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A A : 17 2017
A

A A

Recurrent Processing of Contour Integration in the Human Visual Cortex as Revealed By fMRI-Guided TMS

1, 1 2,3,4,5

1 , , 710062, , 2 , k , 100871, , 3 } , k , 100871, , 4 / , k , 100871, , 5 ( ), k , 100871, ,

A , k ,5 , } , 100871, : @ k .

Abstract

.} , ( ) fl 1 2 (1/ 2 3) 1/ 2 3 . fi 3 (90–110). 1/ 2 (120–140), k fi - 1/ 2 , 3 fi k .

Key words: k , , , 3

Introduction

fi k (1993; , } 2003). , fi 1, - (k 1997; 2002). - k .

A 2017. A. : @

1 (1995; 2006).
} , fi
1- - 1
} , 4, 1
fi. }
, k
fi. A
(A 2002; 2002; 2003; 2006, 2008; 2007; 2013; 2013; 2014; 2016). -
k
fi - -
(2006; 2008; } k 2011).
, ( ) (A 2003; 2003; 2016). } , , fi
1
(2014)
1 4 k.
4 1,
1
k 4. } ,
,
4
k 1.
( ),
fi
, .
(1/ 2) (3)
k. 3
k, 4
(} k 2001; 2003),
(k 2009; 2010; 2016) (
2008; 2009; 2014).
1, 1/ 2 3
4 (A)
fi (., A)
90–110 3 120–140
1/ 2,
2, fi 2 -
fi. A 2 ,
2 fi fi
1
3 1/ 2. fi -
k .

Materials and Methods

Experiment 1

Participants

(10 , 10 ; = 21 ; = 18–25) k -
- . A
, k -

Stimuli and Aperture

k
100 } -
3 (1997; 1997; 2007) A A (k ,
k, A) -
k fi. (12.66° × 12.66°) -
(k : 6.62 / , σ: 0.10°,
: 100%). A fi.
11
( )
fi. ( ) (1
1A).
fl
k fi
fi.
0.86°.
fi

Procedure

1 3 : 2
fi. ( )
(2008; ,
2015).
1 3
fi.
fi 1 3
k.

fMRI Session

(1 3) ,
, k ,
, fi ,
fi ( )
(2005). A , k
fi. fi .
,

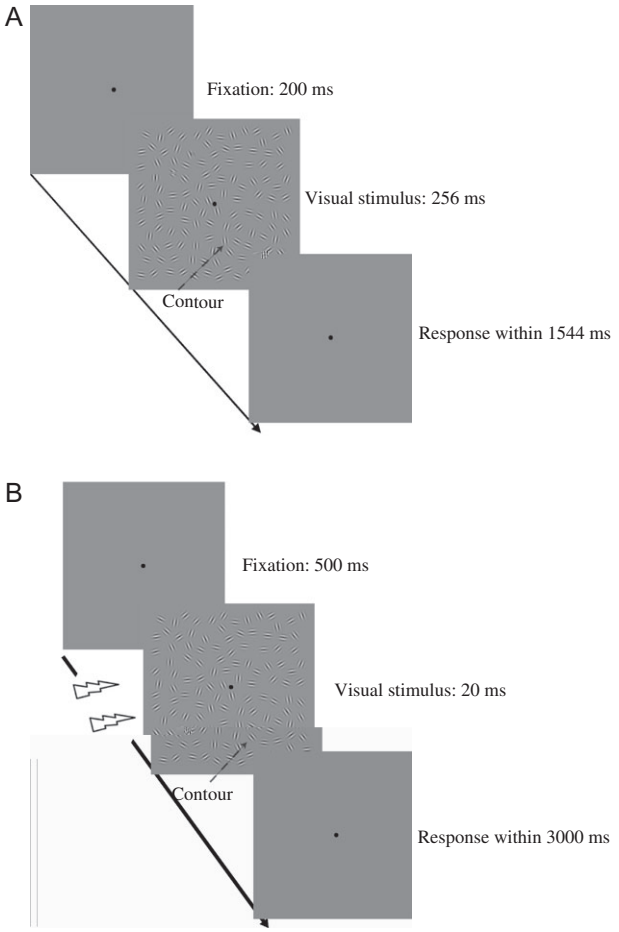

Figure 1. (A) A k. (B) A k fi. A k. fi , 1/ 2 3 4 A (60/80, 90/110, 120/140 150/170.) (-) 1 2 A (90/110. 120/140.) (-). 2.

2 : (1) - fi. (2) fi. fi - .

Data acquisition: 3 20- (= 2000. , = 30. , = 152 × 152. 2, : 76 × 76, fl : 90°, = 0. ; : 28, k : 2.5. , :). A - 1- (A , = 2530. , = 2.98. , = 256 × 224. 2, fl : 7°, - : 0.5 × 0.5 × 1. 3, : 192, k : 1. , :).

pRF mapping task: (1, 2, 3, 3) 5 : 1 ()), 4 fl. k. - k. (100%) - (1). } 8 k 308 . A fl. k. k. (10.35°, 100%) . 4 , 32 k. k. 8 k 4 k k. k. 36 . A (: 2.14°) (: 10.22°). 18 (: 1.07°). k. - (0°, 45°, 90°, 135°). . A 8- k. , 12- k } . k. fi. fi.

Contour detection task: k, 4 - 81 (2), k (8) (12) (- , , fi) - (2002). A 1A, 200 fi , fi. - fi. 256 fi. fi k, k, k.

TMS Sessions

2 3 1/ 2 3 1/ 2, 1 , k. 2 1 (2011; , 2005; - 2012). } , 1 , 1 (1995; . 2006; . 2014).

TMS protocol: 2 (,) 70- fi - -8 (. 2A). - , fi (1/ 2 3) - (2; A , , ,) k. , 2 60% ,

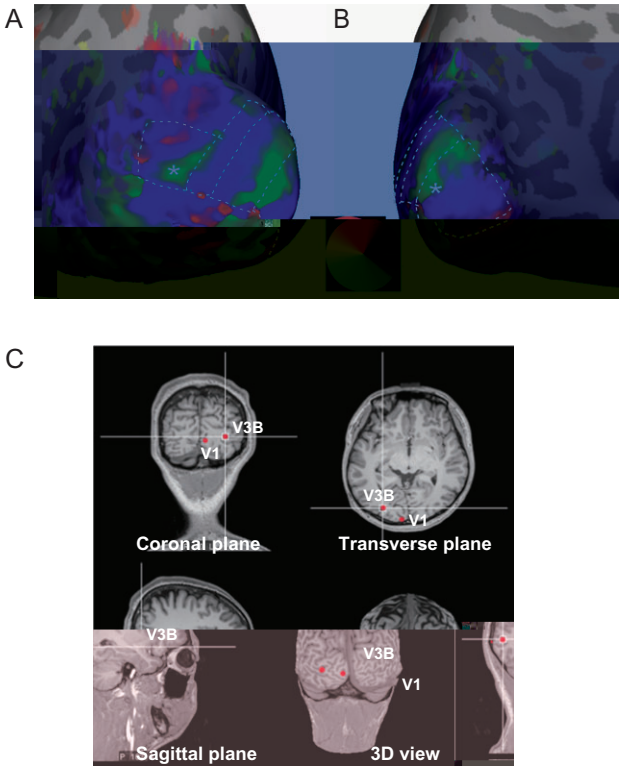

Figure 2. k (A) 3 (B) 1. (A) ( ), fl fi , fi 1, 2, 3, 3 . (C) 1/ 2 3

(, 2005; 2012).

A (60/80 , 90/110 , 120/140 , 150/170) 1/ 2 3 . A k (2003; , 2005) fi (2003). A , .

Contour detection task with TMS: , fi k 1/ 2 k 3 . A fi 3 1/ 2 , k. fi , 16 2 fi (A : 60/80, 90/110, 120/140, 150/170 ; : -) k, 96 12

fi , fi . A 1B, 500 fi , fi 20 . k 3 fi fi . k. k.

Data Analysis: A (., , , fi) 2- (A A), A - , 3 fi (.,) (2006, 2009; 2008; 2010; 2012; 2014). A (-) A. , fi fi , - t- (, 0). A , , A , fi - t- , .

Experiment 2

Participants

(11 , 9 ; = 20–26) , 8 1. k A. - , k .

Stimuli and Aperture

2 1, k fi fi. , 2 fi.

Procedure

2
1,
fi
84%
1,
,
k ,
k

Psychophysics Session

1- 4-
84% 5°
fi ,
2°.
k k
(., fi).
7 7
k
84%
k. k 40
(fi).
k 1000 (.,) k
k,
k k fi
1°
fi
200
15

fMRI Session

2
1.

TMS Sessions

2
1
2 k fi
,
A (90/110 120/140) 96
A
(1/ 2 3).

Data Analysis:
2- A A
(1/ 2 3) A (90/110 120/140)
fi , t-
(, 0)
A
t-
fi

fMRI Data Analysis

Data preprocessing:
1- 3 ,
(1999; 1999). fi 4
8
( ).
,
fl
( ) 2014;
k 2014; A 2015)
,

pRF and GLM analyses:
(2008).
A A
(k 2014; A 2015)
k k
fi
, fi fi fi (k
2014,
fi).
fi ,
fi
(1, 2, 3)
(2007). 3 fi
fi
fi 3.
3A 3 fi
fi 1–5°
–80 –10°
fi
fi. A
k. 1 3
fi fi fi
fi , fi
k
2

Results

Experiment 1

1, 1/ 2 3
A (60/80, 90/110, 120/140, 150/170)
( )
k.
85.7 ± 5.8%,
k fi
, fi-
(3). fi ,

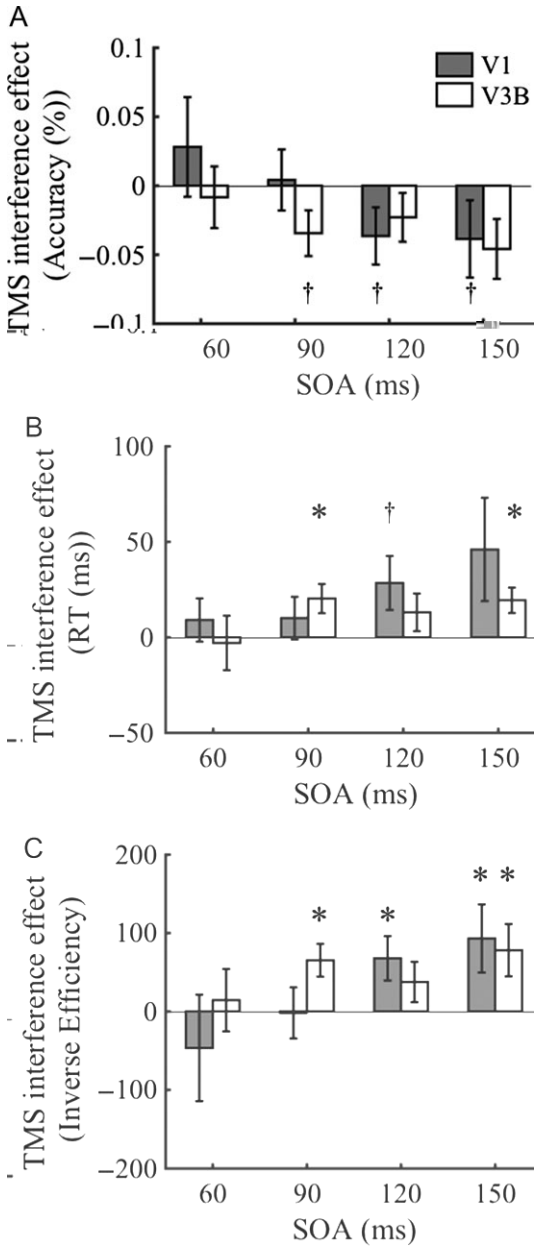

Figure 3. A 1/ 2 3 1 (A) , (B) , (C) fi fi k fi fi t- (**P <0.01 ; *P <0.05 ; †P <0.05).

fi fi A. fi , , fi 2- (× A) A A A A fi A ($F(3,57) = 2.93$, $P < 0.05$, $\eta_p^2 = 0.13$). fi - 60/80 150/170 A ($P = 0.03$, - = 0.0083).

($F(1,19) = 0.64$, $P = 0.42$, $\eta_p^2 = 0.03$) ($F(3,57) = 0.83$, $P = 0.48$, $\eta_p^2 = 0.04$) fi A A fi ($P > 0.1$). , A A fi fi A ($F(3,57) = 3.22$, $P < 0.05$, $\eta_p^2 = 0.15$). ($F(1,19) = 0.42$, $P = 0.52$, $\eta_p^2 = 0.02$) ($F(3,57) = 1.19$, $P = 0.31$, $\eta_p^2 = 0.06$) fi fi 60/80 90/110. A ($P = 0.05$, - = 0.0083).

1/ 2 3 , t- (- = 0.00625), (- = 0.01875), fi (- = 0.025) A - fi (3). 1/ 2, fi- fi 120/140. A ($t(19) = -1.76$, $P = 0.05$, ' $d = -0.39$), ($t(19) = 2.02$, $P = 0.03$, ' $d = 0.45$), fi ($t(19) = 2.40$, $P = 0.01$, ' $d = 0.54$). 3 , fi fi 90/ 110. A ($t(19) = -2.07$, $P = 0.03$, ' $d = -0.46$), ($t(19) = 2.66$, $P = 0.008$, ' $d = 0.60$), fi ($t(19) = 3.18$, $P = 0.002$, ' $d = 0.71$). 120/140 90/110. 1/ 2 3 . A , fi 120/140. A 3 fi ($t(19) = 1.46$, $P = 0.08$, ' $d = 0.33$). , fi k 120/140. 3 , fi fi 150/170. A 1/ 2 (- : $t(19) = -1.38$, $P = 0.09$, ' $d = -0.31$; : $t(19) = 1.70$, $P = 0.05$, ' $d = -0.38$; fi : $t(19) = 2.17$, $P = 0.02$, ' $d = 0.49$) 3 (: $t(19) = -2.12$, $P = 0.02$, ' $d = -0.47$; : $t(19) = 2.91$, $P = 0.004$, ' $d = 0.65$; fi : $t(19) = 2.37$, $P = 0.01$, ' $d = 0.53$). fi fi , 2, 2. A (90/110 120/140) 1/ 2 3 . k fi fi. 2.

Experiment 2

2, k - 87.3 ± 2.8% (fi : 89.1 ± 4.0%; fi : 85 ± 5.2%) 1. A , , fi 4. A 1, , fi 2- (- × A) A A - , , (.,). A A fi A ($F(1,19) = 7.37$, $P = 0.014$, $\eta_p^2 = .28$).

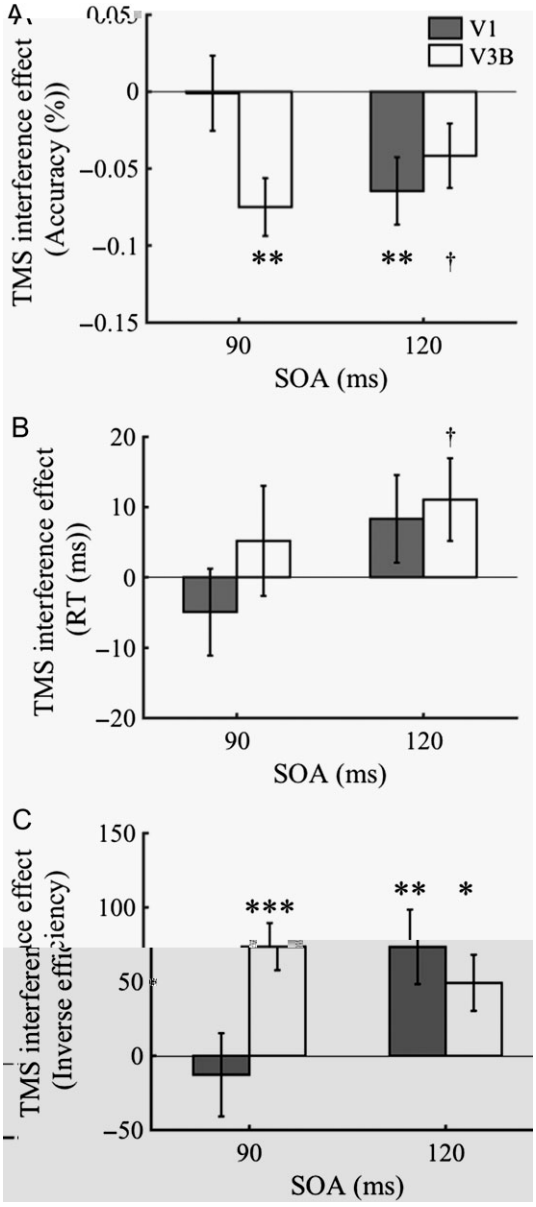

Figure 4. A 1/ 2 3 2 (A) , ( ) , ( ). fi fi k fi fi t- (***P < 0.001 ; **P < 0.01 ; *P < 0.05 ; †P < 0.05).

2 A. , 120/140 A 90/110 A 1/ 2 ($F(1,19) = 6.09$, $P = 0.02$, $\eta_p^2 = .24$). , fi 2 A 3 ($F(1,19) = 1.93$, $P = 0.18$, $\eta_p^2 = 0.09$). , A A fi A ($F(1,19) = 3.24$, $P = 0.09$, $\eta_p^2 = 0.15$; $P > 0.3$). , A A fi , fi A ($F(1,19) = 7.34$, $P = 0.01$, $\eta_p^2 = 0.28$). ($F(1,19) = 2.37$, $P = .14$, $\eta_p^2 = 0.11$) A ($F(1,19) = 3.07$, $P = 0.10$, $\eta_p^2 = 0.14$) fi , 1/ 2, 120/140 A 90/110 A ($F(1,19) = 7.67$, $P = 0.01$, $\eta_p^2 = 0.29$). , fi A 3 ($F(1,19) = 1.23$, $P = 0.28$, $\eta_p^2 = 0.06$).

, t- (= 0.0125) , , fi 1/ 2 3 1/ 2, fi 120/140 A ($t(19) = -2.95$, $P = 0.004$, ' $d = 0.66$) fi ($t(19) = 2.92$, $P = 0.004$, ' $d = 0.65$). 3 , fi 90/110 A ($t(19) = -3.99$, $P < 0.001$, ' $d = -0.89$) fi ($t(19) = 4.64$, $P < .001$, ' $d = 1.04$).

120/140 1/ 2 90/110 3 , , A , fi ($t(19) = -1.99$, $P = 0.03$, ' $d = -0.45$) ($t(19) = -1.88$, $P = 0.04$, ' $d = 0.42$), fi fi ($t(19) = 2.60$, $P = 0.009$, ' $d = 0.58$) 120/140 A 3 .

, 2 fi fi 1 fi 3 1/ 2,

Discussion

(1995; 2006; 2013) (1993) 1 fi . } , fi. (A 2003; k 2009; 2010). , (2014) 1 4 k. - 4 1. 1 1 4. fi (3) , 1/ 2 3 , - k 1/ 2 fi 3 . - 3 90/110 k, 1/ 2

. 2015.
(A) ( ).
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. 2016.
A
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594–600.
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k } , , fi , k . 1997.
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2112–2127.
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A. 2008.
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A, , } . 2013.
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A, , } . 2016. fi .
fi :
1. . 1–13.
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k . 15:843–856.
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2003. :
k . 37(2):333–346.
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2014. A -
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(3):441–452.
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. 15:1–16.
} , , , , . 2017.
k
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21(6):1204–1214.
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k , A , } , , .
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k , , . 2009. .
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1 ( )
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5/ . , , . 15
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? , .
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} , , . 2003. .
: “ ”
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, } k , A . 2005. -
. 27:95–105.
. 2014. k -
. 5:
264.
, - A. 2003. -
: . (A):
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A, , AA. 2007.
} . 56(2):366–383.
A, . 2015. .
fi . , . 19(6):
349–357.
kk , k A , } , A . 2013.
: k -
. 24:63–71.
, . 2010. -
A
A. 107(30):13503–13508.