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# ERP correlates of social conformity in a line judgment task

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## Abstract

**Background:** Previous research showed that individuals have a natural tendency to conform to others. This study investigated the temporal characteristics of neural processing involved in social conformity by recording participants' brain potentials in performing a line judgment task. After making his initial choice, a participant was presented with the choices of four same-sex group members, which could be congruent or highly or moderately incongruent with the participant's own choice. The participant was then immediately given a second opportunity to respond to the same stimulus.

**Results:** Participants were more likely to conform to the group members by changing their initial choices when these choices were in conflict with the group's choices, and this behavioral adjustment occurred more often as the level of incongruence increased. Electrophysiologically, group choices that were incongruent with the participant's choice elicited more negative-going medial frontal negativity (MFN), a component associated with processing expectancy violation, than those that were congruent with the participant's choice, and the size of this effect increased as the level of incongruence increased. Moreover, at both levels of incongruence, the MFN responses were more negative-going for incongruent trials in which participants subsequently performed behavioral adjustment than for trials in which they stuck to their initial choices. Furthermore, over individual participants, participants who were more likely to conform to others (i.e., changing their initial choices) exhibited stronger MFN effect than individuals who were more independent.

**Conclusions:** These findings suggest that incongruence with group choices or opinions can elicit brain responses that are similar to those elicited by violation of non-social expectancy in outcome evaluation and performance monitoring, and these brain signals are utilized in the following behavioral adjustment. The present research complements recent brain imaging studies by showing the temporal characteristics of neural processing involved in social conformity and by suggesting common mechanisms for reinforcement learning in social and non-social situations.


**Keywords:** Social conformity, Behavioral adjustment, Reinforcement learning, ERP, MFN

## Background

I di id al e d cha ge hei i i ial ch ice i- i a ch i h he aj i f he g he a e i , a he e ha ha bee e ed a cial c - f i [1]. Si ce A ch' i ee i g e e i e i g a li e j dg e a k [2], diffe e i a i de l i g cial c f i ha e bee e l ed i a be f die ( ee [3] f a e ie ). I di id al ha e he de i e f a acc a e i e e a i f eali a d he i f a i c ce i g eali i i fficie , he a el he ide ch i f a i i e e- a i a d beha e acc di gl (i f a i al c f i ). I di id al al ha e he de i e b ai a al f g e be a d a cha ge hei beha i a id cial ejec i , e e h gh he i a el c i e h ld hei igi al a i de ( a i e c f i ; ee [4]). The e ce e a e cl el i e ela ed a d dif- fic l di e a gle he e icall a d e i icall [5].

Rece die f c he b ai c e i l ed i cial c f i , h i g ha cial (g i- i ) a al e he b ai ac i i i l ed i e cei i g he a k-ele a i f a i . Be e al. [6] f d ha

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e e e e f he c ld al e a ici a ’ i i ial j dg e i a e al a i a k a d he b ai ac i i i egi i lica ed i e al a i . Zaki e al. [7] de - a ed ha e e cial , i.e., g i i , affec ed i di id al’ e al e e e a i f bjec i e al e a ig ed i li b i c ea i g he ac i i i b ai egi i l ed i e a d ce i g, ch a cle acc be a d bi f al c e ( ee al [8]). O he he ha d, he i di id al ick hei ch ice i face f g e be ’ c flic i g i i , he b ai egi i l ed i e i ce i g, ch a a gdala a d ca da e a e ac i a ed [6]; he i di id al fi d ha hei ch ice a e diffe e f he aj i f he g , he b ai egi a cia ed i h ega i e affec i e a e , i.e., a e i i la a d a e i ci g la e, a e ac i- a ed [9], a d he e ac i a i a e he b e- e beha i al adj e . A d b Kl cha e e al. [10] f d ha c flic i h g i i igge ed ac i a- i i he al ci g la e e a d deac i a i i he e - al ia a d ig al cha ge i he e egi edic ed e e di ec l ided i h feedback c i ge hei ac i ch ice , a di i i che e a be e e hele c a ed i h a i lici , l g-e abli hed cial c ce i g a e di ib i a d a i la i f hi b he di i i che e ld elici he FRN e acc a el , he MFN e e . Ba ed he e d-ie a d ba ed he gge i ha cial g e ke c f i ia echa i f ei f ce e lea -i g [10], e edic ed ha g ch ice i c g e i h he a ici a ' i i ial ch ice i he li e j dg e a k ld elici e ega i e-g i g MFN e e he a ici a ha c g e g ch ice , a i-a ch i h he c i e a ki d f i la i f cial [3]. M e e , he ag i de f MFN igh i-c ea e a a f c i f he le el f i c g e ce. F he-e, e h he i ed ha he ag i de f MFN i e cei i g i c g e g ch ice c ld be diffe e -ia ed acc di g he he he a ici a b e e l cha ged hei i i ial ch ice . I he d , e ega-i e-g i g MFN e e ld lead a highe likeli-h d f he a ici a b e e l cha gi g hei i i ial ch ice . Fi all , ac a ici a , he i e f he MFN diffe e ce c ld al edic i di id al diffe e ce i he he cha gi g i i ial ch ice c f g i i . S ch fi di g ld ide i a i igh c ce i g he e al cha ac e i ic f e al -ce e del i g cial c f i .

## Results

A g he e -f EEG a ici a , f a ici-a a ed ha he di belie ed he e f he e e i-e i a -e e i ai e; e a ici a c f ed g e be i le ha 5 ial f ei-he highl de a el i c g e c di i . The e a ici a e e e cl ded f f he da a a al i .

### Behavioral results

T ial i hich he a ici a did e d i hi i e li i (2 ec d ) he i i ial a d/ ec d e e-a i f he li e i l e e e cl ded f da a a a-l i , a i g 1.18% f he al da a i (180 ial f he "highl i c g e ", 140 f he " de a el i c g e ", a d 180 f he "c g e " f each a ici-a ). T ial i hich he a ici a cha ged hei i i ial ch ice d i g he ec d e e a i f he li e i l (i.e., e hibi i g cial c f i ) e e e c ded a "cha ge" (a ed " cha ge") ial . We calc la ed he cha ge a e a he e ce f cha ge ial f he al ial a each le el f i c g e ce.

A i dica ed b Fig e 2, he a e f cha ge i c ea ed a a f c i f he i c g e ce le el. A al i f a ia ce (ANOVA) e ealed a ig ifica ai effec , $F(2, 36) = 43.81$, $p < 0.001$, i h he diffe e ce be ee c di i all bei g ig ifica ($ps < 0.01$): highl i c g e ( ea ± SD, 0.60 ± 0.29) . de a el i c g e (0.16 ± 0.11) . c -g e (0.07 ± 0.13) c di i .

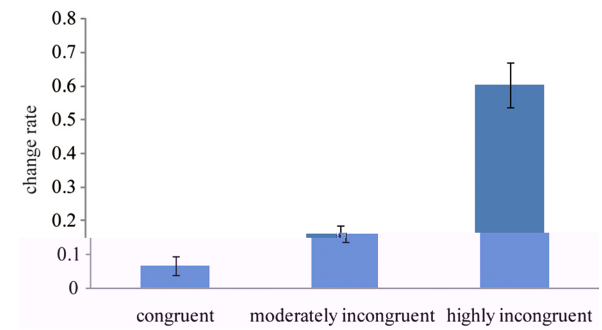


**Figure 2 The rate of making behavioral adjustment (i.e., making a response different from the initial one) in the second presentation of the line stimulus, depicted as a function of the incongruence level.** Error bars represented standard errors of the means.

### ERP results

We f c ed he ERP e e i e-l cked he e-e a i f g ch ice (Fig e 3A), i g he ea a li de i he 250–350 i e i d f a i ical . ANOVA i h le el f i c g e ce (highl i c -g e . de a el i c g e . c g e ), elec de (F , FC , C , CP , P ) a d la -e ali (lef , lef - iddle, iddle a d igh - iddle, igh ) a h ee i hi - a ici a fac f d a ig ifica ai ef-fec f i c g e ce le el, $F(2, 36) = 64.57$, $p < 0.001$, g-ge i g ha he MFN e e e e i c ea i gl e ega i e-g i g f he c g e ial (8.56 ± 1.13 μV), he de a el i c g e ial (5.72 ± 1.07 μV), a d he highl i c g e ial (3.98 ± 1.13 μV). The diffe e ce be ee c di i e e all ig ifica af e B fe i c ec i , $ps < 0.001$. The ai effec f elec de a al ig ifica , $F(4, 72) = 5.00$, $p < 0.01$, a d i i e ac ed i h le el f i c g e ce, $F(8, 144) = 6.17$, $p < 0.001$. I i clea f Fig e 4A ha , agai he c g e c di-i , he c g e ce (i.e., he MFN) effec f b h he highl i c g e a d de a el i c g e c di i e e la ge a a e i -f al i e .

Gi e ha he MFN a ef c ld be affec ed b b e e P300 e e hich a e ai l a cia ed i h l f e e c EEG , e fil e ed he EEG da a i h a 2 – 20 H ba d a ( ee [14,20,21] f i ila e a e ). Mea a li de i he 250 – 350 i e i d af e fil e i g e e b i ed he 3 (highl i c g e . de a el i c g e . c g e ) 5 (F , FC , C , CP , P ) 5 (lef , lef - iddle, iddle a d igh - iddle, igh ) e ea ed- ea e ANOVA. The a e f effec a e e iall he a e a he e i he ab e a al i . The ai effec f i c g e ce le el

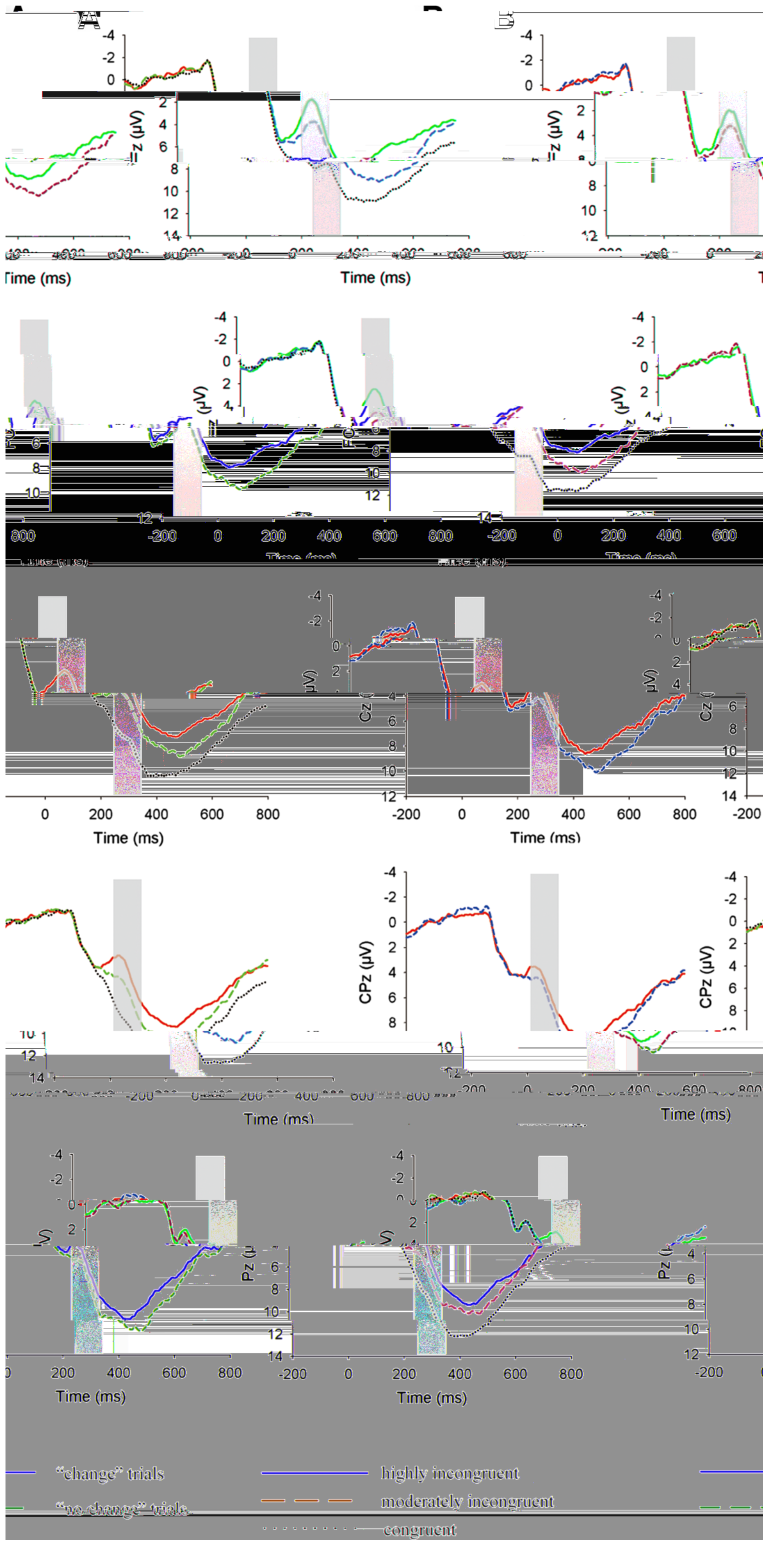


**Figure 3 (A) ERP responses at the midline Fz, FCz, Cz, CPz, and Pz, time-locked to the onset of the presentation of group choices and categorized by level of incongruence.** The shaded 250–350 ms window was for the calculation of the mean amplitudes of the MFN responses; **(B)** ERP responses at the midline Fz, FCz, Cz, CPz and Pz, time-locked to the onset of the presentation of incongruent group choices and categorized by subsequent behavioral tendency (change vs. no change), clasping over the highly and moderately incongruent conditions. The shaded 250–350 ms window was for the calculation of the mean amplitudes of the MFN responses.

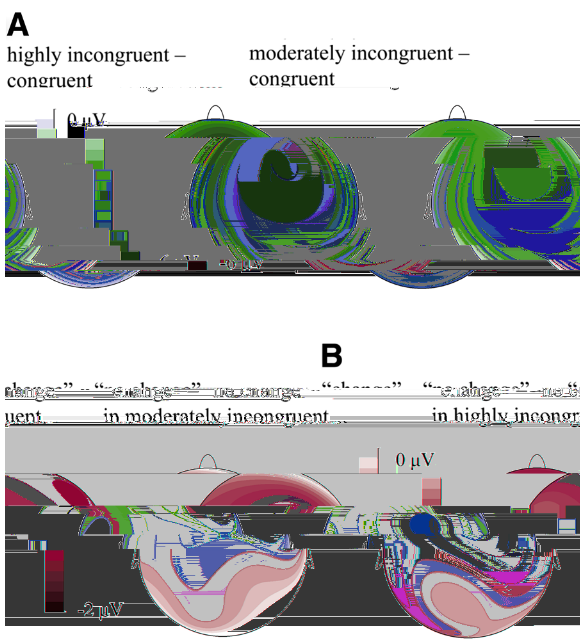


**Figure 4** **(A) topographic maps for the MFN effects evoked by group choices, categorized by level of incongruence; (B) topographic maps for the MFN differences evoked by incongruent group choices, categorized by behavioral tendency (change vs. no change).**

a ig ifica , $F(2, 36) = 30.78$, $p < 0.001$, i dica i g ha he MFN e e e e i c ea i gl e ega i e-g i g f he c g e (0.26 ± 0.32 μV), he de a el i c g e (−0.54 ± 0.23 μV), a d he highl i c g e (−1.05 ± 0.32 μV) ial . The i e ac i be ee elec de a d i c g e ce le el a al ig ifica , $F(8, 144) = 4.93$, $p < 0.02$, gge i g ha he MFN effec a ied e elec de i e ( he la ge i he a e i -f al e gi ). De ailed c a i c fi ed hi b e a i .

N e ha , f i lici f e , he f ll i g a al i he MFN effec a e ic ed he effec a ife ed he a e i -f al elec de (F3, F1, F , F2, F4, FC3, FC1, FC , FC2, FC4) he e he MFN effec a he la ge .

T e a i e he he he MFN e e i ce i g g ch ice a edic i e f he he he a ici a ld be e l cha ge hei i i ial ch ice i he ec d e e a i f li e i l , e c a ed ERP e e f de a el a d highl i c g e ial ha e e f ll ed b beha i al adj e i h h e ial i hich he a ici a ick i h hei i i ial ch ice (Fig e 3B). He e e a al ed he da a i a . Fi l e c lla ed ERP e e e he de a el a d highl i c g e ial b di ided he acc di g he he he a ici a cha ged ck hei i i ial ch ice i he ial (Fig e 3B). ANOVA i h beha i al e de c (cha ge . cha ge) a d elec de a i hi - a ici a fac f d a ig ifica ai effec f beha i al adj e , $F(1, 18) = 11.24$, $p < 0.01$, i h ial c ai i g ch ice cha ge elici i g e ega i e-g i g FRN e e (2.32 ± 1.16 μV) ha ial c ai i g cha ge (3.56 ± 1.12 μV). A e ial ble i h hi a a-l i i ha i ig ed he ibili f he MFN effec f beha i al adj e i e ac i g i h he le el f i c g e ce. The ef e e c d c ed a ec d a al i i hich he i c g e le el (highl . de a el i c g e ), beha i al e de c (cha ge . cha ge), a d elec de e e ea ed a h ee i hi - a ici a fac . Gi e ha 5 a ici a ( f he 19) e hibi ed beha i al adj e (i.e., cha gi g hei ch ice ) i le ha 10 ial a ei he he high i c g e de a el i c g e le el, he e a ici a e e e cl ded f a al i ( ee [16,22] f i ila ea e ). ANOVA e ealed a ig-ifica ai effec f beha i al adj e , $F(1, 13) = 8.32$, $p < 0.02$, i h ial i l i g ch ice cha ge eli-ci i g e ega i e-g i g MFN e e (4.38 ± 1.40 μV) ha ial i l i g cha ge (5.31 ± 1.40 μV). I -a l , hi beha i al adj e effec a affec ed b he le el f i c g e ce ( he a e i -f al elec de ; ee Fig e 4B), a he i e ac i be ee beha i al e de c a d le el f i c g e ce a fa f bei g ig ifi-ca , $F(1, 13) < 1$. Th he a f da a a al i d ced he a e a e f beha i al adj e effec .

N e, i hi a al i e did i cl de he "c g e " c di i i hich he a ici a e e h g ch ice c i e i h hei . He e he a ici a faced c flic be ee hei ch ice a d g i i , a d he ce he e ded i ge e al ick hei i i ial ch ice . F he all e ce age f ial he did cha ge hei i d (7%), i a likel ha he a ici-a e f ed he cha ge f cial c f i .

I addi i , e ed a ial-b - ial bi a l gi ic eg e i i e iga e he he he MFN e e a edic -i e f b e e beha i i a a ic la ial. Mea a li de i each 100 i e i d f 150 550 e e defi ed a f i de e de a iable i each ial, i h he MFN efe i g he ec d i e i d (250 – 350 , i.e., he ec d a iable). Whe he f a iable e e e ed i he eg e i a al i i l-a e l , l he MFN edic ed he he he a ici a ld ake cha ge . cha ge ch ice i he highl i c g e c di i , Wald = 5.76, $p < 0.05$, i h he e ce age f acc a e edic i bei g 56.7%. F he de a el i c g e c di i , h e e , hi a al i did fi d a hi g ig ifica . E e i g he MFN fi i he eg e i a d he he a iable ld ield e e iall he a e a e f effec .

F i di id al diffe e ce , e e f ed e f a al i . I he fi e, e li he 19 a ici a i g acc di g he i di id al i de f c f i , hich b ac he a e f cha ge i he c g e c di-i f he a e i he highl i c g e c di i

(Fig e 5A). The highe he c f i i de a , he e likel he a ici a ld c f he de cial i fl e ce. Af e he edia li , he high c f i (N = 10) had a ea i de f 0.83 (SD = 0.12) hile he l c f i (N = 9) had a ea i de f 0.21 (SD = 0.18). ANOVA e he ea a li de i he MFN i e i d , i h he a ici a e a a be- ee - a ici a fac a d beha i al e de c (cha ge . cha ge) a d elec de a i hi - a ici a fac , e ealed a ig ifica ai effec f beha i al e de c , $F(1, 17) = 12.81$, $p < 0.01$, i h he MFN e e e ega i e-g i g f he “cha ge” (2.34 ± 1.19 μV) ha f he “ cha ge” (3.55 ± 1.36 μV) ial . I a l , hi ai effec a alified b a ig- ifica i e ac i be ee beha i al e de c a d a - ici a e, $F(1,17) = 4.93$, $p < 0.04$. Si le-effec e h ed ha f he high c f i g , he MFN e e e e e ega i e-g i g f he “cha ge” ial (1.83 ± 1.64 μV) ha f he “ cha ge” ial (3.78 ± 1.59 μV), $F(1,9) = 14.19$, $p < 0.01$. H e e hi c a did each a i ical ig ifica ce f he l c f i g , $F(1, 8) = 1.22$, $p > 0.30$.

I he ec d e f a al i , e c ed he c el- a i , e i di id al a ici a , be ee he i e f he MFN diffe e ce be ee he “cha ge” a d “ cha ge” ial a d he i de f c f i (Fig e 5B). Thi c el- a i a ig ifica , $r = -0.47$, $p < .05$, i dica i g ha he e likel a a ici a c f ed g e be , he e ega i e he MFN diffe e ce a .

## Discussion

Thi d de a e ha i di id al a e e likel

be ee he i de ec ed. W a d Zh [15] a i - la ed h g all he e a d ale ce, e a d ag i de, a d e ec a c a d ag i de i a e a ga - bli g a k. The f d ha he FRN effec he feedback a e i i e l e a d ale ce, b al e - ec a c a d e a d ag i de, i h i la i f e - ec a c elici i g e ega i e-g i g FRN e e . Th i a ea ha he edic i e ca be defi ed l i e f he ale ce f c e b al i e f he he he c e fi e-e abli hed, - ale ce e ec a c [15,26,27]. F he die a e eeded ecificall add e he diffe e ia i be ee ale ce-ba ed . e ec a c -ba ed acc f he MFN/FRN effec .

Vi la i f cial e ec a c cial ca al elici e ha ced MFN e e . I ha bee c i e l f d ha fai ffe i ec ic e cha ge e ke e ega i e-g i g MFN ( FRN) e e ha fai ffe [16-19]. W e al. e f he de a e ha , c a ed i h fai ffe , b h di ad a age ( ega i e) fai ffe a d ad a age ( i i e) fai ffe eli- ci ed e ega i e-g i g MFN e e (W , H , a Dijk, Leli eld, Zh : B ai ac i i i fai e c ide- a i d i g a e di ib i : D e he i i ial e hi la a le?, b i ed).The MFN effec a eflec he de ec i f cial e ec a c i la i a egali a ia di - ib i f a e i a e ec ed cial [28,29]. D - i g e l i , he h a b ai a ha e de el ed ecific echa i de ec g i g de ia i f - cial [30]. I i ible ha he e echa i ha e he a e e al c ela e a h e e gaged i edic i g e d i g - cial ei f ce e lea i g [10,31]. The MFN ca he ef e eflec l he e c di g f edic i e f e a e a d e f a ce feedback b al i la i f e ec a c a d cial . I he e e d , i di id al c ld c a e hei i ial ch ice i h i i f he g e be a d he diffe e ce i h he c ld be e c ded a a e- dic i e . A ece ERP d cial c f i al gge ed ha cial de ia ce ac i a e he b ai ' e - i i g e [32].

I hi d , e al f d ha MFN e e i - ce i g g ch ice i c g e i h he a ici a ' ch ice ca be edic i e f he he he ld b- e e l cha ge hei i d he he e e gi e a ec- d i ake li e j dg e (c.f., [22]). A b h le el f i c g e ce, ial i hich he a ici a cha ged hei i d h ed e ega i e-g i g MFN e e ha ial i hich he ick hei i i ial j dg e . The ei f ce e -lea i g he f MFN [25,33] gge ha he MFN eflec he c di g f e- dic i e i he idb ai d a i e e , hich e d ig al he a e i ci g la e c e (ACC) a d g ide ac i elec i edia ed b he ACC h gh he

ei f ce e f ac i a cia ed i h i i e e a d a d he i h e f ac i a cia ed i h ega i e c e . S cial c f i ca be c ide ed a e f g al-di ec ed ac i i hich he g al f beha i i cl de a i i i g he e a d f ll i g acc a e e f a ce a d cial acce a ce, a d i i i i g he i h e f l- l i g e e e e a d cial ejec i [3]. I he e e d , he e ega i e g i g MFN e e f he "cha ge" ial , a ed he " cha ge" ial , de a ed ge e al ig al e ACC, hich g ided b e e beha i al adj e (i.e., ac i c - i e i h g i i cial ). I deed, a e- ce fMRI d al h ed ha he a li de f c flic - ela ed ig al i b ai egi i lica ed i ei f ce e lea i g, i.e., al ci g la e e a d he e al ia , ca edic b e e beha i al c - f i [10].

The acc ha cial c f i i i a ia ed ia ei f ce e lea i g echa i i f he e g h- e ed b he fi di g ha i di id al h e e e likel c f he he e hibi ed a ge MFN diffe - e ce be ee "cha ge" a d " cha ge" ial he c - a ed i h i di id al h e e le likel cha ge hei i d. P e i die ha e h ha he MFN e e a e e i i e i di id al diffe e ce al g dif- fe e di e i , i cl di g e ali ali . F e a le, Ye g e al. [34] e ed a c ela i be ee he MFN a li de a d he a ici a ' a i g h ch he fel be i l ed i he ga bli g a k, i h la ge MFN a li de c e di g highe i l e- e a i g . B k e a d De C e e [16] f d ha he MFN a li de a e ced i e cei i g - fai a ed fai ffe a d hi effec a la ge f a ici a i h highe c ce f fai e ha f a- ici a i h l e c ce . Vi la i f cial i a ki d f edic i e ha ca be ili ed a ei f ce e lea i g ig al f b e e beha i al adj e . The e ig ifica he edic i e i al ed b a i di id al, he e likel he ld b e- e l cha ge i d c f he ( ee al [10]).

N e ha , i he ab e dic i , e ha e la gel ca eg - i ed he c f i effec e b e ed a " a i e c - f i " a d a ib ed he de i e be c i e i h he i ch ice elec i a a ki d f cial ei f ce e . H e e i i al ible ha a ici a had i l ed he ' ch ice i li e j dg e a a ce f i f a i i de ake e acc a e j dg e (i.e., i f a i al c f i ). A die cial c f i , he e- e i e al de ig e ed c ld all defi i el diffe e ia e he e f c f i . A ible a i e he de ig i i cl de a c l c di i i hich he g i i c e f c e g a ( ee [35]). H e e , if he c e g a ge e a e ch ice ba ed ed k ledge, a ici a igh a h hi e he c e g a (i.e., ea i g he c e a h a i ed age ), a d he c f i effec b ai ed i hi i a i ca ill be ake a bei g f a i e c f i ; if he c e g a ge e a e ch ice a d l , a ici a igh ea he e ch ice diffe e l . I deed, idi g a ici a i h "b " " b "ch ice f ck a d l d ced b f chi a ee [36] idi g a ici a i h a- ac i e e j dg e f h a face a d l d ced b c e [11] did affec a ici a ' ch ice beha i b he e effec e e ch eake ha he i ac f g ch ice d ced b h a ee .

M e e g i i d ced b h a ee a d g ch ice ge e a ed b c e g a elici diffe e ial e al ig al i b ai egi i li- ca ed i ei f ce e lea i g b i b ai egi i l ed i e - e ce al ce i g [11]. Take - ge he e igh c cl de ha he c f i effec b e ed i hi a d e he die i e e iall f a i e c f i . Tha i , a ici a ' b e- e beha i al adj e "i edia ed b he ei f ce e lea i g echa i i hich b h e a d f bei g alig ed i h g a d a e i bei g - alig ed a ha e ac ed a ei f ce " [11].

A he i e ha eed di c i c ce he he he MFN effec b e ed igh be e lai ed i e f a e i de ed he c g e ce f g i i . I a ic la he a ici a igh ha e aid le a e- i a he a f e ial , aki g he ig e he g i i . C e e l he h ed alle e al e e i c g e g i i a d a eake e de c b e e l adj hei ch ice . H e e hi li e f a g e ee i la ible a he P300, hich i ge e all belie ed eflec he di ib - i f a e i al e ce [37], a ac all e i i e f he " cha ge" ial ha f he "cha ge" ial (Fig e 3B).

## Conclusions

B a i la i g he le el f (i )c g e ce be ee he a ici a ' i i ial ch ice a d g e be ' ch ice i a li e j dg e a k, he e e d de a ed ha 1) i c g e g ch ice ld elici e ega i e g i g MFN e e ha c g e e he he a ici a e e e e ed i h he ch ice ; 2) i c g e g ch ice i ial i hich he a i- ci a cha ged hei i d he gi e he ec d - i ake li e j dg e elici ed e ega i e- g i g MFN e e ha i c g e g ch ice i ial i hich he a ici a ck hei igi al i i ; 3) e i di id al a ici a , a ici a h e e e likel c f he e hibi ed ge MFN diffe e ce be ee "cha ge" a d " cha ge" ial ha h e h e e . The e fi di g gge ha i c g e ce i h g ch ice i i ( hich ac a a ki d f cial ) ca elici b ai e e ha a e i ila h e elici ed b i la i f - - cial e ec a c i c e e al a i a d e f a ce i i g, a d he e b ai ig al ca be ili ed i he f ll i g beha i al adj e . The e e d c - le e ece b ai i agi g die b h i g ha he b ai a idl c e he cial ba ed g e be ' i i a d c a e e' ac- i i h he . The d al gge c echa i f ei f ce e lea i g i cial a d - cial i a i .

## Methods

### Participants

T e -f de g ad a e a d g ad a e de (13 fe ale ; ea age 22.5 ea , SD = 1.93) a ici- a ed i he e e i e . F de , h e e a ge he a ici a , e e ec i ed a c - fede a e . T e cl de ible i fl e ce f e - cial c f i , each EEG a ici a a g ed i h 4 a e- e c fede a e [38].

All he a ici a e e igh -ha ded a d had al c ec ed- - al i i . The had hi f e l gical chia ic di de . I f ed c e a b ai ed f each a ici a bef e he e . The e e i e a e f ed i acc da ce i h he Decla a i f Hel i ki a d a a ed b he E hic C i ee f he De a e f P ch l g , Peki g U i e i . Each a ici a a aid 60 Chi e e a (ab USD$ 9.5) a ba ic a e a d a i f ed ha addi i al e a e a d ld be aid acc d- i g hei e f a ce i he a k.

### Design and procedures

The e e i e ed a e-fac i hi - a ici a de- ig i h h ee le el f g ch ice. F he highl i - c g e c di i , h ee f g e be ade ch ice diffe e f he a ici a ' i i ial ch ice; f he de a el i c g e c di i , g e- be ade ch ice diffe e f he a ici a ' hile he he e be ade he a e ch ice ; f he c g e c di i , e g e be ade ch ice diffe e f he a ici a ' .

Whe a a ici a ca e he lab a , he a d he f c fede a e e e ld ha he ld i i e a a e c le e a a k ge he h gh he c e e k. B a ig i g he a ici a a d he c fede a e e-de e i ed ca d , he e e e i el led e a a e c bicle la diffe e le i he a k. The a ici a a he ld ha he a ell a he he f g e- be ld fi i h a li e j dg e a k ge he . He a al i f ed f he ced e f he e e i e (Fig e 1). Tha i , a he begi i g f each ial, he a ici a a e ed i h a allel e ical li e , i h a le g h f ei he 5.5 6.0 c , ei he lef igh ide f he c ee ( i h e c l a ea i g a e ide i half f he ial ) a d a h i al black li e ( i h a le g h f 6.0 c ). He had j dge hich e f he e ical li e i f he a e le g h a he h i al e b e i g a b i h he i de fi ge f he lef igh ha d (i.e., a bi a j dg e ). The i i f he h i al li e a ei he he f he b f he e ical li e hile he ela i e i i f he e ical li e a ied ligh l al g he e ical ie a i e ial . Pa ici a e ed i a -e e i e e i ai e ha i a al i ible f he be e hich e ical li e ( i h a diffe e ce f 0.29 deg ee i i al a gle be ee he li e ) a f he a e le g h a he h i al li e. A de ailed e a i a i f he a ici a ' e e h ed ha he acc ac f he a ici a ' e e (i.e., ch i g he e ical li e i h 6.0 c ) a 43.38%, hich did diffe ig ifica l f he cha ce le el (50%), t(18) = 1.27, p > 0.1.

The a ici a a he e ed i h a f a e i dica i g, h gh c l i g ca fig e , h a f he 4 he g e be had ch e he ed bl e li e . The g ch ice e e ede e i ed b a c e g a i h he a ici a ' k ledge, a d ed bl e li e e e a d l a ig ed. The a ici a a h he a e li e i l agai , a d a i c ed i dica e hi ch ice he ec d i e b e i g a e e b . The a ici a a i f ed be f e he e e i e ha he c e ld ec d hi e e a d he e a a e a de e de he acc ac f hi ec d ch ice i each ial. The i e li e f he e e a i f each f a e i each ial a ill a ed i Fig e 1.

The a ici a a c f abl ea ed ab 1.0 i f fac e c ee i a di l li . The e e i e a ad i i e ed a c e i h a Del 22-i ch CRT di la i g P e e a i f a e (Ne beha i al S e I c.) c l he e e a i a d i i g f he i li. F he highl i c g e c di i , all he f g e be ' ch ice e e diffe e f he a ici a ' i 120 ial a d h ee e be ' ch ice e e diffe e i 60 ial . F he de a el i c g e c di i , g e be 'ch ice e e diffe e f he a ici a ' i 140 ial . F he c g e c di i , h ee g e be (b e) had he a e ch ice a he a ici a i 60 ial , a d all he f g e be had he a e ch ice a he a ici a i 120 ial . The 500 ial e e a d l i ed a d e e di ided i e al be i 5 e bl ck i h he e ici ha e ha h ee c ec i e ial e e a he a e i c g e ce le el. A ac ice bl ck f 30 ial i hich he a ici a de e he a e ced e a ha i he f al e a ad i i e ed fa ilia i e he a ici a i h he e e i e . Pa ici a e e deb iefed, aid, a d ha ked a he e d f he e e i e .

## EEG recording and analysis

EEG e e ec ded f 64 cal i e i g i elec de ed i a ela ic ca (B ai P d c , M ich, Ge a ) acc di g he i e a i al 10–20 e . The e ical elec c l g a (VEOG ) a ec ded a- bi all f he igh e e. The h i al EOG (HEOG) a ec ded f elec de laced a he e ca h f he lef e e. All EEG a d EOG e e efe e ced li e a e e al elec de, hich a laced he i f e, a d e e e- efe e ced ffli e he ea f he lef a d igh a id . Elec de i eda ce a ke bel 10 kΩ f EOG cha el a d bel 5 kΩ f all he elec de . The bi - ig al e e a lified i h a ba d a f 0.016 100 H a d digi i ed - li e i h a a li g f e e c f 500 H .

Se a a e EEG e ch f 1000 ( i h a 200- e i l ba eli e) e e e ac ed ffli e, i e-l cked he e f g i i . Oc la a ifac e e c ec ed i h a e e- e e c ec i alg i h ha e l a eg e i a al i i c bi a i i h a ifac a e agi g [39]. E ch e e ba eli e-c ec ed b b ac i g f each a le he a e age ac i i f ha cha el d i g he ba eli e e i d. All he ial i hich EEG l age e ceeded a h e h ld f 80 μV d i g ec di g e e e cl ded f f he a al i . The EEG da a e e l - a fil e ed bel 30 H .

F he MFN, he ea a li de i he i e i d f 250–350 e e a al ed. Thi i e i d a elec ed acc di g he cla ical defi i i f he MFN a d acc di g i al i ec i f a ef . The G ee h e-Gei e c ec i f i la i f he a i f he ici a a lied he e a ia e. The B fe i c ec i a ed f l i le c a i .

The ea be f ial ha a e e ed i MFN a a l i a 132.2 ( a gi g f 79 175) e a ici a f he highl i c g e c di i , 100.1 (f 52 131) f he de a el i c g e c di i , a d 133.7 (f 71 173) f he c g e c di i . Af e di ca di g he fi e a ici a h had le ha 10 "cha ge" ial i ei he he highl he de a el i c g e c di i , f he e ai i g 14 a ici a , he ea be f ial ha a e e ed i he "cha ge" . " cha ge" c a i a 70.4 (f "cha ge", a gi g f 27 156) a d 54.9 (f " cha ge", a gi g f 17 111) e a ici a i he highl i c g e c di i a d e e 23.1 ( a gi g f 11 38) a d 73.3 ( a gi g f 12 106) e a ici a i he de a el i c g e c di i .

I i clea f Fig e 3 ha he ch ice c g e ce effec a d diffe e ce be ee "cha ge" a d " " cha ge" ial a ea ed l i he MFN i d , b al i a la e ibl he P300, i e i d . B gi e ha he a e f effec i he la e i e i d a e e- iall he a e a he e f he MFN, e did e he a al i f he effec i hi i d .


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## Authors' contributions

JC, YW, GT, XG and XZ codesigned the experiment. JC and GT performed the experiment and the data analysis. JC, YW and XZ wrote the paper. All authors read and approved the final manuscript.


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