Supplementary materials

Table S1. *Sample questionnaire of the LHQ 3.0*

Language History Questionnaire

Language history questionnaire (LHQ). Go to https://blclab.org/lhq3/ to use the online version and for reference.

(1) Participant ID number				(2) Age	
(3) Gender	☐ Male	☐ Female	☐ Non-binary	☐ Non-relevant	
(4) Education	☐ Graduate school (Doctor)	☐ Graduate school (Master)	☐ College (Bachelor)		
	☐ High school	☐ Middle school	☐ Elementary school	☐ Other	
(5) Parents' Education – Father	☐ Graduate school (Doctor)	☐ Graduate school (Master)	☐ College (Bachelor)		
	☐ High school	☐ Middle school	☐ Elementary school	☐ Other	
(5) Parents' Education – Mother	☐ Graduate school (Doctor)	☐ Graduate school (Master)	☐ College (Bachelor)		
	☐ High school	☐ Middle school	☐ Elementary school	☐ Other	
(6) Handedness	☐ Right-handed	☐ Left-handed	☐ Ambidextrous		

(7) Indicate your native language(s) and any other languages you have studied or learned, the age at which you started using each language in terms of listening, speaking, reading, and writing, and the total number of years you have spent using each language.

*Notes For "Years of use", you may have learned a language, stopped using it, and then started using it again. Please give the total number of years.

Language	Listening	Speaking	Reading	Writing	Years of use*

(8 If you have lived or traveled in countries other than your country of residence for three months or more, then indicate the name of the country, your length of stay (in Months), the language you used, and the frequency of your use of the language for each country.

* You may have been to the country on multiple occasions, each for a different length of time. Add all the trips together

Never	Rarely	Sometimes	Regularly	Often	Usually	Always
1	2	3	4	5	6	7

Country	Length of stay (in Months)*	Language	Frequency of use
			☐ 1, ☐ 2, ☐ 3, ☐ 4, ☐ 5, ☐ 6, ☐ 7.
			☐ 1, ☐ 2, ☐ 3, ☐ 4, ☐ 5, ☐ 6, ☐ 7.

(9) Indicate the way you learned or acquired your non-native language(s). Check one or more boxes that apply.

* e.g., Immigrating to another country where the dominant language is different from your native language so you learn this language through immersion in the language environment.

Non-native Language	Immersion*	Classroom instruction	Self-learning
	☐	☐	☐
	☐	☐	☐

(10) Indicate the age at which you started using each of the languages you have studied or learned in the following environments (Including native language).

Language	At home	With friends	At school	At work	Language software	Online games

(11) Indicate the language used by your teachers for instruction at each educational level. If the instructional language switched during any educational level, then also indicate the "Switched to" language. If you had a bilingual education at any educational level, then simply check the box under "Both Languages".

Environment	Language	(Switched to)	Both Language
Elementary school			☐
Middle school			☐
High school			☐
College (Bachelor)			☐
Graduate school (Master)			☐
Graduate school (Doctor)			☐

(12) Rate your current ability in terms of listening, speaking, reading, and writing in each of the languages you have studied or learned (including the native language).

Very poor Poor Limited Average Good Very good Excellent

1 2 3 4 5 6 7

Language	Listening	Speaking	Reading	Writing

(13) If you have taken any standardized language proficiency tests (e.g., TOEFL, IELTS, TOEIC, etc.), then indicate the name of the test, the language assessed, and the score you received for each. If you do not remember the exact score, then indicate an "Approximate score" instead.

Test	Year taken	Language	Score	Approximate score

(14) Estimate how many hours per day you spend engaged in the following activities in each of the languages you have studied or learned (including the native language).

Language	Watching television	Listening to radio	Reading for fun	Reading for school/work	Using social media and Internet	Writing for school/work

(15) Estimate how many hours per day you spend speaking with the following groups of people in each of the languages you have studied or learned (including the native language).

Note *Include significant others in this category if you did not include them as family members (e.g., married partners)
**Include anyone in the work environment in this category (e.g., if you are a teacher, include students as co-workers).

Language	Family members	Friends*	Classmates	Others (co-workers**, roommates, etc.)

(16) Use the comment box below to indicate any additional answers to any of the questions above that you feel better describe your language background or usage.

Table S2. *Rating scores for Experiment 1 stimuli*

	Match	Mismatch		χ^2	*p*
		Same-effector	Different-effector		
Verb:					
L1					
Familiarity	6.60 (0.26)	6.61 (0.18)	6.67 (0.17)	1.70	.42
Imageability	6.08 (0.31)	6.21 (0.22)	6.15 (0.22)	1.41	.49
Concreteness	5.73 (0.31)	5.71 (0.28)	5.78 (0.23)	0.42	.81
Effector involvement	6.00 (0.41)	5.97 (0.42)	6.03 (5.40)	0.26	.88
Frequency (counts per million)	2695.50 (588.83)	3042.57 (624.34)	2480.62 (383.50)	0.54	.76
Strokes	13.69 (6.06)	13.31 (5.73)	13.77 (6.71)	0.04	.98
L2					
Familiarity	6.24 (0.44)	6.18 (0.33)	6.06 (0.49)	4.99	.08
Imageability	5.93 (0.60)	6.11 (0.49)	5.85 (0.58)	4.06	.13
Concreteness	5.65 (0.51)	5.37 (0.45)	5.56 (0.51)	2.89	.23
Effector involvement	5.76 (0.54)	6.08 (0.50)	5.80 (0.54)	3.78	.15
Frequency (counts per million)	123.38 (260.45)	195.11 (349.91)	151.24 (349.83)	2.42	.29
Length	4.46 (0.94)	4.27 (0.91)	4.58 (0.95)	1.59	.45
Picture:					
Familiarity	5.79 (0.38)	5.48 (0.59)	5.31 (0.23)	0.39	.48
Imageability	5.71 (0.57)	5.64 (0.23)	5.43 (0.21)	3.04	.29
Visual complexity	3.21 (0.44)	3.48 (0.69)	3.85 (0.96)	1.92	.57
Effector involvement	5.76 (0.38)	5.91 (0.58)	5.55 (0.37)	4.19	.16

Notes: Mean (*SD*) data for stimuli. Kruskal-Wallis rank sum test (non-parametric) was used to calculate Kruskal-Wallis chi-square (χ^2) and *p* values. Familiarity, ranging from 1-very unfamiliar to 7-very familiar; Imageability, ranging from 1-very low to 7-very high; Concreteness, ranging from 1-very concrete to 7-very abstract; Visual complexity, ranging from 1-very plain to 7-very complex; Degree of effector involvement, ranging from 1-very low to 7-very high. The English and Chinese word frequency corpora differ in corpus size. We utilized the SUBTLEX database for English frequency, specifically adopting $SUBTL_{WF}$ as the word frequency (per million words). We employed the SUBTLEX-CH-CHR database for Chinese frequency, where *CHR/million* represents the character frequency (per million).

Text 1. *Distinct contributions of bilingual experience (Experiment 1)*

Although the modulation effect of bilingual experience was evident, the individual contributions of the four dimensions to the L2 embodiment effect remained to be explored further. To this end, we conducted a multiple regression analysis with the L2 embodiment effect as the dependent variable and the four bilingual experience dimensions as independent variables. However, the degree of collinearity among the four variables was high (see correlations in Figure S2), so they cannot be directly entered into multiple regression analysis. So, we first used a principal component analysis (PCA) to address the multicollinearity issue to achieve the goal of dimension reduction. The data of the four bilingual experience dimensions entered into a PCA. The Kaiser-Meyer-Olkin (KMO) test for sampling adequacy was 0.54, above the commonly recommended value of 0.50 (Field, 2009). Bartlett's test of sphericity was significant, χ^2 (6) = 168.86, $p < .001$, indicating the correlations between the four variables of bilingual experience were appropriate for PCA. Table S3 presents the results of PCA. Two components were extracted with eigenvalues greater than 1, accounting for 92% of the variance.

Subsequently, the two components from the PCA were entered as independent variables into a multiple regression analysis, with the difference score between mean RTs in the same-effector condition and the different-effector condition as the dependent variable. Corresponding results are shown in Table S4, indicating the effect of the first component was significant ($\beta = -13.81$, $p = .004$). The second component reached marginal significance ($\beta = -12.63$, $p = .07$). Then we transformed the current principal components regression results into the original relationship among the four dimensions of bilingual experience. We performed this transformation procedure in R. The converted coefficients for L2 AoA ($\beta = -6.87$), L2 proficiency ($\beta = -11.11$), L2 exposure ($\beta = 134.03$), and L2 dominance ($\beta = 9.39$) showed the relative weight of L2 exposure was the highest, indicating it may play a crucial role in facilitating the employment of embodied mechanism in L2 semantic processing.

Table S3. *Results of the Principal Component Analysis in Experiment 1*

	Component 1	**Component 2**
L2 AoA	0.50	0.53
L2 proficiency	−0.44	0.58
L2 exposure	−0.54	−0.40
L2 dominance	−0.49	0.45
Eigenvalues	2.58	1.10
% variance	64.66	27.68
Cumulative variance	64.66	92.34

Table S4. *Multiple regression analysis results for two components in Experiment 1*

	β	*SE*	*t*	*p*
(Intercept)	46.14	7.43	6.21	< .001
Component 1	−13.81	4.62	−2.99	**.004**
Component 2	−12.63	7.06	−1.79	.07

Table S5. *Rating scores for Experiment 2 stimuli*

	Semantic-related	Semantic-unrelated		χ^2	*p*	Semantic-related		χ^2	*p*	Semantic-unrelated		χ^2	*p*
		Same-effector	Different-effector			Critical	Filler			Critical	Filler		
L1													
Familiarity	6.52 (0.25)	6.56 (0.21)	6.49 (0.34)	0.27	.87	6.46 (0.30)	6.29 (0.67)	3.58	.16	6.53 (0.28)	6.11 (0.12)	0.68	.67
Imageability	5.91 (0.33)	6.01 (0.32)	5.89 (0.45)	1.69	.43	5.86 (0.40)	5.21 (0.27)	2.85	.27	6.00 (0.31)	5.74 (0.38)	0.26	.33
Concreteness	5.57 (0.35)	5.66 (0.34)	5.53 (0.43)	1.46	.48	5.53 (0.40)	5.95 (0.46)	0.41	.71	5.56 (0.32)	5.21 (0.55)	3.12	.21
Effector involvement	5.86 (0.46)	6.03 (0.34)	5.84 (0.51)	2.27	.32	5.86 (0.47)	1.32 (2.47)	8.28	.02	5.96 (0.39)	1.48 (1.97)	9.43	.01
Frequency (counts per million)	1820.82 (939.35)	1585.16 (377.84)	1574.92 (394.18)	1.86	.39	1157.93 (318.72)	1024.35 (487.97)	1.08	.54	1626.93 (520.78)	1423.77 (412.98)	2.30	.35
Strokes	15.48 (5.65)	16.96 (5.83)	16.28 (5.79)	1.14	.56	16.36 (5.37)	19.01 (3.24)	0.48	.75	16.82 (5.78)	18.8 (4.32)	3.09	.22
L2													
Familiarity	6.29 (0.61)	6.38 (0.71)	6.52 (0.48)	2.34	.31	6.12 (0.81)	5.88 (0.65)	0.73	.62	6.36 (0.79)	6.10 (0.78)	0.65	.67
Imageability	5.60 (0.71)	5.68 (0.82)	5.84 (0.73)	3.02	.22	5.59 (0.74)	5.36 (0.12)	0.40	.72	5.77 (0.75)	5.52 (0.45)	0.89	.56
Concreteness	5.35 (0.61)	5.45 (0.69)	5.55 (0.60)	2.48	.30	5.40 (0.64)	5.12 (0.56)	0.39	.78	5.52 (0.64)	5.21 (0.67)	0.28	.86
Effector involvement	5.67 (0.57)	5.59 (0.89)	5.87 (0.57)	2.36	.31	5.64 (0.64)	1.65 (2.16)	9.43	.01	5.78 (0.67)	1.12 (0.26)	9.43	.01
Frequency (counts per million)	108.68 (264.20)	85.64 (173.09)	106.98 (187.26)	0.83	.66	112.74 (262.19)	108.87 (287.43)	2.87	.28	122.99 (260.90)	143.78 (289.70)	3.09	.22
Length	4.66 (1.26)	4.48 (1.05)	4.76 (1.42)	0.26	.88	4.71 (1.29)	5.28 (1.98)	2.30	.35	4.65 (1.31)	5.67 (1.01)	1.04	.55

Notes: Mean (*SD*) data for stimuli. Kruskal-Wallis rank sum test (non-parametric) was used to calculate Kruskal-Wallis chi-square (χ^2) and *p* values. Familiarity, ranging from 1-very unfamiliar to 7-very familiar; Imageability, ranging from 1-very low to 7-very high; Concreteness, ranging from 1-very concrete to 7-very abstract; Degree of effector involvement, ranging from 1-very low to 7-very high. The frequency measures are the same as those in Table S2.

Table S6. *Language background of participants in Experiment 2*

Measurements	Range	Mean	*SD*
L1 AoA	0–4	1.12	1.49
L1 proficiency (0–1)	0.64–1	0.84	0.10
L1 exposure (0–1)	0.68–0.96	0.87	0.09
L1 dominance (0–1)	–	1	0
L2 AoA	3–12	7.88	1.91
L2 proficiency (0–1)	0.29–0.86	0.64	0.11
L2 exposure (0–1)	0.48–0.79	0.63	0.08
L2 dominance (0–1)	0.36–0.89	0.73	0.11

Note: AoA = age of acquisition; The scores from LHQ have been normalized into a range between 0–1 for each dimension.

Text 2. *Distinct contributions of bilingual experience (Experiment 2)*

In Experiment 2, the relative contribution of each of the four dimensions to the L2 embodiment effect remains to be explored further. Given that the degree of collinearity among the four variables was relatively high (see correlations between these variables in Figure S3), we used PCA to address the multicollinearity problem. The KMO test of sampling adequacy was 0.53, a bit above the commonly recommended value of 0.50 (Field, 2009). Moreover, Bartlett's test of sphericity was significant, χ^2 (6) = 128.24, $p < .001$. Table S7 presents the results of PCA. Two components were extracted with eigenvalues greater than 1, accounting for 90% of the variance.

The two components from the PCA were then entered as independent variables into a multiple regression analysis, with the difference score between mean RTs in the same-effector condition and the different-effector condition as the dependent variable. Corresponding results are summarized in Table S8. The effect of the first component was significant ($\beta = -20.37$, $p < .001$), and the second component reached marginal significance ($\beta = -12.20$, $p = .08$). Then we transformed the current principal components regression results into the original relationship among the four dimensions of bilingual experience. This transformation procedure was performed in R. The converted coefficients for L2 AoA ($\beta = -8.71$), L2 proficiency ($\beta = 10.35$), L2 exposure ($\beta = 190.57$), and L2 dominance ($\beta = 37.17$) showed that the relative weight of L2 exposure was the highest, in line with the Experiment 1.

Table S7. *Results of the Principal Component Analysis in Experiment 2*

	Component 1	**Component 2**
L2 AoA	0.52	0.49
L2 proficiency	−0.41	0.60
L2 exposure	−0.56	−0.40
L2 dominance	−0.48	0.47
Eigenvalues	2.39	1.23
% variance	59.81	30.86
Cumulative variance	59.81	90.67

Table S8. *Multiple regression analysis results for two components in Experiment 2*

	β	*SE*	*t*	*p*
(Intercept)	49.12	7.81	6.29	< .001
Component 1	−20.37	5.05	−4.03	**< .001**
Component 2	−12.20	7.03	−1.74	.08

Note: $R^2 = 0.28$; $F\ (2, 49) = 9.64$; $p < .001$

Table S9. *Results of the models with effector in Experiments 1 & 2*

Fixed effects	Experiment 1			Experiment 2		
	β	*SE*	*t*	*β*	*SE*	*t*
Model 1						
(Intercept)	6.52	0.09	75.42 ***	6.57	0.08	76.24 ***
Effector type	0.12	0.03	3.85 ***	0.15	0.02	5.25 ***
Language	0.03	0.08	0.37	0.02	0.04	4.14 ***
L2 AoA	0.01	0.01	0.53	0.01	0.01	0.05
Effector 1	−0.04	0.02	0.38	0.02	0.01	1.27
Effector 2	0.02	0.01	1.22	−0.01	0.02	−0.54
Effector type×Language	0.15	0.05	2.39 *	0.08	0.05	1.69
Effector type×L2 AoA	−0.01	0.03	2.33 *	−0.01	0.01	−3.51 ***
Language×L2 AoA	0.04	0.01	0.43	−0.01	0.01	−0.15
Effector type×Language×L2 AoA	−0.02	0.01	−2.49 *	−0.01	0.01	−2.01 *
Model 2						
(Intercept)	6.57	0.13	48.73 ***	6.59	0.15	41.54 ***
Effector type	−0.05	0.04	−1.15	−0.12	0.05	−2.59 **
Language	0.19	0.13	1.52	0.23	0.08	2.69 **
L2 exposure	−0.02	0.22	−0.09	−0.02	0.02	−0.08
Effector 1	−0.04	0.02	−1.63	0.01	0.01	1.06
Effector 2	0.02	0.01	1.23	−0.01	0.01	−0.12
Effector type×Language	−0.21	0.08	−2.60 **	−0.21	0.09	−2.15 *
Effector type×L2 exposure	0.18	0.06	2.78 **	0.30	0.07	4.01 ***
Language×L2 exposure	−0.21	0.20	−1.02	−0.07	0.13	−0.53
Effector type×Language×L2 exposure	0.34	0.13	2.61 **	0.31	0.15	2.06 *
Model 3						
(Intercept)	6.67	0.12	57.80 ***	6.84	0.13	54.67 ***
Effector type	0.05	0.02	3.41 **	0.06	0.01	4.57 ***
Language	0.06	0.02	3.34 **	0.19	0.01	13.64 ***
L2 proficiency	−0.15	0.18	−0.87	−0.39	0.19	−2.07 *
Effector 1	−0.04	0.02	−0.61	0.02	0.01	1.10
Effector 2	0.02	0.01	1.22	−0.01	0.01	−0.15
Model 4						
(Intercept)	6.75	0.12	56.27 ***	6.91	0.14	50.11 ***
Effector type	0.05	0.02	3.34 **	0.06	0.01	4.56 ***
Language	0.06	0.02	3.35 **	0.18	0.01	13.63 ***
L2 dominance	−0.26	0.16	−1.58	−0.45	0.18	−2.41 *
Effector 1	−0.04	0.02	−1.61	0.02	0.01	1.12
Effector 2	0.02	0.01	1.22	−0.01	0.01	−0.15

Notes: *$p < .05$, **$p < .01$, ***$p < .001$; The three-level effector (foot, hand, mouth) variable was turned into two contrasts, with the first contrast (effector 1) comparing foot and mouth (foot = 0.5, hand = 0, mouth = −0.5) and the second contrast (effector 2) comparing hand and mouth (foot = 0, hand = 0.5, mouth = −0.5).

Table S10. *Summary of model results for repeated measures omnibus analysis*

Fixed effects	*β*	*SE*	*t*	*p*
Model 1: concerning L2 AoA				
(Intercept)	6.57	0.07	90.32	< .001
Effector type	0.14	0.02	6.89	**< .001**
Language	0.11	0.05	1.82	.07
L2 AoA	−0.00	0.01	−0.03	.98
Experiment	0.01	0.02	0.69	.49
Effector type×Language	0.13	0.04	3.25	**< .01**
Effector type×L2 AoA	−0.01	0.01	−3.95	**< .001**
Language×L2 AoA	0.00	0.01	0.34	.74
Effector type×Language×L2 AoA	−0.01	0.01	−3.11	**< .01**
Model 2: concerning L2 exposure				
(Intercept)	6.55	0.12	55.38	< .001
Effector type	−0.07	0.03	−2.20	**.03**
Language	0.22	0.09	2.33	**.02**
L2 exposure	0.03	0.18	0.16	.87
Experiment	0.01	0.02	0.71	.48
Effector type×Language	−0.18	0.06	−2.89	**.003**
Effector type×L2 exposure	0.22	0.05	4.56	**< .001**
Language×L2 exposure	−0.15	0.15	−0.99	.32
Effector type×Language×L2 exposure	0.32	0.09	3.25	**< .01**
Model 3: concerning L2 proficiency				
(Intercept)	6.75	0.10	66.40	< .001
Effector type	0.07	0.01	7.12	**< .001**
Language	0.13	0.02	7.69	**< .001**
L2 proficiency	−0.29	0.16	−1.79	**.08**
Experiment	0.01	0.02	0.50	.62
Model 4: concerning L2 dominance				
(Intercept)	6.80	0.11	63.77	< .001
Effector type	0.06	0.01	7.12	**< .001**
Language	0.12	0.16	7.69	**< .001**
L2 dominance	−0.33	0.15	−2.21	**.03**
Experiment	0.01	0.16	0.49	.63

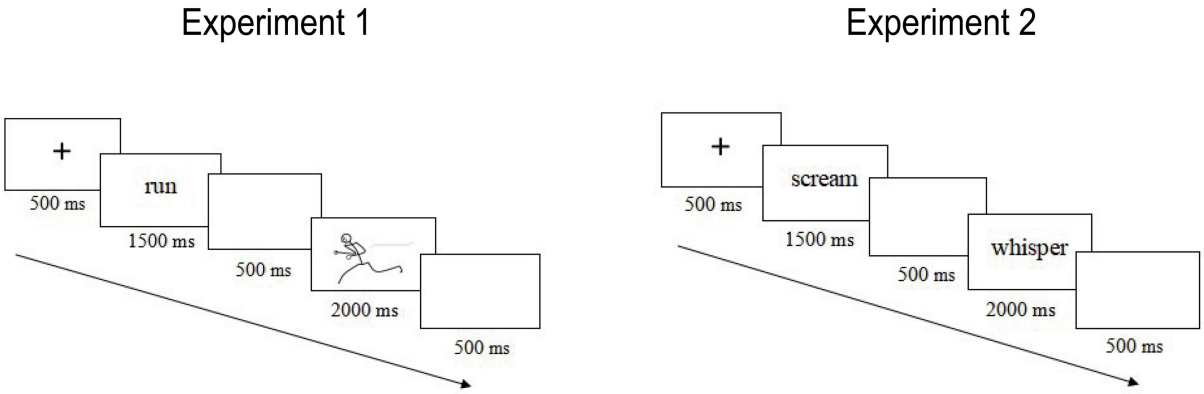

Figure S1. The verb-picture matching task (English session) in Experiment 1 (left) and the semantic relatedness judgment task (English session) in Experiment 2 (right). *Note:* The Chinese session is similar to the English session.

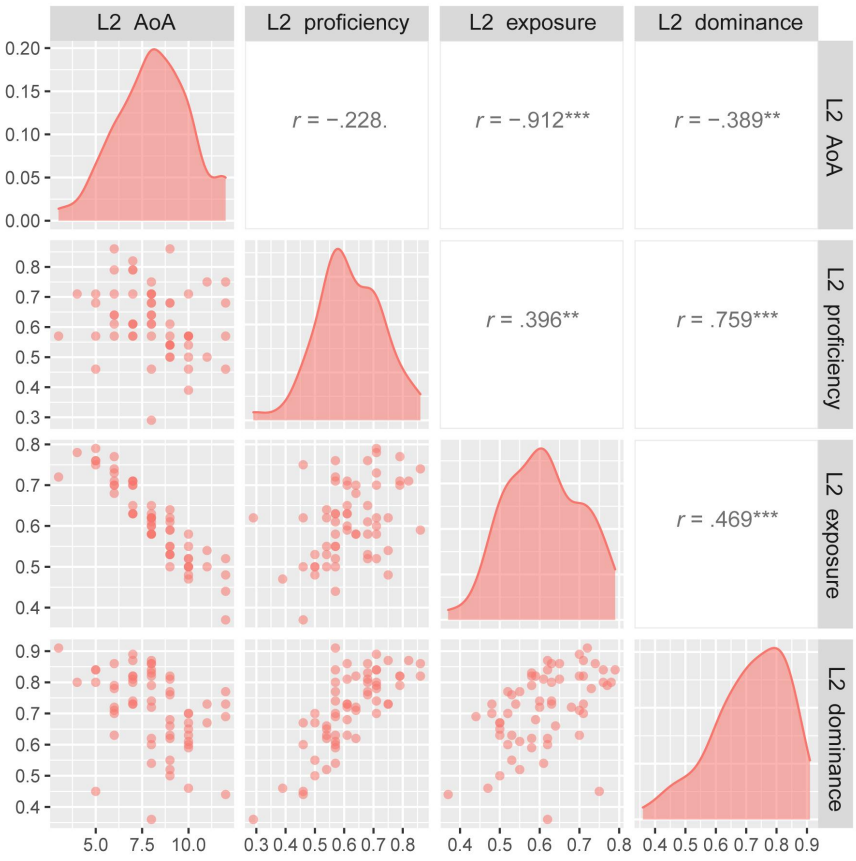

Figure S2. Correlations between four dimensions of bilingual experience in Experiment 1. Correlational coefficients and significance levels are provided in the boxes of the upper right areas (**$p < .01$, ***$p < .001$).

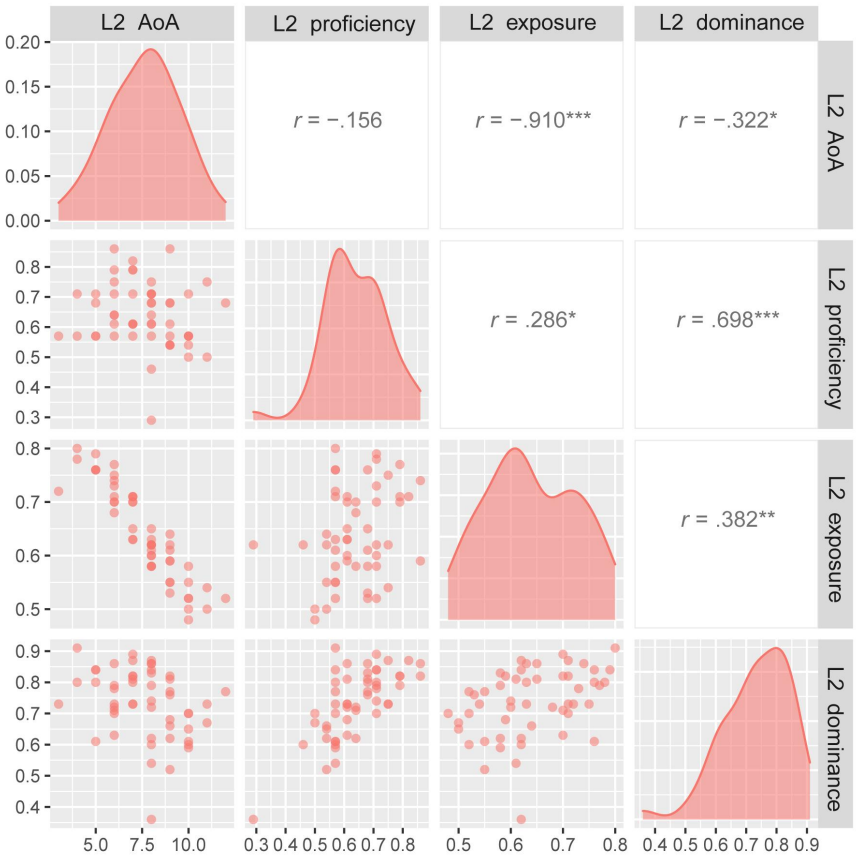

Figure S3. Correlations between four dimensions of bilingual experience in Experiment 2. Correlational coefficients and significance levels are provided in the boxes of the upper right areas (*$p < .05$, **$p < .01$, ***$p < .001$).