Reward interacts with modality shift to reduce cross-modal conflict

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Previous studies have shown that reward can enhance cognitive control and reduce conflict in visual processing. Here we investigate (a) whether and how reward influences cross-modal conflict control and (b) how the shift of attention across modalities modulates the effect of reward on cross-modal conflict control. In four experiments, a cue indicating the reward availability of a given trial (reward vs. no reward) was presented prior to a target. The target was either a visual or an auditory letter, which was accompanied by a distracting letter from the other modality. The identity of the distracting letter was either the same as or different from the identity of the target letter (congruent vs. incongruent). When the cue modality was constant (Experiment 1) or changed across different experimental blocks (Experiment 3), the interference effect (i.e., the response time difference between incongruent and congruent trials) was smaller following a reward cue than a no-reward cue, suggesting that reward can reduce cross-modal conflict. In contrast, when the cue modality was changed trial-by-trial in an unpredictable way (Experiments 2 and 4), reward reduced cross-modal conflict only when the cue and the target were from different modalities and had a long stimulus onset asynchrony (SOA) between them but not when they shared the same modality or had a short SOA between them. These results suggest that reward can facilitate cross-modal conflict resolution, and this effect may critically depend on both the preparatory state between the cue and the target and timing to initiate cognitive control.

Introduction

I a , a a a , a a a . C - a a a a a b a . T , a a - a a a a - a a- (a V & Ca , 2006). F a , a a b , a a b a a a b . O a a a a a . E b a a , - a a a a a a a a a (B & B a , 2015; Pa a a & P a, 2011;

Citation: Kang, G., Wang, L., & Zhou, X. (2017). Reward interacts with modality shift to reduce cross-modal conflict. *J a V , 17*(1):19, 1–14, doi:10.1167/17.1.19.

doi: 10.1167/17.1.19 Received August 16, 2016; published January 12, 2017 ISSN 1534-7362

P a, 2015; S , S , Pa , Wa , & S b , 2015; V , W b a , & S , 2015; Wa , Y , & Z , 2013). F a , Pa a a a P a (2011) a a b a a a a a a a a b . T a ("XXXXX"), ("HOUSE"), - ("BUILDING") (. ., a). A a a , a a a a a a a a a a a a a .

T a (. ., [RT] RT a) a a a a a a - a . T b a a a a b a a , a (. ., a), a a a a a (MPFC), a b- (B , B a , Ba , Ca , & C , 2001; Pa a , R -H , Za a a, & R -F , 2015; R , U , C , & N , 2004). T a MPFC a b a a a a - a a a a b a - . Ba , a a a a - a - , a b a a a - a a (Pa a a & P a, 2011). W a a a a , a a a a a a b a - a (E , C , Za , Ka , & B a , 2015; H , Ma a , & Y , 2013; a B , K b , L , & W , 2014; V a ., 2015).

R a a b a a a a a a (Pa a a & P a, 2011; S a ., 2015; a B a ., 2014; V & Aa , 2010). I , a a a a a - a . T a b a a a a a , a - a a a a a a a b (C & Z , 2013; D , A - ba , Pa , R b , & W , 2013; E , C a , & Va -I a , 1998; W a , Wa , & W , 2004, 2009). W a a a a a a a a a a a a . T a a a a a a , a a a b a a a a . T b (C & Z , 2013; W a a ., 2009). Pa a a a (. ., a a) a a (. ., a a). W a , a a - a , - a b a a a a a a a a a a .

A , a - a a a a a a a , a b . I a , a a a a a a b a a a a b a . W a a a , a a a a a a a b . T a a a a a , a a a a a a . I ab a , a b a a a a b a (T a , B , Ga a , & U à, 2002; T a , Ga a , B a , & U à, 2004; Wa , Y , & C , 2012). F a , T a a . (2002) (S1, S2) a a a a a a S2. T b a a a . R a S2 a S1 a S2 a a a a a , a a S1 S2 a a a S2.

A b a a a a a a - a , a a a a a a . A (Ma , Aa , & C , 2014) ab - a a a (T a a ., 2002) a . I , a a a a a , a a . T a a a a b a a a a b b a a . T a a a a a a a a a ab (. ., ab a), - a a

a a (. ., a a) b a a (Ma a ., 2014). S a , a a a , B , C , a Aa (2009) a a a a a -b - a a . T a , a b a a , a a - a a - a b a (. ., a a a a a), a (. ., a - a a). Ta , a a a a a ab ,

(B a ., 2009; Ma a ., 2014). I , a a b a b a a a (SOA) b a a . W a a a a a a b - a , a a - - b b a a b a a . M , a a a a (C & B a , 2016), a a b a a a b b SOA b a a .

E 1 a a ba , a a a b (a a b a a a b), a a a a a a a a a . I E 2, a a ab a a -b - a ba , . ., b a a a a (a) a a (- a) a a a a (a /) a a (/a). E 3 a a a - a , b a a a a ab . E 4 a a E 2 b a SOA : (310 350) . (910 950) a a SOA (1050 1450) E 2.

Experiment 1

E 1 a a a - a . T a - (a . a) a a b : a a a a a a . I b , a a a a , a a a a a a a ; a a , a a a a a . I a , a a a a ab a a - a a a a a a ; a , a a .

Method

Participants

A 19 a a a (a , a a 18 26 a) B a E 1. A a a - a , a a - - a , a - a a . T a a a D a a H a a a b E C S P a a C S , P U - .

Apparatus and materials

F a a a a . V a b (&, #) a a (A, O) a a , a a a b a ba . T a a a 1.5° (a) × 2° (a) a a . Pa a a 57 a a a CRT . T a a a 200 H ( ) a 600 H ( ) a (A, O) a a , a a a a 44,100 H (16 b ,) a a . A a a a a a 55 B, b a a , a . T a a a 450 .

Design and procedure

T a : a a a a a a a (F 1). A b a a , a a (+), a 0.2° × 0.2° a a , a 500 . A a a a a a a a a a 450

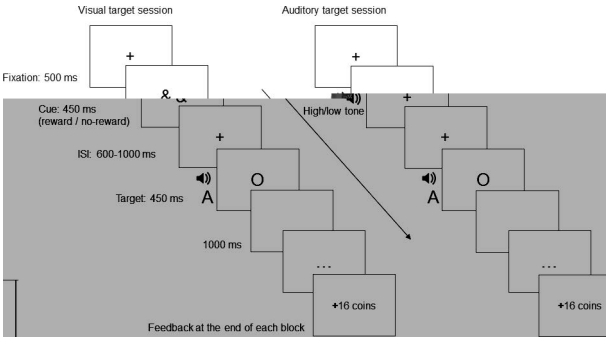

Figure 1. Trial structure i(of)-3ityleft) and the auditory tsession (right) of Exp 1

. A unimodicT4496.7(cue)T-1.9552-1.2007TD(with)-33.3(the)-336.7(same)-342.4(modicity)-332.5 experimental conditio .

. F a a , a (. ., &) a a a b a a (. ., a), a a (. ., #) a a a b (. ., - a). F a a , a (. .,) a a , a a (. .,) a - a . T a a b a a a ab a a ba a a a a . A a a ab a 600 1000 , a a a a 450 . Pa a a a a a (A . O), a a , . T a b b b a a a a ba a a a a . T a a a 600 1000 .

T , a a 2 (a a : a a . a a) × 2 (a : a . a) × 2 (a : .) - a a a a . T 48 a a a . T 384 a a b a b a a . T a ba a a a a . T a a (a - , a - , a , - a) a b a b a a .

P a , a a 24 a a a a a 24 a a a a a . T a a a a a a a a a a a a (. .,) a a a b a - a b . R ba (.) a a a b . Pa a a a a a a a b . F a a - a , a RT a (a a a a a a) a a a a a a a ba RT a . Pa a a a a ab a b a . F a , a a a (b a a a a a ba RT) a a a ba RT. F - a , a a a a . F ba a b a a b a a a

b . A , a a a a 1:0.06, (a , a 0.06 a , 1 a ≈ $0.16). Pa a a 12 a a ba a , b a ba a (20 a) a a .

Data analysis

I a RT a a . F a a a , a RT a a a a ab b a RT a a - a a . I , 1.0% a a a . A a - a ANOVA a a RT a a a a a a (a a . a a), a (a . a), a a (.) a - b a ab . S a a a a a a , a a a a a a .

Results

ANOVA RT (F 2) a a a a , (1, 18) = 6.32, = 0.022, $\eta^2 = 0.26$, RT a a a a a (400 . 424). T a a a a , (1, 18) = 12.21, = 0.003, $\eta^2 = 0.40$, a a a a a a a - a a (401 . 424). T a a a a , (1, 18) = 52.35, < 0.001, $\eta^2 = 0.74$, RT a (402 . 423). M , a b a a a a a a , (1, 18) = 5.80, = 0.027, $\eta^2 = 0.24$, a a a b a a , (1, 18) = 19.58, < 0.001, $\eta^2 = 0.52$. T - a a a a , (1, 18) = 0.45, = 0.511, $\eta^2 = 0.02$.

A a a 2 (a . a) × 2 (.) ANOVA a a a a a a , . F a a , a a a , (1, 18) = 37.84, < 0.001, $\eta^2 = 0.68$, RT a (410 . 390). H , a a a a , (1, 18) = 2.83, = 0.110, $\eta^2 = 0.14$. T a b a a a a , (1, 18) = 7.21, = 0.015, $\eta^2 = 0.29$. A a a (. ., RT RT) a a a a - a (14 . 26), (18) = 2.67, = 0.015. F a , a a a RT a a a - a a , (18) = 2.17, = 0.043, , (18) = 0.93, = 0.363.

F a a , a a a a , (1, 18) = 15.90, = 0.001, $\eta^2 = 0.47$, a a a a , (1, 18) = 17.75, = 0.001, $\eta^2 = 0.50$. Pa a a a a a a - a a (407 . 441) a a a a (413 . 435). T a - b a a a a , (1, 18) = 8.51, = 0.009, $\eta^2 = 0.32$. A a a a a a a a - a (13 . 31), (18) = 2.91, = 0.009. F a , a a a a (. ., RT - a RT a) a a a (25 . 43), (18) = 2.93, = 0.009.

A 2 × 2 × 2 ANOVA a a a a , (1, 18) = 16.11, = 0.001, $\eta^2 = 0.47$, a a a (4.7% . 2.2%).

Discussion

I E 1, a a a , a a a a a b a a a (K , D - , & E , 2009; Pa a a & P a, 2011, 2014; W & Ka , 2014). M , a a - a b a a a a a a , a a a a a a (B & B a , 2015; Pa a a & P a, 2011; P a, 2009) a a ab .

Experiment 2

I E 2, a a a a a a a a - a . W a a a a

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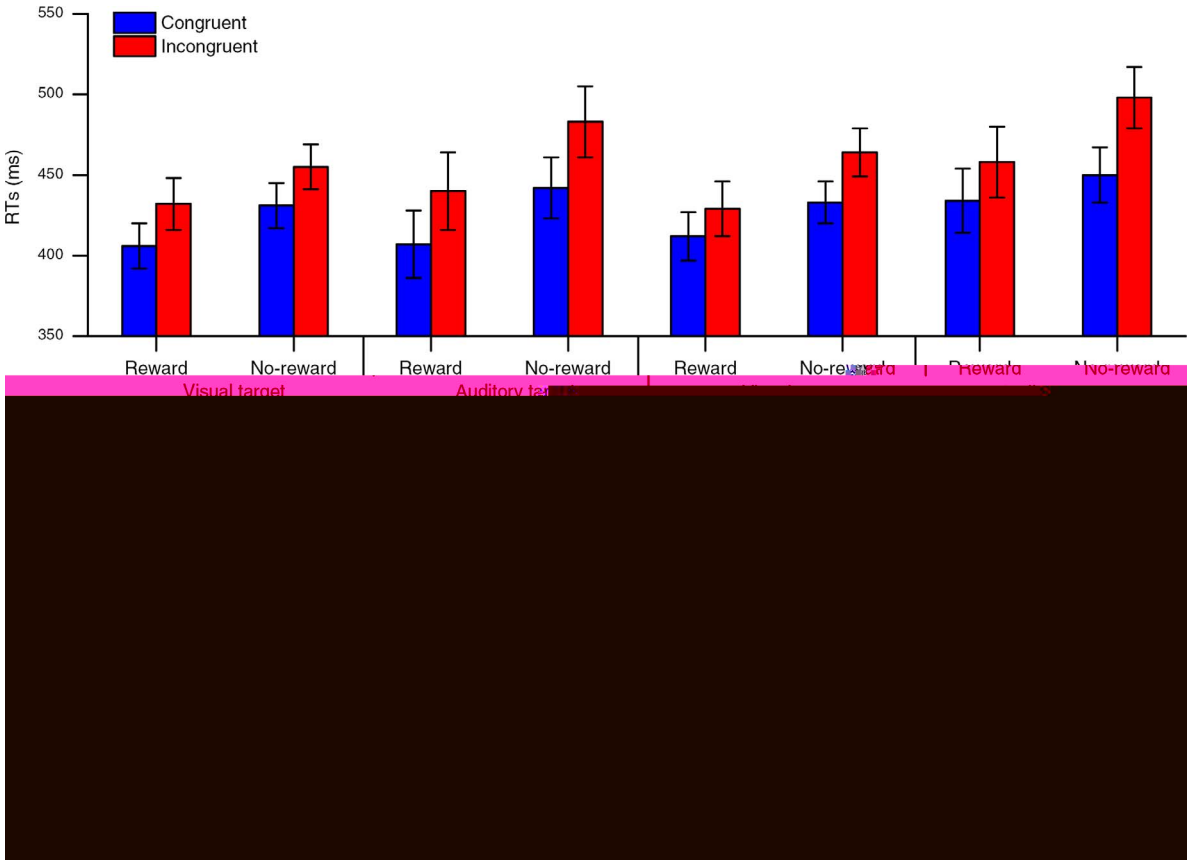

Figure 3. Experiment 2. Top: Mean RTs with standard errors as a function of the experimental condition. Bottom: the interference effects with standard errors as a function of the experimental condition.

0.35, a a a (4.6% . 2.4%). N a a .

Discussion

I E 2, b RT - a a a - , a a a a a (a /) a a (/a). T RT a (T a a ., 2002; T a a ., 2004), a a a a a a a a a a a a a a a a a a a . I a , a a - a , a . T a a a a a a a a a a a a (Ma a ., 2014). A b a a a b a a a a a a - a a a a b a . I a ab a a a a , b a a a a b a a , a a - a - a a a . T b a .

Experiment 3

T a E 3 a a a - a a a a ab . T - a a a a a a a

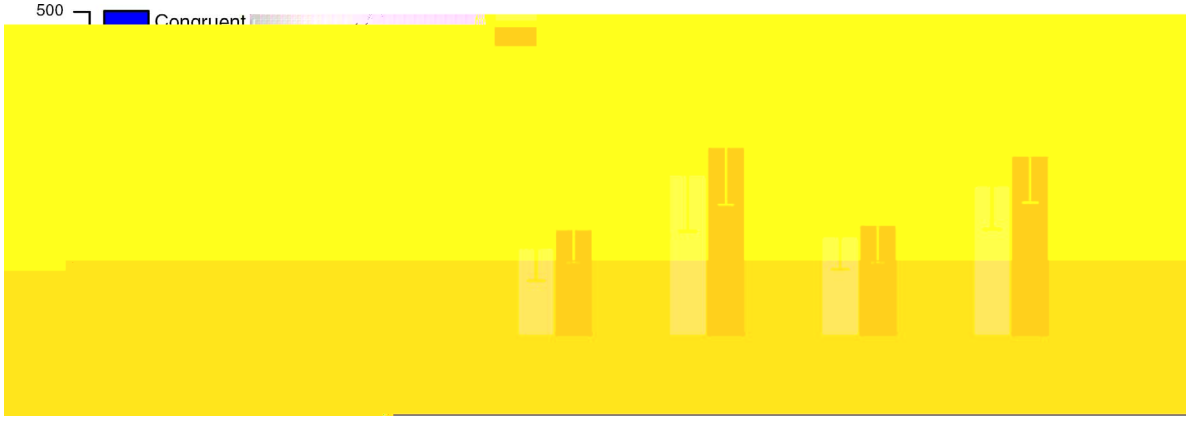

Figure 4. Experiment 3. Left: Mean RTs with standard errors as a function of the experimental condition. Right: the interference effects with standard errors as a function of the experimental condition.

a - a b a .

Method

Participants

A 16 a a a (11 a , a a 19 26 a) a E 3. A a a - a , a a - - a , a - a a . T a a .

Apparatus and materials

T a a a a a a a a .

Design and procedure

G a a b E 1 a 2 a a a , a a E 3. T a a a a a a E 2 a a a a a E 3. T a a a (a) a a a (- a). S a , a , a a a ab a a b a a ( ), a a , a a a ab a a b a a (# &).

Results

O a a a . F a a a , a RT a a a a ab b a RT a a a a a a a a (0.8%). A 2 (a . - a) × 2 (a . a) × 2 (.) a - a ANOVA RT (F 4) a a a , (1, 15) = 4.79, = 0.045, $\eta^2 = 0.24$, RT a a - a (396 . 427), a a a a a , (1, 15) = 16.26, = 0.001, $\eta^2 = 0.52$, RT a a a (406 . 416). T a a a a a (> 0.1), a ab a . T a b a a a a , (1, 15) = 4.92, = 0.042, $\eta^2 = 0.25$, b - a a a , (1, 15) = 0.78, = 0.391, $\eta^2 = 0.05$. C a a (a) a - a (a) , a a a a a - a (7 . 13), (15) = 2.22, = 0.042; a a a a a (28 . 34), (15) = 2.34, = 0.034. T a a a a a a .

Discussion

I a E 2, a a a a a a a ab E 3 a b a b a a - . A a , RT a - a a . T , a a a b ab a - E 2 (a T a a ., 2002;

T a a ., 2004), a a a a a a a E 3. R a a - a a b a , a a a a a a a a .

Experiment 4

I E 4, a a b a a a E 2 a b a a a b a . A a a a

b a a a (C & B a , 2016). H a a , a a a a a a a b a a a , a b a b a a ab a a . T , a a a SOA E 4.

Method

Participants

T a a a (a , 18~26 a) a E 4. A a a a a - - a , - a a , a - a . T a a .

Apparatus and materials

T a a a a a a a a a a .

Design and procedure

T a a a E 3 : T a a a a a a a a -b - a ba a E 2. M , 300 , a a SOA a a a a . F SOA , a SOA a 310 350 ; SOA , SOA a 910 950 . T a SOA a ba a a a a a . T a a 2 (SOA: .) × 2 (a a : a . - a) × 2 (a : a . a) × 2 (a : .) - - a a . T 768 a a , 12 b 64 a a b . Pa a 32 a a , a a ba a .

Results

O a a a . F a a a , a RT a a a a ab b a RT a a

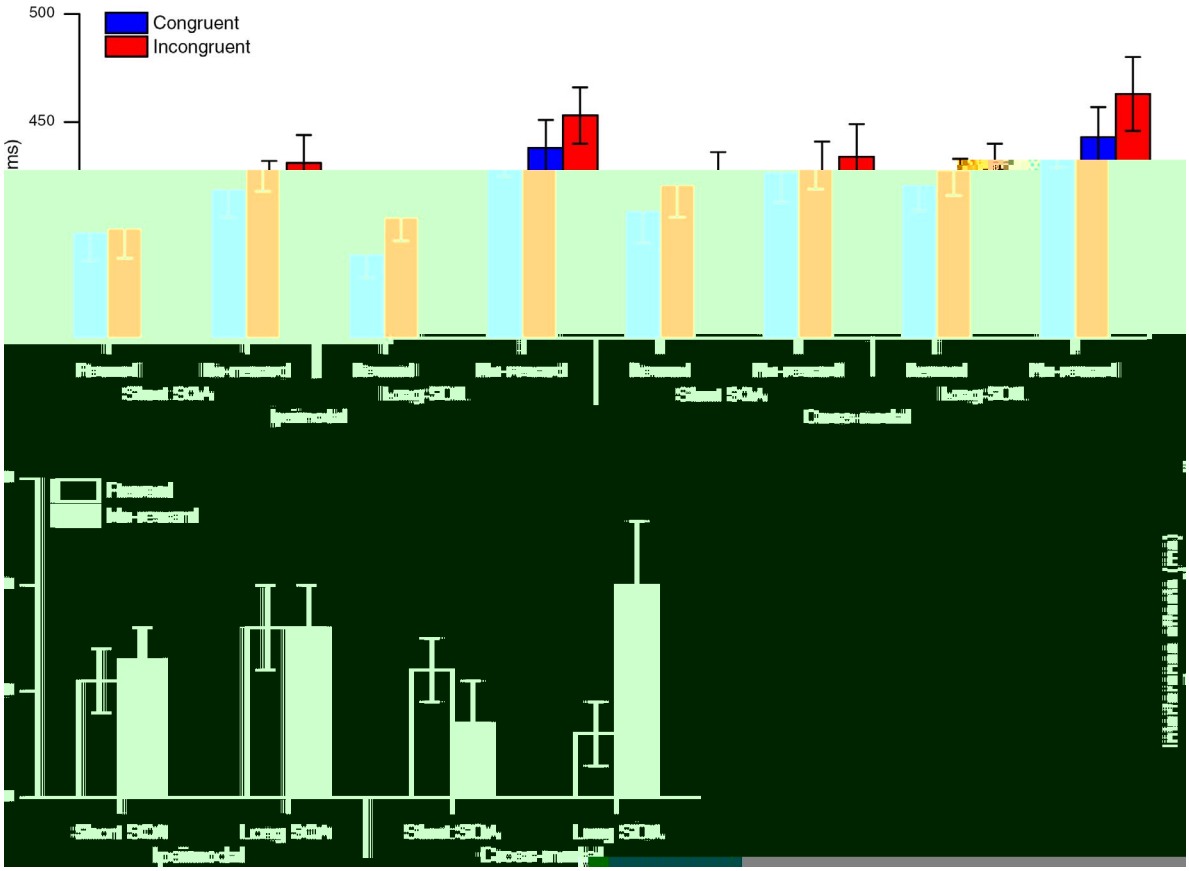

Figure 5. Experiment 4. Top: Mean RTs with standard errors as a function of the experimental condition. Bottom: the interference effects with standard errors as a function of the experimental condition.

ANOVA a a a b a a a , (1, 19) = 4.42, = 0.049, $\eta^2 = 0.19$, a a a a a a b SOA a a a , (1, 19) = 4.24, = 0.053, $\eta^2 = 0.18$. C a a a SOA a a a , a a a , b - a a (2.8% . 2.2%), (1, 19) = 2.45, = 0.024, a a a (2.6% . 2.7%), (1, 19) = 0.36, = 0.724. S a , a a a a a a a , b a a a a - a , b SOA a (3.0% . 2.1%), (19) = 3.01, = 0.007, a SOA a (2.4% . 2.7%), (19) = 0.52, = 0.612.

Discussion

I E 4, b a RT - a a a , a a a ab (E 2). M , a - a a a a a - a a SOA b a SOA, a a a a b a a a a . T ab a - a a SOA a b b a a a a (C & B a , 2016).

General discussion

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Acknowledgments

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References

B , K. C., & R b , T. E. (2003). Pa
a . (9), 507 513,
:10.1016/S0166-2236(03)00233-9.
B , E., C , R., & Aa , H. (2009). T

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(11), 1313 1315.

B , M. M., & B a , T. (2015). M a a
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a . (1), 83 113,
:10.1146/a - -010814-015044.

B , M. M., B a , T. S., Ba , D. M., Ca ,
C. S., & C , J. D. (2001). C
a . (3),
624 652.

B , J. W., & S , E. A. (1989). T
a . (1982),
109 131, :10.1146/a . .40.1.109.

C , Q., & Z , X. (2013). V a a
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(17), 7109 7121, :10.1523/JNEUROSCI.
1985-12.2013.

C , K. S., & B a , T. S. (2016). R a a
a : I a a - a
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(1), 52 66.

D , S. E., A ba , L. G., Pa , C. J.,
R b , K. C., & W , M. G. (2013). C -
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a . (4), 62802.

E , E. M., C a , N., & Va -I a , F. (1998).
T a - a -
. (5), 761 767,
:10.3758/BF03206061.

E , J. A., C , M. W., Za , J. M., Ka , K. N., &
B a , T. S. (2015). R a a a
a a a .
1 13, :10.1093/ /b 327.

H , G., Ma a , S., & Y , N. (2013). EEG
a a a a -
ab a a a a .
(1), 590 600, :10.1016/ . a .2012.09.
003.

Ka , G., Z , X., & W , P. (2015). I
a a a a a a-
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. (9), 2571
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K , M., D , J., & E , M. (2009). R a
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(2), 245 251.

Ma , H., Aa , H., & C , R. (2014). R a -
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(6), 771 778, :10.1007/ 11031-014-9439-9.

N ba , W., & B a , S. (2015). Pa
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Pa a a, S., & P a, L. (2011). R a
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_a_00011.

Pa a a, S., & P a, L. (2014). M a
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450 454, :10.1037/a0036112.

Pa a , G., R -H , B., Za a a, L. P., &
R -F , A. (2015). E a
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, 458 468.

Pa , F. B., E , G., E a, C., A é , P., &
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P a, L. (2009). H a a
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(4), 160 166, :10.1016/ . .2009.01.
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P a, L. (2015). M a
a a .
(1 2), 272 290, :10.1080/13506285.2014.974729.

R , K. R., U , M., C , E. A., &
N , S. (2004, O 15). T
a a .
(5695), 443 447.

S , A., S , C., Pa , L., Wa , H., &
S b , T. (2015). D ab a-
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(2), 409 423, :10.1162/ _a_00712.

T a , M., B , F., Ga a , G., & U à, C.
(2002). N a a a a b a -
a .
(3), 628
639, :10.1037/0096-1523.28.3.628.

T a , M., Ga a , G., B a , B., & U à, C.
(2004). S a - a - a -
a a a , a a a
. (3), 301
310, :10.1007/ 00221-003-1724- .

a B , B., K b , R. M., L , M. M., & W , M. G. (2014). U a a - a a a a a - . (2), 561 577, :10. 3758/ 13415-014-0281- .

a V , V., & Ca , C. S. (2006). C a b a . (5), 237 240.

V , H., & Aa , H. (2010). C a a a a : R a a a a a a S a . (2), 184 190.

V , L., W b a , D., & S , D. (2015). ERP a a a- a a . , 126 133, :10.1016/ . a.2015.02.025.

Wa , L., Y , H., & Z , X. (2013). I a b a a a a a - a a a . (3): 5, 1 13, :10.1167/13.3.5. [P bM] [A]

Wa , L., Y , Z., & C , Q. (2012). C - a a a b . (5), 867 878, :10.3758/ 13414-012-0289-9.

W , P., & Ka , G. (2014). Ta a a a b a a a . (6), 1783 1791, :10.1007/ 00221-014-3870-8.

W a , D. H., Wa , L. M., & W , M. G. (2004). T a a - a a . (48), 10941 10949, :10.1523/ JNEUROSCI.3669-04.2004.

W a , D. H., Wa , L. M., & W , M. G. (2009). M a a a a . (3), 609 615, :10.1016/ . a . 2009.06.081.