SCIENCE CHINA

•RESEARCH PAPER•

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Decoding six basic emotions from brain functional connectivity patterns

C L [1], [2*], [1], [5] & F F [1,3,4*]

[1]

[2]
[3]
[4]
[5]

J 6, 2022; 26, 2022; N 11, 2022

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(M I) (A) . H ,
(FC) - A
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, FC- A- . ,
FC
FC .

decoding, basic emotions, functional connectivity, voxelwise activation, multivariate pattern analysis

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INTRODUCTION

(E , 1992; ., 2019).
I , -
H -
(C ., -
2021; F H , 2021; G ., 2021). C , (B ., 2007),
(. ., (., 2003),
, , , , ,), (H , 2010).
, - H ,

(K L B , 2016;
M ., 2003). I ,

*C (F F , : @ . . ;
: 15@ . .)

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(A) (A -
C , 2018; I ., 2020; .,
2020; ., 2021). C -
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(FC) (K L B , 2016).
B -
(M PA)
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A ,
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., 2018), / / ,
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(., 2016; .,
2018). H / , /
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(M I) . N ,
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A- M PA
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A-
M PA (N ., 2011).
I A- M PA, FC- M PA FC
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FC (P -
G A , 2022; P , 2018; ., 2021;
., 2019). F , .
- FC
FC
(
., 2019). B FC- M PA, L . (L
., 2018) / / . (., 2022)

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. FC- -
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(P ., 2012). ,
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112 H -
O (D ., 2006), -
(L ., 2018), -
. M PA
F (F) FC -
-
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RESULTS

FC-based decoding of six basic emotions

85 (20) 61 (
24) FC -
. A
(F 1A), - -
(
) (F 1B). A
F 1A,
(50%) (, 11 =7.57,
<0.001, C =2.19; , 11 =11.29, <0.001,
C =3.26; , 11 =10.41, <0.001, C
=3.00; , 11 =5.58, <0.001, C =1.61;
, 11 =7.31, <0.001, C =2.11; ,
11 =7.80, <0.001, C =2.25). -
- 28.16%,

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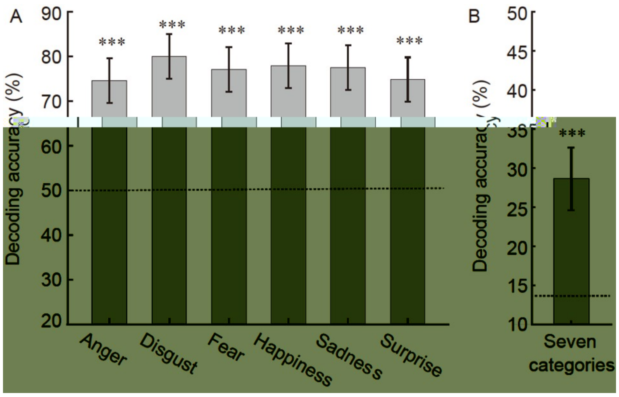

Figure 1 A FC . A, A -
. B, A
. E EM ; ***, <0.001 (- -).
D .

(11 =10.00, <0.001, C
=2.89) (14.29%). ,
- FC -
.

Major contributing FCs in basic emotion decoding

N , FC -
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FC
. F -
FC, FC
;
(., 2016). , FC -
-
. F 2 -
. F ,
, (F 2C)
FC (
) ;
(A ,
2008; P A , 2010). - -
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(. .,
), (. .,),
(. .,), -
(. .,).

Major contributing brain regions in FC-based decoding

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- -
(L ., 2018 ; , 2012).

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FC
(FC <0.001, 0;
FC 0.001, 1). -
FC-
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1.
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I , -
. F , FC
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, B N
10
. A F 3,
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Optimal number of brain regions for FC-based decoding

FC-
-
. A
, FC
. 112 -
FC
5, 10, 30, 50, 70, 90, 112
. -
. , 6 (
) 7 ( ) AN-
O A
(6,66 =5.31, <0.001, ^{2}=0.33). H , -
(30,330 =0.72,
=0.859, ^{2}=0.06). I ,
-
. I ,
5 10 -
(F 4, : 11 =
2.43, =0.033, C =0.70; : 11 =2.37,
=0.037, C =0.68; : 11 =2.52, =0.029, C -
=0.73; : 11 =3.52, =0.005, C
=1.02; : 11 =2.19, =0.051, C =0.63;
: 11 =2.02, =0.069, C =0.58),
.

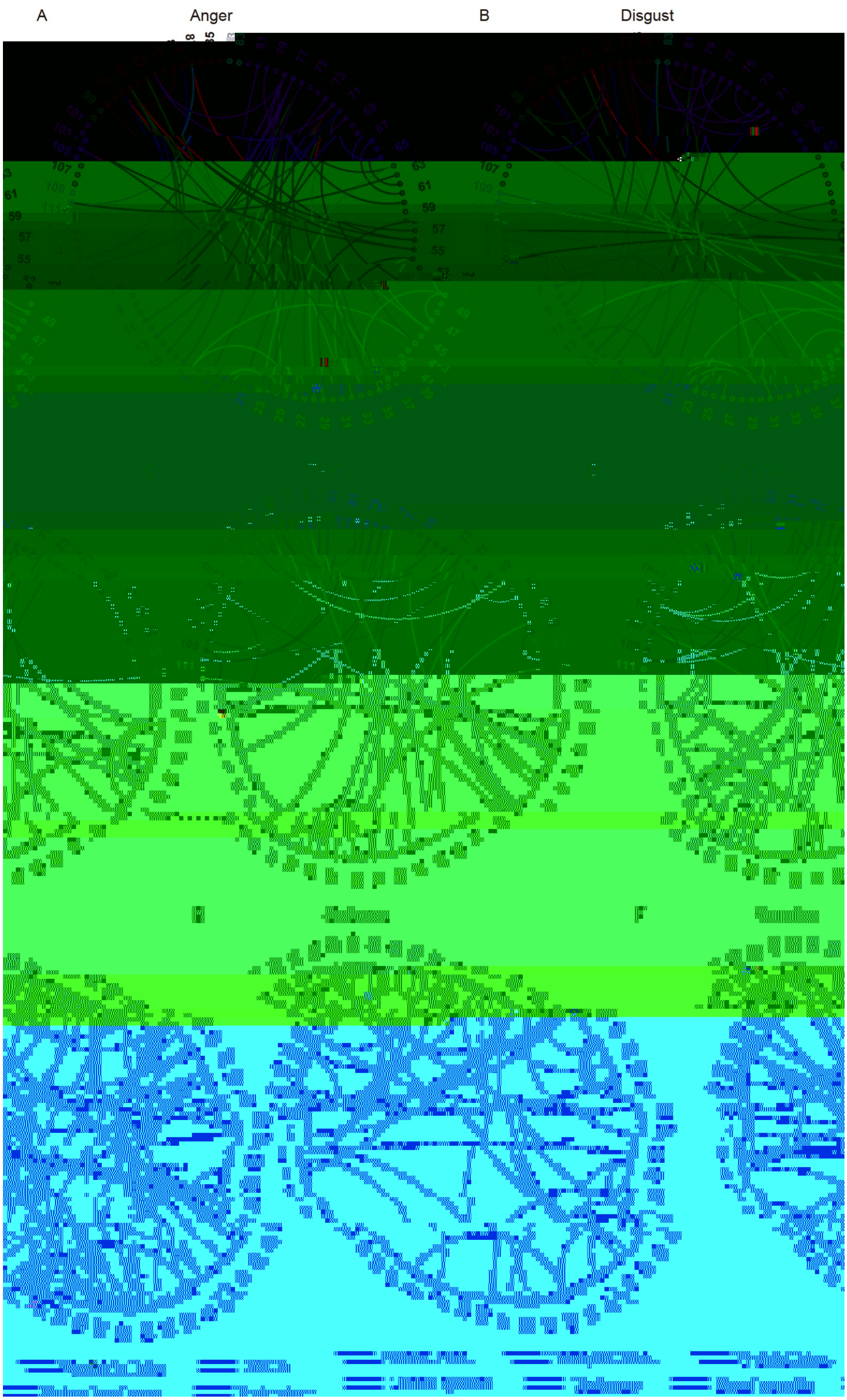

Figure 2 E - . FC (A), (B), (C), (D), (E), (F) ( ). N . E . I 1 I .

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Table 1 10

E	N	E	N
	( ),		F (L),
	( ),		( ),
	( ),		( ),
	( ),		( ),
A	( ),	H	( ),
	( ),		( ),
	( ),		( ),
	( ),		( ),
	(L),		( ),
	( )		( )
	(L),		I ( ),
	( ),		( ),
	(L),		(L),
	( ),		( ),
D	( ),		(L),
	( ),		(L),
	(L),		( ),
	(L),		( ),
	(L),		(L),
	(L)		( )
	A ( ),		(L),
	( ),		- (L),
	(L),		( ),
	(L),		( ),
F	( ),		( ),
	( ),		( ),
	(L),		(L),
	(L),		(L),
	( ),		( ),
	( )		( )

. (10 . 30, 11 =2.71, =0.021, C =0.78; 10 . 50, 11 =2.28, =0.044, C =0.66; 10 . 70, 11 =2.48, =0.030, C =0.72; 10 . 90, 11 =2.41, =0.041, C =0.67; 10 . 112, 11 =2.18, =0.052, C =0.63). FC - .

Comparison between FC-based and VA-based decoding

M PA A- , FC- - . H , A , FC

FC A - . , FC- - A FC . - FC- A- M PA , M PA , . , FC- A- . FC- 112 (<0.01, B) A- 112 (<0.01, B) (F 5). M , FC A (F 5A, : 11 =2.74,

https://engine.scichina.com/doi/10.1007/s11427-022-2206-3

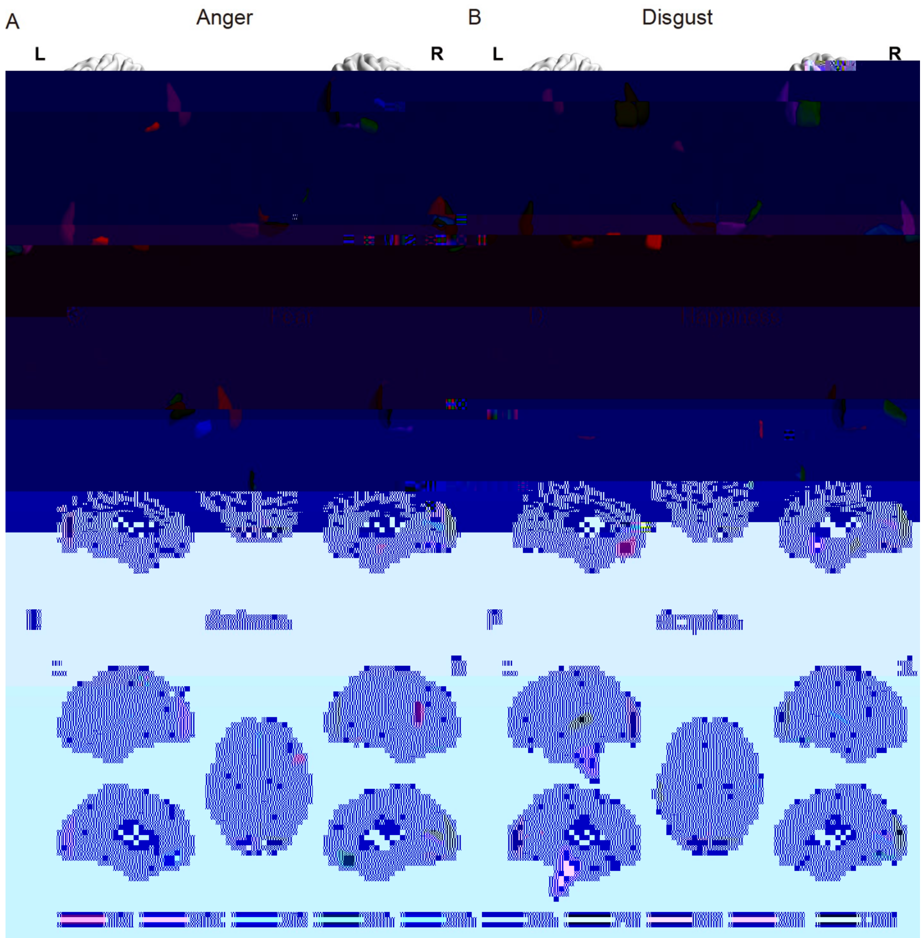

Figure 3 D 10 . 10 ,
.

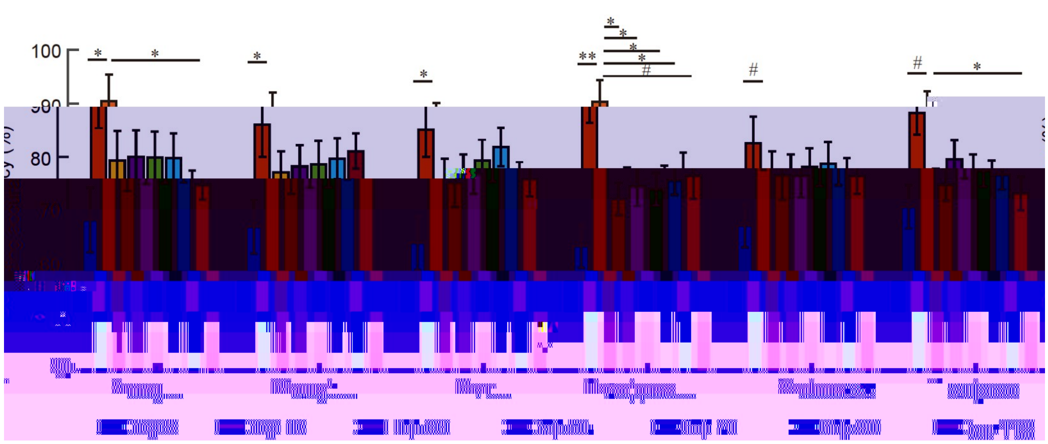

Figure 4 E . D . I
FC- . #, <0.07; *, <0.05; **, <0.01 (- -). E EM .

=0.019, C =0.79; : 11 =6.90, <0.001, 10 .
C =1.99; : 11 =6.89, <0.001, C =1.99; - - , F 5B -
: 11 =2.95, =0.013, C =0.85; : FC- -
11 =3.63, =0.004, C =1.05; : 11 =4.51, A-
<0.001, C =1.30). N , - (F 5B, : 11 =5.72, <0.001, C =1.65;

A (H ., 2013; ., 2021).
M M PA A
(L ., 2017; L L , 2020; ., 2022).
-
- -
(., 2022). H ,
. A FC-
,
FC
(L ., 2018; P L FC -

: 11 =3.71, =0.003, C =1.07; : 11 = 6.81, <0.001, C =1.96; : 11 =5.16, <0.001, C =1.49; : 11 =6.66, <0.001, C =1.92; : 11 =5.01, <0.001, C =1.45). I , A- ( ) (11 =16.32, <0.001, C =4.71). O , FC A .

DISCUSSION

O FC- , - F ,
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F , - -
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FC

(A , 2008). B
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FC ,
(C ., 2016). FC
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(C ., 2021; H , 2010; .,
2014; ., 2016).
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(P ., 2012).
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(, 2010). ,
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(H ., 2019), -
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<0.001). F ,
(I -
, 2020).

CONCLUSION

B F
, FC
. O -
FC
A .
O , -
. F
FC .

MATERIALS AND METHODS

Participants

(; 18 24)
P , C . O -
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P .

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Stimuli

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(., 2019). A
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12.5 [2]). -
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1024 768)
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8 6.3 .

Experimental procedure

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E
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20 10
10 24 -
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I ,
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, 0.8 , 0.2
. A
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5
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2 . P
. O
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fMRI data acquisition

- M I 3.0 -
P M I C M I
P . A - -
EPI (64
; =2000 ; E=30 ; =90 ;
FO =224 224 ; =112 112; =
2 ; =0.2 ; G APPA =2;
=2). A 1- - 3D
3D-MP AGE (
: 1 1 1).

fMRI data preprocessing

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, , ,
PM8 (D C N ,
C L , L , K) DPABI
(., 2016). M I
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M N I
4- -
G .

FC-based decoding

O M I
:

$$f: fMRI\_sequence(t_1 - t_2) \rightarrow k, \quad (1)$$

1, 2 ,
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FC 1 2 -
.

FC

(., 2016). ,
( ) 36
( ) . A ,
85 61 .

FC
. -
FC

$$\rho_{i,j,p,w} = \frac{\sum_{s=S_p}^{s=E_p}(y_{i,s}-\tilde{u}_{i,w})(y_{j,s}-\tilde{u}_{j,w})}{\sqrt{\left(\sum_{s=S_p}^{s=E_p}(y_{i,s}-u_{i,w})^2\right)\left(\sum_{s=S_p}^{s=E_p}(y_{j,s}-u_{j,w})^2\right)}}, \quad (5)$$

, (1
112
H -O), $\tilde{u}_{i,w}$
.
, , , , FC
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FC
:

$$X_t^k = (\rho_{i,j,p,w})_{i,j}, \quad (6)$$

, =1, ,112. FC
. , FC
112 112 .
FC
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, FC
. FC x_t^k:

$$\begin{aligned} x_t^k &= linearly\left\{lowhalf\left(X_t^k\right)\right\} \\ &= linearly\left\{(\rho_{i,j})_{i,j(i>j)}\right\} \\ &= (\rho_{2,1},\rho_{3,1},\ldots,\rho_{112,1},\rho_{3,2},\ldots,\rho_{112,111}), \end{aligned} \quad (7)$$

FC
-
:

$$X^k = \left\{x_t^k | t = 1,\ldots,n\right\}, X^k \subseteq \Omega^k, \quad (8)$$

FC
,
.

O FC
. -
FC (F 6D)
:

$$\begin{aligned} Train &= \left\{(x_l,k) | l = 1,\ldots,n_1\right\}, x_l \in X^k, \\ Test &= \left\{(x_q,k) | q = 1,\ldots,n_2\right\}, x_q \in X^k, \end{aligned} \quad (9)$$

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, [1], [2] .
I , M I
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F , ,
FC . F -
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(L ., 2011).
-
. A ,
CA - -
G -
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:

$$i(x_t) = \sum_{k \neq c} p(k|x_t)p(c|x_t), \quad (10)$$

, , $p(k|x_t)$
FC
.
:
( ) FC
; ( )
-
CA ; ( ) F
-
.
. F
P 3.8 : = ,
=G , = , -
=0.0, =1, -
=2, ( )=40, =1.

VA-based decoding

A-
. A-
FC-
FC- A- -
.
F , 112 -
H -O :

$$\overline{W} = (w_1, w_2, \ldots, w_{112}), \quad (11)$$

$\overline{W}$, -
.
A
- -
:

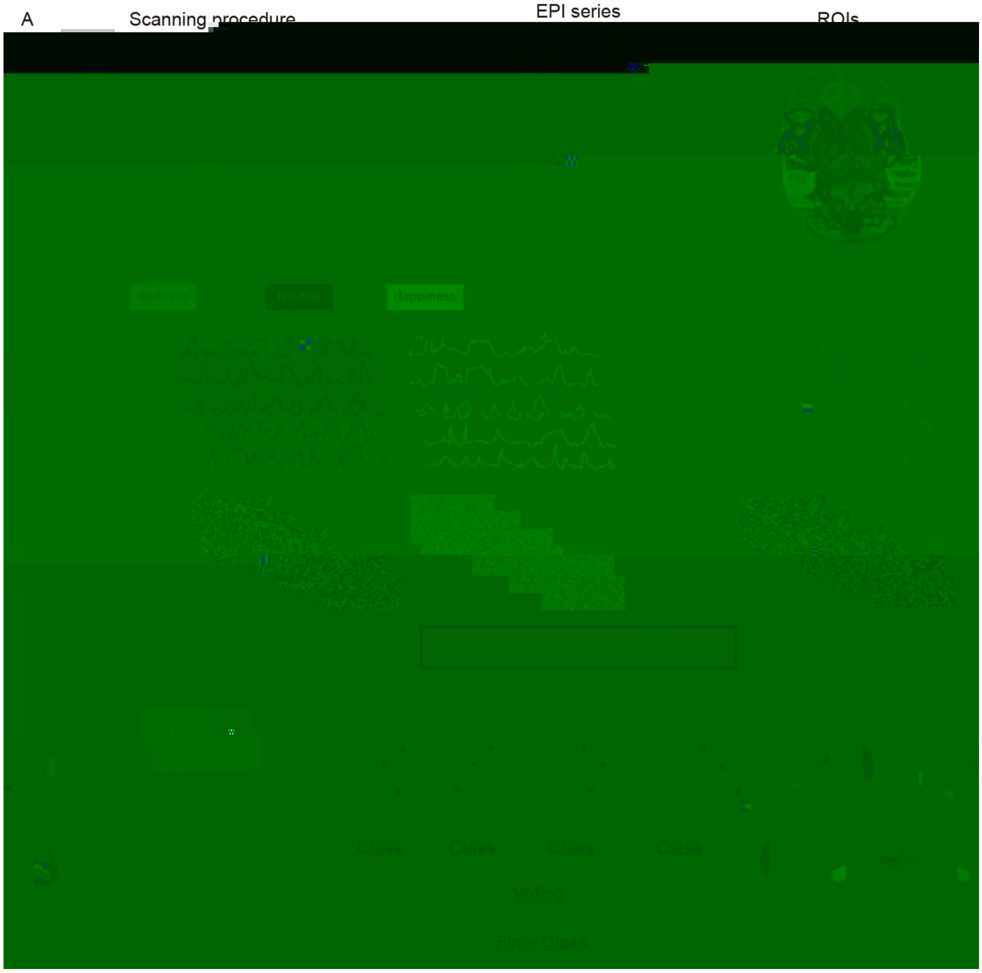

Figure 6 F FC . A, ( ) . F (. ., , , , , ,) . P - . ( ) F . ( ) A 112 H -O . B, 112 . C, FC 112 . FC FC . D, A - ( ) FC F ( ) - ( ) .

$$x_{v_i} = w_i * X, \quad (12)$$

M I . A ( ) :

$$x_v = (x_{v_1}, x_{v_2}, \dots, x_{v_j})_{j \leqslant 112}, \quad (13)$$

.

M I ( ), . H , , M PA . , M I , , . FC- , M I . ,

96 100 , . L , F FC- . FC- .

Compliance and ethics

Acknowledgements

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C , J., D D , D., N , ., I , J., G , ., H , G., M -P , L. . (2016). C - . J N 36, 4708 4718.
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C , M. ., I , ., C , C., - , . (2021). - . J N 41, 2684 2702.
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I , ., H , L., M , ., C , C., C , M. . (2020). D . C 24, 25 38.
J , F., J , H., G , ., , ., C , J., , A., N , . (2022). - M I MEG . N I 254, 119131.
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SUPPORTING INFORMATION

:// . /10.1007/ 11427-022-2206-3.
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