PSYCHOPHYSIOLOGY

Significance?... Significance! Empirical, methodological, and theoretical connections between the late positive potential and P300 as neural responses to stimulus significance: An integrative review

Greg Hajcak ✉, Dan Foti

working to better understand the development and risk for anxiety and depression—as well as training students to treat these disorders

Yang Ziyang

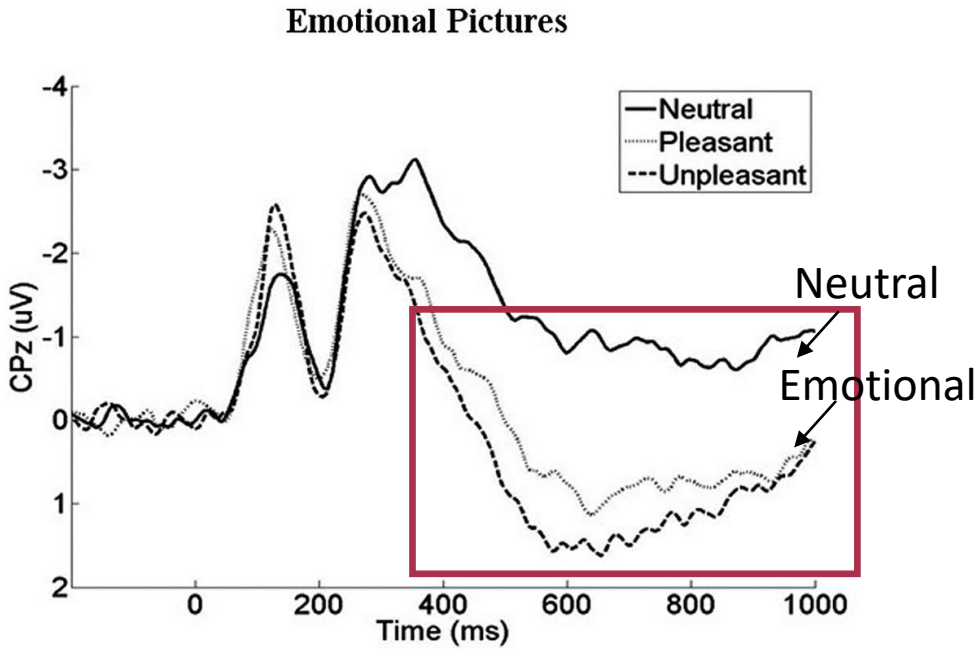
2024.03.29

Historical introduction

event-related potentials (ERPs)

emotionally evocative stimuli
modulate a broad range of ERPs

time-course of
emotional processing



early perceptual processing

later stages that involve elaborative processing and sustained attention

time-course

LPP (Late Positive Potential)

LPP as a neural index of
emotional reactivity and regulation

regulation strategies

relative degree of emotional reactivity across different stimulus

dynamic allocation of attention to emotional stimuli

Hajcak, Dunning, Foti, & Weinberg, 2014; Hajcak, Weinberg, MacNamara,& Foti, 2012

Historical introduction

LPP ⟺ Emotion Process

⇩

Clinical Neuroscience

utilized the LPP as an indicator of abnormal emotional processing in psychopathology

Nearly every psychiatric disorder is characterized by a form of dysregulated affect

identifying disorder-specific ? transdiagnostic deficits ?

⇩

LPP provides an objective indicator of emotional reactivity

a selective review of the LPP literature on normal and abnormal emotional processing

- seminal studies ⇩ theoretical account of the LPP ⇩ general comments

⇨ stimulus characteristics and task parameters that shape emotional processing

⇨ index of stimulus *significance*
(stimulus activates appetitive or aversive motivational systems)

Foti, Novak, Hill, & Oumeziane, 2018; Weinberg, Perlman, Kotov, & Hajcak, 2016

Seminal studies

Before 2000

emotional images elicit an enhanced positivity

targets ⊗ infrequent ⊗

faces, adj., lines } Similar results ➡ emotional content itself is sufficient to potentiate the ERP waveform (first few hundred ms of stimulus processing)

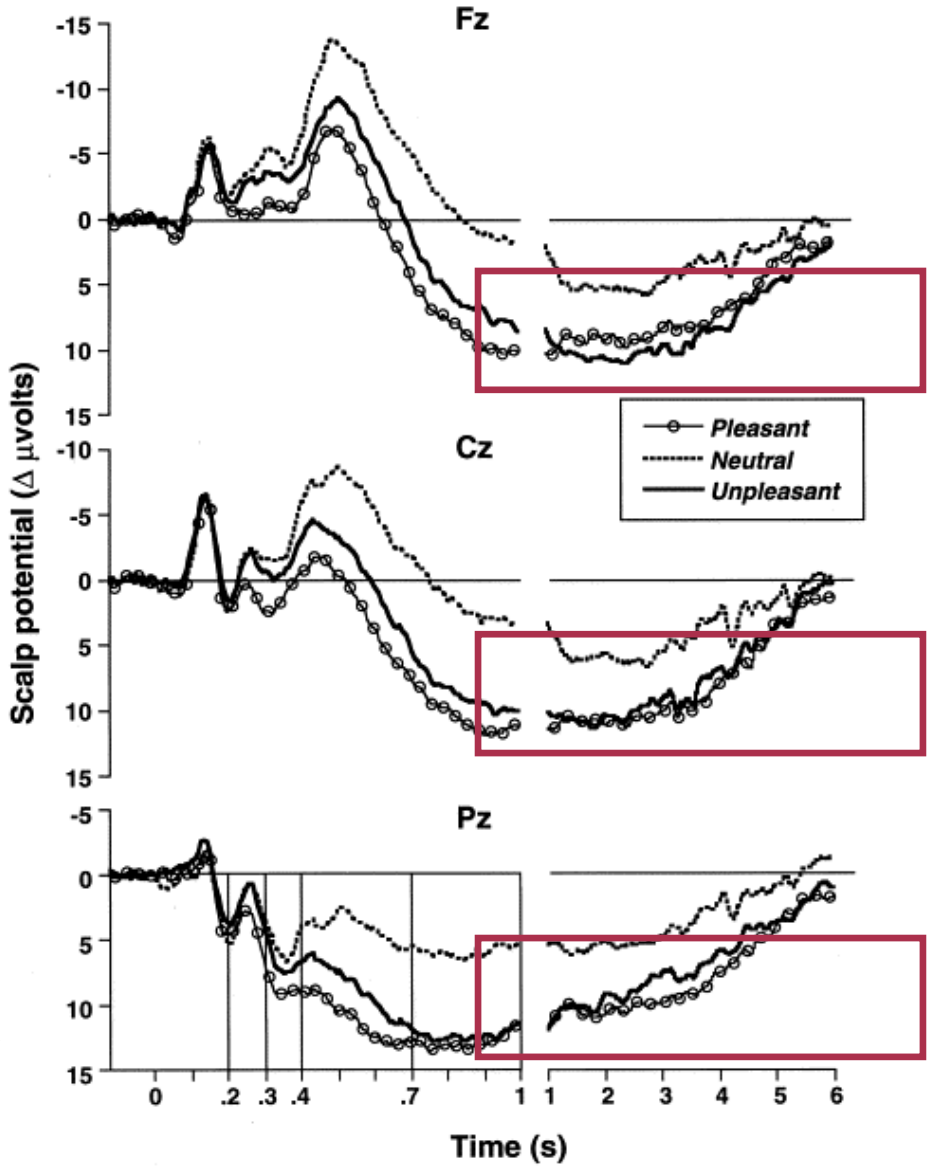
After 2000

a highly influential paradigm from *Cuthbert, Schupp, Bradley, Birbaumer, and Lang (2000)*

LPP amplitude ↔ autonomic systems
- ➢ emotional arousal (as opposed to valence)
- ➢ skin conductance

LPP amplitude ↔ subjective experience ➢ self-reported arousal ratings

ATTENTION ➡ *"reflecting activation of motivational systems in the brain that simultaneously prompt autonomic arousal, emotional facial expression, and reports of affective experience."*



Foti, Novak, Hill, & Oumeziane, 2018; Weinberg, Perlman, Kotov, & Hajcak, 2016

Seminal studies

WHY? Attention ➡ emotional content is important ➡ Conveys information about potential threats and opportunities that are salient to an organism's survival

Emotional content naturally captures attention and facilitates action tendencies to approach or avoid

✓ EVEN irrespective of the goal at hand

Bradley argues that the LPP is a neural response indicating that ***significance*** has been detected in the environment

"activation of cortico-limbic appetitive and defensive systems that mediate the sensory and motor processes that support perception and action"

➡

emotional content

⬇

activates appetitive or aversive motivational systems

⬇

elicits an increased LPP

fMRI

LPP relates to activation in both cortical and subcortical neural areas involved in emotional processing

(e.g., occipital, parietal, and temporal cortices)

(e.g., amygdala, ventral striatum)

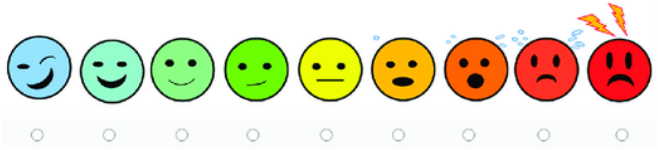
Bradley, 2009; Keil, & Ding, 2012; Sabatinelli, Keil, Frank, & Lang, 2013; Sabatinelli, Lang, Keil, & Bradley, 2006

Seminal studies

the key stimulus dimension that modulates LPP amplitude is

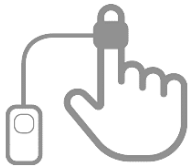
significance

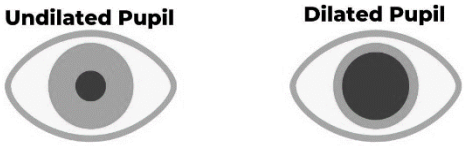
- Subjective ratings of arousal



**NOT Valence*

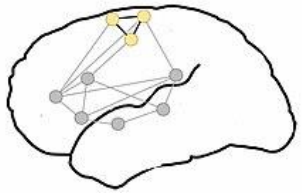
- Skin conductance
- Pupil dilation





autonomic response

- Activation of specific neural circuits



BUT :

specific stimuli are often chosen based on normative ratings of subjective valence and arousal—but not ***significance*** per se

➡ while significance can be expected to correlate with arousa

RESEARCH :

emotional arousal ⬆

- exciting sports images
- erotic images → *only*
  - LPP amplitude ⬆
  - Pupil dilation ⬆

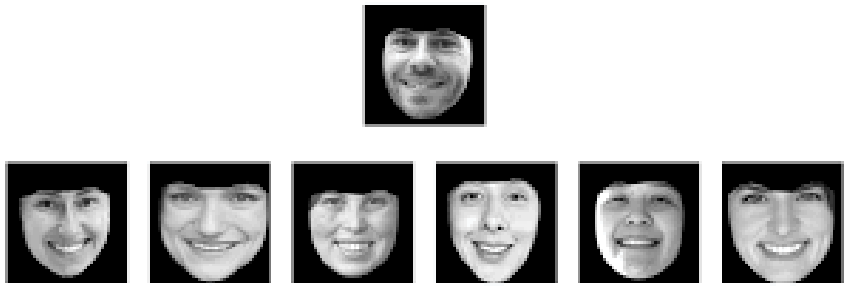
erotic images activate appetitive motivational systems to a greater extent, because they are more significant

Bradley, Codispoti, Cuthbert, & Lang, 2001; Bradley et al., 2003

Seminal studies

Although most neutral stimuli are low in significance, there are notable exceptions

- neutral images containing people elicit a larger LPP compared to neutral images that do not contain people
- the LPP is potentiated to faces of relatives, faces of romantic partners, as well as one's own name and face



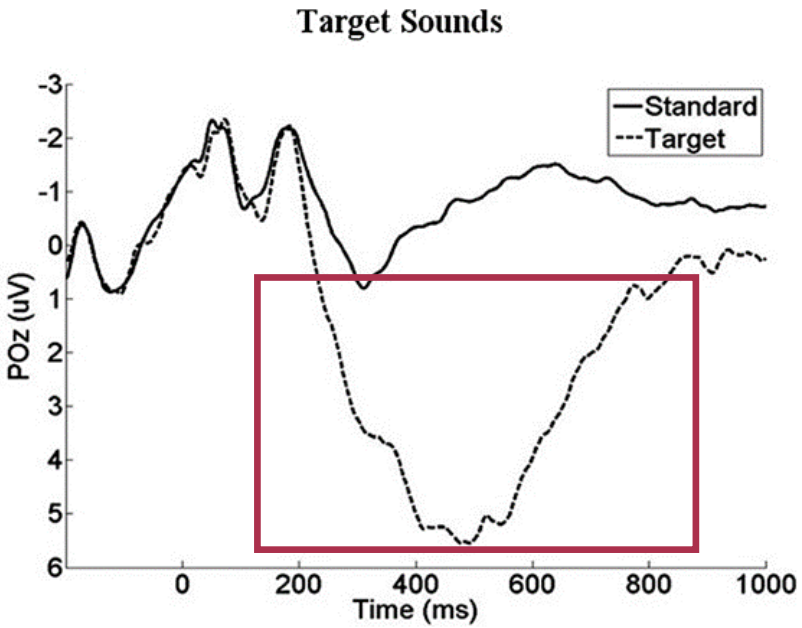
Ferri, Weinberg, & Hajcak 2012; Grasso & Simons, 2011; Burdwood & Simons, 2016; Tacikowski & Nowicka, 2010

The time-course of the LPP

The term LPP describes the protracted slow-wave elicited by emotional compared to neutral stimuli.

⇩

the LPP appears to have a distinct time-course compared to the positivity studied in traditional cognitive tasks of attention and target detection.



LPP does not only reflect a "late" ERP difference between emotional and neutral stimuli

the morphological difference between the canonical ERP waveform to target stimuli and the LPP is **duration**:

- typical ERP responses to target stimuli are relatively transient
- LPP is evident as a more protracted positive potential

Hajcak, Dunning, & Foti, 2009

The time-course of the LPP

the morphological difference between the canonical ERP waveform to target stimuli and the LPP is **duration**:

- typical ERP responses to target stimuli are relatively transient
- LPP is evident as a more protracted positive potential

LPP reflects the relatively automatic and sustained engagement with emotionally significant content

Why so long?

A straightforward answer is that a potential threat or opportunity continues to be significant for as long as it persists before an organism

Hajcak et al, 2012; Weinberg, Ferri, & Hajcak, 2013

The time-course of the LPP

A straightforward answer is that a potential threat or opportunity continues to be significant for as long as it persists before an organism

If emotionally significant stimuli sustain engagement and ***attention*** for the duration of their presentation, this should be evident in other measurement domains

attention ↑ other measurement domains ↓

presented an irrelevant but loud auditory probe several seconds after the presentation of emotional and neutral pictures ↑

found that the target ERP response elicited by the auditory probe was reduced when participants were viewing emotional ↓

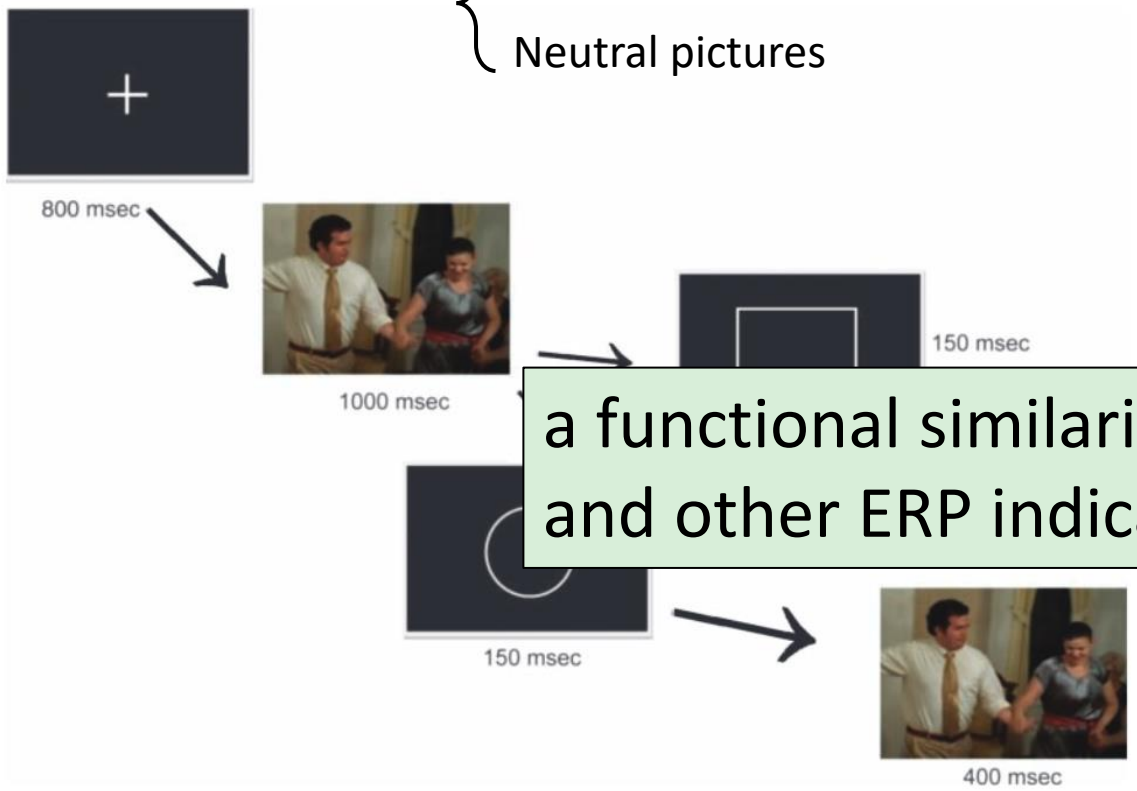
suggest that the sustained engagement with emotional picture content interferes with the processing of salient startle probes

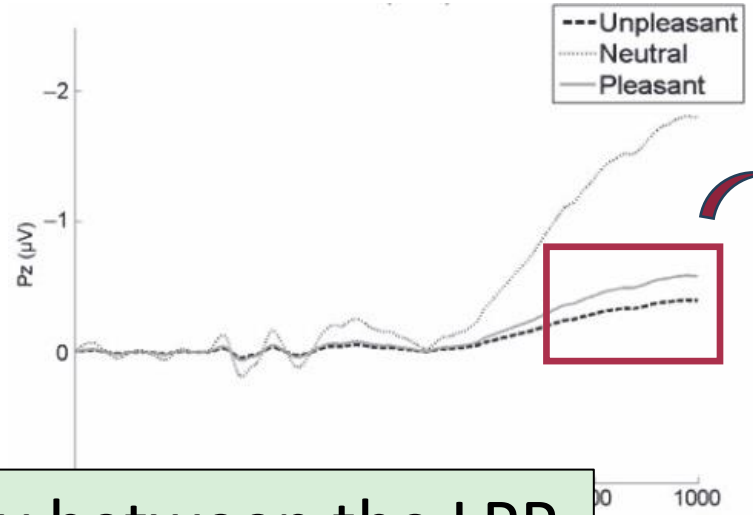
Hajcak et al, 2012; Weinberg, Ferri, & Hajcak, 2013

The time-course of the LPP

Emotional pictures

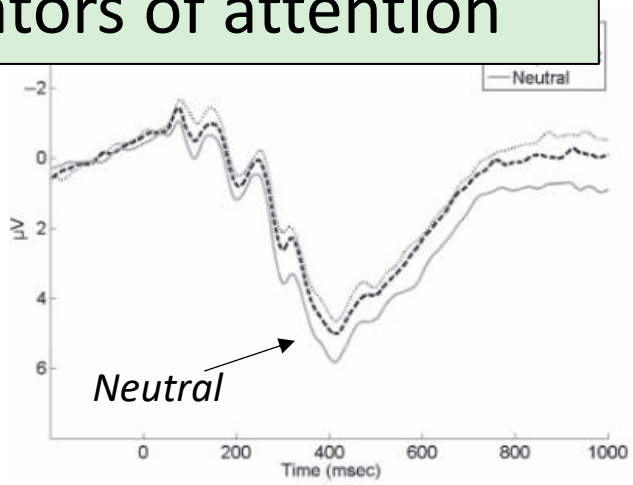
Neutral pictures

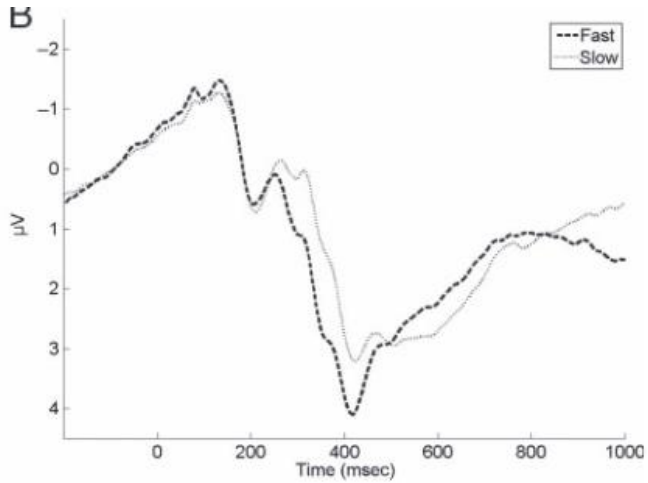




slower to perform the categorization task

a functional similarity between the LPP and other ERP indicators of attention



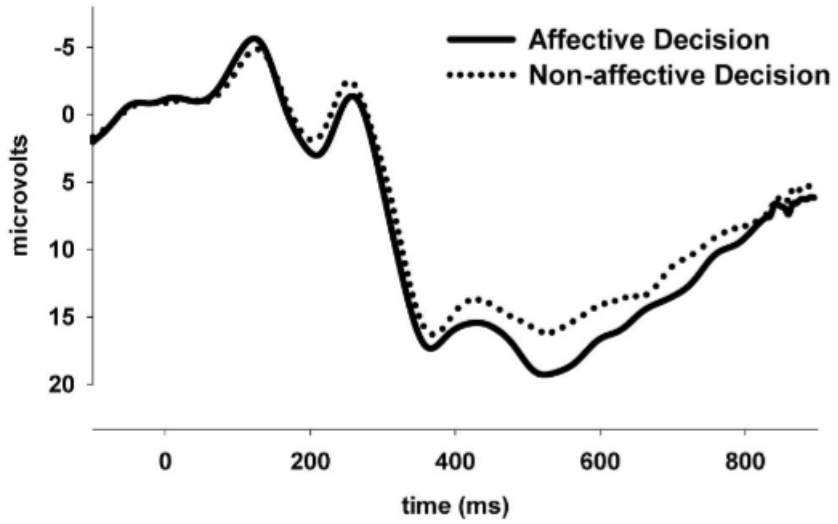


Participants characterized by a larger LPP on average tended to have smaller subsequent target ERPs

Mitchell, Richell, Leonard, & Blair, 2006; Stange et al, in press; Weinberg & Hajcak, 2011

The amplitude of the LPP and manipulations of significance

manipulate the significance of specific stimuli, and thereby alter the LPP



Affective Decision : Is this emotional or neutral?

Non-Affective Decision : How many people are in the picture?

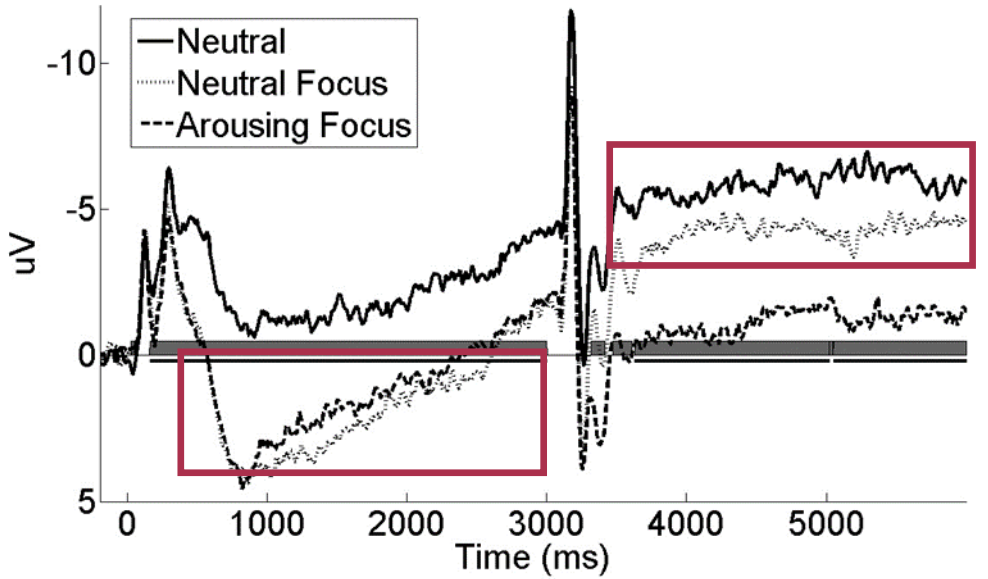
The LPP was reduced when participants made non-emotional compared to emotional decisions

drawing attention to non-emotional features might reduce the significance of picture content

Mitchell, Richell, Leonard, & Blair, 2006; Stange et al, in press; Weinberg & Hajcak, 2011

The amplitude of the LPP and manipulations of significance

meaning-based manipulations may alter the way in which unpleasant pictures are visually explored



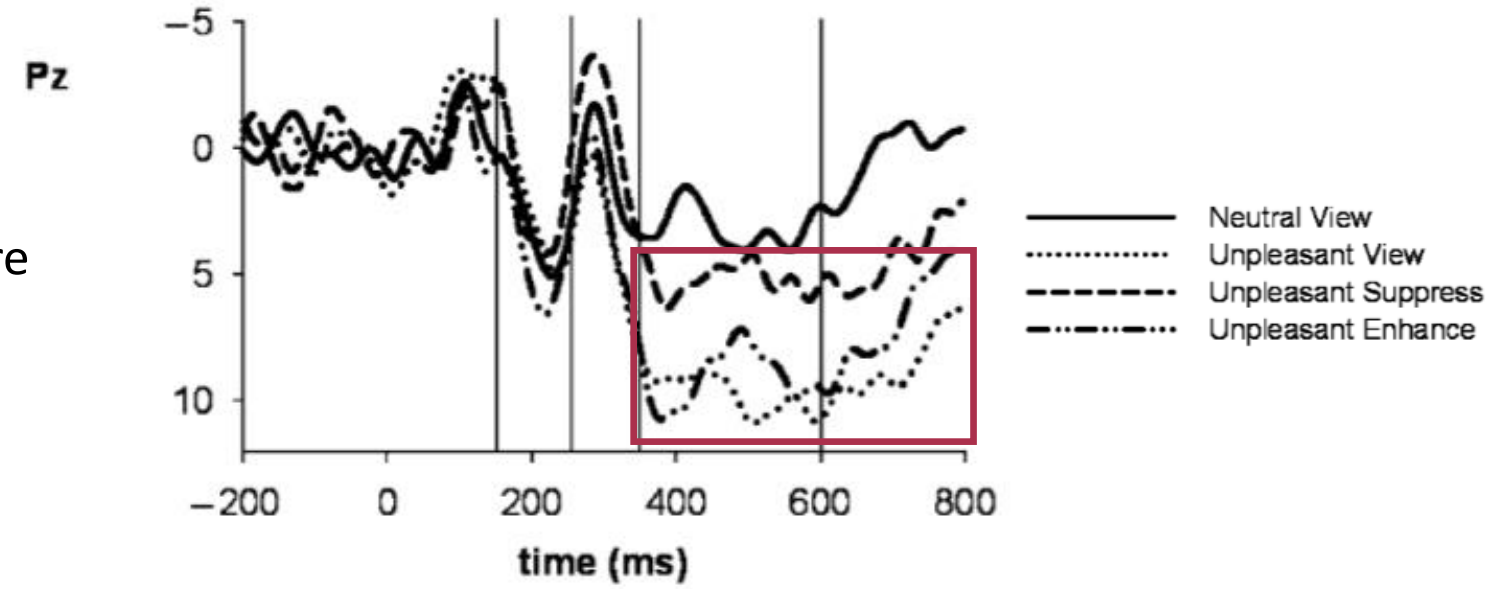
directing attention to non-emotional foci eliminated the difference between unpleasant and neutral pictures.

visual-spatial attention in determining LPP amplitude

Dunning & Hajcak, 2009; Hajcak et al., 2009; Hajcak, MacNamara, Foti, Ferri, & Keil, 2013

The amplitude of the LPP and manipulations of significance

explicitly alter the significance of picture content based on ***task instructions***



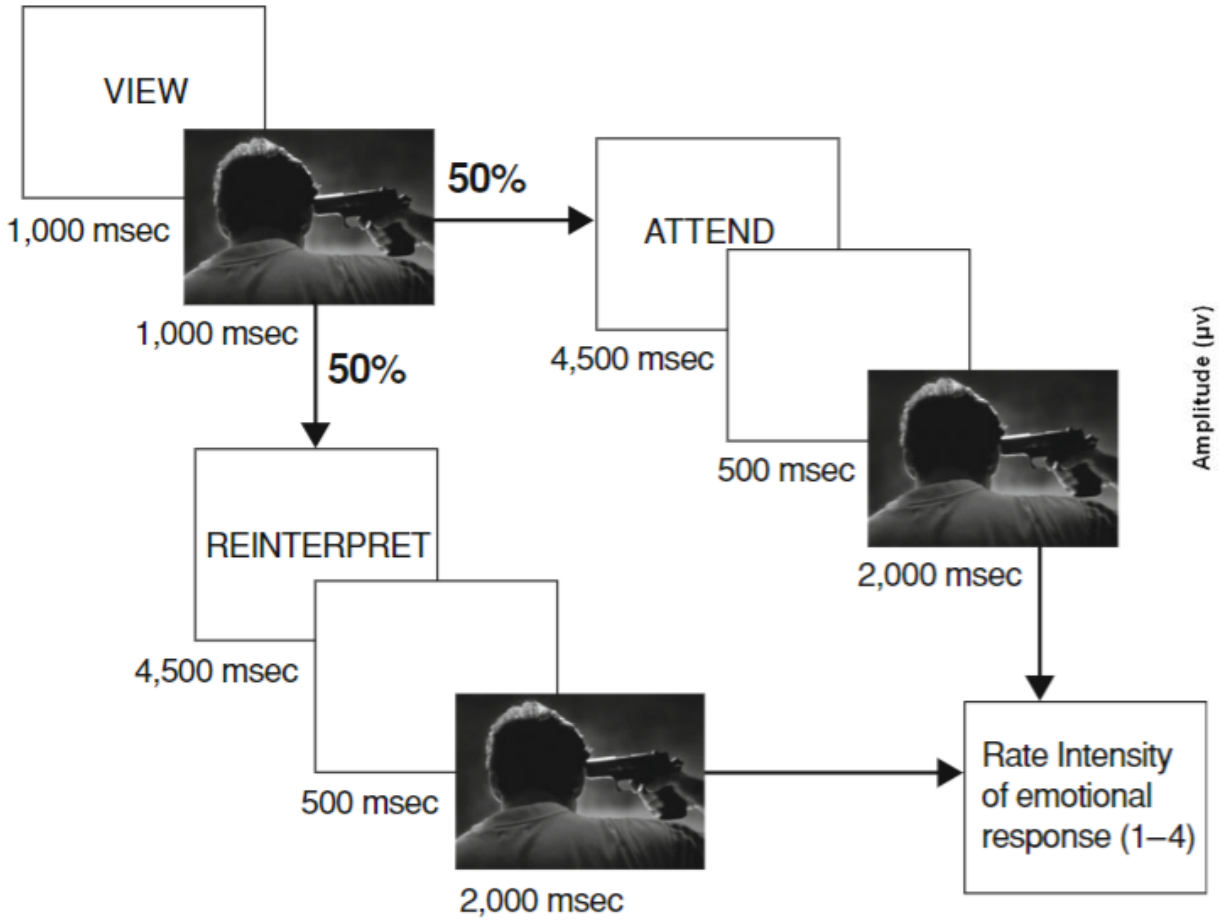
Emotional content, in this case, is not less relevant to the task

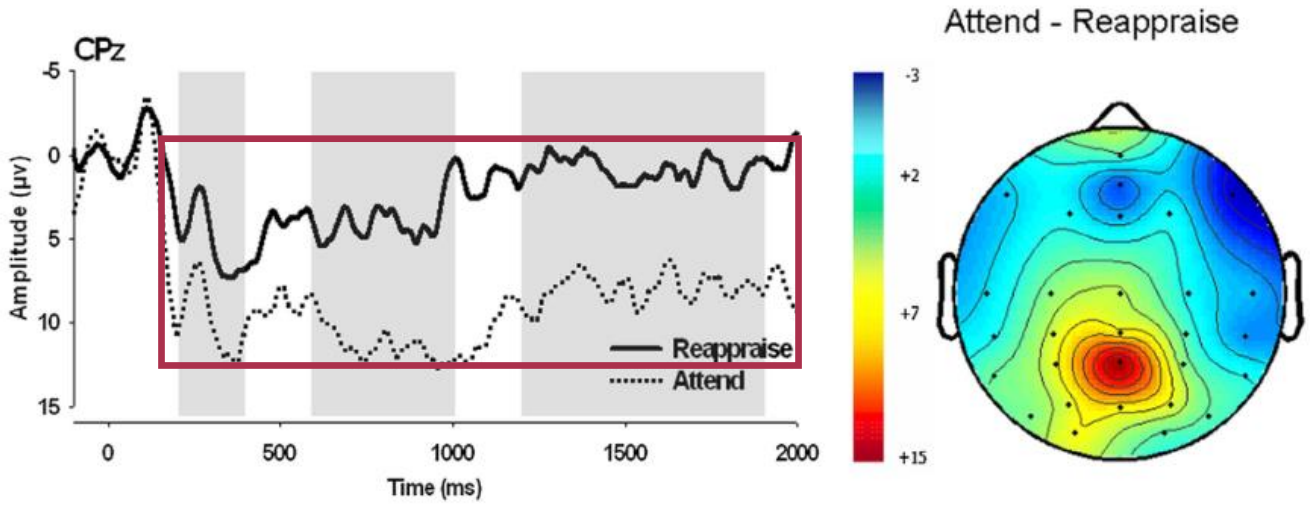
⇩

reappraisal involves altering the meaning of that content

Moser, Hajcak, Bukay, & Simons, 2006

The amplitude of the LPP and manipulations of significance

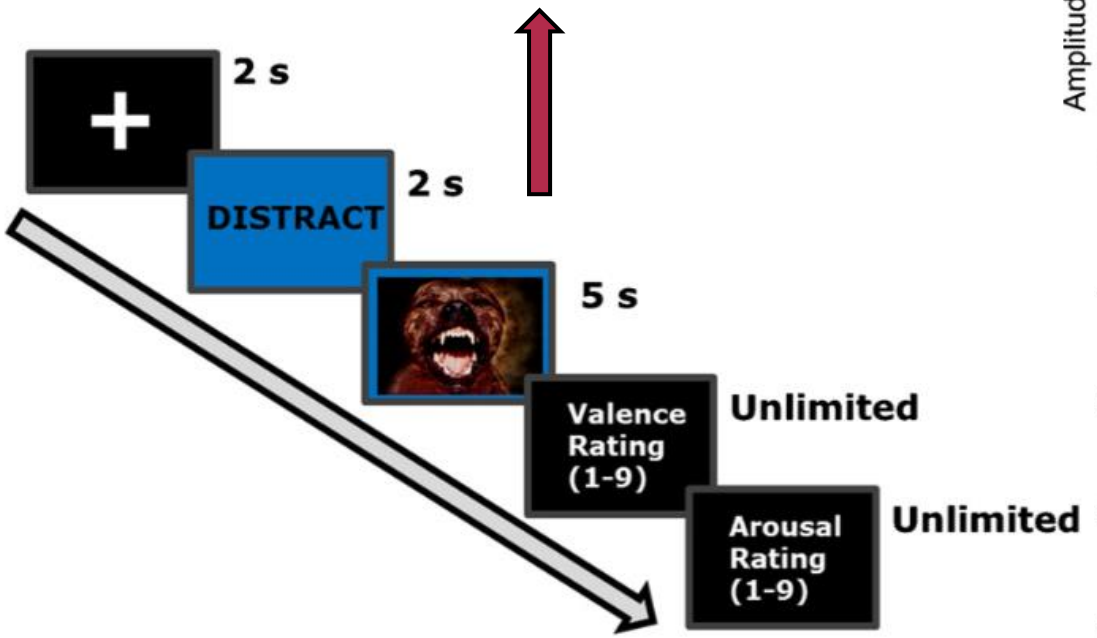


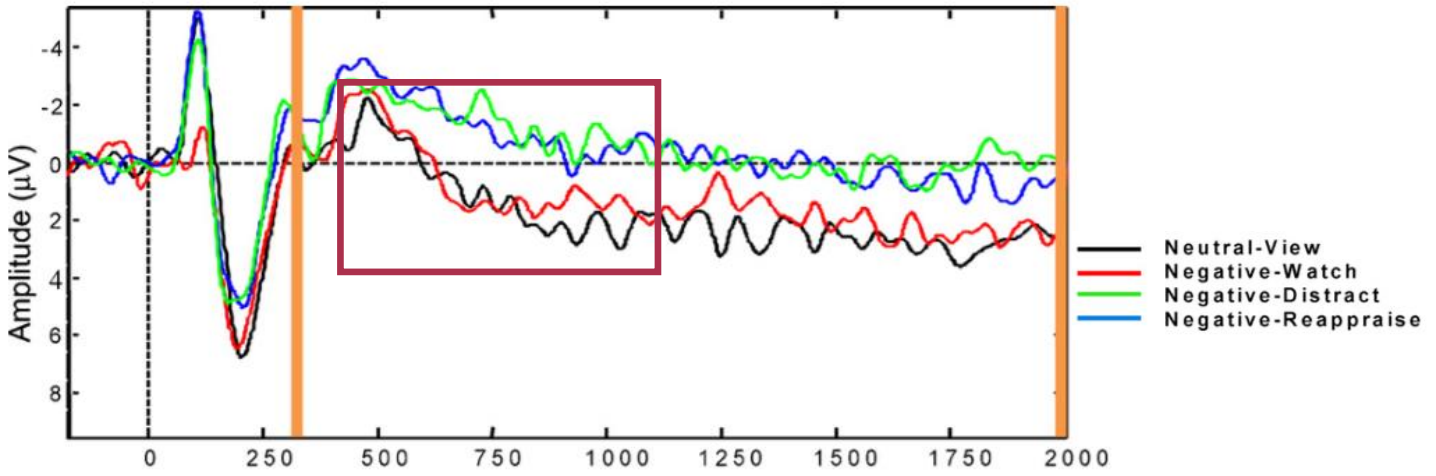


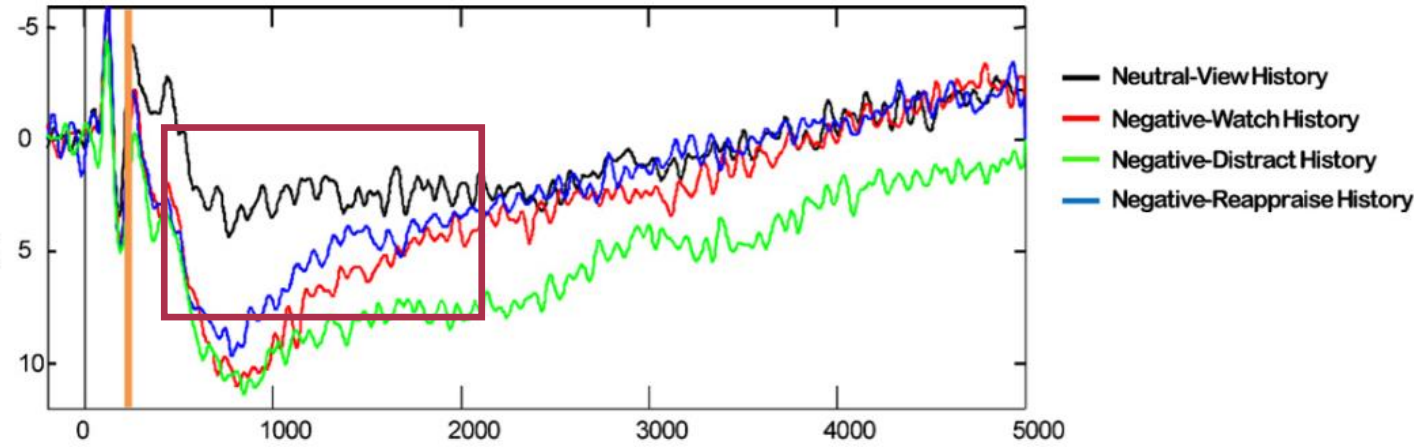
Hajcak & Nieuwenhuis，2006; Krompinger, Moser, & Simons, 2008; Langeslag & Sanchez, 2018; Paul, Simon, Kniesche, Kathmann, & Endrass, 2013

The amplitude of the LPP and manipulations of significance

previously reappraised pictures were viewed 30 min later

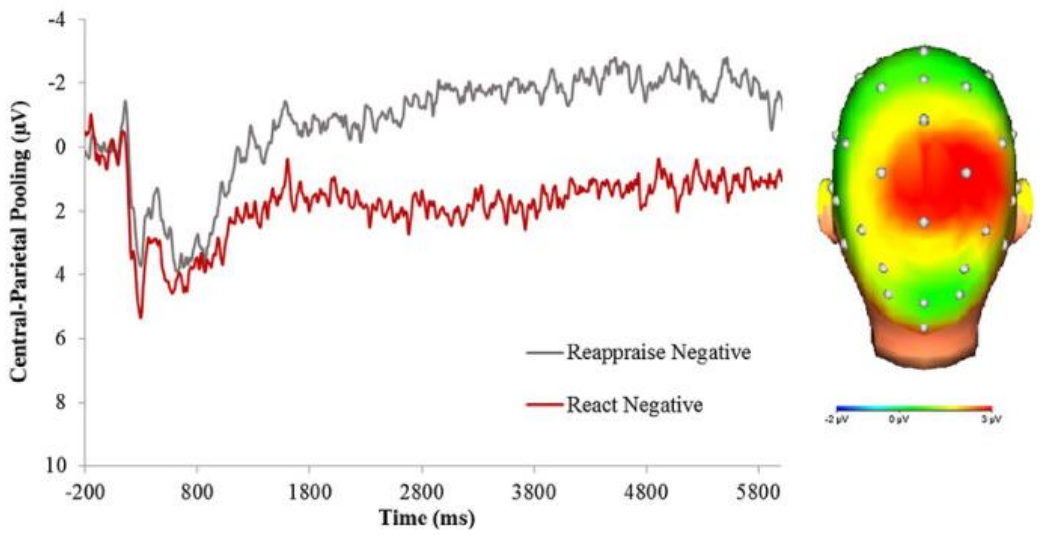


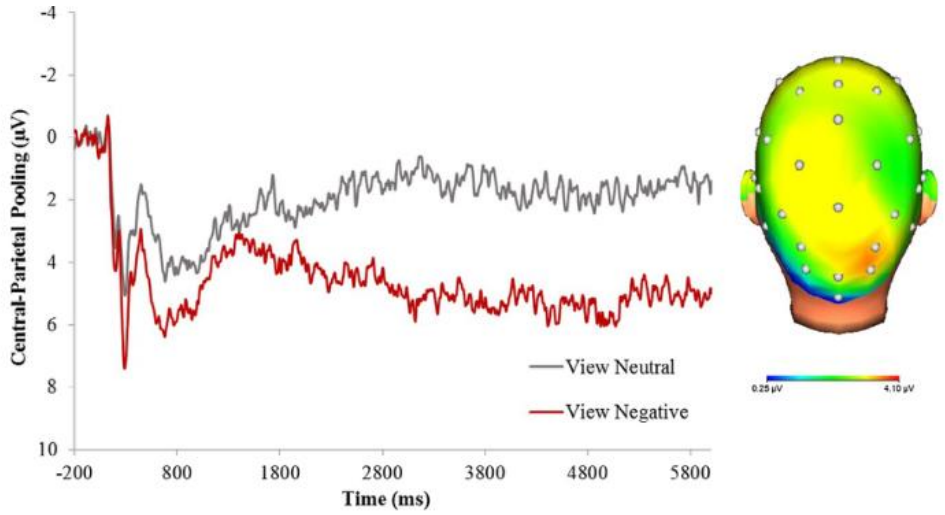




Hajcak & Nieuwenhuis，2006; Krompinger, Moser, & Simons, 2008; Langeslag & Sanchez, 2018; Paul, Simon, Kniesche, Kathmann, & Endrass, 2013

The amplitude of the LPP and manipulations of significance





reappraisal involves altering the meaning of that content

cross these studies, there are several potential pitfalls in interpreting reappraisal-related effects on the LPP.

Other interpretations also warrant consideration: Participants might be ***distracting*** themselves or even struggling to do reappraisal.

general instruction

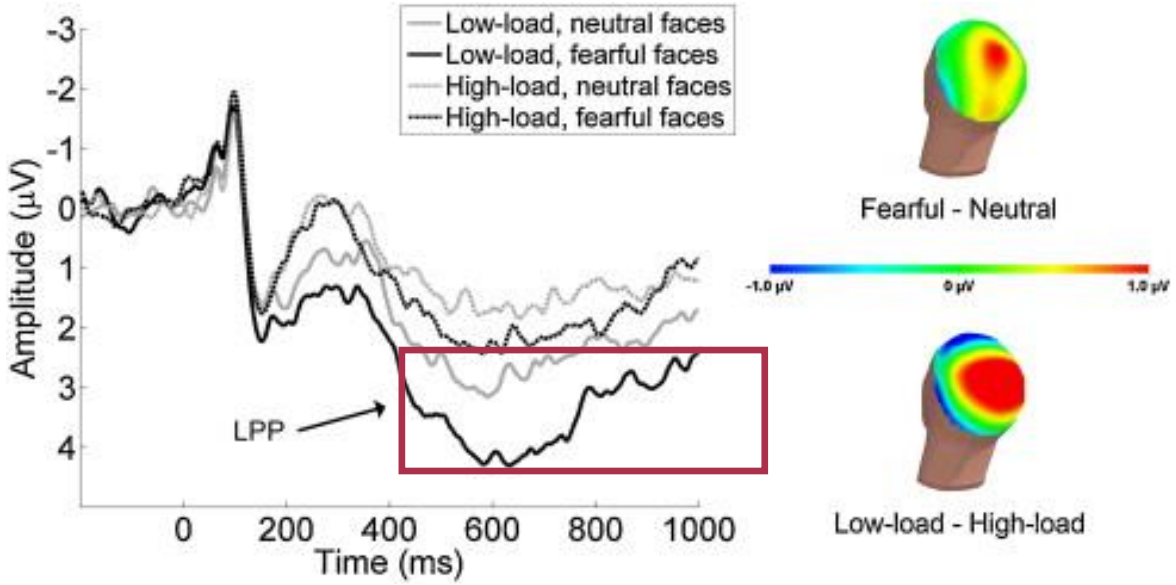
⇩ ?

not clear what participants are actually doing

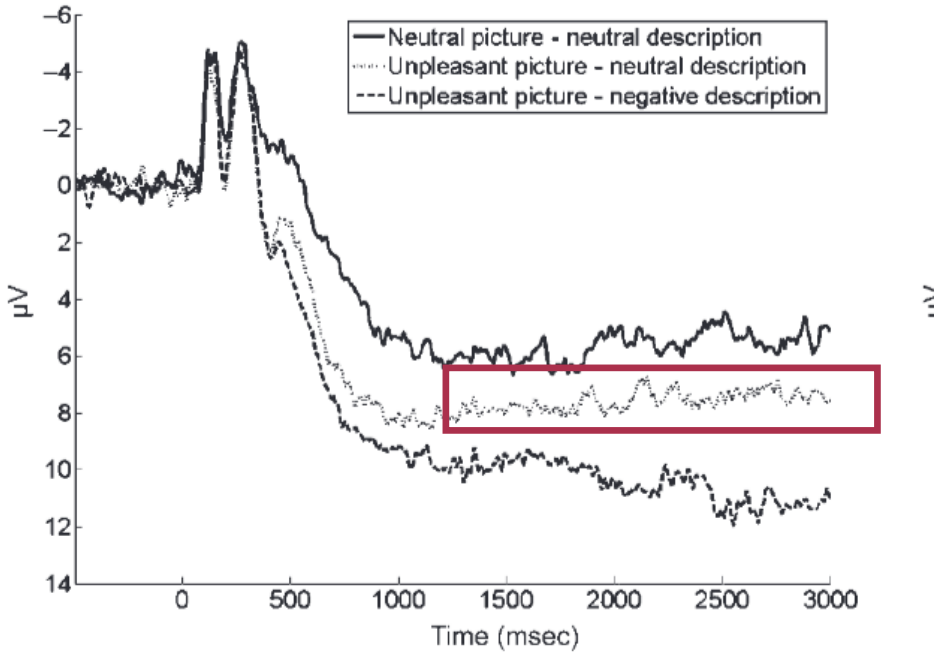
reappraisal is generally more cognitively challenging than the control condition such as passive viewing

Hajcak & Nieuwenhuis，2006; Krompinger, Moser, & Simons, 2008; Langeslag & Sanchez, 2018; Paul, Simon, Kniesche, Kathmann, & Endrass, 2013

The amplitude of the LPP and manipulations of significance



reappraisal ➡ ***preappraisals***



The LPP continued to be affected by the previously paired description

MacNamara, Schmidt, Zelinsky, & Hajcak, 2012; Gan, Yang, Chen, Zhang, & Yang, 2017

The amplitude of the LPP and manipulations of significance

- Meaning-based
- attentional
- working memory load

reduce the activation of motivational neural circuits

variability in the amplitude of the LPP reflects stimulus significance and associated activation of motivational circuits

effects traditionally understood to indicate successful emotion regulation operate directly on the motivational significance of the stimuli.

Ochsner & Gross, 2005

Theoretical implications

theoretical implications of the research on late positive potentials (LPP) and P300 as neural responses to stimulus significance

- major depressive disorder (MDD) and the LPP
- theory of context updating and orienting
- potential involvement of the locus coeruleus-norepinephrine (LC-NE) system

Ochsner & Gross, 2005

PSYCHOPHYSIOLOGY

Significance?... Significance! Empirical, methodological, and theoretical connections between the late positive potential and P300 as neural responses to stimulus significance: An integrative review

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working to better understand the development and risk for anxiety and depression—as well as training students to treat these disorders

Yang Ziyang

2024.03.29

EffortEmpathy实验结果

Yang Ziyang

2024.03.19

Design

13.5s/trial

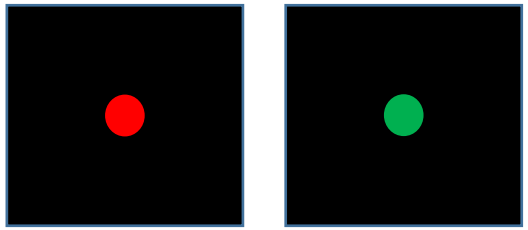
200 trials (2effort*2pain*50)

正式实验时长(平均每个回合休息1.5s计) > **45** min

总时长> **103**min = 40准备+ 45正式 + 7指导语 + 5练习 + 3*2mins休息

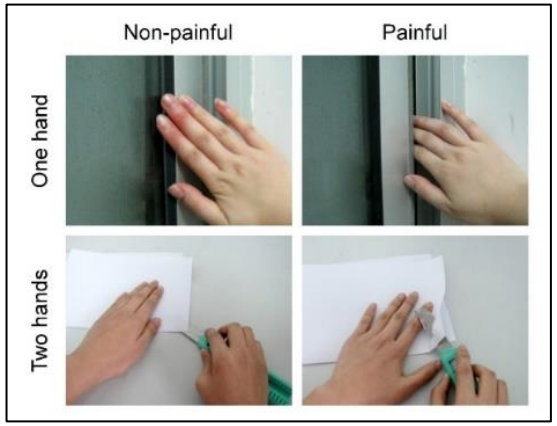
2color*2gender = 4balance

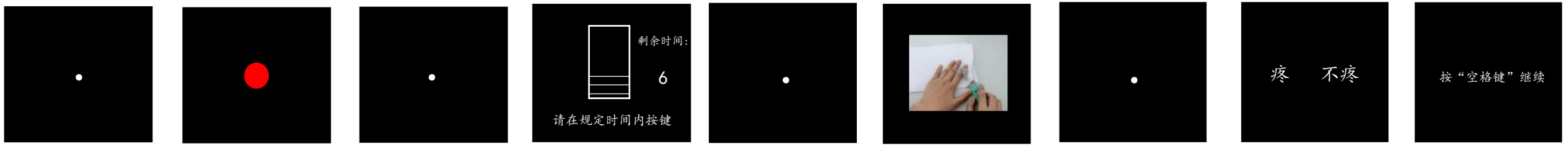
41 participants(20 female)



(2effort: low – high)

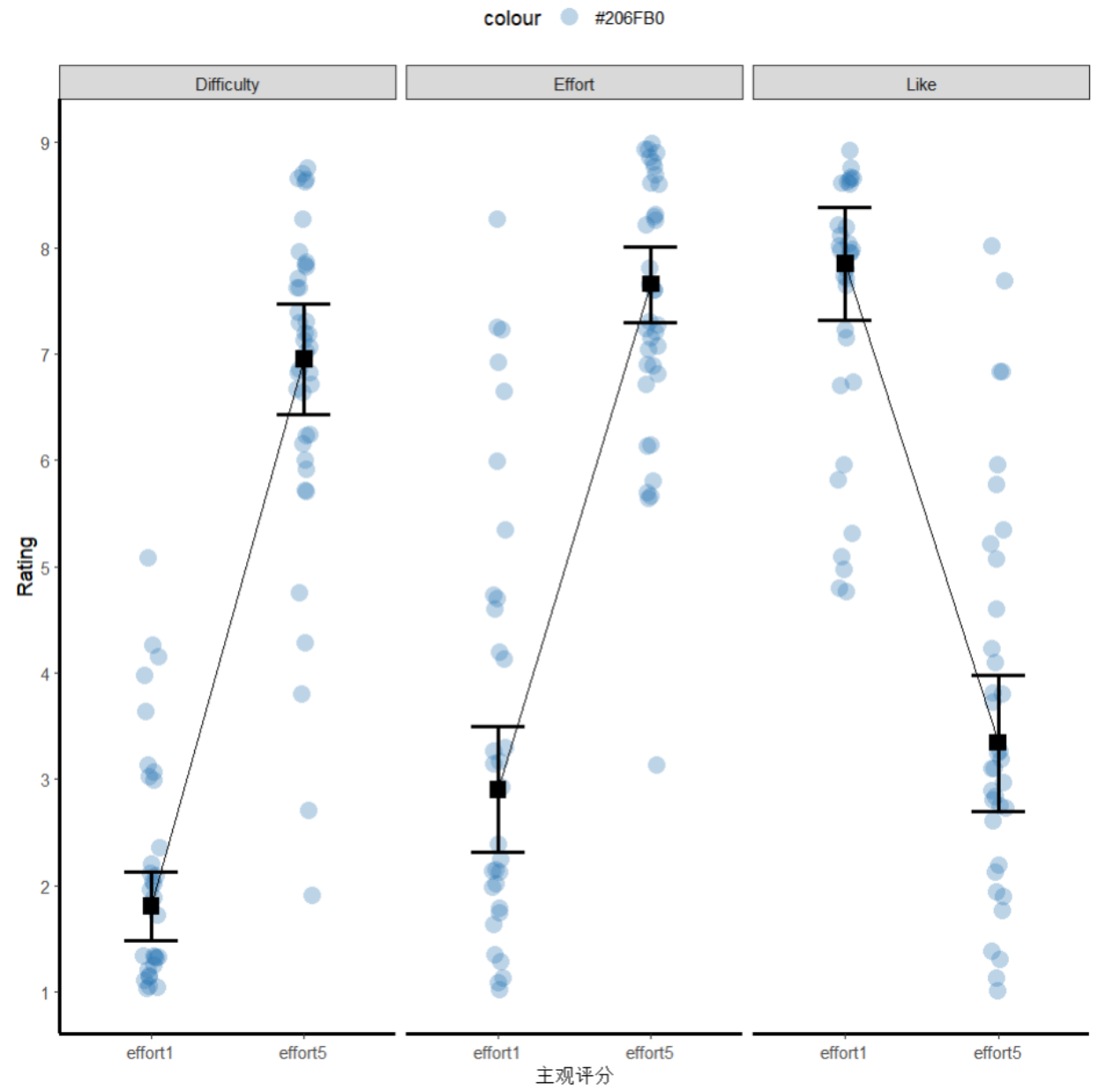
(EPSS-Limb)





900 - 1100ms | 1000 ms | 900 - 1100ms | RT | 1800 - 2200ms | 1500 ms | 900 - 1100ms | RT | /

Rating



Difficulty

ANOVA Table:
Dependent variable(s): Rating
Between-subjects factor(s): –
Within-subjects factor(s): Type
Covariate(s): –

	MS	MSE	df1	df2	F	p	η²p [90% CI of η²p]	η²G
Type	542.939	2.189	1	40	248.028	<.001 ***	.861 [.793, .900]	.776

Effort

ANOVA Table:
Dependent variable(s): Rating
Between-subjects factor(s): –
Within-subjects factor(s): Type
Covariate(s): –

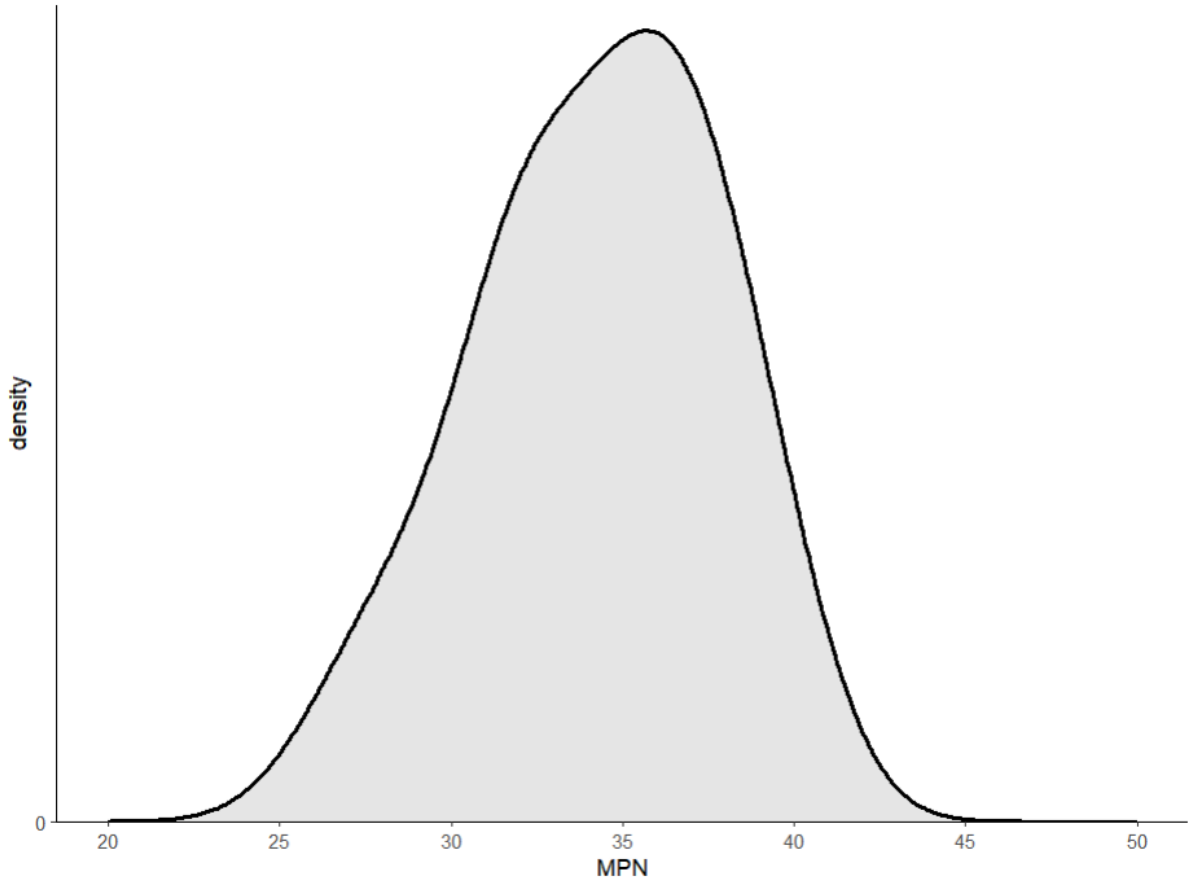
	MS	MSE	df1	df2	F	p	η²p [90% CI of η²p]	η²G
Type	463.720	2.145	1	40	216.235	<.001 ***	.844 [.768, .888]	.649

Like

ANOVA Table:
Dependent variable(s): Rating
Between-subjects factor(s): –
Within-subjects factor(s): Type
Covariate(s): –

	MS	MSE	df1	df2	F	p	η²p [90% CI of η²p]	η²G
Type	417.378	3.353	1	40	124.477	<.001 ***	.757 [.643, .825]	.644

MaxPressNumber




```
> summary(MPN)
    MeanMaxNum
 Min.   :26.33
 1st Qu.:31.67
 Median :34.67
 Mean   :34.26
 3rd Qu.:37.00
 Max.   :40.00
```

```
        Shapiro-Wilk normality test

data:  MPN$MPN
W = 0.97056, p-value = 0.3597
```

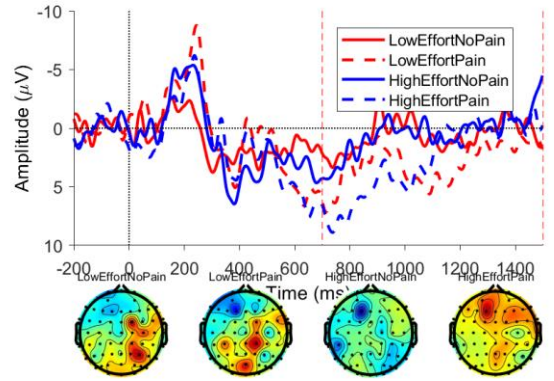
符合正态分布

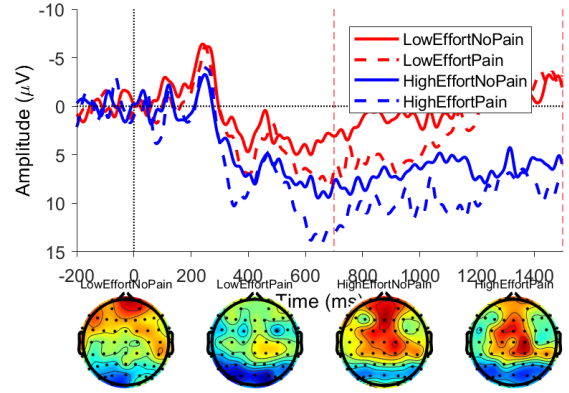
sd_MPN	3.48277941291498

Accepted Trials

subj	LENP	LEPP	HENP	HEPP
201	49	50	50	50
202	50	47	44	45
203	50	49	48	49
204	48	43	42	43
205	48	49	50	50
206	49	47	48	49
207	47	49	49	50
208	50	49	47	50
209	49	50	47	44
210	48	47	48	49
211	38	43	33	32
212	48	48	46	44
213	48	47	47	50
214	47	47	46	48
215	45	46	45	44
216	47	48	46	44
217	49	49	49	50
218	41	42	43	43
219	47	46	49	49
220	49	49	50	47

subj	LENP	LEPP	HENP	HEPP
301	47	49	40	40
302	50	47	46	49
303	48	49	50	48
304	48	47	50	48
305	49	50	48	48
306	49	48	49	47
307	50	49	49	49
308	43	49	43	44
309	47	48	45	50
310	47	49	45	49
311	37	34	40	35
312	46	48	40	42
313	49	49	45	46
314	50	50	49	47
315	49	49	48	48
316	48	49	47	44
317	49	47	48	48
318	47	48	46	47
319	50	50	45	50
320	45	50	45	49
321	43	43	43	46

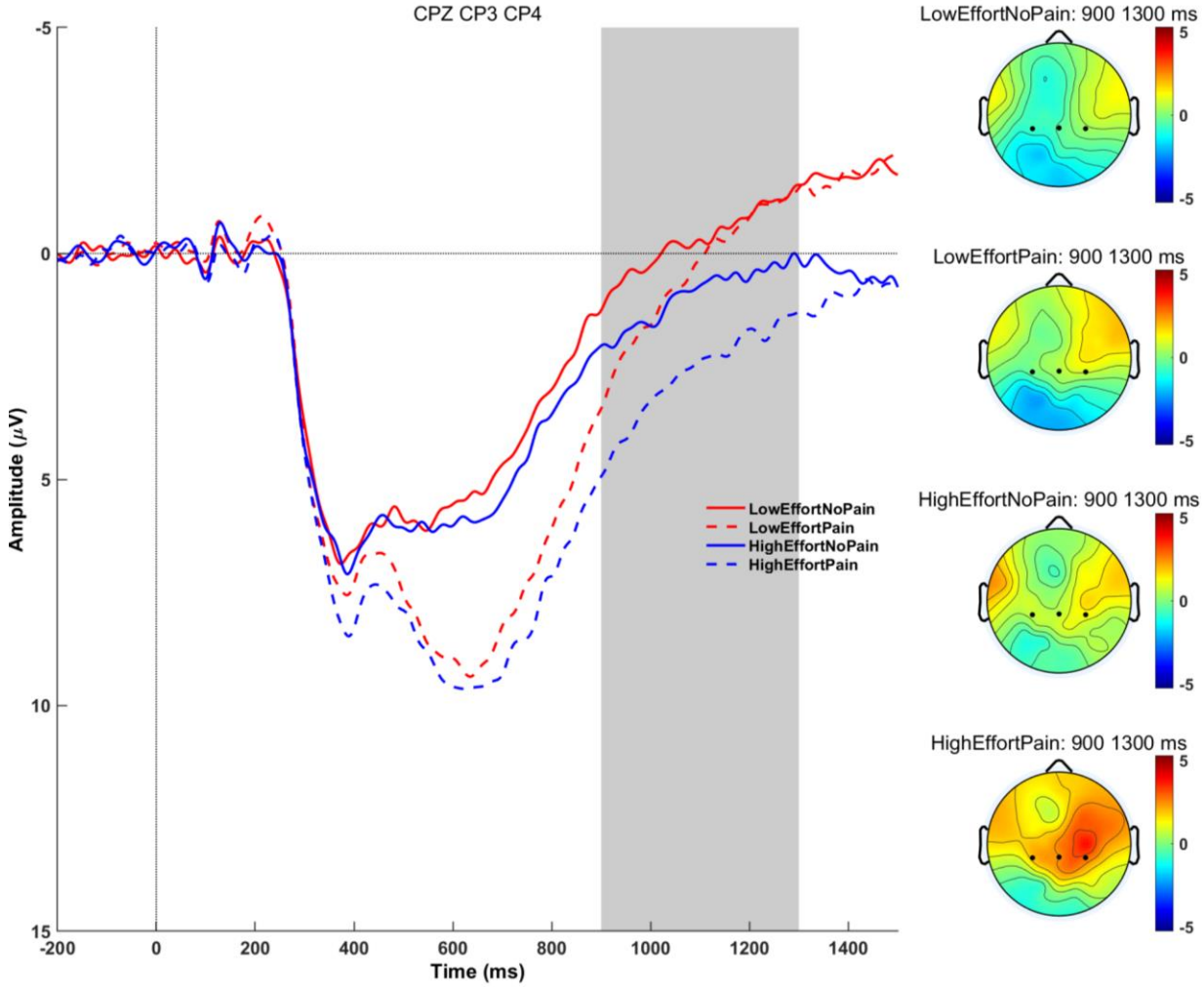




ERPs

LPP *print (summary(Mod_LPP <- lmer(LPP ~ Effort*Pain+(Effort|Subject), a1,REML=FALSE)))*

LMM TW:900-1300ms 电极点：CP3 CPZ CP4



LPP

Predictors	*Estimates*	*CI*	*p*
(Intercept)	0.83	0.03 – 1.62	**0.041**
Effort2-1	1.58	0.64 – 2.51	**0.001**
Pain2-1	1.10	0.66 – 1.54	**<0.001**
Effort2-1:Pain2-1	0.90	0.02 – 1.78	**0.045**

Random Effects

σ^2	90.00
$\tau_{00\ Subject}$	5.75
$\tau_{11\ Subject.Effort2\text{-}1}$	6.71
$\rho_{01\ Subject}$	0.22
ICC	0.08
$N_{\ Subject}$	38
Observations	7182
Marginal R^2 / Conditional R^2	0.010 / 0.085

(*Effort*Pain|Subject*)
(*Effort+Pain|Subject*)
均未能拟合
(*Pain|Subject*)
畸形拟合

ERPs

LPP *print (summary(Mod_LPP <- lmer(LPP ~ Effort*Pain+(Effort|Subject), a1,REML=FALSE)))*

LMM TW:900-1300ms 电极点：CP3 CPZ CP4

	LPP		
Predictors	*Estimates*	*CI*	*p*
(Intercept)	0.83	0.03 – 1.62	**0.041**
Effort2-1	1.58	0.64 – 2.51	**0.001**
Pain2-1	-1.10	-1.54 – -0.66	**<0.001**
Effort2-1:Pain2-1	-0.90	-1.78 – -0.02	**0.045**
Random Effects			
σ^2	90.00		
τ_{00} Subject	5.75		
τ_{11} Subject.Effort2-1	6.71		
ρ_{01} Subject	0.22		
ICC	0.08		
N Subject	38		
Observations	7182		
Marginal R^2 / Conditional R^2	0.010 / 0.085		

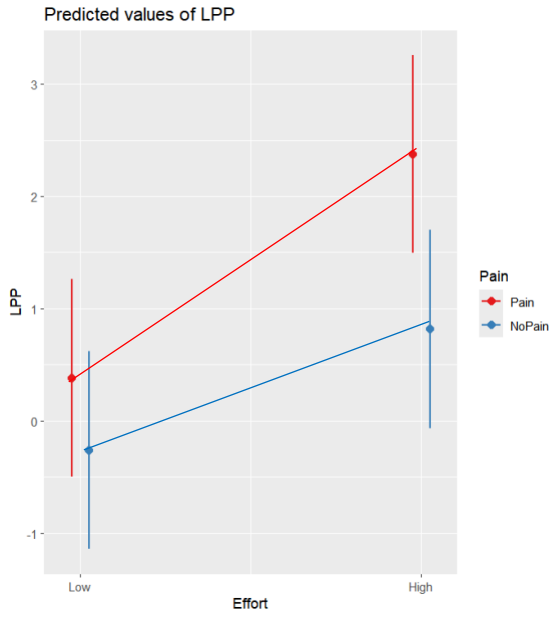
```
$contrasts
Effort = Low:
 contrast      estimate    SE  df z.ratio p.value
 NoPain - Pain   -0.649 0.315 Inf  -2.061  0.0393

Effort = High:
 contrast      estimate    SE  df z.ratio p.value
 NoPain - Pain   -1.549 0.319 Inf  -4.860  <.0001
```

在High\Low Effort两种条件下，

Pain的激活都显著大于NoPain

但在HighEffort条件下效应更大



ERPs

LPP *print (summary(Mod_LPP <- lmer(LPP ~ Effort*Pain*cTrial+(Effort|Subject), a1,REML=FALSE)))*

LMM TW:900-1300ms 电极点：CP3 CPZ CP4

Predictors	*Estimates*	*CI*	*p*
(Intercept)	0.82	0.03 – 1.62	**0.041**
Effort2-1	1.59	0.66 – 2.52	**0.001**
Pain2-1	1.12	0.68 – 1.55	**<0.001**
cTrial	-0.41	-0.75 – -0.08	**0.015**
Effort2-1:Pain2-1	0.88	0.01 – 1.76	**0.048**
Effort2-1:cTrial	-0.28	-0.90 – 0.35	0.387
Pain2-1:cTrial	-0.55	-0.99 – -0.11	**0.014**
Effort2-1:Pain2-1:cTrial	0.35	-0.53 – 1.23	0.434

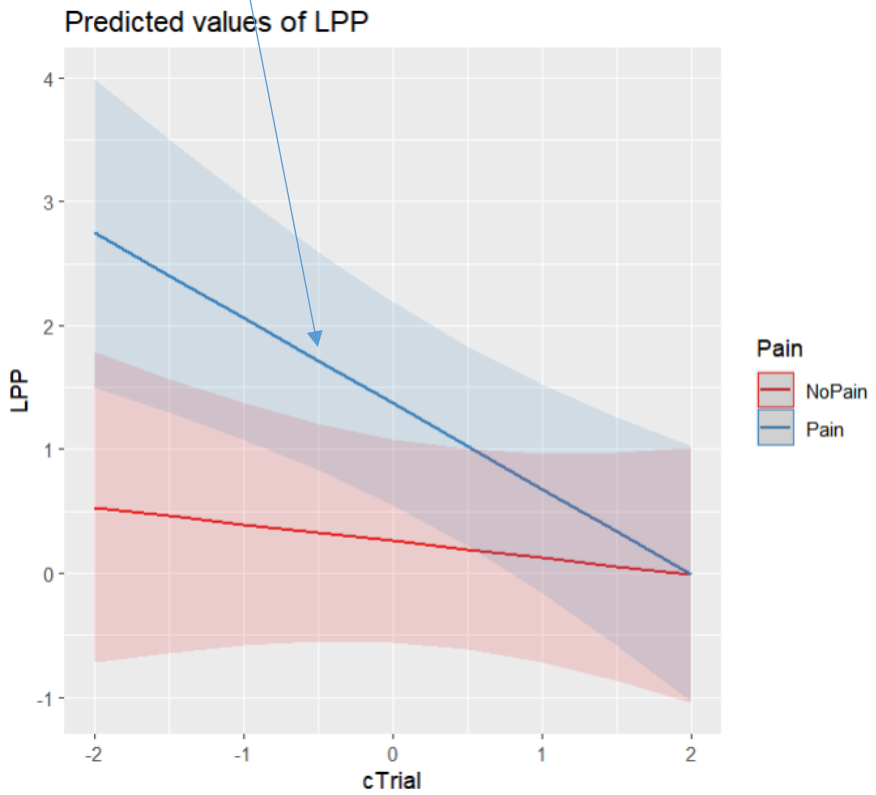
Random Effects

σ^2	88.67
$\tau_{00\ Subject}$	5.74
$\tau_{11\ Subject.Effort2-1}$	6.72
$\tau_{11\ Subject.cTrial}$	0.62
$\tau_{11\ Subject.Effort2-1:cTrial}$	1.94
ρ_{01}	0.22
	-0.31
	0.33
ICC	0.09
$N_{Subject}$	38
Observations	7182
Marginal R^2 / Conditional R^2	0.013 / 0.099

```
$emtrends
 Pain    cTrial.trend    SE   df lower.CL upper.CL
 Pain          -0.689 0.205 79.9    -1.10   -0.280
 NoPain        -0.139 0.206 81.3    -0.55    0.271
```

```
$contrasts
 contrast       estimate    SE   df t.ratio p.value
 Pain - NoPain     -0.55 0.225 7105  -2.443  0.0146
```

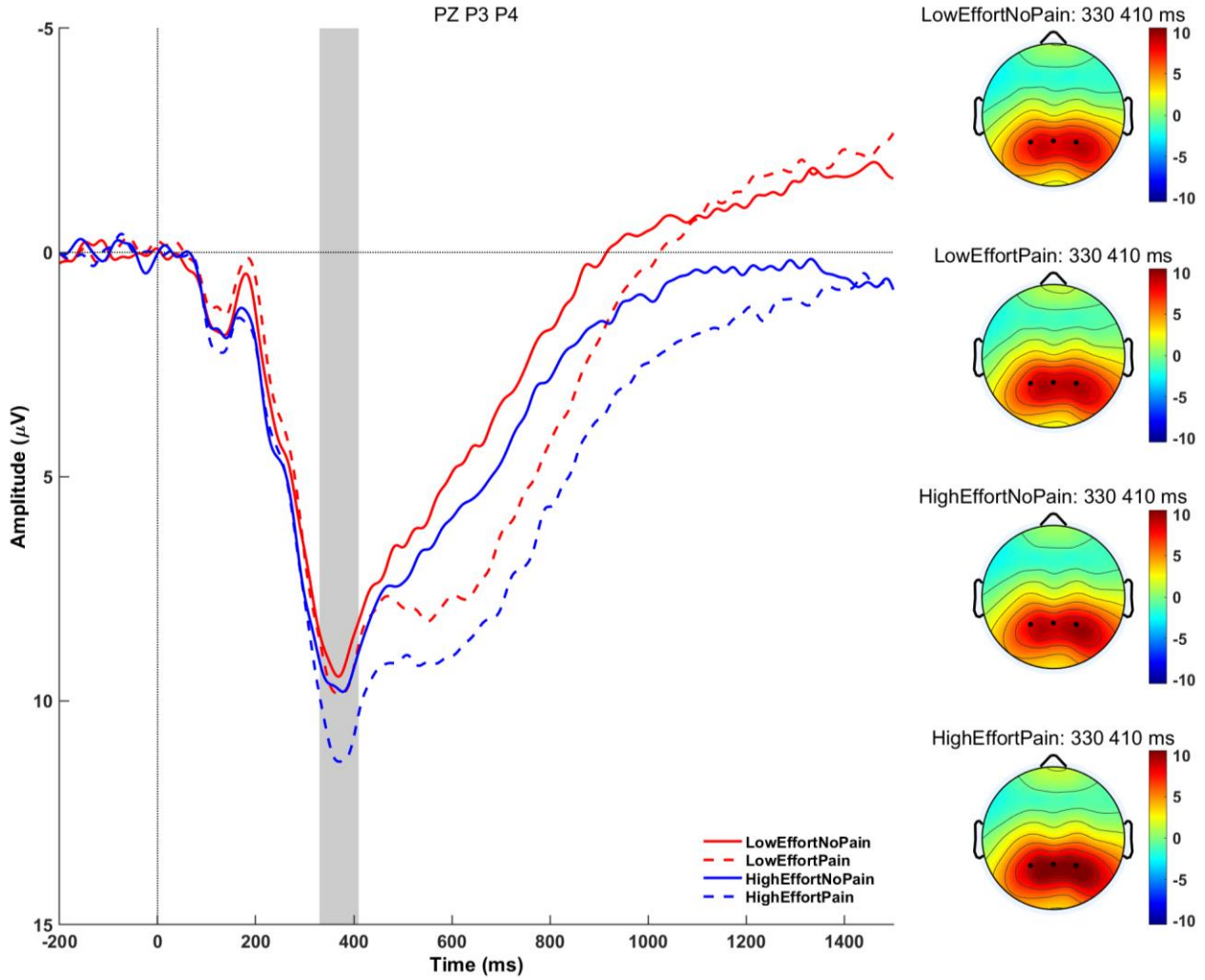
(*Effort*cTrial*Pain*|Subject)
(*Effort*cTrial+Pain*|Subject)
(*Effort*Pain*|*Subject*)
畸形拟合
(*Effort+Pain*|*Subject*)
(*Pain*|*Subject*)
未能拟合



ERPs

P3 *print (summary(Mod_P3 <- lmer(P3 ~ Effort*Pain+(Effort+Pain|Subject), a1,REML=FALSE)))*

LMM TW:330-410ms 电极点：PZ P3 P4



	P3		
Predictors	*Estimates*	*CI*	*p*
(Intercept)	8.92	7.84 – 10.00	**<0.001**
Effort2-1	0.91	0.43 – 1.39	**<0.001**
Pain2-1	0.84	0.43 – 1.26	**<0.001**
Effort2-1:Pain2-1	0.81	0.04 – 1.58	**0.039**
Random Effects			
σ^2	69.00		
$\tau_{00\ Subject}$	11.19		
$\tau_{11\ Subject.Effort2\text{-}1}$	0.82		
$\tau_{11\ Subject.Pain2\text{-}1}$	0.25		
ρ_{01}	0.07		
	0.77		
ICC	0.14		
$N_{\ Subject}$	38		
Observations	7182		
Marginal R^2 / Conditional R^2	0.005 / 0.147		

(*Effort*Pain*|*Subject*)
畸形拟合

ERPs

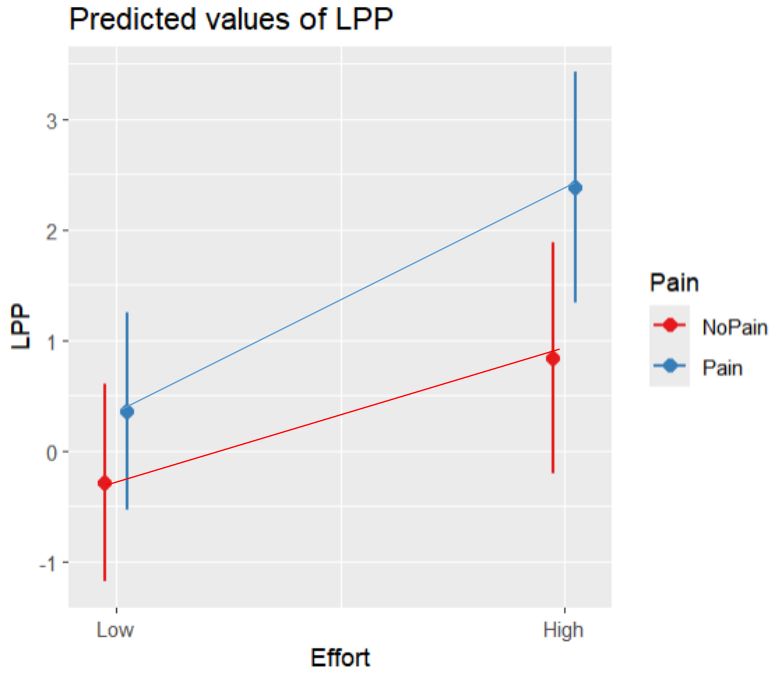
P3 *print (summary(Mod_P3 <- lmer(P3 ~ Effort*Pain+(Effort+Pain|Subject), a1,REML=FALSE)))*

LMM TW:330-410ms 电极点：PZ P3 P4

	P3		
Predictors	*Estimates*	*CI*	*p*
(Intercept)	8.92	7.84 – 10.00	**<0.001**
Effort2-1	0.91	0.43 – 1.39	**<0.001**
Pain2-1	0.84	0.43 – 1.26	**<0.001**
Effort2-1:Pain2-1	0.81	0.04 – 1.58	**0.039**
Random Effects			
σ^2	69.00		
$\tau_{00\ Subject}$	11.19		
$\tau_{11\ Subject.Effort2\text{-}1}$	0.82		
$\tau_{11\ Subject.Pain2\text{-}1}$	0.25		
ρ_{01}	0.07		
	0.77		
ICC	0.14		
$N_{Subject}$	38		
Observations	7182		
Marginal R^2 / Conditional R^2	0.005 / 0.147		

```
$contrasts
Effort = Low:
 contrast      estimate    SE   df t.ratio p.value
 Pain - NoPain    0.643 0.315 7113   2.044  0.0410

Effort = High:
 contrast      estimate    SE   df t.ratio p.value
 Pain - NoPain    1.542 0.318 7113   4.845  <.0001
```



ERPs

P3 *print (summary(Mod_P3 <- lmer(P3 ~ Effort*Pain*Gender +(Effort|Subject), a1,REML=FALSE)))*

LMM TW:330-410ms 电极点：PZ P3 P4

P3

Predictors	*Estimates*	*CI*	*p*
(Intercept)	8.89	7.82 – 9.96	**<0.001**
Effort2-1	0.92	0.44 – 1.40	**<0.001**
Pain2-1	0.83	0.44 – 1.21	**<0.001**
Gender2-1	1.10	-1.04 – 3.24	0.314
Effort2-1:Pain2-1	0.79	0.02 – 1.55	**0.045**
Effort2-1:Gender2-1	-0.40	-1.35 – 0.56	0.416
Pain2-1:Gender2-1	1.06	0.29 – 1.83	**0.007**
Effort2-1:Pain2-1:Gender2-1	1.42	-0.12 – 2.96	0.070

Random Effects

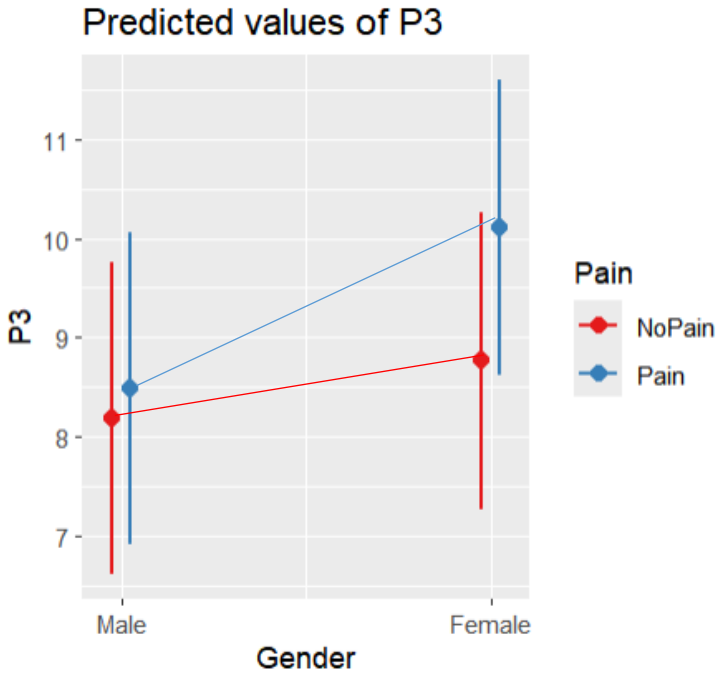
σ^2	68.96	(*Effort*Pain*|*Subject*)
$\tau_{00\ Subject}$	10.90	未能收敛
$\tau_{11\ Subject.Effort2-1}$	0.79	(*Effort+Pain*|*Subject*)
$\rho_{01\ Subject}$	0.11	(*Pain*|*Subject*)
ICC	0.14	畸形拟合
$N_{\ Subject}$	38	
Observations	7182	
Marginal R^2 / Conditional R^2	0.010 / 0.147	

```
$contrasts
Gender = Male:
 contrast      estimate    SE   df t.ratio p.value
 Pain - NoPain    0.296 0.283 7111   1.046  0.2957

Gender = Female:
 contrast      estimate    SE   df t.ratio p.value
 Pain - NoPain    1.354 0.272 7114   4.985  <.0001
```

对于男性来说，Pain和NoPain诱发的P3波幅无显著差异，

但对于女性来说，Pain诱发的P3波幅显著大于NoPain



P3 *MANOVA(data=a1, dv="P3", subID= "Subject",within=c("Effort","Pain"),between = ("Gender"))*

ANOVA TW:330-410ms 电极点：PZ P3 P4

	MS	MSE	df1	df2	F	p	η²p [90% CI of η²p]	η²G
Gender	46.520	47.439	1	36	0.981	.329	.027 [.000, .162]	.024
Effort	32.825	2.399	1	36	13.683	<.001 ***	.275 [.090, .454]	.017
Gender * Effort	1.458	2.399	1	36	0.608	.441	.017 [.000, .140]	.001
Pain	26.552	1.551	1	36	17.118	<.001 ***	.322 [.126, .495]	.014
Gender * Pain	10.948	1.551	1	36	7.059	.012 *	.164 [.023, .346]	.006
Effort * Pain	6.223	1.070	1	36	5.817	.021 *	.139 [.012, .319]	.003
Gender * Effort * Pain	4.948	1.070	1	36	4.624	.038 *	.114 [.004, .290]	.003

Contrast	"Gender"	Estimate	S.E.	df	t	p	Cohen's d [95% CI of d]
NoPain - Pain	Male	-0.300	(0.294)	36	-1.020	.314	-0.166 [-0.496, 0.164]
NoPain - Pain	Female	-1.375	(0.278)	36	-4.936	<.001 ***	-0.762 [-1.075, -0.449]

Contrast	"Effort"	Estimate	S.E.	df	t	p	Cohen's d [95% CI of d]
NoPain - Pain	Low	-0.432	(0.254)	36	-1.700	.098 .	-0.239 [-0.525, 0.046]
NoPain - Pain	High	-1.242	(0.272)	36	-4.574	<.001 ***	-0.688 [-0.994, -0.383]

P3 *MANOVA(data=a1, dv="P3", subID= "Subject",within=c("Effort","Pain"),between = ("Gender"))*

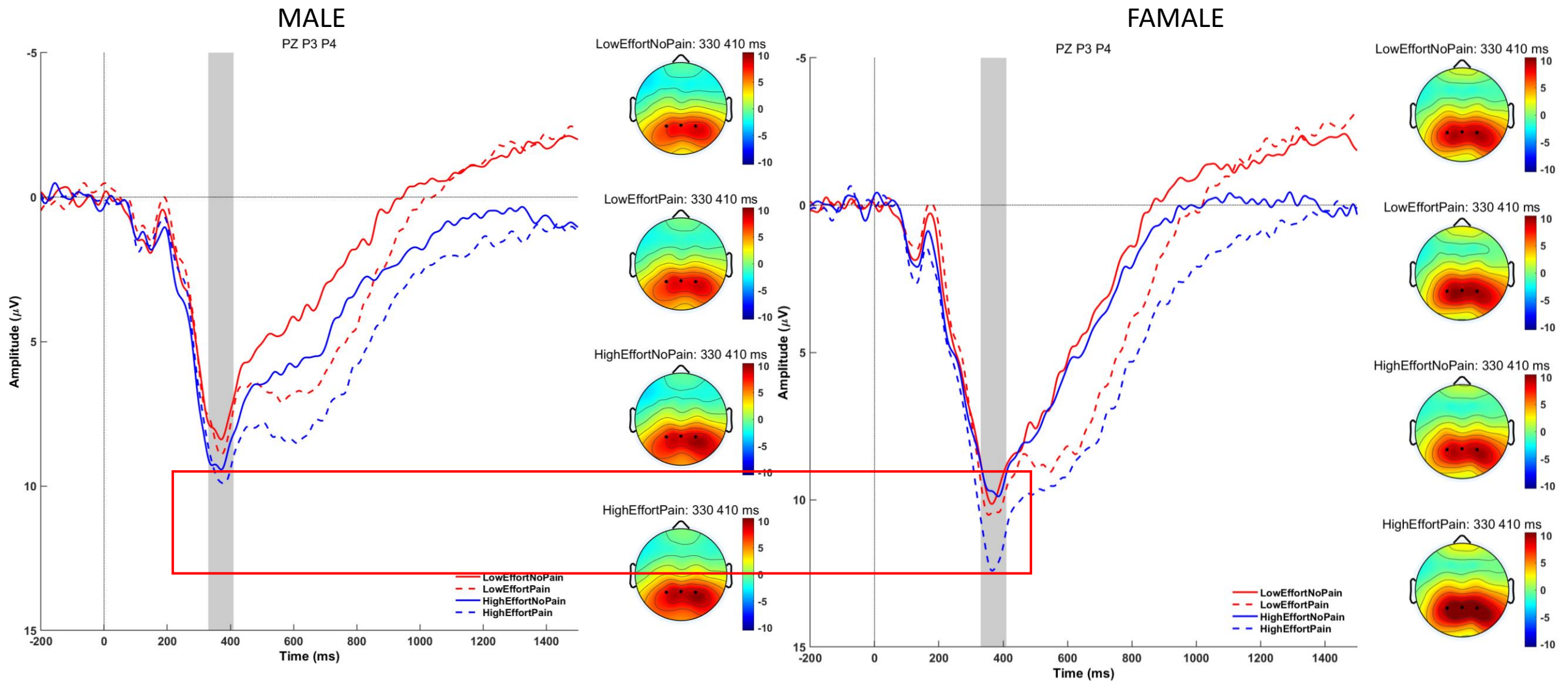
ANOVA TW:330-410ms 电极点：PZ P3 P4

Pairwise Comparisons of "Pain" & "Gender":

Contrast	"Effort"	Estimate	S.E.	df	t	p	Cohen's d [95% CI of d]
NoPain Male - Pain Male	Low	-0.256	(0.369)	36	-0.693	1.000	-0.142 [-0.712, 0.429]
Pain Female - Pain Male	Low	1.480	(1.206)	36	1.227	1.000	0.820 [-1.046, 2.687]
Pain Female - NoPain Male	Low	1.736	(1.157)	36	1.500	.853	0.962 [-0.828, 2.752]
NoPain Female - Pain Male	Low	0.872	(1.162)	36	0.751	1.000	0.483 [-1.314, 2.281]
NoPain Female - NoPain Male	Low	1.128	(1.110)	36	1.016	1.000	0.625 [-1.093, 2.343]
NoPain Female - Pain Female	Low	-0.608	(0.350)	36	-1.738	.544	-0.337 [-0.878, 0.204]
NoPain Male - Pain Male	High	-0.343	(0.394)	36	-0.871	1.000	-0.190 [-0.800, 0.419]
Pain Female - Pain Male	High	1.811	(1.263)	36	1.434	.961	1.003 [-0.950, 2.957]
Pain Female - NoPain Male	High	2.154	(1.190)	36	1.811	.471	1.194 [-0.647, 3.035]
NoPain Female - Pain Male	High	-0.330	(1.197)	36	-0.276	1.000	-0.183 [-2.035, 1.669]
NoPain Female - NoPain Male	High	0.013	(1.120)	36	0.012	1.000	0.007 [-1.726, 1.740]
NoPain Female - Pain Female	High	-2.141	(0.374)	36	-5.727	<.001 ***	-1.187 [-1.765, -0.608]

仅在高努力条件下，女性会在Pain相比NoPain条件下诱发出更高的P3幅值
而低努力条件下，不论男女在Pain和NoPain下都无差异

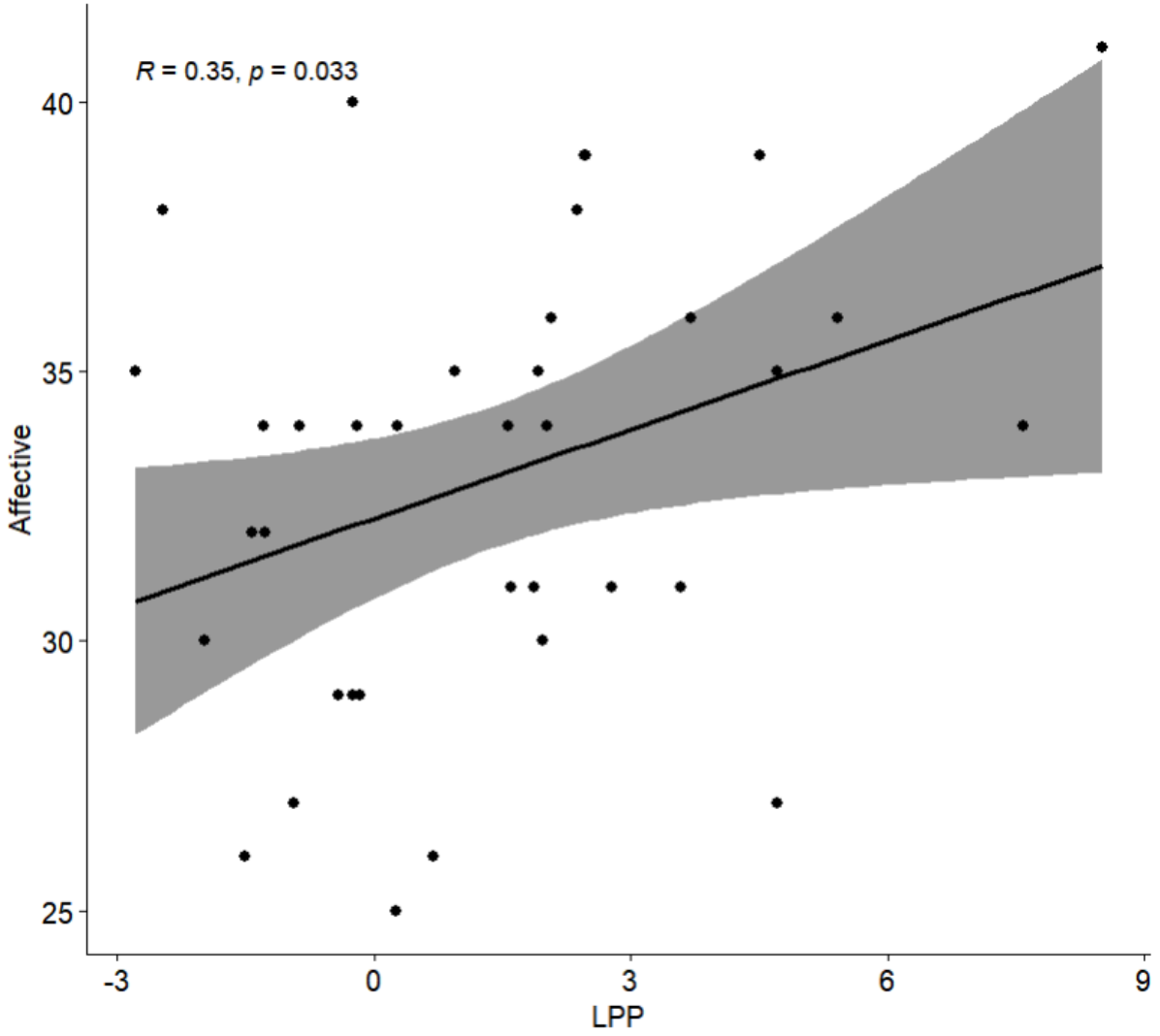
ERPs



仅在高努力条件下，女性会在Pain相比NoPain条件下诱发出更高的P3幅值
而低努力条件下，不论男女在Pain和NoPain下都无差异

Cor

Pain:LPP~Affective



Pain:P3~Affective