 4.082$, $p = .052$, $\eta_p^2 = 0.120$. Finally, we added action-outcome interval as an extra independent factor and there was no effect of action-outcome interval, the overall pattern of conclusions remained unchanged. Given that action-outcome interval was not a key factor of interest in present study, therefore, it will not be discussed further (see Fig. 2. 1 A-1B).

Discussion

The results of this experiment replicated previous studies that people receive most fair offers while generally declining unfair ones[15,17]. Additionally, participants may consider unfair division proposed by humans more offensive as they rejected more unfair offers from humans than from the computer. Moreover, we tested the temporal compression in the UG. Here, we observed that rejecting unfair offers led to greater temporal compression compared to accepting fair offers. This was evident from a more significant reduction in the judged time interval between action and outcome. The results suggest that rejecting unfair offers, despite the cost of monetary loss, may reflect the human desire to fulfill reciprocity beliefs and/or assert assertiveness[17,18]. Our findings did not reveal any significant effect of the proposer type on temporal compression. However, future studies may benefit from a more refined experimental design to thoroughly investigate this potential effect.

Experiment 2
Methods
Participants and procedures
Thirty-four volunteers were enrolled and were financially compensated for their participation. All participants were right-handed, had normal or corrected to normal vision and had no self-reported neurological or psychiatric disorders. Four participants were excluded because there were not enough trials (less than 30% trials) that remained for EEG analyses since their EEG data was too noisy or they accepted most (more than 60% trials) of the unfair offers. Finally, 30 participants remained for data analysis (15 females, mean age = 23.15 years, *SD* = 3.18).

A similar method was used as in experiment 1, and the practice phase was the same as in experiment 1. In the experimental phase, participants only received offers from humans, and they did not have to interact with computers. After they made their responses toward the monetary splits, a tone would appear, and they still had to judge the time interval between the tones and their responses. Meanwhile, EEG data was recorded during the whole experiment. The whole experiment included 66 trials per condition (22 trials at each action-tone interval, in random order).

EEG recording and analysis
EEG data were collected using 64 Ag/AgCl scalp electrodes placed according to the international 10–20 system (Brain Products). EEG signals were continuously recorded at a 1000 Hz sampling rate. The horizontal and vertical electrooculograms (EOG) were recorded using electrodes that were mounted next to both eyes and above and below the left eye. During the recordings, the electrode FCz was used as the recording reference, and all electrode site impedances were maintained below 10 kΩ.

All offline analyses were performed using MATLAB-based custom scripts and EEGLAB toolbox[46]. EEG signals were band-pass filtered between 0.1 and 40 Hz. The data were re-referenced to the bilateral mastoid electrodes, and the original reference (FCz) was recovered. Based on visual inspection, continuous data contaminated by movement artifacts or extreme noise were deleted. The remaining data were submitted to independent component analysis (ICA). Independent components identified as ocular and muscular artifacts were subsequently removed. Besides, any epochs where EEG activity exceeded +/−200 μV were excluded (3.10% trials were excluded). ERPs were computed time-locked to the stimulus (offer) or action-outcome (tone) onset for each participant and each condition.

Offer-locked ERPs.

Offer-locked epochs were selected from 200 ms pre-stimulus to 800 ms post-stimulus relative to the onset of proposed division. Baseline correction was applied with a 200 ms interval before prime onset. Separate ERPs were calculated for fair and unfair condition. Based on previous studies[47–49] and observation of grand ERPs, FRN was measured as the average amplitude from 250 to 320 ms post offer at Cz; P3 was measured as the mean amplitude from 350 to 450 ms post offer at electrode Pz .

Outcome (Tone)-locked ERP.

Outcome-locked epochs were selected from 200 ms before stimulus (the auditory tone) to 800 ms after, with a 200 ms pre-stimulus baseline. The N1 has a frontocentral maximum and was measured as the average amplitude from 80 to 110 ms using the pooled recordings at electrode sites FCz and Cz, based on observation of the data and previous research[42,50].

Results
Behavioral results - the ultimatum game and intentional binding
As expected, participants accepted most relatively fair offers (98.85%) but rejected a significant proportion of unfair offers (11.72%). The included trial counts for *human fairness accepted* (*M* = 65.07, *SD* = 1.66), *human unfairness rejected* (*M* = 58.26, *SD* = 12.29).

Again, we found a significant effect on the temporal compression in experiment 2. Agents' interval estimates were analyzed using paired-samples t tests. The judged interval when rejected unfair offers (M_{reject} = 323.52, *SD* = 116.23) was significantly shorter than the judged interval when accepted fair offers (M_{accept} = 341.80, *SD* = 118.24), t (30) = 2.73, p = .011, dz = 0.499 (see Fig. 2. 2 A-2B).

Electrophysiological results

Offer-locked ERPs (FRN and P3 see Fig. 3*).*FRN.

A paired-samples t-test was conducted to compare the FRN in the fair condition and in the unfair condition. We found a significant effect of fairness with more negative amplitudes for the unfair condition (*M* = 0.04 μV, *SD* = 4.43) relative to the fair condition (*M* = 0.94 μV, *SD* = 4.29), t (29) = 2.64, p = .013, d = 0.481.

P3.

The analyses of P3 showed a significant effect of fairness as well, with a larger P3 for the fair condition (*M* = 4.91 μV, *SD* = 4.54) than the unfair condition (*M* = 4.17 μV, *SD* = 5.14), t (29) = 2.22, p = .034, d = 0.406.

Outcome (Tone)-locked ERP (N1 see Fig. 4*).*

A paired sample t-test was conducted to compare the N1 in the acceptance of fair offers and in the rejection of unfair offers. We observed that tones following rejecting (unfair offers) responses elicited an attenuated N1 (*M* = -7.03 μV, *SD* = 3.94) compared to those following accepting (fair offers) responses (*M* = -7.82 μV, *SD* = 4.02), t (29) = 2.31, p = .028, d = 0.421.

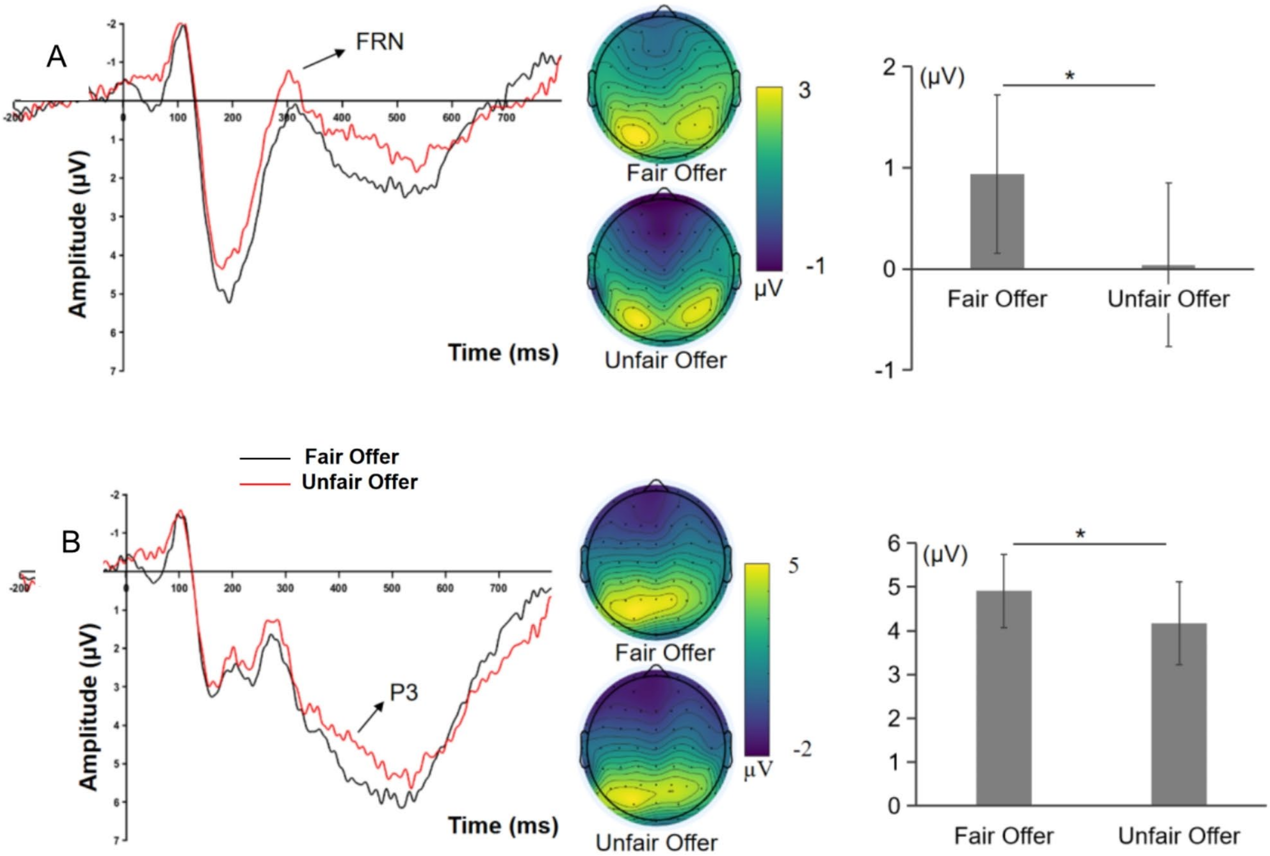

Fig. 3. Offer-locked ERPs results. (**A**) FRN results - Left: Grand-average ERP waveforms at Cz electrode, as elicited by the Fair Offer condition and Unfair Offer condition; Middle: Scalp distributions of FRN (250–320 ms); Right: Mean FRN amplitudes. Error bars represent standard errors of the mean, *$p < .05$. (**B**) P3 results: Left: Grand-average ERP waveforms at Pz electrode; Middle: Scalp distributions of P3 (350–450 ms); Right: Mean P3 amplitudes. Error bars represent standard errors of the mean, *$p < .05$.

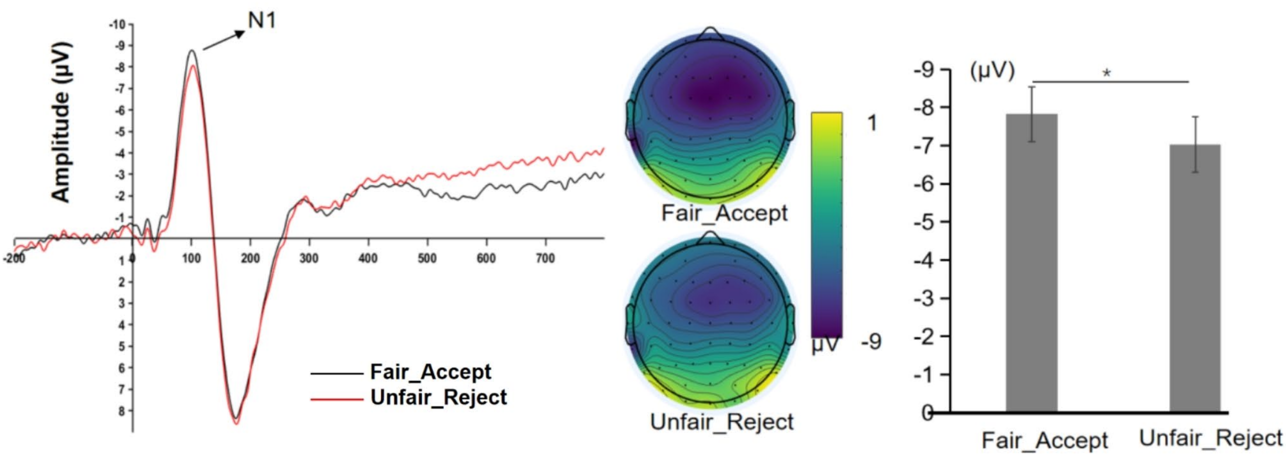

Fig. 4. Outcome (Tone)-locked ERP - N1 results: Left: Auditory evoked potentials with pooled mean amplitudes at FCz and Cz as elicited by Accepting-fairness condition and Rejecting-unfairness condition; Middle: Scalp distributions of N1 (80 – 110 ms); Right: Mean N1 amplitudes. Error bars represent standard errors of the mean, *$p < .05$.

Discussion

The behavior results replicated those of experiment 1. Rejecting unfair offers enhanced temporal compression effect. Again, the results indicated that the rejection of unfair offers produced an experience that participants felt closer toward action outcomes. ERP analyses showed that a more pronounced FRN was elicited by unfair offers compared to fair offers, indicating a more negative social outcome caused by unfair treatment from others. The present experiment also revealed a significant main effect of fairness on P3. Taken together, our results of FRN and P3 replicated previous research on the UG[37,51], suggesting that recipients in the UG may expect fair splits from others (even from strangers) who were supposed to adhere to a social fairness norm, and the unfair division was considered as negative and/or unexpected. Moreover, our results showed an attenuated auditory N1 to self-produced sounds following the rejection of unfair offers than following receiving fair offers. Prior research found that sensory attenuation was closely associated with the sense of agency. This finding suggested that the brain may consider the outcomes of one's veto action as more self-caused in the current experimental setting. The results strengthen precious physiological research testing the relation between sensory attenuation and voluntary actions[40,41,52].

General discussion

In this study, we investigated how a social norm violating context influenced the implicit SoA by measuring temporal compression with electrophysiological recordings. We used the Ultimatum Game to manipulate social interactions. The results of the two experiments replicated previous research on the UG in that participants rejected unfair offers and accepted fair offers more often[16–18]. More interestingly, the rejection of unfair offers increased the temporal compression effect. Furthermore, we found that the brain response (N1) evoked by the sounds, was reduced in amplitude following rejecting unfair splits, compared to accepting fair splits.

A distinctive feature of humans is the high rate of social interaction with strangers. Moral judgments often occur among strangers who interact only once and people generally judge one's behaviors as acceptable or unacceptable based on certain social norms[53]. As in the Ultimatum Game, an unequal split would be considered unfair and unacceptable most of the time, people often reject an unequal split that was even against their own interests[18,19]. The findings suggest that people don't act purely out of actual personal interest, and social factors such as social rules play a significant role in shaping behaviors. More importantly, we found that temporal compression was reduced following the rejection of unfair offers compared to the acceptance of fair ones. One possible explanation for this effect is that people have a social need to adhere to social norms, and the principles of fairness and reciprocity should be maintained. Therefore, rejecting unfair offers is considered a more desirable action than accepting fair ones. As a result, a stronger prediction of the action-effect might be generated, and the following outcome would be psychologically more linked to self-produced effects, which led to the increased temporal compression effect.

Moreover, although participants were unfairly treated and experienced negative emotions, the opportunity to address the unfairness could be quite rewarding[54]. Prior neuroimaging studies have provided evidence that there is no unique social reward pathway in the brain; instead, subjective rewarding experiences during social interactions share the same area with monetary rewards. Hence, punishing norm violators, can activate reward areas irrespective of monetary loss[54,55]. Accordingly, this positive rewarding experience may enhance temporal compression. These results are consistent with previous studies, which have shown that positive emotions (e.g., a positive reward signal) increases temporal compression, while negative emotions (e.g., fear or anger) decreases temporal compression[36]. It has been suggested that emotions are closely linked to self-awareness; when people feel scared, they tend to feel vulnerable and perceive less control over the external world. In contrast, when people feel satisfied, they tend to have a greater sense of control over their action outcomes[56]. There is also a possibility that both cognitive (e.g., action-outcome prediction) and affective processes may influence temporal compression in an interactive way. However, the exact nature of this interaction still needs to be explored in future studies.

Alternatively, as social creatures, people have inner desires to feel justified pride and to avoid feeling shame[57], and the desires are still present when interacting with anonymous strangers[58]. In the UG, players rejected unfair offers may not be out of their concern for reciprocity but of maintaining status and self-power. No matter whether people are aware of their tendency to feel pride and shame or not, they probably are unable to fully control or inhibit these feelings. They may get more aroused in unfair conditions than in fair conditions. Moreover, punishing individuals who violate social norms may contribute to the restoration of pride. This heightened arousal positive emotion may, in turn, enhance temporal compression. These findings align with previous research that explored the impact of arousal and valence on time perception. Specifically, studies have shown that for high-arousal stimuli, positive slides (e.g., puppies) are perceived as shorter in duration compared to negative slides (e.g., snakes)[59]. Another study investigated the influence of arousal on temporal compression and found that greater arousal triggered by stimulus color led to a stronger temporal compression effect[60]. The authors suggested that red color induces a higher arousal status than black color. In the study, controlling the red square produced an increased binding effect compared to controlling the black square.

Additionally, we observed that it took longer to reject unfair offers than to accept fair ones. This suggests that responders deliberate more over how to respond to unfair offers, while fair offers are relatively easy to decide upon. At first glance, these results might seem inconsistent with previous evidence suggesting that difficult action selections reduce temporal compression and the SoA[61]. However, previous studies usually examined action selection in non-social and neutral situations. In contrast, in the present study, emotions are deeply involved, and the meaningful action outcome might have compensated for the effort required in decision-making when rejecting unfair offers.

As mentioned above, we observed increased temporal compression for the rejection of unfair offers, which may be influenced by an interaction between cognitive and emotional factors. The results not only showed that the rejection of unfair offers significantly modifies the temporal perception of self-caused outcomes, but it also provided evidence that the veto attenuates the neural processing of outcomes. The results were consistent with prior electrophysiological research testing action-perception connection in the auditory domain[40,41]. Previous research generally found that sounds caused by voluntary actions generate a reduced neural response than passively listening sound, and it has been suggested that this auditory attenuation generally indicates a predictive mechanism to distinguish between self-produced stimuli and those caused by external factors. Accumulating evidence showed that action intention and the sense of agency generate attenuated neural responses to tones produced by one's own actions[29,41]. Our study demonstrated that rejection of unfair offers caused an attenuated N1 for self-generated sounds indicating that the rejections boosted the implicit sense of agency. In our study, we observed that temporal compression and attenuated neural responses were influenced by the social context. However, it's important to note that the two implicit measures—temporal compression and sensory attenuation—may not be directly related. Previous literature also demonstrated that temporal compression and sensory attenuation are not closely related[31,36], and the underlying mechanisms of the two implicit measures may be different[27,29,36].

It is important to note that the current study did not measure the explicit SoA. Therefore, there is a limitation in linking the results of temporal compression and sensory attenuation directly to SoA. Particularly, prior research indicates that temporal compression might be linked to a more general process which associates causes and effects in time, regardless of agency[33,34]. Some studies have demonstrated an association between temporal compression, sensory attenuation, and agency judgments, while other research has found that implicit and explicit measures of the SoA are not always comparable[36]. Another limitation to note is that, while emotion may play an important role in shaping implicit measures of agency, we did not test emotion directly during the UG task. Future studies are needed to address this gap. In the present study, participants' action choices were confounded with fairness processing, making it challenging to disentangle the two processes. Hence, understanding how these processes interact with each other remains elusive.

Taken together, our findings demonstrate that unfairness not only affects people's behavior but also influences their perception of time and neural responses. We observed that unfair offers were frequently rejected, while fair offers were usually accepted. Additionally, compared to the fair condition, the rejection of unfair offers increased temporal compression and attenuated neural responses to self-initiated sounds. These results suggest that the social context significantly influences both behavior and subjective experience. Future research could provide a more precise understanding of the relationship between social behavior and agency experiences by measuring both implicit and explicit agency and examining neural responses during social interactions.

Data availability

The datasets used and/or analysed during the current study available from all authors (including the corresponding author, first author, and the second author) on reasonable request.

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Author contributions
Y Wang contributions to the conception or design of the work; data analysis; interpretation of data; have drafted the work, and substantively revised it. JX Zhou contributions to data acquisition, data analysis, interpretation of

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Declarations

Competing interests
The authors declare no competing interests.

Ethical standards
All procedures performed in this study were in accordance with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. The local ethics committee approved the experimental protocol. This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

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