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Selective Audiovisual Semantic Integration Enabled by Feature-Selective Attention

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An audiovisual object may contain multiple semantic features, such as the gender and emotional features of the speaker. Feature-selective attention and audiovisual semantic integration are two brain functions involved in the recognition of audiovisual objects. Humans often selectively attend to one or several features while ignoring the other features of an audiovisual object. Meanwhile, the human brain integrates semantic information from the visual and auditory modalities. However, how these two brain functions correlate with each other remains to be elucidated. In this functional magnetic resonance imaging (fMRI) study, we explored the neural mechanism by which feature-selective attention modulates audiovisual semantic integration. During the fMRI experiment, the subjects were presented with visual-only, auditory-only, or audiovisual dynamical facial stimuli and performed several feature-selective attention tasks. Our results revealed that a distribution of areas, including heteromodal areas and brain areas encoding attended features, may be involved in audiovisual semantic integration. Through feature-selective attention, the human brain may selectively integrate audiovisual semantic information from attended features by enhancing functional connectivity and thus regulating information f ows from heteromodal areas to brain areas encoding the attended features.

An a dio i al objec in he eal. o ld ma con ain m l iple eman ic fea e , ch a he gende and emo ional fea e of a peake face and oice. D ing he ecogni ion of an a dio i al objec , he h man b ain in eg a e he eman ic info ma ion f om he e fea e ob ained b he i al and he a di o modali ie, i.e., a dio i al eman ic in eg a ion ma cocc in he b ain. A dio i al in eg a ion facili a e apid, ob and a oma ic objec pe cep ion and ecogni ion¹³. Compa i on of i al-onl and a di o constant i m li ha e e ealed ha cong en a dio i al im li lead o onge ne al e pon e han ei he specifi im l alone in he po e io

a, peci c ne \cdot o k in \cdot hich he pa ie al and pe hap, la e al f on al co ice appear o be op imall i a ed o media e he in eg a ion and a en ional, elec ion of mo ion informa ion ac o, modali ie ¹². In a dio i al face pe cep ion, c o, modal a en ion in ence c o, modal binding d ing, peech eading^{13,14}, \cdot , a en ion and a dio i al in eg a ion in e ac \cdot i heach o he in a ophi ica ed manne. Ho, e e, fea e, elec i e a en ion in a dio i al condi ion and he ela ion hip be en fea e, elec i e a en ion and high-le el a dio i al eman ic in eg a ion emain o be e plo ed.

In a ingle (i al o a di o 3) modali 3 fea e- elec i e a en ion ma lead o elec i e p oce ing of he a ended fea e of an objec¹ in he b an^{7 9,15 17}. Nob e *et al.*⁸ demon a ed ha ERP a e mod la ed b fea e- elec i e a en ion and ha i ele an fea e a e inhibi ed d ing he ea la age of pe cep al anal si in h man . In monke 3, Mi abella *et al.*¹⁷ ob e ed ha ne on in i al a ea V4 e hibi elec i i 30 o element al objec fea e . Ba ed on he e, die ha ha e emplosed nimodal, im li, he e e e polo e he he and ho a, imila fea e- elec i e a en ion mechani m in an a dio i al condi ion i in ol ed in a dio i al eman ic in eg a ion.

male

female



Figure 1. Experimental stimuli and time courses. (A) Fo e Ample of a dio i al, im li; he ed n mbe indica e n, i h hen mbe a k onl (B) Time co , e of a ial fo he n, i h hen mbe a k, in hich he, im li incl ded andoml \mathfrak{g} p e en ed n mbe, and ideo /a dio /mo ie clip. (C) Time co, e of a ial fo he n, i h he gende, e^{i} mo ion, o bi-fea e a k. Fo bo h (B,C), he p e en a ion of a im l (i deo/ a dio/mo ie clip) la ed 1,400 m and a epea ed fo ime d ing he eigh econd in a ial. A i al c = (+) appeared a he 8 h, econd and per i ed for i k econd.

Fo each of he hee n, i h he n mbe a k, in addi ion o he co e ponding a dio i al, i al-onl So a di o SonlSfacial, im li f om hemo ie clip, n mbe, in ed appea ed, eq en iallSfa he cen e of he, c'een (ee Fig. 1A).ⁱ e, bjec,ⁱ a k, a oa end o hen mbe, in ead of he o he, im li (ee Table 1). We de igned a di c l n mbe a k fo he, bjec, in, hich hest e ea ked o nd and co n he epea ed n mbe, oen e ha hest fillsigno ed he fea e of he, i al-onlas a di o stonlas o a dio i al facial, im li, e efo e, he bjec, pe fo med hi a k, i h lo. acc ac a , ho n in Fig. S3. A he beginning of each block, he e, e e fo econd, befo e he ______ial, and a ho in, c ion in Chine e (ee Table 1), a di pla do n he c een in he econd befo e he o, econd (he la o, econd e e e e d o di pla n mbe , a indica ed belo). A he beginning of each ial, a i al-only a dio yonly o a dio i alfacial in 1, . a pe ened o he bjec fo 1,400 m, follo ed by a 600-m blank pe iod. i o- econd cycle i h he ame im l a epea ed fo ime, follo ed by a i^{x} econd blank pe iod. e efo e, one ial l i^{x} ed 14 econd . In addi ion o he abo e, im li, eigh n mbe i^{y} in ed appea ed one bgone a he cen e of he, c een, each a andom in ege f om 0 o 9. Each n mbe la ed 900 m, and he in e, al be¹, een , o, b, eq en n mbe , a, 350 m, e , n mbe appea ed 2, econd, befo e he beginning of hi, ial. e, bjec, e e a ked o nd and co n he epea ed n mbe, A e he, im la ion, a

Xa ion c o, appea ed on he, c een. e, bjec, hen e ponded by p e, ing he igh -hand key acco ding o he in c ion fo hi block (ee Table 1). e Xa ion c o, changed colo a he 12 h, econd, indica ing ha he ne i al. o ld begin, ho lo (ee Fig. 1B). In o al, a n la ed 1,350, econd . e p oced e fo he h ee n, i h he gende /emo ion a k, a, imila o ha fo he n, i h he n mbe a k, e keep ha no n mbe, appea ed on he, c een and he, bjec, pe fo med a gende /emo ion j dgmen a k (See Table 1). Speci cally he, bjec, e e a ked o foc, hei a en ion on ei he he gende o he emo ion of

 \circ o \mathcal{L}_{2} , ime, e ie, de ending, and no mali a ion of he ime, e ie, in each block o e o mean and ni \circ a iance. All p ep oce, ing, ep. e e pe fo med , ing SPM8²³ and c , om f nc ion in MATLAB 7.4 (Ma hWo k , Na ick, Ma , ach , e , , USA).

Univariate GLM analysis. i e spe imen incl ded fo e spe imen al a k (n mbe, gende, emo ion, and bi-fea e). Fo each e $\frac{1}{2}$ e imen al a k, h ee n co e ponding o he i al-onl \mathbb{S} he a dio \mathbb{S} onl \mathbb{S} and he a dio i al im l condition e e pe fo med. To con m ha a dio i al en d Sin eg a ion occ ed fo each e åpe imen al a k and de e mine he he e omodal a ea a ocia ed i h a dio i al in eg a ion, e pe fo med. o žel-, i eg o p anal si of he fMRI da a ba ed on a mi žed-e ec ... o-le el GLM in SPM8. In pa ic la, ing he da a f om he h² een mbe n, epe fo med GLM anal i o e sploe he a dio i al in eg a ion a he, en o Sole el, hen he, bjec, f llSoigno ed he, i al-onlSola di o Solon Solo a dio i al facial im li, hile onl 🖓 a énding o hen mbe, e GLM anal 💱 i incl ded hé follo, ing da áp oce, ing. e fMRI da a fo each, bjec . e e, bjec ed o a , -le el GLM, and he e ima ed be a coe cien, ac o, all, bjec, e e hen combined and anal de , ing a, econd-le el GLM. e follo ing, a i ical c i e ion , a , ed o de e mine b ain a ea fo a did i al, en o Sin eg a ion: $[AV>ma (A,V) (p<0.05, FWE-co ec ed)] \cap [V>0 o A>0 (p<0.05, nco ec ed)]^{1,4,6,24}$ 27, he e \cap deno e he in e e ion of \cup o e. Fo each bjec, each a k, and each, im 1, condi ion, e al o comp ed he pe cen ignal change of he pSTS/MTG cl e, ia egion-of-in e e (ROI)-ba ed anal i (implemen ed ba he MATLAB oolbo Ma BaR-0.43²⁸). Speci call . eiden i ed he cl., e, con i ingʻof igni can l&ac i å ed o žel in he bila e al pSTS/MTG ia g o pGLM anal a abo e. Fi, , a GLM model, a e ima e ima ed f om he mean BOLD, ignal of he cl, e, , and he pe cen ^y ignal change in he cl., e, a, hen comp ed a, he a io be een he ma Am m of he e ima ed e en e pon e and he ba eline.

MVPA procedure for the calculation of the reproducibility ratio and decoding accuracy. Fo each, bjec, he e. e e a o al of 12 n, i h fo e per imen al a k and h ee, im 1, condi ion. Fo each n, e calc la ed a ep od cibili a io co e ponding o he gende fea e and one co e ponding o he emoion fea e bapplang an MVPA me hod o he fMRI da a. e ep od cibili a io i an inde ha mea e he imila i sof he ne al ac i i apa e n, i hin a cla, (e.g., he male cla, in he gende dimen ion) and he di e ence in ne al ac i i apa e n, be een o cla, e (e.g., male, female in he gende dimen ion). e highe he ep od cibili a io, he onge he imila i sof b ain pa e n, i hin each cla, and he la ge he di e ence be een he o cla, e of b ain pa e n a, ocia ed, i h he o gende o o emo ion ca ego ie. U ing he fMRI da a, e al o decoded he gende and emo ion ca ego ie of he, im li pe cei ed ba he, bjec.

e ne al ep e en a ion of gende and emo ion fea e e e anal sed b scompa ing he ep od cibili se a io o decoding acc ac se fo di e en im l condi ion (i al-onlyst a di o se onlyst and a dio i al) and e pe imen al a k (h mbe, gende, emo ion, and bi-fea e). In pa ic la, he, bjec onlyst a ended o he n mbe, d ing he h ee n mbe n, b he MVPA, a ba ed on he gende and emo ion fea e of he i al-onlyst a di o se onlyst o a dio i al facial, im li. In hi manne, e anal sed he ne al ep e en a ion of gende and emo ion fea e , hen none, a a ended. Belo, , e e solain he MVPA p oced e fo gende ca ego ie (he MVPA p oced e fo emo ion ca ego ie a jimila).

Fo each n, 10-fold c 0, -a alida ion, a pe fo med fo he calc la ion of he ep od cibili a io and decoding acc acace e ponding o he o gende ca ego ie (efe o Fig. S1 in S pplemen al Info ma ion). Speci calla he da a f om 80 ial e e eq alla pa i ioned in o 10 non-o e lapping da a e. Fo he k h fold of he c o -alida ion (k = 1, ..., 10), he k h da a e (eigh ial) a ed fo he e, and he o he nine da a e. (72 ial) e e ed fo o all election and clarit e aining. A e he 10-fold c o - alida ion, he a e age ep od cibili a io and decoding acc aca a e e calc la ed ac o, all fold ed a p oce, ing p oced e fo he k h fold incl ded he follo. ing:

1) Voxel selection based on the training data. A, phe ical, ea chligh algo i hm ha a, eq en iall scen e ed a each, o xel, i h a 3-mm adi, ea chligh highligh ing 19, o xel, a applied o he aining da a, e fo o xel, elec ion²⁹. Wi hin each, ea chligh co e ponding o a, o xel, e comp ed a Fi he a io h o gh Fi he linea di c iminan anal xi, and hi a io indica ed he le el of di c imina ion be een he o gende ca ego ie in he local neighbo hood of hi, o xel. A Fi he a io map, a, h, ob ained fo he, hole b ain. K info ma i e, o xel, i h he highe, Fi he a io, e e hen, elec ed (e.g., K = 1500 in hi, d.g.

2) Pattern extraction. U ing he K elec ed. $o \stackrel{*}{>} el$, e con c ed a K-dimen ional pa e n ec o fo each ial of he aining da ain hich each elemen ep e en ed he mean BOLD e pon e of a elec ed. $o \stackrel{*}{>} elf$ om he 6 h o he 14 h econd of hi ial (he la fo ol me, o acco n fo he dela in he hemod shamic e pon e; each ial la ed 14

. he e $\theta_{i,j}$ i he angle be seen so pase no eco prove P_i



Figure 2. Brain areas for audiovisual sensory integration that met the criterion $[AV>max (A,V) (p < 0.05, FWE-corrected)] \cap [V>0 or A>0 (p < 0.05, uncorrected)]. (A) No b ain a ea e Ahibi ed a dio i al en o ain eg a ion fo hen mbe a k. (B) B ain a ea e Ahibi ing a dio i al en o ain eg a ion fo hen mbe a k. (B) B ain a ea e Ahibi ing a dio i al en o ain eg a ion fo hen gende a k, incl ding he le pSTS/MTG (Talai ach coo dina e of he cl e cen e : <math>(-57, -34, -5)$; cl e i e: 76). (C) B ain a ea e Ahibi ing a dio i al en o ain eg a ion fo he emo ion a k, incl ding he le pSTS/MTG (cl e cen e : (-60, -40, 1); cl e i e: 98) and he igh pSTS/MTG (cl e cen e : (45, -34, 19); cl e i e: 13). (D) B ain a ea e Ahibi ing a dio i al en o ain eg a ion fo he bi-fea e a k, incl ding he le pSTS/MTG (cl e cen e : (-54, -40, 10)) and the igh pSTS/MTG (cl e cen e : (-54, -40)) and he igh pSTS/MTG (cl e cen e : (-54, -40)) and he igh pSTS/MTG (cl e cen e : (-54, -40)) and he igh pSTS/MTG (cl e cen e : (-54, -40)) and he igh pSTS/MTG (cl e cen e : (-54, -40)) and he igh pSTS/MTG (cl e cen e : (-54, -40)) and he igh pSTS/MTG (cl e cen e : (-54, -40)) and he igh pSTS/MTG (cl e cen e : (-54, -40)) and he igh pSTS/MTG (cl e cen e : (-54, -40)) and he igh pSTS/MTG (cl e cen e : (-54, -40)) and he igh pSTS/MTG (cl e cen e : (-54, -40)) and he igh pSTS/MTG (cl e cen e : (-54, -40)) and he igh pSTS/MTG (cl e cen e : (-54, -40)) and he igh pSTS/MTG (cl e cen e : (-54, -40)) and he igh pSTS/MTG (cl e cen e : (-54, -40)) and provide the pSTS/MTG (cl e cen e : (-54, -40)) and provide the pSTS/MTG (cl e cen e : (-54, -40)) and provide the pSTS/MTG (cl e cen e : (-54, -40)) and provide the pSTS/MTG (cl e cen e : (-54, -40)) and provide the pSTS/MTG (cl e cen e : (-54, -40)) and provide the pSTS/MTG (cl e cen e : (-54, -40)) and provide the pSTS/MTG (cl e cen e : (-54, -40)) and provide the pSTS/MTG (cl e cen e : (-54, -40)) and provide the pSTS/MTG (cl e cen e : (-54, -40)) and provide the pSTS/

di e en ia ed fo di e en e p e imen al a k o di e en eman ic fea e . . . , a dio i al en o p in eg a ion a he han a dio i al eman ic in eg a ion occ ed in he iden i ed he e omodal a ea of he pSTS/MTG, con i en i h p e io e 1.¹⁰.

MVPA results of the reproducibility ratios and decoding accuracy rates. U ing an MVPA me hod, fo each of he 12 n of he e per imen i h fo a en ional a k and h ee, im 1, condi ion, e calc la ed o ep od cibili a io, co e ponding o he gende ca ego ie (male , female) and he emo ion ca egoie (c ang , la ghing) of he, im li e pec i ela F he mo e, each calc la ion of ep od cibili a io a ba ed on 1500, elec ed. o el (ee Ma e ial and Me hod); he e l, of ep od cibili a io a e ho n in Fig. 3. We al o a ema icalla a ied he n mbe of elec ed. o el fom 25 o 1500 o calc la e he ep od cibili a io and ob aihed, imila e l. (ee Fig. S4).

Fo he ep od cibili a io of he gende /emo ion ca ego ie , o- a epea ed mea e ANOVA e ealed igni can main e ec, of im l, condi ion (gende ca ego ie : $p < 10^{-17}$, F(2, 8) = 88.73; emo ion ca ego ie : $p < 10^{-16}$, F(2, 8) = 51.37) and e be imen al a k (gende ca ego ie : $p < 10^{-17}$, F(3, 8) = 81.13; emo ion ca ego ie :



Figure 3. Reproducibility ratios (means and standard errors across all subjects) and the corresponding comparison results. Le /Righ : gende /emo ion ca ego ie ; he 3 o : a dio i al, i al-onl% and a di o & onl% im l condi ion , e pec i el & he 4 h o : he ep od cibili & a io in he a dio f al condi ion min he ma im m of he ep od cibili & a io in he i al-onl% and a di o & onl% condi ion .

 $p < 10^{-17}$, F(3, 8) = 68.26) (Fig. 3A C, E G). e e a al o a igni can in e ac ion e ec be en he o fac o of im 1 condi ion and e Δpe imen al a k (gende ca ego ie : $p < 10^{-17}$, F(6, 8) = 30.07; emo ion ca ego ie : $p < 10^{-8}$, F(6, 8) = 10.05). Po hoc Bonfe oni-co ec ed pai ed - e , on he im l condi ion e ealed he follo ing: (i) fo each a k- ele an fea e (gende ca ego ie i h he gende o he bi-fea e a k, le panel of Fig. 3; emo ion ca ego ie i h he emo ion o he bi-fea e a k, igh panel of Fig. 3), he ep od cibili 🔊 a io e e, igni can loghighe fo he a dio i, al, im l, condi ion han fo he, i, al-o a di o ogonlog im l, condi ion (all p < 0.001 co ec ed); and (ii) fo each a k-i ele an fea e (gende ca ego ie i h he h mbe o he emo ion a k, le panel of Fig. 3; emo ion ca ego ie i h he n mbe o he gende a k, igh panel of Fig. 3), he e. e e no, igni can di e ence, be . een he a dio i, al and he i, al-onloso a di o sonlos im l, condi ion (all p > 0.05). F he mo e, po hoc Bonfe oni-co ec ed pai ed - e on he e spe imen al a k e ealed ha (i) in each of he a dio i al, i al-only and a dio yonly im l condi ion, he ep od cibili y a io fo gende /emo ion ca ego ie e e igni can 🕼 highe fo éach ^rele an a k (gende ca ego ie : he gende o he bi-fea e a k, le panel of Fig. 3; emo ion ca² ego ie : he emo ion o he bi-fea e a k, igh panel of Fig. 3) han fo each i ele an a k (gende ca ego ie : he n mbe o he emo ion a k, le panel of Fig. 3; emo ion ca ego ie : hen mbe o he gende a k, igh panel of Fig. 3) (all p < 0.05, co ec ed) and ha (ii) in each of he a dio i al, i al-only and a di o geonly im l, condition, he e e e no igni can di e ence in he ep od cibili ge a io fo gende /emo ion ca ego ie be een o ele an a k o be een o i ele an a k (all p > 0.05).

Fo each n of he experimen, ef he calc la ed he decoding acc acie of he gende ca ego ie (male , female) and he emo ion ca ego ie (c ging , la ghing) (ee Ma e ial and Me hod), hich a e p e en ed in Fig. S5. e decoding e l al o e eal he enhancemen e ec p od ced b he a dio i al im li on for a k- ele an fea e (ee Fig. S5).

When he bain i ecei ing boha di o Sand. i al. ignal, moe ep od cible ep e en a ion ma be pod ced e en if no a dio i al in eg a ion occ¹. We h cond c ed a con ol e pe imen ha incl ded an incong en a dio i al nfo he gende a kand one fo he emo ion a k. e e pe imen al poced e fo each n a imila o ha of he cong en a dio i al n. i h gende /emo ion a k of he main e pe imen al e l demona ed ha compa ed i h he i al-onl and a di o Sonl in the cond i in li condition, he incong en a dio i al ep e en a ion of he a ended fea e (ee he con ol e pe imen in he spe imen in he spe imen al e l pe en a ion of he a ended fea e (ee he con ol e pe imen in he spe imen in he spe imen al line i no in the spe imen al ended fea e (ee he con ol e pe imen in he spe imen in he spe imen al Info ma ion fo de ail).

MVPA results for informative voxels, cross-reproducibility ratios, and functional connectivity. By applying an MVPA me hod o he da a collec ed in he a dio i al condi ion i h bi-fea e a k, e ob ained he informa i e. o xel fo gende /emo ion ca ego y di c imina ion (ee Ma e ial and Me hod). e di ib - ion of he e informa i e. o xel a e p e en ed in Table 2 and 3 fo gende ca ego ie and emo ion ca ego ie, e pec i el

Ba ed on he e of he info ma i e l e oeg).

	Tal coordinates				Numbers of voxels	
Brain region	x	у	z	max weight	in the clusters	
Righ P ec ne	12	-50	52	0.087	23	
Le Middle F on al G	-38	36	30	0.067	26	
Righ Middle F on al G	40	27	43	0.084	32	
Righ Middle Tempo al G	60	-21	-10 2	13836 30	0.067 10-221 1) 21 21
1						

 $(p < 10^{-9}, F(2, 8) = 36.97$ fo gende ca ego ie; $p < 10^{-11}, F(2, 8) = 46.13$ fo emo ion ca ego ie). F he mo e, po hoc Bonfe oni-co ec ed pai ed - e demon a ed ha he co - ep od cibili a io e e igni can la highe fo he ele an a k han fo he i ele an a k (gende ca ego ie : p < 0.001 co ec ed, (8) = 16.23 fo gende a k . . n mbe a k; p < 0.001 co ec ed, (8) = 15.49 fo gende a k . . emo ion a k; emo ion ca ego ie : p < 0.001 co ec ed, (8) = 16.05 fo emo ion a k . . n mbe a k; p < 0.001 co ec ed, (8) = 14.36 fo emo ion a k . . gende a k) and ha he e a no igni can di e ence be een he n mbe a k and he i ele an emoion/gende a k (all p > 0.05) (Fig. 4). Ba ed on he e of info ma i e o Xel fo he gende /emo ion ca ego ie , e al o pe fo med gende ca ego and emo ion ca ego aca a e a e p e en ed in Fig. S6. F om Table 2 and 3 and Fig 3 and S6, e can concl de he follo ing: (i) he info ma i e. o Xel in Table 2/Table 3 a e in ol ed in he p oce ing of he gende /emo ion fea e in he a dio i al condi ion; (ii) he co e ponding. o Xel in Table 2/Table 3 a e info ma i e on A ei a ended.

Fo hep po e of f nc ional connec i i Scalc la ion, e elec ed fo o Xel cl. e each i h i e 62 f om he he e omodal a ea le STS/MTG (cl. e cen e : (-52 - 22 8)), igh STS/MTG (cl. e cen e : (54 - 18 9)), le pe i hinal co e X(cl. e cen e : (-26, -20, -22)), and igh pe i hinal co e X(cl. e cen e : (26, -18, -22)), a de c ibed in he ela ed efe ence ^{10,32}. Fo each of he a dio i al n i h n mbe, gende and emo ion a k, e calc la ed hef nc ional connec i i Xe i h o di ec ion be een he he e omodal a ea and he info ma i e b ain a ea in Table 2 (fo gende ca ego ie) o Table 3 (fo emo ion ca ego ie). ia G ange ca ali Sanal a a



Figure 5. The functional connectivity between the heteromodal areas and the brain areas encoding the gender feature (A) or the emotion feature (B). G een, phe e : b ain a ea f om Table 2 in (A) o Table 3 in (B). Magen a, phe e : he e omodal a ea . Yello. line : connec ion f om he he e omodal a ea o he info ma i e b ain a ea . Bl e line : connec ion f om he info ma i e b ain a ea o he he e omodal a ea . P ple line : connec ion i h bi-di ec ion. N mbe, in b acke, : o al n mbe, of f nc ional connec ion.

he g o p le el (ee Ma e ial and Me hod). A ho n in Fig. 5, he e e e mo e f nc ional connec ion f om he he e omodal a ea o he b ain a ea encoding he gende /emo ion fea e (Table 2/Table 3) fo he ele an a k (gende /emo ion a k) han fo he i ele an a k (n mbe and emo ion/gende a k). We h ob e ed ha in he a dio i al condi ion, fea e elec i e a en ion enhanced he f nc ional connec i i and h eg la ed he info ma ion o f om he he e omodal a ea o he b ain a ea encoding he a ended fea e. F he mo e, hi enhancemen of he f nc ional connec i i ama@impl@ ha bo h he he e omodal a ea and he b ain a ea encoding he a ended fea e a e in ol ed in a dio i al eman ic in eg a ion.

Discussion. In hepeen, da exploed hene al mod la ion of a dio i al eman ic in eg a ion basse e-elecie a en ion. D ing hefMRI experimen, he bject e ein ced o neglec all fea e, a' end o a ingle fea e (gende o emo ion), o im laneo la end o ofea e (boh gende and emoion) of a e ie of facial mo ie clip in he i al-onla a dio aonla and a dio i al im l condi ion. To a e, he eman ic info ma ion of a fea e encoded in heb an, e calc la ed a ep od cibili a io fo each fea e, experimen al a k and im l condi ion bassapplang an MVPA me hod o hefMRI da a, and ef he anala ed hef nc ional conneci i abe en heb ain a ea encoding he eman ic fea e and he he e omodal a ea¹. O e l gge ed ha in¹ he a dio i al condi ion, fea e- elec i e a en ion maass f nc ion a a p eeq i i e fo he a dio i al eman ic in eg a ion of a fea e and ha heh man b ain migh elec i elas in eg a e he eman ic info ma ion of he a ended fea e basenhancing hef nc ional connec i i and h in encing he info ma ion o, f om he he e omodal a ea o he b ain a ea encoding he fea e. F he mo e, he ep od cibili a io maasse e a an inde x fo e al a ing he a dio i al eman ic in eg a ion of a fea e.

Feature-selective attention: enhancing the neural representations of the attended features in the audiovisual condition. Con ide ing he a dio i al condi ion i h n mbe, gende, emo ion, and bi-fea e a k, e ob e e ed ha he ep od cibili a aio and decoding acc aca a e e e highe fo he a ended fea e han fo na ended fea e (Fig 3 and 4, S4 S6). i e l indica e ha fea e-elec i e a en ion enhanced he ne al ep e en a ion of he a ended fea e and h inc ea ed bo h he imila i a for he ne al ac i i apa e n i hin a cla, (e.g., male o female cla,) and he di e ence be een he o cla, e of he ne al ac i i apa e n (e.g., male , female). To foc, on ele an info ma ion and igno e ha i i ele an, he h man b ain eq ipped i h a elec ion mechani m accompli hed ba he cogni i e f nc ion of a en ion³⁴. Speci calla in he i al-onla o a di o a condition, he b ain elec'i elap oce, e one o e e al fea e ia fea e e elec i e a en ion mechani m, ill pe mi, elec i e p oce, ing of he a ended fea e . In con a o he i al-onla o a di o a di o a en ion in he a dio i al condi ion, elec i elapenhanced he

f nc ional connec i i 🕅 f om he he e omodal a ea and he b ain a ea encoding he a ended fea e (Fig. 5). i enhancemen mod la ed he co e ponding info ma ion o, and plased an impo an ole in achie ing he enhancemen of ne al ep e en a ion of he a ended fea e in he a diò i al condi ion.

Feature-selective attention: a prerequisite for the audiovisual integration of a semantic feature. Fi, , o da a anal \Im i e l, fo he experimental n, i h hen mbe a k, ppo ed he concl, ion ha fea e-elecie a ^genioni ape eqiie fo he a dioi al in egaion of a emanic fea e. A, ho nin Fig. 2 (A,E), hen none of he fea e of he a dio i al, im li e e a ended, a dio i al, en o Sin eg aion a no ob e ed, no o men ion highe le el a dio i al eman ic in eg a ion. Second, ing lie da a fo he a dio i al n. i h he bi-fea e a k, e, epa a el locali ed he b ain a ea a, ocia ed. i h he gende and emo ion ca ego gdi e en ia ion, (Table, 2 and 3, e pec i elg). P e io ____ die, ha e demon, a ed ha ome of he elec ed b ain a ea , peci call he STS and he f ifo m g , a e in ol ed in facial info maion p oce ing^{35 38}. Fo each of he a dio i al n i h he n mbe, gende and emo ion a k , e calc la ed c o, - ep od cibili a io and c o, -decoding acc aca a e fo he gende and emo ion fea e ing he elec ed. o zel in Table 2 and 3. We h, demon, a ed ha he e o zel encoded he eman ic info ma ion of a fea e (gende o emo ion) onla hen he fea e a a ended (Fig 4 and S6). A di ib ed ne o kincl ding he do, al medial, pe io empo al and, en al in apa ie al a ea i in ol ed in hem l i en o Sin eg a ion of i al and, e ib la info ma ion³⁹. Acco dingl🗶 einfe ha hea dio i al eman ic in eg a ión co e ponding o a fea e migh be accompli hed ba a di ib ed ne o k incl ding he he e omodal a ea and he b ain a ea encoding he fea e (Fig. 5). When a fea e of an a dio i al objec i no a ended, o e l indica e ha he co e ponding info ma i e b ain a ea a e no in ol ed in he p oce ing of hi fea e (Fig 4 and S6), po en iall Sinhibi ing he a dio i al eman ic in eg a ion fo hi na ended fea e.

Feature-selective audiovisual semantic integration. In $|hi|_{\mathcal{F}}$ dSf om hepe pecie of ne al info ma ion encoding and f nc ional connec i i 🐒 e demon a ed he mod la ion e ec, of fea e- elec i e a en ion on a dio i al eman ic in eg a ion. Speci call be hen one o ofea e of he a dio i al objec. e e a ended, he enhancemen of he ne al e pon ele el in he he e omodal a ea of he pSTS/MTG indica ed he occ ence of a dio i al en o 🔊 in eg a ion (Fig. 2B D,F H), p o iding he ba i fo he a dio i al eman ic in eg a ion co e ponding o he a ended fea e . MVPA anal si demon a ed ha fo onl he a ended fea e, he eman ic info ma ion encoded in he b ain a imp¹o ed b he a dio i al im h compa ed i h he i al-onlyand he a di o goolg im li (Fig 3, S4, and S5). We p'e io lycon ide ed he ca, e in hich a, ingle fea e of he, im li a a ended²², a in he e $\frac{2}{2}$ pe imen i h he gende and emo ion d Scompa ed i h he i al-onl Sand a di o Sonl Sim l condi ion, e ob e ed ha he a k in hi cong en a dio^Y i al im lienhanced he ne ^Y al ep e en a^Y ion of he a ended fea e. Ho e e, ho hi enhancemen i implemen ed in he b ain emain nclea. In hi d e e X ended hi concl. ion fo he ca e in hich none of he fea e a a ended o mo e han one fea e of he im l a a ended. F he mo e, he G ange ca al connec i i Sanal Si indica ed ha no onl Si he he e omodal a ea b al o he b ain a ea encoding he a ended fea e ma Si be in ol ed in he a dio i al eman ic in eg a ion. In he a dio i al condi ion, fea e- elec i e a en ion en hanced/ ed ced he f nc ional connec i i 🐉 f om he he e omodal a ea and he b ain a ea encoding he a ended/ na ended fea e (Fig. 5) and he efo e mod la ed he info ma ion o among he e a ea . i mod la ion ma be e pon ible fo he enhancemen of he eman ic info ma ion of he a ended fea e by he a dio i al, im li. o gh hi mod la ion of fea e- elec i e a en ion, he h man b ain ma🖇 elec i el🖓 in eg a e he, eman ic info ma ion fo he a ended fea e of he a dio i al facial, im li. BScon à , fo he na ended fea e , he co e ponding a dio i al eman ic in eg a ion a inhibi ed.

Reproducibility ratio: an index for the audiovisual semantic integration of a feature. To fo m high-le el concep al ep e en a ion of he eman ic fea e of an a dio i al objec, he b ain pe fo m a dio i al eman ic in eg a ion, hich maS be ba ed on a dio i al in eg a ion a he en o S le el¹⁰. N me o ne oimaging and elec ophy iological, die ha e demon, a ed ha cong en a dio i al, im li can enhance ne al ac i i ie, e.g., in he bila e al pe io empo al g (STG)¹⁸ ²¹. Con e el Sin he a dio i al condi ion, he enhancemen of b ain ac i i ie in he e omodal a ea ch a he pSTS/MTG mass e e a an indica o of a dio i al en o Sin eg a $ion^{4,24}$ 26. Rega ding a dio i al eman ic in eg a ion, n me d' , die ha e di c , ed he in ence of eman ic fac o on a dio i al in eg a ion (ee efe ence⁴⁰ and he efe ence he ein). Ho e e, no die ha e add e ed he di e en ia ion of he e ec, of a dio i al eman ic in eg a ion fo di e en eman ic fea e. e di c l 🔊 ma 🖓 lie in he a, e, men of he in eg a ed and nin eg a ed info ma ion con ained in he b ain, ignal. In hi, 🛛 🖓 'é ob e d ha he a dio i al eman ic in eg a ion e ec, a ocia ed i h di e en fea e e elec i e a en ion $r_a k$ co ld no be di e en ia ed ba ed on he le el of ne al aci i ie in he pSTS/MTG (e e Re l and Fig. 2). i e l i con i en i h hef nc ion of he pSTS/MTG a a p e eman ic, he e omodal egion fo c o modal pe cep al fea e^{10} . MVPA app oache open he pojibili Sof epa a ing and locali ing pa iall Sdi ib ed pa e^{n} , hich gene all a e oo eak o be de ec ed b in a ia e me hod, cha GLM^{23,41–43}. U ing an MVPA me hod, c calc la ed a 'èp od cibili 🖉 a io co e ponding o a fea e o a, e, he, eman ic info ma ion encoded in he b ain; he co e ponding, eman'ic info ma ion, a enhanced on sto he a ended fea e, hen he a dio i, al, im 1, condi ion a compa ed i h he i al-onland a di o a onla im l condi ion (Fig 3, S4 and S5). We h ob e ed he di e en ial e ec of a dio i al eman ic in eg a ion fo he a ended and na ended fea e F he mo e, he ep od cibili 🖉 a io migh be , ed a, an inde Xfo e al a ing he a dio i, al, eman ic in eg a ion of a fea e.

Finall, e'de c ibe e al limi a ion of hi, da o ill, a e f e di ec ion . Fi, , e emploaded a ela i elas comple 2 pe imen al de ign, hich led o he collection of la ge amo n, of da a. Fo each, bjec, he collection of he f nc ional and, c al MRI da a la ed abo, i xho, no incl ding p epa a ion ime. Beca, e of he di c l Sun da a collection, e, ed a ela i el mall n mbe of bjec, B, a i icall gigni can e xpe imen al

e l, e e, ill ob ained. Second, only i al-only a di o yonly and a dio i al facial, im li e e con ide ed e, em , implifso e pe imen al de ign, inc ea e hen mbe of bjec, and f he d**S**In he f in hi con ide non-facial, im li o e x end o concl, ion.

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Author Contributions

Y.L. de igned e ea ch and o e he pape ; J.L. and W.W. anal de dhe da a; B.H., T.Y. and P.L. pe fo med he e ea ch; F.F. and P.S. e i ed he pape ; all a ho e ie ed he man c ip .

Additional Information

Supplementary information accompanie hi, pape a h p://....na e.com/ ep

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