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time task against one or more opponents. In reality, both the outcome of the reaction time and the opponents' behavior are under control of the experimenter. In the classical TAP, the winner of the task from each trial gets to punish the loser with an aversive stimulus of variable intensity. We modified the classical TAP so that the participant played the game in two phases. During the first (passive) phase, the participant could only be punished (to elicit aggressive retaliation motivation), in the second (active) phase he was the one able to punish the opponents (to measure aggressive reactive behavior). The experimental conditions were manipulated between the first and the second phase, i.e., one opponent wrote an apologizing note, and the other one did not apologize in his note.

The punishment was moderately painful electric stimulations. The use of electric shock has been used in a number of studies investigating social emotions (e.g., Crockett et al., 2014, 2015; Winston et al., 2014). It has the benefits of eliciting more primitive instincts and more intensive emotional arousals than monetary loss (which is widely adopted as a way of interpersonal transgression). It is presumably less vulnerable to inter-individual variations. An intra-epidermal needle electrode was attached to the left wrist of the participant for cutaneous electrical stimulation (Inui et al., 2002). Great care was taken to ensure that no permanent damage could occur. The participants were informed, at the time of recruitment and before the experiment, that the stimulation would not produce any irreversible effect. Two participant-specific pain intensities were calibrated such that the high intensity stimulation was rated as 8 and the low intensity was rated as 3 on a 0–10 scale (0, no sensation; 10, unbearably painful).

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We employed an IAT (Greenwald et al., 1998) to measure the participant's implicit attitude toward the apologizing and non-apologizing opponents. Compared to explicit measures, such as self-report and behavioral punishment, IAT has the strength to assess unconscious and automatic responses to social and affective stimuli, largely unaffected by the influence of reputation, social desirability, and self-image (cf. Phelps et al., 2000). For our study, the participant had to associate belongings from the apologizing and non-apologizing opponents (memorized before the task) with either negative or positive attributive words. This modified version of IAT was used in a number of previous studies (e.g., Huang et al., 2009; Wu et al., 2013). We hypothesized that participants would respond faster to the apologizing opponent with positive attributive words and to the non-apologizing opponent with negative attributive words (congruent trials), and slower for the non-apologizing opponent's belonging with positive attributes and apologizing opponent with negative words (incongruent trials).

Design and Procedure

Upon arrival, each participant was told that he/she would later play an interactive game together with two opponents already in another room, via intranet. We first measured the pain threshold of the participant and determined the two critical pain intensities for each participant. The low intensity corresponded to the participant's self-report of 3 and the high intensity corresponded to 8 on a scale ranging from 0 to 10. Then each participant was told that the experiment was divided into two parts: first a passive phase during which the participant would be passively punished by the two opponents each time he/she lost a trial. Then an active phase where the participant could actively punish the opponents when they lost. The participant was made to believe that the opponents did not know about the role switching until the second phase.

During the whole experiment, the participant did not meet the two opponents (confederates); the identity of the two opponents was given by his/her (facial) portrait and the label A and B through the intranet. The two opponents were of the same sex as the participant and the associations between portraits and apologizing/non-apologizing were counterbalanced over participants.

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At the beginning of each trial (**Figure 1**, top panel), the computer presented the identity of the opponent (the portrait and the label A or B), indicating against whom the participant was playing for this trial and that this opponent (the active player) was selecting the intensity of the punishment (high or low). Then the reaction time task required the players to press a button ("space key") as fast as possible when a white dot appeared in the center of screen. The punishment intensity chosen by the opponent was subsequently presented on the screen. After that, the outcome of the reaction-time game was displayed. If the opponent won the trial (i.e., responded faster than the participant), the participant would receive the punishment with the intensity chosen by the opponent at the beginning; if the opponent lost the trial, the participant would not be punished. In fact, the outcome of each trial was predetermined by the experimenters.

The participant played as the passive player for a total of 64 trials. For each trial, one of the two opponents (A or B) was randomly selected by the computer to interact with the participant in that trial. A and B opponents were each selected for 32 trials. The probability of winning a trial was 50% for both A and B and the proportion of high intensity punishment chosen by A and B was 75% (24 trials) in total. All the trials were pseudorandomized and the condition with the same punishment intensity would not appear more than three consecutive times.

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After the first passive phase, participants and the opponents had a break time during which the participant received one message from each opponent, which was passed on by the experimenter (the participant did not meet the opponent directly throughout the experiment). Specifically, one opponent apologized to the participant while the other did not. The message from the apologizing opponent was: "Sorry, the punishments I gave you were a bit high, I will modify my choices for the next part. Sorry again for the harm I caused to you." The message from the non-apologizing opponent was: "I find this game rather exciting, I guess the electrical stimulation does not hurt that much, so I chose some higher intensity." The opponent labels (A or B) and the apologizing/non-apologizing messages were counterbalanced over participants.

TABLE 1 | Procedure of the Implicit Association Test.

Block	Task (number of trials)	Corresponding key	
		Left key (F)	Right key (J)
i	Target stimuli reaction (24)	A belongings	B belongings
ii	Attributive words reaction (24)	Positive words	Negative words
iii	Initial association task (24)	A belongings/positive words	B belongings/negative words
iv	**Initial association task (48)**	**A belongings/positive words**	**B belongings/pegative words**
v	Reversed target stimuli reaction (24)	B belongings	A belongings
vi	Reversed association task (24)	B belongings/positive words	A belongings/negative words
vii	**Reversed association task (48)**	**B belongings/positive words**	**A belongings/negative words**

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After the participant read the messages, he/she completed a number of subjective ratings. On a 7-point scale, he/she answered his/her level of unhappiness, anger, willingness to forgive, willingness to punish, willingness to be a friend, and impression for the two opponents respectively. For the "impression" item, 1 means "very bad," and 7 means "very good." For the other items, 1 means "not at all," and 7 means "extremely strong."

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Right after the completion of the subjective ratings, the IAT began. Each participant first had to take 2 min to memorize and associate a number of objects/belongings (target stimuli) to their owners (i.e., the opponents, A and B). Then, the participant performed seven IAT blocks (**Table 1**) in which he/she was instructed to respond to target stimuli and/or attributive words as correctly and quickly as possible. The first two blocks were training blocks. In Block 1, the participant pressed one key (F or J on the keyboard) when A's belongings were presented, and the other key for B's belongings. In Block 2, he/she pressed one key for positive words and the other for negative words. In Block 3 and Block 4, the participant pressed one key for A's belongings or positive words, and pressed another key for B's belongings or negative words. Block 3 served as a training block, familiarizing the participant with the key codes, and Block 4 served as a testing block. In Block 5, the key code for the belongings switched and the participant had to respond to belongings only, as in Block 1. It should be noted that the key code for the attributive words remained the same throughout the whole IAT experiment. Block 6 and Block 7 were similar to Block 3 and Block 4, except that the key code for the belongings switched. Given that we hypothesized that the participant has positive attitude toward the apologizing opponent and negative attitude toward the non-apologizing opponent, we defined the congruent block as the testing block in which the apologizing opponent's belongings and positive attributive words

TABLE 2 | Subjective ratings for apologizing/non-apologizing opponents in Experiment 1.

	Apologizing opponent (Mean ± SD)	Non-apologizing opponent (Mean ± SD)	*t*-value ($n = 36$)	*p*-value
Unhappy	2.08 ± 1.32	2.39 ± 1.62	−1.43	0.160
Anger	1.71 ± 0.98	1.89 ± 1.27	−1.27	0.213
Forgiveness	5.76 ± 1.64	5.84 ± 1.50	−0.27	0.791
Willingness to punish	4.13 ± 1.30	4.00 ± 1.27	0.68	0.500
Willingness to be friend	5.61 ± 1.29	5.37 ± 1.36	1.10	0.277
Impression	5.74 ± 1.13	5.55 ± 1.29	1.16	0.255

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the participant won the trial, the opponent would receive the punishment with the intensity chosen by the participant at the beginning; if the participant lost the trial, the opponent would not be punished. All trials were pseudorandomized such that the same condition would not appear three or more consecutive times. Similar to the passive phase, the active phase consisted of 64 trials. The two opponents interacted with the participant respectively for 32 trials, whose performance was in fact controlled by our program. The proportion of winning trials was 50% for both opponents. After this second phase, the participants were paid and thanked. No participants expressed suspicion of the experiment manipulation.

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The intensity of punishments that the participant selected for the two opponents in the second phase of the TAP was used as an index for the retaliation/forgiveness behavior. For the IAT (implicit attitude), we analyzed the reaction times of congruent and incongruent trials. Steps for the analysis followed the procedure implemented in previous research (i.e., Wu et al., 2013). (1) We removed one participant whose error rate was over 20%, leaving 35 participants for further data analysis. (2) We excluded all the error trials from the analysis of reaction time, i.e., when the participant answered with the wrong response key (average error rate: 5.8%). (3) From the remaining trials, those in which participants did not respond within 3 s and trials in which the reaction times exceeded three standard deviations from the mean in each experimental condition were excluded from the data analysis (0.18% of the trials). Thus, in total, less than 6% of the total trials were excluded.

Results

Subjective Ratings

Ratings on the six items after receiving the messages of the two opponents did not show any significant difference between the two opponents (**Table 2**). There was no gender difference either.

IAT Reaction Time

To examine the impact of apology on the implicit attitude of the victim toward the offenders, we used an IAT construct (Greenwald et al., 1998) to reflect the implicit attitude (positive or negative) toward the apologizing or non-apologizing opponent. Shorter response times in the congruent block and longer response times in the incongruent block indicated stronger association between the apologizing opponent (relative to non-apologizing opponent) and positive concept. The association with positive/negative concept was interpreted as reflecting the participant's implicit attitude toward the target objects. Here, we carried out a two-way ANOVA with congruency as a within-participant factor and gender as a between-participant factor. The interaction was significant, $F(1,33) = 4.76$, $p = 0.036$. Pair-wise comparisons were carried out separately for each gender (**Figure 2**). We found that the reaction times for the female participants in the congruent condition ($M = 786$ ms, SD = 132) were significantly faster than those in the incongruent condition ($M = 885$ ms, SD = 171), $F(1,33) = 5.7$, $p = 0.022$, while there was no significant difference between the two conditions for male participants (congruent: $M = 936$ ms, SD = 299; incongruent: $M = 906$ ms, SD = 221). The main effects of congruency, $F(1,33) = 1.34$, $p = 0.25$, and gender, $F(1,33) = 2.43$, $p = 0.13$, were not significant. For error rate, no significant difference was found between genders, $F(1,30) = 1.16$, $p = 0.29$, or between congruent and incongruent conditions, $F(1,30) = 0.48$, $p = 0.43$. However, the interaction between gender and congruency was significant, $F(1,30) = 4.3$, $p = 0.047$. Specifically, pairwise comparisons

FIGURE 2 | IAT reaction time (Error bars represent standard deviation of the mean value). Congruent: apologizing opponent belongings-positive words/non-apologizing belongings-negative words; incongruent: apologizing opponent belongings-negative words/non-apologizing belongings-positive words). Significance indicators: $*n < 0.05$.

FIGURE 3 | Task display and timing of Experiment 2. Active phase, when the participant selects high level punishment. The critical events for EEG analysis are marked with dash line.

fronto-central area (FC5, FC3, FC1, FCz, FC2, FC4, and FC6), centro-parietal area (CP5, CP3, CP1, CPz, CP2, CP4, and CP6), and parieto-occipital area (PO7, PO5, PO3, POz, PO4, and PO8). The nose was used as online reference channel, and all channels impedances were kept lower than 10 kΩ. To monitor ocular movements and eye blinks, electro-oculographic (EOG) signals were simultaneously recorded from four surface electrodes, one pair placed over the higher and lower eyelid of left eye, the other pair placed lateral to the outer canthus of the each eye.

EEG Data Analysis

Standard procedure for data analysis was employed for the analysis of ERP data (Luck, 2005, Chap. 4). We used Analyzer 2.0 software to analyze the EEG recordings. EEG data were re-referenced offline to the mean of the left and right mastoids. The EEG data contaminated by eye-blinks and movements were corrected using an independent component analysis (ICA) algorithm as implemented in the software. For both the decision phase and the outcome phase, EEG epochs were extracted using a time window of 1000 ms (200 ms pre-stimulus and 800 ms post-stimulus), and baseline corrected using the pre-stimulus time interval. All trials in which EEG voltages exceeded a threshold of ±85 μV during recording were excluded. The EEG data were low-pass filtered below 30 Hz.

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From the grand average ERPs across all the participants in the decision phase, N2 and the LPP were analyzed.

N2, a fronto-centrally distributed negativity around 200–300 ms post-onset, was defined as the mean amplitudes in the time window of 200–280 ms. N2 has been associated with aggressiveness in a previous study (Krämer et al., 2008). EEG data from three participants were excluded due to excessive artifact contaminations within this time window (leaving 23 participant for analysis). For these participants, the number of trials for at least one condition was less than 10 trials (about 30% of the total number of trials in that condition) after artifact rejection. For the simplicity of statistical analysis, we focused on the FCz electrode. We performed a three-way ANOVA with opponent (apologizing vs. non-apologizing) and the punishment intensity that the participant subsequent chosen (high vs. low) as the within-participant factors, and participants' gender as the between-participant factor. Effects over the whole scalp are illustrated with the topographic map (**Figure 4**).

Late positive potential, a component strongly modulated by the emotional intensity of a stimulus (Schupp et al., 2000; Sabatinelli et al., 2007), was defined as the mean amplitudes in the time window of 400–800 ms. EEG data from the same three participants were excluded due to excessive artifact contaminations within this time window. From the grand average ERPs across all the participants in the decision phase, we chose five electrodes along the midline (Fz, FCz, Cz, CPz, and Pz) to represent the LPP component. For statistical analysis of the magnitude of LPP, we carried out a four-way ANOVA with opponent (apologizing or non-apologizing), punishment intensity (high and low), and electrode position (five levels: Fz, FCz, Cz, CPz, and Pz) as the within-participant factors and the participant's gender as the between-participant factor. Again, effects over the whole scalp are illustrated with the topographic map (**Figure 5**). The rationale for the selection of the electrodes for N2 and LPP was that the grand average ERPs showed the strongest effects on the corresponding electrodes for these components and that the electrodes are typically reported for these components in the literature (see, for example, Smillie et al., 2011; Moser et al., 2006, for similar methods of electrodes selection). PASW 20 software was used in the statistical analyses. The Greenhouse–Geisser correction for violation of the ANOVA assumption of sphericity was applied where appropriate. Bonferroni correction was used for multiple comparisons.

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We analyzed ERPs during the outcome phase to see if apology had an effect on the affective/motivational evaluation of win or loss trials. For the grand average ERPs over all the participants in the outcome phase, the FRN and P300 were analyzed. EEG data from four participants were excluded due to excessive artifact

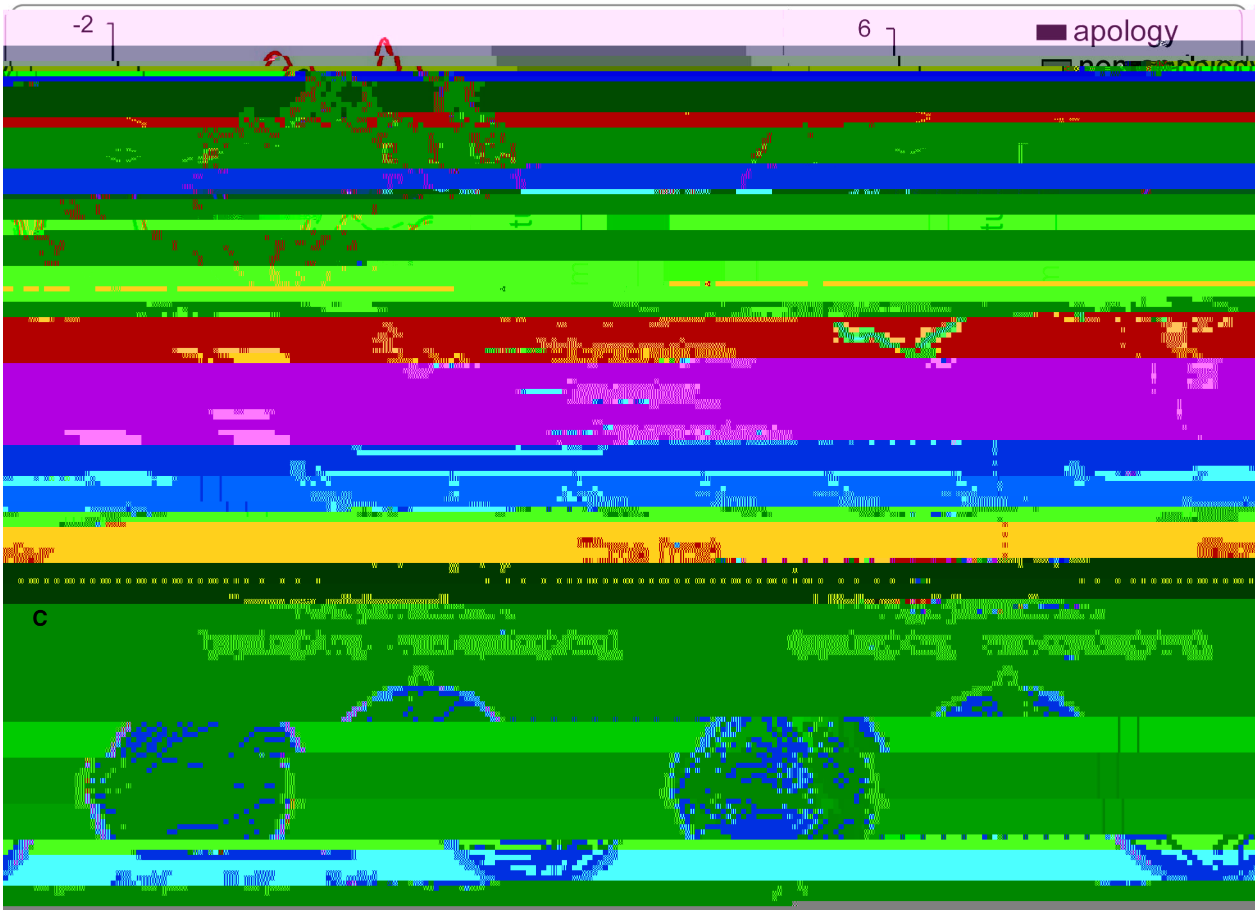

FIGURE 5 | EEG results of the decision phase: LPP. (A) The grand average ERP in the decision phase condition of LPP. **(B)** LPP mean amplitude as a function of opponent and participants' gender. **(C)** Topography of "apologizing—non-apologizing" in high and low punishment. Significance indicators: $^{**}n < 0.001$.

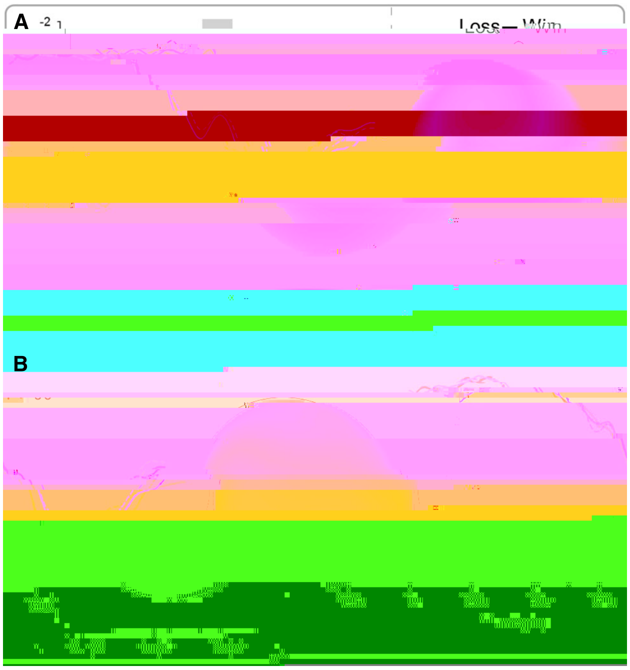

FIGURE 6 | EEG results in the outcome phase. The grand average ERPs of **(A)** FRN and **(B)** P300.

Second, there was a significant interaction between gender and opponent, $F(1,21) = 14.98$, $p = 0.001$ (**Figure 5B**). Pair-wise comparisons showed that the LPP amplitude for the apologizing opponent ($M = 3.77$ μV, SD = 2.91) was significantly larger than for the non-apologizing opponent ($M = 2.27$ μV, SD = 2.81) among female participants, $F(1,21) = 13.9$, $p = 0.001$, whereas for male participants the amplitude did not significantly differ between the apologizing opponent ($M = 0.9$ μV, SD = 2.75) and the non-apologizing opponent ($M = 1.65$ μV, SD = 2.21), $F(1,21) = 3.18$, $p = 0.089$. Additionally, LPP amplitude for the apologizing opponent was significantly larger among female participants ($M = 3.77$ μV, SD = 2.91) than male participants ($M = 0.9$ μV, SD = 2.75), $F(1,21) = 7.7$, $p = 0.011$, whereas female and male participants' amplitudes did not significantly differ for the non-apologizing opponent, $F(1,21) = 0.36$, $p = 0.55$.

We tested the correlation between the apology effect on behavior (the difference between the proportion of high punishment for non-apologizing and apologizing opponent) and the difference between the magnitude of LPP when choosing high intensity punishment for the apologizing opponent and the non-apologizing opponent. The correlation was not significant, $r = 0.041$, $p = 0.85$, consistent with the finding in Experiment 1.

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FRN. FRN (**Figure 6A**) is more pronounced for negative feedback associated with an unfavorable outcome, such as incorrect response or monetary loss (Gehring and Willoughby, 2002). Therefore, if apology influences FRN responses, we would predict a stronger negativity for loss trials against the non-apologizing opponent than the apologizing one. The three-way ANOVA of gender by opponent by outcome valence revealed that the main effect of opponent was not significant, $F(1,21) = 0.367$, $p = 0.55$. However, the main effect of outcome valence was significant, $F(1,21) = 22.91$, $p < 0.001$, with the mean amplitude for the "loss" trials ($M = 4.23$ μV, SD = 3.35) less positive than for the "win" trials ($M = 6.24$ μV, SD = 3.82). The interaction between gender and outcome valence was significant, $F(1,20) = 5.65$, $p = 0.028$. Females had a larger amplitude for winning trials ($M = 7.31$ μV, SD = 3.9) than for losing trials ($M = 4.29$ μV, SD = 3.65), $F(1,20) = 31.37$, $p < 0.001$, whereas the difference between winning ($M = 5.16$ μV, SD = 1.2) and losing trials ($M = 4.15$ μV, SD = 1.1) did not reach significance for males, $F(1,20) = 2.45$, $p = 0.133$.

P300. P300 (**Figure 6B**) has been shown to be sensitive to valence of rewards (Hajcak et al., 2005). Therefore, we expected that the amplitude would be larger in win trials where the non-apologizing opponent would be punished. The main effect of outcome was significant, $F(1,20) = 4.53$, $p = 0.046$. The mean amplitude for "win" trials ($M = 12.95$ μV, SD = 6.05) was significantly larger than that of "loss" trials ($M = 11.97$ μV, SD = 7.02). The main effect of opponent was not significant, $F(1,20) = 0.01$, $p = 0.94$. The main effect of gender was not significant either, $F(1,20) = 3.84$, $p = 0.064$, nor was the interaction between apology and gender, $F(1,20) = 2.216$, $p = 0.15$.

Discussion

The behavioral results of Experiment 2 replicated Experiment 1. Both male and female participants selected significantly lower intensity punishments for the apologizing opponent relative to the non-apologizing opponent.

For the decision phase, when participants were presented with the identity of the opponent for whom they would have to select the punishment, ERP showed that the N2 was not altered by apology. However, the amplitude of N2 was altered by punishment intensity. Specifically, its amplitude was larger when participants chose to inflict high punishment to the opponents than when they chose low punishment. This replicates the results from a previous study using a modified version of the TAP, showing that among the higher trait-aggressive participants, selecting high punishments elicited larger N2 than selecting low punishments (Krämer et al., 2008). Therefore, in line with Krämer et al. (2008), N2 in our experiment might be an indicator of aggressiveness.

As for the LPP amplitude during the decision phase, we found two significant interactions. First, choosing low intensity punishment for the apologizing opponent elicited larger LPP than choosing low punishment for the non-apologizing opponent; but no difference was found between the two types of opponents when high intensity punishments were chosen. Second, we found that gender moderated the LPP amplitude between the apologizing and the non-apologizing opponent. Namely, the apologizing opponent elicited a significantly larger LPP among female than male participants, whereas there was no difference between male and female LPP amplitude for the non-apologizing opponent. Third, we found no significant correlation between LPP responses and behavioral punishment. We defer our discussion of these results to the General Discussion.

TABLE 3 | Subjective ratings for apol[redacted]

	Apolog[redacted] (Mean ±[redacted]	[redacted]ponent [redacted] ± SD)	[redacted]	[redacted]
Unhappy	2.62 ± 1.39	2.73 ± 1.54	−0.36	0.722
Anger	2.12 ± 1.40	2.35 ± 1.29	−0.84	0.407
Forgiveness	5.85 ± 1.35	5.46 ± 1.63	1.10	0.284
Willingness to punish	4.12 ± 0.77	4.65 ± 0.85	−2.67	0.013*
Willingness to play friend	5.19 ± 1.30	4.88 ± 1.56	0.96	0.349
Impression	4.85 ± 1.26	4.65 ± 1.38	0.71	0.486

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During the outcome phase, when the result of the reaction time competition was displayed on the screen, FRN and P300 components were only sensitive to outcome valence (Wu et al., 2012) but were not affected by apology or the participant's punishment choice. Given that no firm conclusion can be drawn from the null effects, these findings will not be discussed further.

GENERAL DISCUSSION

The present study investigated how apology facilitates forgiveness in an interpersonal transgression context. We used an interactive paradigm in which the participant could actively punish two opponents after being passively punished by them. Before he/she had the opportunity to retaliate, the participant received a message from each of the opponents—one apologized for his/her previous behavior and the other one not. Therefore we were able to observe not only the behavioral changes (i.e., the proportion of high punishments selected during retaliation) but also the changes at the cognitive (implicit attitude) and affective/motivational level (ERP) elicited by apology. We discuss the significance of our findings at each of the three levels of analysis and offer a coherent interpretation of such findings, which may help broaden our understandings of the mechanisms of apology and forgiveness.

Apology Changes Female Victims' Implicit Attitude Toward the Offender

In Experiment 1, an IAT administrated after receiving the apology and the non-apology messages revealed that the female participants had a more positive implicit attitude toward the apologizing opponent than to the non-apologizing one, although such an effect was not observed for the male participants (**Figure 2**). The pattern of error rates was consistent with the pattern of the reaction times: for the female participants, responses in the congruent block were both faster and no less accurate than in the incongruent block; for the male participants, responses in the congruent block were both less accurate and no faster than in the incongruent block, indicating that the females had a stronger association between positive concepts and the apologizing opponent.

In accordance with previous studies using only explicit measure of attitude and reactive aggressive behavior, our IAT results confirmed, although only in female, the role of apology in improving victim's impression of their offender (Ohbuchi et al., 1989; Tabak et al., 2012). Tabak et al. (2012) investigated how apology and conciliatory gestures influence forgiveness. They found that the victims' perception of their transgressors' agreeableness mediated the effects of apology and compensation on forgiveness. Importantly, in our paradigm, the participants believed that none of the opponents were aware of the fact that the roles in the game would be switched for the second phase; therefore the apology could not be taken as a strategic move to avoid revenge from the participants. Instead, after being harmed, the expression of remorse and repentance positively changed female participants' perception of the opponent, as the apologizing opponent might have appeared to be a more trustful and considerate person, relative to the non-apologizing opponent.

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