

Cultural influences on the processing of social comparison feedback signals—an ERP study

Daniela M. Pfabigan,¹ Anna M. Wucherer,² Xuena Wang,¹ Xinyue Pan,¹ Claus Lamm,² and Shihui Han¹

¹School of Psychological and Cognitive Sciences, PKU-IDG/McGovern Institute for Brain Research, Beijing Key Laboratory of Behavior and Mental Health, Peking University, 52 Haidian Road, Beijing 100871, China and

²Social, Cognitive and Affective Neuroscience Unit, Department of Basic Psychological Research and Research Methods, Faculty of Psychology, University of Vienna, Liebiggasse 5, Vienna 1010, Austria

Correspondence should be addressed to Shihui Han, School of Psychological and Cognitive Sciences, PKU-IDG/McGovern Institute for Brain Research, Beijing Key Laboratory of Behavior and Mental Health, Peking University, Beijing, China. E-mail: shan@pku.edu.cn.

Abstract

This study investigated cultural differences regarding social connectedness in association with social vs non-social comparison feedback. We performed electroencephalography in 54 Chinese and 49 Western adults while they performed a time estimation task in which response–accuracy feedback was either delivered pertaining to participants' own performance (non-social reference frame) or to the performance of a reference group (social reference frame). Trait interdependence and independence were assessed using a cultural orientations questionnaire. Applying a principal component approach, we observed divergent effects for the two cultural groups during feedback processing. In particular, Feedback-Related Negativity results indicated that non-social (vs social) reference feedback was more salient/motivating for Chinese participants, while Westerners showed the opposite pattern. The results suggest that Chinese individuals perceive a non-social context as more salient than a social comparison context, possibly due to their extensive experience of social comparisons in daily life. The reverse pattern was found in Western participants, for whom a social comparison context is less common and presumably more salient. The cultural differences in neural responses to social vs non-social feedback might be caused by culturally diverse cognitive traits, as well as by exposure to culturally defined behaviour on a systemic level—such as the education system.

Key words: social comparison; culture; FRN; PCA; culture–behaviour–brain loop model

Introduction

Monitoring our own behaviour in relation to fellow human beings facilitates successful social interactions. Individuals can apply internal standards and/or objective criteria to evaluate whether their behaviour is adequate (i.e. applying a non-social reference frame alias an absolute performance standard), or they assess the appropriateness of their behaviour in reference to other individuals (i.e. applying a social reference frame alias a relative performance standard). Performance

comparisons serve as a basis for school/university evaluation systems, competitive sports, as well as (neuro)psychological performance tests (Lindner *et al.*, 2015). These two performance standards pose different processing demands since they differ regarding perceived outcome controllability (higher for non-social reference frames; Neil *et al.*, 1999) and involvement of social comparison processes (higher in social reference frames; Kim *et al.*, 2010). Our recent electrophysiological research further supports this notion by demonstrating these diverging processing demands during early stimulus evaluation when

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comparing social and non-social reference frame feedback (Pfabigan et al., 2018).

However, experimentally induced social context situations often neglect the influence of more abstract concepts on performance monitoring, such as the impact of participants' cultural orientations. Culture, with its shared beliefs and behavioural scripts and norms within a group of individuals (Han et al., 2013), can be regarded as an integral aspect of the social environment. Recent models of culture emphasize a dynamic interaction between cultural values, overt behaviour and biological foundations (e.g. Kitayama and Uskul, 2011; Kim and Sasaki, 2014; Han and Ma, 2015; Han, 2017). The effects of culture on brain and behaviour have often been studied comparing East Asian and Western individuals. For example, East Asians paid more attention to the context and the relationship between objects, while Westerners focused rather on the central object (Kitayama et al., 2003; Imada et al., 2013; Miyamoto, 2013). East Asian individuals are often characterized to view and define their self in relation to others; they view their selves as more interconnected with significant others and encompassing them—referring to an interdependent self-construal style. In contrast, Westerners are thought to view and define their self rather as independent from others and the social context; they view their selves as more autonomous, more egocentric and disjoint from others—referring to an independent self-construal style (Markus and Kitayama, 1991). The different conceptualizations of the self can be traced back to diverging neuronal activation patterns of East Asian and Western individuals (e.g. Zhu et al., 2007; Han and Ma, 2014; Ma et al., 2014). These findings strongly suggest that cultural experiences affect performance monitoring in a social context. Indeed, studies investigating the link between cultural background and performance monitoring showed a moderate association between self-construal style and performance monitoring (Park and Kitayama, 2014; Hitokoto et al., 2016; Zhu et al., 2017).

Cultural traits—and in particular, self-construal style—might be especially important for processing feedback in relation to different reference frames. More interdependent individuals, who are thought to emphasize conformity with socially prescribed roles and duties (Markus and Kitayama, 1991), are inherently required to often compare their own behaviour to their fellow group members. In contrast, more independent individuals engage less often in social comparisons (White and Lehman, 2005). Theoretical accounts of social comparisons (Festinger, 1954) suggest that individuals frequently compare their own behaviour with others for self-evaluation, which is certainly subject to cultural influences. Indeed, recent brain imaging studies reported that, relative to independent individuals, interdependent individuals are more sensitive to social comparisons (Kang et al., 2013) and social norm violations (Mu et al., 2015). Thus, one may assume differences in processing social vs non-social reference feedback in individuals with varying degrees of interdependent self-construal. Intuitively, one could hypothesize that the brain is more sensitive to social vs non-social feedback in East Asian cultures, whereas to non-social vs social feedback in Western cultures (i.e. due to the inherent significance of social feedback for Chinese and of non-social feedback for Western individuals). In line with this assumption, Kang et al. (2013) reported enhanced reward-related activation patterns in East Asian compared to Western participants during social comparison processes. Alternatively, one could hypothesize that the brain is more sensitive to non-social vs social feedback in East Asian cultures due to its frequent practices of respond-

ing to social feedback, whereas the brain may be more sensitive to social vs non-social feedback in Western cultures due to its frequent practices of responding to non-social feedback. In line with this hypothesis, previous research has revealed enhanced frontal and parietal brain activation during culturally non-preferred than during culturally preferred perceptual judgments (Hedden et al., 2008).

This study tested these opposing assumptions by assessing behavioural and neural correlates of social vs non-social reference frame feedback in Chinese (as a subgroup of East Asian individuals) and Westerners and related differences in interdependent self-construal. In contrast to previous studies, we focused on the performance aspect of feedback (asking whether an action was correct or incorrect) instead of its utilitarian aspect (asking whether the optimal reward option was chosen or not) and thus investigated a feedback facet that is regularly encountered in daily lives. Participants performed a time estimation task (Miltner et al., 1997) during electroencephalogram (EEG) recording. They received feedback either in reference to their own performance in the previous trial (non-social reference frame, based on an objective criterion) or in reference to the performance of a group of previous participants (social reference frame, based on the performance of the group).

Previous research has often assessed two specific event-related potentials (ERPs) to capture feedback processing. The Feedback-Related Negativity (FRN; Miltner et al., 1997) is a fronto-central negative deflection within 200–300 ms after feedback onset with amplitude enhancement in response to incorrect compared to correct, unexpected compared to expected and salient compared to irrelevant feedback outcomes (Miltner et al., 1997; Nieuwenhuis et al., 2004; Alexander and Brown, 2011; Pfabigan et al., 2011; Talmi et al., 2013). Functionally, its amplitude variation seems to reflect an early coarse stimulus evaluation (Hajcak et al., 2006), which is considered as an unsigned (or saliency) prediction error signal (Hayden et al., 2011; Talmi et al., 2013). The FRN is followed by the positive-going P300 component, which is most pronounced at parietal electrode sites around 300–500 ms after feedback onset (Duncan Johnson and Donchin, 1977; Polich, 2007). During feedback processing, P300 variation is assumed to reflect already more elaborate stimulus processing caused by motivational saliency, context updating in working memory and top-down cognitive appraisal (Nieuwenhuis et al., 2005; Bellebaum and Daum, 2008; Leng and Zhou, 2010).

It has been shown that an early stimulus evaluation stage indexed by the FRN component differentiated between outcomes of the participants themselves and outcomes of anonymous players during a gambling task (Luo et al., 2015), and that only more elaborate stimulus processing stages (P300) were sensitive to a social comparison manipulation (Wu et al., 2012). Another line of studies directly induced a social evaluation context in which participants had to judge whether unknown individuals had given spontaneous 'like/dislike' or 'accept/reject friendship request' judgements when presented with their faces. The later processing stages (P300) are reported to be sensitive to social evaluations (van der Veen et al., 2014; Dekkers et al., 2015; van der Veen et al., 2016). Reports for early stimulus evaluation are less consistent, although some also reported FRN amplitude variation in response to social evaluations (Kujawa et al., 2014; Sun and Yu, 2014).

As has been previously established in cultural comparison studies (e.g. de Greck et al., 2012; Ma et al., 2014), we used nationality/mother tongue as a proxy for cultural group membership, but additionally assessed dispositional self-construal traits (Singelis, 1994; Korn et al., 2014). We tested

Chinese participants in Beijing and Western participants in Vienna with comparable paradigms. We complemented classical ERP assessment with principal component analysis (PCA; Dien et al., 2005; Dien, 2017), which transforms the data recorded in different laboratories to the same scale of values. This allowed an exploratory descriptive comparison of the results of the two cultural groups. We hypothesized that the reference frame manipulation would be reflected in differential effects for social compared to non-social feedback (Wu et al., 2012; Kujawa et al., 2014; Sun and Yu, 2014; van der Veen et al., 2014; Dekkers et al., 2015; Luo et al., 2015). Our EEG results allowed to test and disentangle two hypotheses with opposing predictions. If cultural experiences lead to enhanced brain activations in response to culturally preferred feedback, Chinese participants should show increased neural responses (FRN and P300 amplitudes) to social than non-social feedback, and Western participants should show increased neural responses to non-social than social feedback. Opposite predictions would stand if cultural experiences result in enhanced brain activations in response to culturally non-preferred feedback. We tested these hypotheses by examining ERP amplitude variation, and we further explored whether possible effects were associated with individuals' independent and interdependent self-construal styles.

We also explored whether participants' sex/gender interacts with the experimental manipulation and cultural traits. Current research suggests effects of sex/gender on social evaluation situations and considers sex/gender as important factor contributing to individual differences in social feedback research (van der Veen et al., 2016; Vanderhasselt et al., 2018). Moreover, an interaction between sex/gender and self-construal traits has been reported previously (Guimond et al., 2006; Flinkenflogel et al., 2017).

Methods

The following section describes the central methodological aspects of our study; additional details are provided in the Supplementary Material.

Participants

Via online platforms and bulletin boards, 56 Chinese and 49 Western volunteers were recruited. Two Chinese participants were excluded from data analysis due to excessive drift artefacts in their EEG data. Thus, the final sample consisted of 103 right-handed volunteers [54 Chinese (29 women); 49 Westerners, (29 women)]. The study conformed to the Declaration of Helsinki (seventh revision, 2013) and was approved by the respective ethics committees. Participants filled in the self-construal scale (SCS; Singelis, 1994) to assess their dispositional independent and interdependent self-construal styles.

Stimuli and procedure

In a modified version of a time estimation task (Miltner et al., 1997; Pfabigan et al., 2014, 2015a), participants were required to estimate the passing of one second and to indicate their estimation via button press. Both experimental conditions (social vs non-social reference) had in common that each trial started with the central presentation of a black fixation dot on a grey screen (1000 ms). Afterwards, a black star replaced the dot for 250 ms. The star indicated the starting point of each time estimation. Subsequently, a blank grey screen was presented for 1750 ms,

during which participants indicated the estimated elapse of 1 s via button press. Feedback was presented 2000 ms after star onset and lasted for 1000 ms to provide time estimation accuracy. Feedback stimuli consisted of black plus and minus symbols (positive/negative feedback). The subsequent intertrial interval depicted again the black fixation dot (1400–1600 ms). Feedback was provided based on individual performance. However, task difficulty (the time window for correct estimations) was adjusted to the individual performance level to guarantee comparable numbers of correct and incorrect trials per condition.

Importantly, for both reference frame conditions, participants were explicitly informed about the adaptive nature of the task and the exact rules. For the non-social reference condition, participants' current estimations were compared to their estimations in preceding trials. For the social reference condition, participants were told that their time estimations were compared to the average estimations of a group of previous participants at our laboratory—see Supplementary Material Section 2.3. The criteria described in both reference conditions were matched approximately and implied comparable changes of the time window for correct estimations. The instructions emphasized a critical aspect of social comparisons: an individual's performance is highly dependent on the often ill-described performance standard of the reference group. Importantly, participants were informed that both conditions were comparable concerning task difficulty and that the reference group should not be seen as competition. Of note, we used the same adaptive algorithm based on individual performance (Miltner et al., 1997) in both conditions to maximize comparability. Nevertheless, in the social reference frame condition, participants were led to believe that their time estimations were compared to the reference group's estimations. The experiment consisted of 10 training and 200 experimental trials (100 per condition). Participants provided ratings regarding their subjective task experience after the experiment.

As behavioural correlates of time estimation performance, differences in response times were calculated between each trial and its preceding trial to describe changes in time estimation directly evoked by feedback; these were further separated in trials yielding correct vs incorrect adjustments.

EEG acquisition and analyses

Stimulus presentation was controlled by E-Prime 2.0 (Psychology Software Tools, Inc., Sharpsburg, PA). For Chinese participants, EEG was recorded via 64 Ag/AgCl ring electrodes mounted in a 10–20 system cap, with an additional electrode below the left eye. EEG signals were collected with a time constant of 10 s up until 1000 Hz (BrainAmp DC; Brain Products GmbH, Gilching, Germany), referenced online against FCz, and AFz as ground electrode. For Western participants, EEG was recorded via 59 Ag/AgCl ring electrodes mounted in a 10–10 system cap, with four additional electrodes to assess eye movements. EEG signals were collected with a DC amplifier set-up (NeuroPrax; neuroConn GmbH, Ilmenau, Germany), referenced online against an electrode on the forehead, which also served as ground electrode.

EEG data were analysed using EEGLAB (Delorme and Makeig, 2004). Offline, high pass (0.1 Hz), and low-pass filters (cut-off frequency 30 Hz, roll-off 6 dB/octave) were applied. All data were re-referenced to linked mastoids, and extended infomax independent component analysis (Bell and Sejnowski, 1995) was applied to detect and discard eye movement-related artefacts.

Table 1. Summary of TSFs chosen to represent FRN and P300 components

		Chinese sample			Western sample			
	TSF	Peak electrode	Peak latency	Extraction cluster	TSF	Peak electrode	Peak latency	Extraction cluster
FRN	TF05SF1	FCz	258	FCz (9 electrodes)	TF07SF1	FCz	248	FCz (7 electrodes)
P300	TF01SF1	Cz	344	Pz (6 electrodes)	TF01SF2	CPz	342	Pz (4 electrodes)

Note: See Supplementary Materials for electrode layouts of the two laboratories.

Table 2. Sample characteristics

		Chinese sample			Western sample				
		Women		Men	Women		Men		
		M	s.d.	M	s.d.	M	s.d.	M	s.d.
Age		21.07	2.03	22.00	2.29	26.00	5.01	27.30	5.78
SCS									
	<i>Independence</i>	4.57	0.60	4.64	0.60	5.00	0.63	4.73	0.68
	<i>Interdependence</i>	4.74	0.59	4.99	0.66	4.16	0.59	4.05	0.52

Afterwards, data segments of the four possible conditions were extracted (social positive, social negative, non-social positive, non-social negative), and semi-automatic artefact correction was conducted. Trials marked by EEGLAB threshold and drift functions were rejected in case visual inspection also indicated artefact affliction. Artefact-free segments were averaged participant- and condition-wise. Please refer to Supplementary Material Section 2.6 for more details.

Afterwards, we computed separate temporospatial PCA (Dien, 2010a, b) of EEG data obtained from each laboratory to complement classical ERP analysis. As a result, two temporospatial factors (TSFs) corresponding to the investigated ERPs were extracted per laboratory (Table 1). This ensured the extraction of functionally equivalent ERPs and minimized effects of overlapping ERP components (Hot et al., 2006; Larson et al., 2016). Acknowledging the variability of the selected TSFs between the groups, we will refer to the factors as FRN TSF and P300 TSF (following Clawson et al., 2017). Please see Supplementary Materials Sections 2.4/2.6 for details regarding the PCA analysis.

Statistical analyses

Separate robust repeated-measure analyses of variance (ANOVAs) were calculated for PCA components per group with the within-subject factors Reference frame (social vs non-social) and Feedback valence (positive vs negative) and the between-subject factor Sex/gender (women vs men). We included Sex/gender as factor in our analyses because recent research suggests that it constitutes an important factor contributing to individual differences in social feedback research (van der Veen et al., 2016; Vanderhasselt et al., 2018). To assess the direction of effects per group, we calculated the overall reference frame effect (social minus non-social trials) for FRN and P300 TSFs, as well as reference frame effects for negative and positive trials separately. We tested these values against zero (one-sample t-test, 1000 bootstrapping runs, 95% confidence intervals) to assess whether and how reference frame influenced amplitude variation in both groups. Since behavioural data were not influenced by technical differences of the recording sites, they were directly compared using the same robust ANOVA model extended by the factor Group (Chinese vs Western).

We also conducted a classical ERP analysis to demonstrate effects in Chinese and Western participants, see Supplementary Materials Section 2.8. Further statistical analyses were performed using PASW 18 (SPSS Inc., IBM Corporation, NY). The significance level was set at $P < 0.05$.

Results

The classical ERP results and the results of additional analyses with age-matched subsamples of Chinese and Western participants are shown in Supplementary Materials Sections 3 and 4.

Behavioural results

Tables 2 and 3 summarize mean and standard deviations (s.d.) of questionnaire, behavioural and rating data. Chinese participants were younger and rated themselves as more interdependent than Western participants, while Western participants rated themselves as more independent than Chinese participants. Only significant main or interaction effects are presented in the main text, see Supplementary Materials Section 3.4 for a complete list of results.

The overall frequency of positive feedback was 48.68% (s.d. = 2.64). Corroborating task validity, trial-to-trial changes in response times were affected by Feedback valence [$T_{Wjt}/c(1.0, 57.0) = 292.41, P < 0.001$] and Estimation adjustment [$T_{Wjt}/c(1.0, 61.3) = 82.052, P < 0.001$] and their interaction [$T_{Wjt}/c(1.0, 83.5) = 270.51, P < 0.001$]. Descriptively, trial-to-trial changes were largest following correct adjustments after negative feedback ($M = 213.75$ ms) and smallest after correct adjustments after positive feedback ($M = 71.74$ ms). All pairwise comparisons were highly significant (all P s < 0.001). Moreover, significant interactions between Group \times Feedback valence [$T_{Wjt}/c(1.0, 57.0) = 6.38, P = 0.012$] and Sex/Gender \times Reference frame \times Feedback valence \times Estimation adjustment [$T_{Wjt}/c(1.0, 90.3) = 5.86, P = 0.019$] were observed. Pairwise comparisons for the first interaction showed that larger trial-to-trial changes in response times were observed in Western compared to Chinese participants [$T_{Wjt}/c(1.0, 58.4) = 4.68, P = 0.031$] following negative feedback. No group differences were found after positive feedback [$T_{Wjt}/c(1.0, 72.4) = 1.06, P = 0.31$]. Significant effects in women drove the latter interaction. The difference between correct and incorrect trial-to-trial adjustments was significant for non-social negative

Table 3. Behavioural and rating data

		Chinese sample				Western sample			
Trial-to-trial changes (ms)		Successful		Unsuccessful		Successful		Unsuccessful	
		M	s.d.	M	s.d.	M	s.d.	M	s.d.
Women	Social pos	77.80	30.83	175.28	94.34	76.20	25.96	158.50	53.25
	Social neg	223.07	101.50	204.48	127.71	225.11	67.85	221.44	81.31
	Non-social pos	74.30	35.97	190.87	109.47	75.29	21.90	164.06	59.44
	Non-social neg	248.98	147.54	215.67	180.26	229.87	83.88	213.35	90.69
Men	Social pos	63.75	18.45	133.98	58.49	71.01	23.67	169.79	59.33
	Social neg	179.62	62.50	145.97	54.10	232.68	65.89	216.11	89.25
	Non-social pos	60.34	16.70	135.32	42.74	84.49	37.44	169.12	54.09
	Non-social neg	178.46	61.08	149.57	64.90	236.59	84.58	227.25	104.84
Post-experimental ratings		Social context		Non-social context		Social context		Non-social context	
		M	s.d.	M	s.d.	M	s.d.	M	s.d.
Women	Blame	4.90	2.01	4.07	2.17	5.45	2.60	5.59	2.85
	Contribution	5.55	1.38	6.00	1.65	6.07	1.46	7.00	1.31
	Controllability	4.55	1.18	4.93	1.49	4.28	2.00	4.72	1.91
	Satisfaction	4.90	1.70	5.00	1.67	5.14	2.03	5.17	2.09
Men	Blame	5.07	2.18	4.81	2.17	6.00	2.58	6.95	2.31
	Contribution	6.00	1.57	5.89	1.72	6.30	2.03	6.90	1.83
	Controllability	4.89	1.63	5.67	1.66	4.60	1.90	5.40	2.46
	Satisfaction	5.00	1.71	5.56	1.65	5.60	2.11	5.05	2.11

Table 4. Means and s.d. of the PCA analysis (in μV)

		Chinese sample				Western sample			
		Women		Men		Women		Men	
		M	s.d.	M	s.d.	M	s.d.	M	s.d.
FRN	Social pos	-0.02	1.45	0.31	1.50	-0.61	2.34	-0.73	1.42
	Social neg	-1.06	2.44	-0.95	1.88	-2.24	3.17	-2.57	1.91
	Non-social pos	-0.29	1.32	0.13	1.50	-0.28	2.04	-0.81	1.47
	Non-social neg	-1.24	2.22	-1.07	1.78	-2.03	2.80	-2.01	2.02
P300	Social pos	5.25	1.86	4.31	1.99	7.53	2.47	6.59	2.67
	Social neg	4.30	2.16	3.91	2.06	7.05	2.83	5.95	2.46
	Non-social pos	5.15	2.12	4.43	1.92	7.60	2.43	6.00	2.55
	Non-social neg	4.44	2.49	4.09	2.16	7.13	2.47	5.39	2.86

trials [$T_{\text{Wjt}/c}(1.0, 51.2) = 13.08, P < 0.001$] but only at a trend level for social negative trials [$T_{\text{Wjt}/c}(1.0, 50.7) = 2.79, P = 0.090$].

PCA results

Figure 1 depicts time courses of the extracted PCA components and the main results per ERP component; Table 4 contains means and s.d.

FRN TSF Chinese. The robust ANOVA resulted in a significant main effect of Feedback valence [$T_{\text{Wjt}/c}(1.0, 47.1) = 21.85, P < 0.001$]. FRN amplitudes were more pronounced after negative than positive feedback. Moreover, Reference frame showed a trend towards more negative FRN amplitudes for non-social than social trials [$T_{\text{Wjt}/c}(1.0, 46.5) = 3.27, P = 0.080$].

FRN TSF Westerners. The robust ANOVA resulted in a significant main effect of Feedback valence [$T_{\text{Wjt}/c}(1.0, 35.6) = 31.14, P < 0.001$] and a significant three-way interaction [$T_{\text{Wjt}/c}(1.0, 40.1) = 4.31, P = 0.042$]. FRN amplitudes were more pronounced after negative than positive feedback. Separate pairwise compa-

risons per Sex/gender showed a significant Reference frame \times Feedback valence interaction in men [$T_{\text{Wjt}/c}(1.0, 17.0) = 8.03, P = 0.013$]. By trend, FRN amplitudes were more negative after social compared to non-social negative feedback in men [$T_{\text{Wjt}/c}(1.0, 17.0) = 4.57, P = 0.045$, not confirmed].

P300 TSF Chinese. The robust ANOVA resulted in a significant main effect of Feedback valence [$T_{\text{Wjt}/c}(1.0, 47.9) = 15.43, P < 0.001$]. P300 amplitudes were more positive following positive compared to negative feedback.

P300 TSF Westerners. The robust ANOVA resulted in a significant main effect of Feedback valence [$T_{\text{Wjt}/c}(1.0, 32.5) = 10.78, P = 0.003$], a trend effect of Sex/gender [$T_{\text{Wjt}/c}(1.0, 35.9) = 3.63, P = 0.060$], and a significant Reference frame \times Sex/gender interaction [$T_{\text{Wjt}/c}(1.0, 43.0) = 5.02, P = 0.033$]. P300 amplitudes were more positive following positive compared to negative feedback. Regarding the interaction, P300 amplitudes were larger following social compared to non-social feedback [$T_{\text{Wjt}/c}(1.0, 17.0) = 8.57, P = 0.032$] in men. Moreover, P300 amplitudes

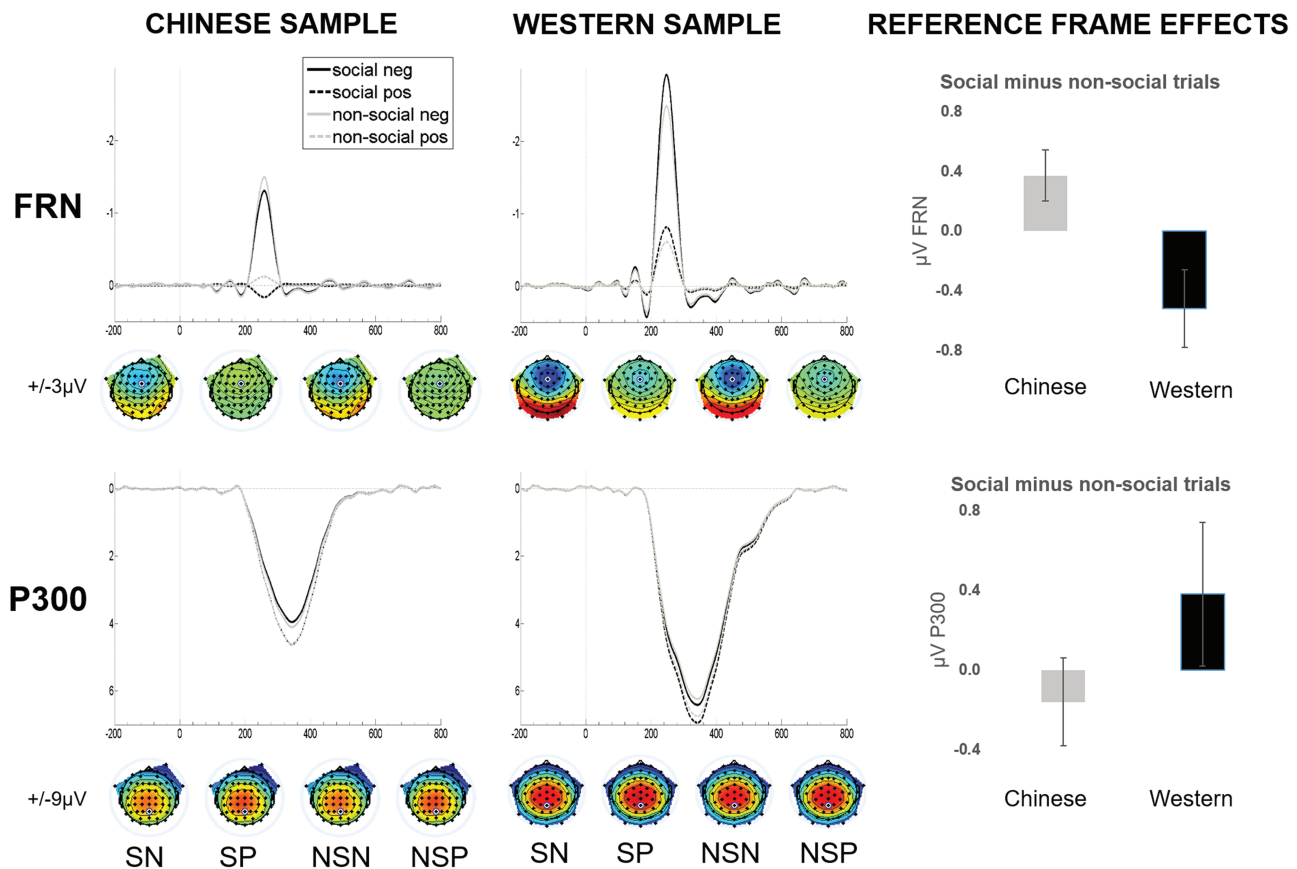


Fig. 1. PCA time courses of the four feedback conditions. PCA components in Chinese (left column) and Western participants (middle column) are presented for FRN and P300 ERPs (negative is plotted upwards per convention). Topographical scalp plots of the respective PCA components per condition are placed below each time course (at the respective peak latencies, Table 1). The right-hand column depicts bar graphs of the overall reference frame effects of each ERP component per group. Error bars denote standard error of mean. Note: SN = social negative, SP = social positive, NSN = non-social negative, NSP = non-social positive.

Table 5. PCA reference frame effects

Reference frame effects	Chinese sample					Western sample				
	Mean	s.d.	P	CI-lower bound	CI-upper bound	Mean	s.d.	P	CI-lower bound	CI-upper bound
FRN TFSF										
Overall	0.37	1.25	0.035	0.05	0.69	-0.52	1.84	0.043	-0.98	-0.02
Negative trials	0.15	0.97	0.260	-0.12	0.41	-0.35	1.34	0.067	-0.71	0.00
Positive trials	0.22	0.80	0.043	0.03	0.44	-0.17	1.07	0.261	-0.46	0.11
P300 TFSF										
Overall	-0.16	1.63	0.476	-0.63	0.27	0.38	2.49	0.301	-0.29	1.10
Negative trials	-0.16	1.12	0.312	-0.48	0.13	0.18	1.43	0.386	-0.20	0.58
Positive trials	0.00	0.92	0.993	-0.25	0.24	0.20	1.47	0.352	-0.20	0.59

were larger in women than men in non-social trials [$T_{WJ}/c(1.0, 33.7) = 5.67, P = 0.027$].

Table 5 demonstrates the results of the t-tests against zero when testing the reference frame effects (social minus non-social trials). Regarding FRN TFSF, Chinese participants showed overall a positive reference frame effect, i.e. more negative amplitudes following non-social than social feedback, which differed significantly from zero. In contrast, Western participants showed overall a negative reference frame effect, i.e. more negative amplitudes following social than non-social feedback, which also differed significantly from zero. The (non-overlapping) confidence intervals of the two groups

indicate opposing overall reference frame effects in Chinese and Western participants. The FRN TFSF reference frame effects for negative and positive feedback pointed descriptively in the same direction but were not significant. No significant effects were observed for P300 TFSF reference frame effects.

Discussion

This study investigated cultural differences in brain responses to social vs non-social comparison feedback. We assessed ERPs in response to accuracy feedback according to either objective performance standards or a social reference standard. In line with

our overall prediction, evaluation of feedback saliency indexed by FRN TSF amplitudes showed opposing effects in the two cultures. While Chinese participants showed generally larger FRN amplitude differences for non-social compared to social feedback, Western participants showed the reversed pattern. More elaborate feedback processing was differentially affected by the experimental manipulation only in male Western participants, who showed enhanced P300 TSF amplitudes for social compared to non-social reference frame feedback. Interdependent self-construals were only weakly linked to the observed neural correlates. Subtle sex/gender differences were observed on both the neural and the behavioural level.

FRN amplitude enhancement is often interpreted as saliency prediction error during early stimulus evaluation (Alexander and Brown, 2011; Pfabigan et al., 2011; Talmi et al., 2013; Hauser et al., 2014). Thus, the current results suggest that Chinese participants evaluated non-social feedback as more salient than social one irrespective of feedback valence, while Western participants showed a reversed evaluation pattern. At first glance, this interpretation seems at odds with claims accompanying interdependent self-construals endorsed by individuals from East Asian cultures and the recent finding that interdependent participants were more sensitive to social comparison than independent ones (Kang et al., 2013). Moreover, it contradicts previous findings of comparable neural responses to self- and other-related errors in East Asian participants, while concurrently, Western participants showed enhanced error activity for self-related errors (Kitayama and Park, 2014). However, interdependent cultures are characterized by emphasizing a focus on the behaviour of others (Markus and Kitayama, 1991) and are thus assumed to frequently engage in social comparison processes (White and Lehman, 2005). Therefore, processing of social comparison information could be regarded as a default state for individuals with higher interdependence scores, since they engage in social comparisons on a daily basis. Consequently, the social reference frame condition might therefore be the default feedback setting for the current Chinese participants, while feedback without any social comparison component might be less common, i.e. therefore more salient for them. This assumption can be further supported by reports of highly competitive educational systems in East Asian countries, in which social comparisons are prevalent (Shih and Alexander, 2000; White and Lehman, 2005). In contrast, for Western participants, the non-social reference frame could be considered as the default state since they are less often required to compare their behaviour/performance to others. Thus, a social comparison context could be more salient for them, which is in line with previous research (Hedden et al., 2008). Along these lines, FRN TSF amplitudes were more negative for social compared to non-social feedback in Western participants (see also Pfabigan et al., 2018).

There is another important aspect of the current reference frame manipulation that is related to social comparisons in educational contexts. Social comparison feedback is often more ambiguous than non-social feedback, since it fails to contain specific information regarding the performance level of the comparison group. For example, the current manipulation explained the adaptive nature and the related changes of the size of the reference group but left out information of the exact numbers in milliseconds. This was only mentioned implicitly with the information that both experimental conditions were comparable regarding task difficulty. Thus, based on social comparison feedback, it might be more difficult to predict whether one's own performance is adequate or not. Along these lines, studies investigating ambiguous feedback reported that feedback ERPs

were distinctively sensitive to this manipulation (Pfabigan et al., 2015b; Gibbons et al., 2016). The different response patterns in both groups thus again suggest that individuals with more social comparison experience are less susceptible to uncertainty introduced by social comparison feedback.

More elaborate feedback processing at a later stage, indexed by P300 TSF amplitudes showed processing differences between social and non-social reference frames only in male Western participants, irrespective of feedback valence. This result indicates that context updating/cognitive appraisal of social stimuli required more attentional resources in those participants (Nieuwenhuis et al., 2005; Bellebaum and Daum, 2008). This is consistent with the idea that social comparison feedback is perceived as less common in Western cultures. P300 sensitivity to the social vs non-social manipulation, as observed for our male Western sample, is in accord with social judgement studies (van der Veen et al., 2014; Dekkers et al., 2015) but in contrast to a social comparison study (Wu et al., 2012). The latter authors linked performance feedback in an estimation task with monetary gains and losses while two Chinese participants (strangers) compared their performance. Thus, this experiment clearly introduced a social reference frame for feedback delivery. However, P300 amplitudes were sensitive to the amount of gains/losses compared to the second participant such that larger P300 amplitudes were associated with larger gains/losses for oneself in comparison to the second participant. In contrast, the current Chinese participants did not significantly differentiate between the two reference frames. However, linking performance feedback with the possibility that two individuals are differently rewarded or punished for the same performance might have induced additional top-down influence of fairness considerations that interacted with social comparison processes. Indeed, fairness of asset distributions is reflected in P300 amplitude variation (Hewig et al., 2011; Qu et al., 2013). Thus, future studies should take the influence of fairness considerations into account when addressing social comparison processes (e.g. Flinkenflogel et al., 2017).

On the behavioural level, changes in trial-to-trial response times were larger in Western than Chinese participants after negative feedback. This diverging pattern of results suggests that the two groups employed different cognitive strategies when performing the time estimation task.

The observed sex/gender effects were rather small in this study but pointed towards different cultural patterns. Trial-to-trial response time changes showed a significant interaction with reference frame only in women, while P300 amplitudes were more pronounced in Western woman than men for non-social feedback. FRN reference frame effects were by trend more pronounced in Western men than women. We consider it important to report the current sex/gender results to provide a more comprehensive account of our experimental manipulation and to avoid biasing our perception of potential sex/gender effects (Eliot, 2011). Therefore, we encourage future studies to always report sex/gender results given that their sample size allows reliable analyses.

The current results are in line with the culture-behaviour-brain loop model of human development (Han and Ma, 2015), which emphasizes the reciprocal influence of culture, behaviour and the brain. As suggested by the model, cultural group differences in brain activity in the current performance monitoring experiment were weakly linked to the cultural value of interdependence. In a similar vein, culture contextualizes behaviour, such as, for example, educational systems, which in turn might shape brain activity observed in the current experiment. Thus,

the current performance monitoring study strongly emphasizes that research has to be cautious when generalizing findings of different cultural groups.

A limitation of the current study pertains to the age difference between the two cultural groups. Since both samples primarily consisted of university students, this reflects another difference between the educational systems in the two cultures. To assess whether observed group differences were due to these age differences, we conducted PCA and ERP analyses again with age-matched subsamples (section 4). Descriptively, the results of this analysis mostly paralleled those of the full sample, though with less statistical power. We are thus confident that the observed cultural group differences were not caused by age differences between the groups.

Our results interpretation focused on the PCA results rather than the classical ERP analysis to decrease disruptive effects of the two recording sites and ERP component overlap. Overall valence effects and FRN results were observed reliably with both methods. Only for P300 results in Chinese, effects of reference frame and interactions with sex/gender were less coherent across both analysis methods (see sections 3.3 and 3.4). Nevertheless, the direction of the effects was mostly comparable. The classical ERP analysis was a bit more 'susceptible' to detect sex/gender effects. This clearly emphasizes the importance of choosing appropriate analytical methods to minimize possible confounding variables in future cultural neuroscience research, in particular given the current replication efforts to establish reproducibility as indisputable component of empirical research (Schmidt, 2009; Pashler and Harris, 2012; Open Science Collaboration, 2015).

The observed FRN TFSF waveforms look different compared to those reported in previous research (e.g. Foti et al., 2011; Ethridge et al., 2017), which observed a positive deflection on rewarding feedback trials, while the current study showed a negative deflection on incorrect feedback trials. This might be due to the fact that previous studies focused on utilitarian feedback aspects (gain vs no-gain), which resulted in a so-called Reward Positivity (Proudfit, 2015). In contrast, the current study emphasized the performance aspect of feedback (correct vs incorrect), which elicits a classical FRN. Along these lines, Van Meel and Van Heijningen (2010) suggested that functionally different processes might be at work when monitoring utilitarian vs performance feedback aspects. Overall, the emphasis on different feedback aspects limits the comparability of the current PCA results with these previous studies.

Our interpretation of diverging default comparison modes for Chinese and Western participants awaits further testing. For example, stronger claims of a 'habitual social (or non-social) comparison style' could be made by using priming procedures to emphasize interdependent vs independent self-construal styles (e.g. Sui and Han, 2007). Moreover, individual differences in social comparison orientation (Gibbons and Buunk, 1999), the individual preference to engage in social comparison processes, might play a role in this regard. Putting social cognition interpretations aside, it is also possible that cultural experiences influence the processing of ambiguous feedback. This would put the personality trait of intolerance of uncertainty in the focus, which is reported to impact feedback processing (Nelson et al., 2016).

Conclusion

The current study suggests that a social comparison context might be more of a default context for Chinese than Western individuals and thus produces less influences on brain activity in

response to social feedback in Chinese participants. This group preference might be partly attributable to cultural values such as interdependence, but also to more systemic cultural influences such as the respective educational system. The current study highlights the role of culture during social comparison processes, which are of considerable importance for individual well-being, social interaction and psychological health (e.g. Swallow and Kuiper, 1988; Baumeister and Leary, 1995; Hughes and Beer, 2013; Rutledge et al., 2016).

Supplementary data

Supplementary data are available at SCAN online.

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