

Semantic integration and age of acquisition effects in code-blend comprehension

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Abstract

Semantic and lexical decision tasks were used to investigate the mechanisms underlying code-blend facilitation: the finding that hearing bimodal bilinguals comprehend signs in American Sign Language (ASL) and spoken English words more quickly when they are presented together simultaneously than when each is presented alone. More robust facilitation effects were observed for semantic decision than for lexical decision, suggesting that lexical integration of signs and words within a code-blend occurs primarily at the semantic level, rather than at the level of form. Early bilinguals exhibited greater facilitation effects than late bilinguals for English (the dominant language) in the semantic decision task, possibly because early bilinguals are better able to process early visual cues from ASL signs and use these to constrain English word recognition. Comprehension facilitation via semantic integration of words and signs is consistent with co-speech gesture research demonstrating facilitative effects of gesture integration on language comprehension.

While bilinguals of two spoken languages (unimodal bilinguals) must alternate between their two languages when mixing their languages in conversations with other bilinguals, bilinguals who are fluent in a spoken language and a signed language (bimodal bilinguals) have the unique ability of producing and perceiving their two languages simultaneously because each language accesses distinct sensory-motor systems. Although bimodal bilinguals can also switch between speaking and signing, they prefer code-blending, that is, producing words and signs at the same time, over code-switching, when conversing with other bimodal bilinguals (e.g., Bishop, 2010; Emmorey, Borinstein, Thompson, & Gollan, 2008; Lillo-Martin, De Quadros, Chen Pichler, & Fieldsteel, 2014; Petitto et al., 2001). The majority of such code-blends are translation equivalents, although instances of simultaneously produced words and signs that are not translation equivalents, but are nonetheless semantically congruent, are also observed.

Processes involved in the production and comprehension of code-blends

While the linguistic and cognitive mechanisms of switching between two spoken languages have been relatively well-studied (see e.g., Kroll, Bobb, Misra, & Guo, 2008), the psycholinguistic processes underlying the *simultaneous* selection or retrieval of lexical representations in two languages during production and comprehension are much less clear (see Emmorey, Giezen, & Gollan, 2015, for review). Investigating the processing of code-blends in bimodal bilinguals therefore promises to provide unique insight into the relative costs of lexical inhibition and selection. Most notably, whereas the serial production or comprehension of code-switches has been associated with processing costs (e.g., Meuter & Allport, 1999; Thomas & Allport, 2000; Verhoef,

Roelofs, & Chwilla, 2009; Von Studnitz & Green, 2002), the production and comprehension of code-blends appears less effortful.

For example, Emmorey, Petrich, and Gollan (2012) compared picture-naming latencies in American Sign Language (ASL) alone, English alone, and with code-blends in hearing native and late ASL-English bilinguals. Although code-blending delayed the onset of speech to facilitate synchronization of the articulators, the results suggested that the simultaneous retrieval of words and signs during production is not associated with additional processing costs compared to retrieving single words or signs (cf., Kaufman, 2014). Furthermore, recent findings from related research with bimodal bilinguals has suggested that switching from just speaking or signing to producing code-blends in a cued language switching task *does not* incur processing costs, whereas switching from code-blending to just speaking or signing *does* (see Emmorey et al., 2015, for discussion). Together, these findings from code-blend production studies indicate that the selection of two lexical representations may be less costly than suppressing one of the two lexical representations.

To investigate the potential processing costs or benefits of code-blending for language *comprehension*, Emmorey et al. (2012) compared response times of native and late bimodal bilinguals for semantic decisions to ASL signs, English audiovisual words and ASL-English code-blends (translation equivalents). They found that code-blends facilitated semantic access during comprehension for ASL – the non-dominant language, but critically also for English – the dominant language. Furthermore, Emmorey et al. (2012) found stronger facilitation effects of ASL on English word recognition in a code-blend for early bilinguals compared to late bilinguals. They suggested that early

bilinguals may be better able to process early visual cues of ASL signs and use these to constrain English word recognition.

Two neuroimaging studies provided further evidence for the absence of dual processing costs when bimodal bilinguals process code-blends. Kovelman et al. (2009) compared picture naming in language mixing (blending and switching) blocks and single language blocks in a fNIRS study with five ASL-English bilinguals and found increased activation in sensory-motor cortical areas and left posterior temporal areas for the language mixing block (with no further differences for code-blending versus code-switching), but no increased activation in prefrontal regions often associated with language switching in unimodal bilinguals (Luk, Green, Abutalebi, & Grady, 2012). Weisberg, McCullough, and Emmorey (2015) replicated code-blend facilitation effects in an fMRI study with ASL-English bilinguals using the same semantic decision task as Emmorey et al. (2012). Code-blends elicited activation that resembled a combination of the networks for each language alone, but did not activate regions typically implicated in the cognitive control network. In contrast, compared to audiovisual English words and ASL signs alone, code-blends elicited reduced activity in auditory association cortex and visual extrastriate cortex, respectively. Furthermore, code-blends elicited reduced activity in inferior frontal cortex compared to ASL signs alone, a region that has been associated with semantic processing. This pattern of results is consistent with bimodal language integration effects at the sensory level as well as the semantic level.

Possible mechanisms underlying code-blend facilitation effects

Facilitation effects in code-blend comprehension could have different underlying mechanisms. One possibility is that code-blend facilitation is an extension of the redundant signals effect (Miller, 1986; Miller & Ulrich, 2003), when information from congruent stimuli is combined and co-activates a common response, thus yielding facilitation (e.g., Laurienti, Kraft, Maldjian, Burdette, & Wallace, 2004). Similarly, the semantic integration of co-speech gestures during language comprehension is often associated with facilitation effects (e.g., Habets, Kita, Shao, Özyürek, & Hagoort, 2010; Kelly, McDevitt, & Esch, 2009; Özyürek, Willems, Kita, & Hagoort, 2007). Critically, however, co-speech gestures do not have independent lexical representations, and in the case of code-blends, such facilitation would reflect the combined activation of redundant lexical-semantic representations in English and ASL. A further possibility is that this dual activation results in a “race” between the two language modalities for recognition. For example, Dijkstra, Van Jaarsveld, and Ten Brinke (1998) found that interlingual homographs facilitated lexical decisions in Dutch-English bilinguals when they were monitoring for words in either Dutch or English, and argued that their participants made their decision based on whichever lexical representation became available first. According to this perspective, code-blend facilitation in bimodal bilinguals may reflect the fact that they sometimes recognize the ASL sign in a code-blend first and sometimes recognize the English word first. Whichever language is recognized first for any given item will determine its response time when presented in a code-blend.

Alternatively, it is possible that code-blend facilitation effects arise from the integration of early phonological cues from English and ASL that constrain lexical

cohorts within each language (Emmorey et al., 2012). For example, whereas the onset of an English word activates several possible word candidates, the onset of an ASL sign similarly activates possible sign candidates, and the combination of these activated cross-modal lexical cohorts may guide lexical access of words and signs in code-blends, and may lead to earlier recognition of lexical items in the two language modalities (see Tye-Murray, Sommers, & Spehar, 2007, for similar observations regarding the interaction between auditory and visual lexical neighborhoods in audiovisual word recognition).

The current study

The goal of the present study was to shed further light on the mechanisms of code-blend facilitation effects in language comprehension. More specifically, we investigated whether there is evidence for facilitation effects at the phonological level by contrasting code-blend processing in a semantic decision task (is an item concrete or abstract in meaning?) and a lexical decision task. Although the meaning of words is activated in lexical decision tasks and can influence decisions through semantic feedback, the decision whether a presented item is a lexical item in a particular language or not is mainly accomplished on the basis of orthographic and/or phonological information, and responses are thus mainly based on phonological processing. In contrast, semantic categorization requires the determination of the meaning of presented items and responses are thus mainly based on semantic processing (e.g., Hino, Lupker, & Pexman, 2002).

If code-blend facilitation effects originate at the semantic level only, then we predict facilitation for code-blends in a semantic decision task (Emmorey et al., 2012;

Weisberg et al., 2015), but weak or no facilitation in a lexical decision task. If on the other hand, code-blend facilitation effects originate primarily at the phonological-lexical level, then we predict larger facilitation effects in lexical decision than semantic decision given the response-relevance of information at the phonological-lexical level for lexical decisions. Finally, if code-blend facilitation effects originate at the form as well as the semantic level, then we predict similar facilitation effects for both tasks, or possibly even larger facilitation effects in semantic decision, given facilitation at two different linguistic levels that might be additive in nature.

It is important to note that English is the dominant language for the majority of hearing bimodal bilinguals, even if they acquired a sign language within deaf signing families, because they are immersed in an English-speaking environment outside the home, and the spoken language is the language of the broader sociolinguistic context (Emmorey et al., 2015). Furthermore, the status of sign language as a minority language heavily influences the amount of exposure to sign language in deaf-parented families (Kanto, Huttunen, & Laakso, 2013; Pizer, Walters, & Meier, 2013). As a consequence, facilitation for code-blends compared ASL alone can simply reflect slower processing of signs in code-blends, and does not demonstrate that bimodal bilinguals integrate spoken and signed information when perceiving code-blends. In contrast, evidence for code-blend facilitation compared to English (their dominant language) would strongly suggest that bilinguals integrate information from both modalities during code-blend processing. Of course, code-blend facilitation effects relative to either language modality alone do provide evidence that the simultaneous processing of two lexical representations in two

modalities does not incur any processing *costs* compared to processing a single lexical representation in a single modality.

Finally, to investigate potential effects of age of acquisition and/or proficiency on the extent and locus of facilitation effects in code-blend processing, both early and late bilinguals were included in the study. In addition, monolingual English speakers and deaf ASL signers were included in order to establish the suitability of the test materials in each language and to confirm the language dominance of the bimodal bilinguals.

Methods

Participants

Thirty-one bilingual users of English and ASL participated in the study (22 female, 9 male). Sixteen participants were early bilinguals, i.e., Children of Deaf Adults (Codas), and fifteen participants were late bilinguals who starting learning ASL in high school or later (M age = 17.3, SD = 5.4). Mean age for the early bilinguals was 24.3 years (SD = 5.3 years) and 32.1 years (SD = 6.3 years) for the late bilinguals. All but one of the late bilinguals were either employed as interpreters or in their last year of an ASL interpreting program (n = 14). Three early bilinguals were also employed as interpreters at the time of the study. All participants self-rated their ASL productive and receptive proficiency on a 1-7 scale ranging from 'almost none' to 'like native'. Mean ASL self-ratings were 6.3 (SD = 0.7) and 5.8 (SD = 0.7) for the early bilinguals and late bilinguals, respectively. An additional three hearing signers (two early bilinguals, one late bilingual) were tested, but excluded from analyses because they rated their ASL proficiency less than 5 (out of 7). Background characteristics for the two bilingual groups are summarized in Table 1.

Data was collected from 16 monolingual native English speakers (16 females, M age = 20.5 yrs, SD = 2.1 yrs; M years of education = 14 yrs, SD = 1.1 yrs) and 15 deaf native or early ASL signers who were exposed to ASL before three years of age (7 females, M age = 28.3 yrs, SD = 6.1 yrs; M years of education = 15.3 yrs, SD = 2.1 yrs). The monolingual English speakers and deaf ASL signers completed the semantic and lexical decision tasks in English alone and ASL alone, respectively.

Table 1. Background characteristics of the two bilingual groups.

	Early bilinguals (n=16, 8 F)	Late bilinguals (n=15, 14 F)
Age	24.3 (5.3)	32.1 (6.3)
Years of education	14.4 (1.6)	17.4 (2.5)
Age of ASL exposure	--	17.3 (5.4)
ASL self-rating	6.3 (0.7)	5.8 (0.7)
English self-rating	7.0 (0.0)	7.0 (0.0)
% current ASL exposure	41.2 (21.5)	31.3 (17.0)
% current ASL use	34.4 (17.5)	37.0 (13.4)

Note. Self-ratings for language proficiency and information on relative language use and exposure were obtained through a language background questionnaire.

Stimuli

The stimuli consisted of 120 lexical items that were recorded as ASL signs, audiovisual English words and ASL-English code-blends (i.e., simultaneously produced ASL signs and English words). In addition, 120 English pseudo-words and 120 ASL pseudo-signs were developed and recorded both individually and as part of English-ASL pseudo-code-blends by creating arbitrary pairings of pseudo-words and pseudo-signs. English pseudo-words were constructed through phonemic substitution of 120 lexical English words that were not used in the study. Similarly, ASL pseudo-signs were created through phonemic substitution of 120 lexical ASL signs that were not used in the study. All pseudo-words were checked by a native English speaker, and all pseudo-signs were checked by a deaf native ASL signer.

All stimuli were produced by the same female native ASL-English bilingual signer and recorded against a blue background using a Sony[®] HD camera. The recorded videos were edited and converted to QuickTime[®] H.264 format (720x480px, 29.97 fps). Each English stimulus started five frames before voice onset until five frames after voice offset as determined by visual inspection of the audio waveform in Final Cut Pro[®] X. Each ASL stimulus started five frames before lexical onset of the sign until five frames after lexical offset of the sign. Lexical onset was defined as the start of contact in signs that make contact with the body (e.g., shoulder, head or other hand) or as a clear change in direction and/or speed of movement of the hand(s), which marks the end of the transitional movement from rest position to the lexically specified location in signing space. Lexical offset was defined as the end of the final contact for signs that make

contact with the body, or as a clear change in direction and/or speed of movement of the hands, which marks the beginning of the transitional movement of the hand from the lexically-specified location in signing space to rest position. Lexical onset/offset for signs without clear contact with the body or a clear change in direction and/or speed of movement was discussed with a deaf native ASL signer until consensus was reached. Each ASL-English code-blend stimulus started five frames before lexical onset and after lexical offset of the ASL sign in the code-blend. Because bimodal bilinguals tend to synchronize spoken and signed lexical onsets in code-blends (e.g., Emmorey et al., 2012), in most of the cases the ASL sign onset coincided with the English voice onset in the code-blend stimuli. However, if this procedure led to the deletion of the onset and/or offset of the English word in the code-blend, voice onset and/or offset of the English word in the code-blend was used instead to edit the code-blend stimulus (this occurred for 12/120 lexical items and 22/120 pseudo-items).

Finally, although ASL signs are often produced together with small mouth movements related to the English translation of a sign (mouthings), the model was instructed to minimize mouthings because this could provide cues as to which signs were ASL signs or pseudo-signs in the lexical decision task. Although this may have created some degree of unnaturalness for the ASL alone condition, it has no impact on the critical comparison between ASL-English code-blends and English alone.

Procedure

In the semantic decision task, participants had to decide whether a presented word, sign or code-blend was concrete ("yes") or abstract ("no") in meaning. Approximately 60% of

the 120 lexical items were concrete items ($n = 75$) and 40% were abstract items ($n = 45$). The 120 stimuli were distributed across three lists of 40 items each (25 concrete items, 15 abstract items). Items in each stimulus list were presented in pseudo-randomized order with the only constraint that there were a maximum of four subsequent yes or no responses.

In the lexical decision task, participants had to decide whether a presented word, sign or code-blend was a lexical item ("yes") or a pseudo-item ("no") in the corresponding language(s). The same counterbalancing and list assignment procedures were followed as described for the semantic decision task. Each stimulus list contained 80 items (40 lexical items, 40 pseudo-items) that were presented in pseudo-randomized order with the only constraint that there were a maximum of three subsequent yes or no responses.

The three stimulus lists for each task did not differ significantly from each other in English lexical frequency (all p s $> .30$) based on Subtlex-US (Brysbaert & New, 2009) or ASL subjective familiarity (all p s $> .60$; based on a 1-7 scale familiarity rating database for ASL signs maintained in the lab of the second author). Each of the lists could be presented in any of three presentation conditions (ASL alone, English alone, ASL-English code-blend), resulting in nine stimulus lists in total. These nine stimulus lists were counterbalanced across language blocks and participants such that each item was presented in each language block, but no participant saw the same item twice within the same task.

Psychscope X60 (Cohen, MacWhinney, Flatt, & Provost, 1993) was used to present the stimuli and record key presses on an iMac desktop (OS 10.6 or 10.7). Each trial

started with a central fixation cross (500 ms), followed by a centrally presented video stimulus (720 x 480 px) against a black background. Participants responded by pressing one of two colored keys, using the index finger of their dominant hand (B key with a red sticker for "no" and M key with a green sticker for "yes"). Between responses, they rested their finger on the N key with a yellow sticker (cf., Emmorey et al., 2012). The video clips disappeared after presentation or after one of the two response keys was pressed, whichever occurred first. The next trial started after 2000 ms. The order of presentation condition in each task was counterbalanced in a Latin square design so that approximately equal numbers of participants in each group saw each presentation modality as the first, middle or last block in the experiment. Each language block was preceded by eight (semantic decision) or twelve (lexical decision) practice items. The order of the two tasks was also counterbalanced across participants.

Statistical analysis

Analyses of Variance were used to analyze the reaction time data from the semantic and lexical decision tasks. Incorrect trials were excluded from the reaction time analysis and only "yes"-responses (lexical items) in the lexical decision task were analyzed.

Furthermore, trials with reaction times that were 2.5 standard deviations below or above the mean for each participant were eliminated from the analysis. For the early bilinguals, this resulted in further exclusion of 3.0% of the ASL trials, 2.3% of the English trials and 2.8% of the code-blend trials for the semantic decision task. For the lexical decision task, this was 1.4%, 1.3% and 1.3% of the trials, respectively. For the late bilinguals, this resulted in further exclusion of 3.4% of the ASL trials, 1.1% of the English trials and

3.5% of the code-blend trials for the semantic decision task. For the lexical decision task, this was 0.6%, 0.8% and 2.2% of the trials, respectively.

Reaction times for ASL and English were not directly compared in the statistical analyses because of confounding effects of presentation modality (manual-visual versus vocal-auditory, cf., Emmorey et al., 2012). Instead, reaction times for ASL and English were analyzed separately in a 2 x 2 ANOVA with bilingual group (early, late) and presentation condition (alone, within code-blend) as independent variables.

Accuracy scores were analyzed through logistic regression analyses in R (R development core team, 2011), with bilingual group (early, late) and presentation condition (English, ASL, code-blends) as contrast-coded predictor variables. Logistic regression analyses were conducted because categorical outcomes (e.g., yes/no-responses) often violate ANOVA's assumption of homogenous variances (see e.g., Jaeger, 2008, for discussion). Presentation condition was coded for two planned contrasts: 1) the contrast between ASL signs alone and ASL signs within a code-blend, and 2) the contrast between English words alone and English words within a code-blend. Accuracy and reaction times for lexical decision and semantic decision were not directly compared to each other because of the different nature of the task (for example, the 120 lexical items either required a "yes"-response or a "no"-response in semantic decision, but always a "yes"-response in lexical decision).

Results

Reaction times

Mean reaction times and standard deviations for the two bilingual groups and the three presentation conditions (ASL, English, code-blend) in the semantic decision task and the lexical decision task (separated for lexical items and pseudo-items) are listed in Table 2.

Table 2. Mean reaction time (RT, in ms) and standard deviation (in parentheses) for early and late bilinguals in the semantic and lexical decision tasks.

Task	Group	ASL	ENG	code-blend	fac.ASL	fac.ENG
Semantic	Early	1255 (206)	1174 (119)	1119 (116)	+136	+55
	Late	1432 (238)	1249 (198)	1260 (213)	+172	-11
Lexical (yes)	Early	1152 (163)	1049 (83)	1030 (112)	+122	+19
	Late	1158 (90)	1099 (123)	1081 (90)	+77	+18
Lexical (no)	Early	1380 (250)	1147 (90)	1118 (111)	--	--
	Late	1379 (239)	1166 (141)	1117 (104)	--	--

Note. Semantic = semantic decision, Lexical = lexical decision (yes/no responses).

‘fac.ASL/fac.ENG’ indexes code-blend facilitation effects and is obtained by subtracting response times in the code-blend condition from response times in the ASL/English alone conditions.

Semantic decision. For ASL, responses were faster when signs were presented within a code-blend than when they were presented alone ($F1(1,29) = 19.60, p < .001, \eta^2 = .11$; $F2(1,111) = 55.38, p < .001, \eta^2 = .13$). In addition, early bilinguals responded faster than late bilinguals ($F1(1,29) = 5.74, p < .05, \eta^2 = .14$; $F2(1,111) = 163.57, p < .001, \eta^2 = .15$). There was no interaction between presentation condition and group ($F1(1,29) < 1, ns$, $F2(1,111) < 1, ns$).

For English, early bilinguals again tended to respond faster than late bilinguals, but this effect only approached significance by subjects ($F1(1,29) = 3.76, p = .06, \eta^2 = .11$; $F2(1,111) = 150.13, p < .001, \eta^2 = .13$). There was no effect of presentation condition ($F1(1,29) = 1.41, p = .24$; $F2(1,111) < 1, ns$). Importantly, the interaction between presentation condition and bilingual group also approached significance by subjects, and was significant by items ($F1(1,29) = 3.69, p = .06, \eta^2 = .11$; $F2(1,112) = 7.14, p < .01, \eta^2 = .01$). Whereas responses for English words presented alone and for English words presented within a code-blend did not differ significantly for late bilinguals ($t1(14) = 0.46, p = .65, 95\% \text{ CI } [-46.74, 72.13]$; $t2(112) = 0.63, p = .53, 95\% \text{ CI } [-31.14, 60.24]$), for early bilinguals responses were significantly faster for English words presented within a code-blend than for English words presented alone ($t1(15) = -2.53, p < .05, 95\% \text{ CI } [-99.43, -8.51], d = 0.47$; $t2(112) = -2.74, p < .01, 95\% \text{ CI } [-81.61, -13.12], d = 0.33$). That is, while code-blends facilitated responses compared to ASL (the non-dominant language) for both early and late bilinguals, code-blends facilitated responses compared to English (the dominant language) only for early bilinguals.

Lexical decision. For ASL, responses were faster when signs were presented within a code-blend than when they were presented alone ($F1(1,29) = 33.43, p < .001, \eta^2 = .15$; $F2(1,119) = 64.66, p < .001, \eta^2 = .13$). The effect of group ($F1(1,29) < 1, ns$; $F2(1,119) = 30.59, p < .001, \eta^2 = .03$), and the interaction between presentation condition and group ($F1(1,29) = 1.78; p = .19$; $F2(1,119) = 30.59, p < .001, \eta^2 = .03$) were both only significant by items. Early bilinguals tended to respond faster than late bilinguals for code-blends, and not ASL signs.

For English, responses for words when presented in a code-blend and when presented alone did not differ significantly ($F1(1,29) < 1, ns$; $F2(1,119) = 2.42, p = .12$). Early bilinguals tended to respond faster than late bilinguals, but this effect was only significant by items ($F1(1,29) = 2.48, p = .13$; $F2(1,119) = 117.84, p < .001, \eta^2 = .02$). There was no interaction between presentation condition and group ($F1(1,29) < 1, ns$; $F2(1,119) < 1, ns$).

That is, similar to the results for semantic decision, code-blends facilitated responses compared to the non-dominant language (ASL) for both early and late bilinguals. However, in contrast to the results for semantic decision, code-blends did not facilitate responses compared to the dominant language (English).

Accuracy

Mean percentage correct and standard deviations for the two bilingual groups and the three presentation conditions (ASL, English, code-blend) in the semantic decision task and the lexical decision task (separated for lexical items and pseudo-items) are listed in

Table 3. Accuracy scores were analyzed with logistic regression models with bilingual group (early, late) and presentation condition (ASL, English, ASL-English code-blend) as predictor variables.

Table 3. Mean accuracy (% correct) and standard deviation (in parentheses) for early and late bilinguals in the semantic and lexical decision tasks.

Task	Group	ASL	ENG	code-blend
Semantic	Early	83.1 (6.3)	88.7 (5.3)	88.4 (6.0)
	Late	82.0 (8.5)	90.4 (4.4)	89.9 (6.0)
Lexical (yes)	Early	91.4 (5.6)	96.9 (2.5)	97.5 (3.2)
	Late	90.8 (4.6)	98.5 (2.1)	98.3 (1.8)
Lexical (no)	Early	82.1 (13.9)	95.0 (5.4)	99.1 (1.5)
	Late	84.4 (12.3)	93.0 (10.1)	99.5 (1.0)

Note. Semantic = semantic decision, Lexical = lexical decision (yes/no responses).

Semantic decision. Responses to code-blends were more accurate than responses to ASL signs alone ($Estimate = 0.54, SE = 0.12, p < .001$). Responses to code-blends and English words did not differ significantly ($Estimate = -0.02, SE = 0.09$). There was no effect of bilingual group ($Estimate = -0.05, SE = 0.10$) and no interaction between bilingual group and either contrast for presentation condition (ASL vs. code-blend: $Estimate = -0.19, SE = 0.23, p = .41$; English vs. code-blend: $Estimate = 0.04, SE = 0.26, p = .88$). There was no interaction between presentation condition and either group contrast.

Lexical decision. The late bilinguals showed a tendency to be more accurate than the early bilinguals, but this effect only approached significance ($Estimate = -0.37, SE = 0.20, p = .07$). Responses for code-blends were more accurate than responses for ASL signs alone ($Estimate = 1.54, SE = 0.20, p < .001$), but not more accurate than English words alone ($Estimate = 0.06, SE = 0.29, p = .83$).

In sum, while presentation of ASL within a code-blend resulted in higher accuracy scores compared to ASL signs alone, it did not result in higher accuracy scores compared to English words alone.

Comparisons with monolingual English speakers and deaf ASL signers

Because of the substantial age differences between the participants in the different language groups (see the Methods section), we only considered accuracy scores for this analysis. Accuracy scores for English and ASL were analyzed separately through logistic regression, comparing each of the bilingual groups to the monolingual English speakers

and deaf ASL signers, respectively. Table 4 provides the mean percentages correct and standard deviations for all groups and presentation conditions in the semantic decision task and the lexical decision task (separated for lexical items and pseudo-items).

Table 4. Mean accuracy (% correct) and standard deviation (in parentheses) for the two bilingual groups, deaf ASL signers and monolingual English speakers in the semantic and lexical decision tasks.

Task	Language	Deaf ASL	Mono ENG	ASL-English Bilinguals	
				Early	Late
Semantic	ASL	85.6 (5.0)	--	83.1 (6.3)	82.0 (8.5)
	ENG	--	89.2 (3.8)	88.7 (5.3)	90.4 (4.4)
Lexical (yes)	ASL	92.9 (4.2)	--	91.4 (5.6)	90.8 (4.6)
	ENG	--	96.0 (3.8)	96.9 (2.5)	98.5 (2.1)
Lexical (no)	ASL	88.9 (7.3)	--	82.1 (13.9)	84.4 (12.3)
	ENG	--	94.4 (6.5)	95.0 (5.4)	93.0 (10.1)

Note. Semantic = semantic decision, Lexical = lexical decision (yes/no responses).

Semantic decision. For ASL, late bilinguals (*Estimate* = 0.30, *SE* = 0.12, $p < .05$), but not early bilinguals (*Estimate* = 0.21, *SE* = 0.13, $p = .09$) were less accurate than deaf signers. For English, neither bilingual group differed significantly from the English monolinguals (early bilinguals: *Estimate* = 0.07, *SE* = 0.14, $p = .61$; late bilinguals: *Estimate* = -0.07, *SE* = 0.13, $p = .64$).

Lexical decision. For ASL, there were no effects of bilingual group. Accuracy did not differ significantly between the deaf signers and the early bilinguals (*Estimate* = 0.21, *SE* = 0.17, *p* = .22) or the late bilinguals (*Estimate* = 0.27, *SE* = 0.17, *p* = .10).

For English, late bilinguals were more accurate than English monolingual speakers (*Estimate* = -1.00, *SE* = 0.36, *p* < .01), while the early bilinguals and monolingual speakers did not differ significantly (*Estimate* = -0.25, *SE* = 0.26, *p* = .34).

These results confirm that the participants in both bilingual groups were highly proficient in both languages, and that English was their dominant language. Whereas their accuracy rates for English did not differ significantly from those of monolingual English speakers (late bilinguals even outperformed monolingual English speakers on lexical decision), their ASL accuracy rates were generally lower than those of deaf signers (see Table 4). However, this difference only reached statistical significance for the late bilinguals in the ASL semantic decision task.

Discussion

The goal of the present study was to investigate the underlying mechanisms of code-blend comprehension in bimodal bilinguals. Early and late bilinguals completed a semantic decision task and a lexical decision task with ASL signs, English words and ASL-English code-blends. The results showed code-blend facilitation in reaction times compared to their non-dominant language ASL in both tasks and for both bilingual groups. Critically, however, facilitation compared to their dominant language English was only observed for the early bilinguals, and only in the semantic decision task. Lexical access to English words in the lexical decision task (i.e., “yes”-responses) did not benefit

from ASL signs in code-blends. These results suggest processing advantages for the simultaneous retrieval of semantic information in two languages compared to retrieval in a single language, especially for early bilinguals.

Processing advantages for bimodal bilinguals when they simultaneously access spoken and signed lexical-semantic representations stand in stark contrast with the widely reported processing costs when bilinguals of two spoken languages switch between their two languages in production or comprehension. In particular, when unimodal bilinguals select lexical items from one language, they have to suppress translation equivalents in the language that is currently not selected, which has been argued to engage cognitive inhibition skills (see e.g., Green, 1998; Kroll, Gullifer, & Rossi, 2013, for discussion). Our finding that code-blends consistently facilitated comprehension compared to ASL signs alone strongly suggests that any dual processing costs are outweighed by the advantages of simultaneously accessing redundant lexical-semantic information in different languages (cf., Emmorey et al., 2012; Weisberg et al., 2015).

However, ASL is the non-dominant language for the majority of bimodal bilinguals and code-blend facilitation compared to ASL signs alone could therefore also “simply” reflect slower processing of ASL signs in code-blends, and consequently, earlier recognition of English words. Whereas Weisberg et al. (2015) did not find behavioral evidence for code-blend facilitation compared to English in a sample of 12 early bilinguals, Emmorey et al. (2012) did report facilitation compared to the dominant language in a sample of 43 early and late bilinguals that was stronger for the early bilinguals (n=18). In the present study, similar to the findings by Emmorey et al. (2012), code-blends facilitated making semantic decisions about English words for the early

bilinguals. However, we did not find code-blend facilitation for the late bilinguals contra Emmorey et al. (2012). The smaller sample size of late bilinguals in the present study (15 vs. 25) may have contributed to the different findings.

Importantly, however, the results from both studies suggest that code-blend facilitation compared to English words alone is weaker for late bilinguals than for early bilinguals. Emmorey et al. (2012) suggested that late learners of a signed language may be less able to quickly process early visual phonological cues of ASL signs and therefore might not benefit from ASL signs in code-blends to the same extent as early bilinguals can. Additional support for this possibility came from their finding that the late bilinguals exhibited a greater benefit to ASL recognition from accompanying words than early bilinguals (i.e., greater code-blend facilitation compared to ASL signs alone). Although the corresponding interaction between bilingual group and presentation modality was not significant in the present study, Table 2 reveals a numerical difference in “ASL benefit” in the same direction (136 ms for early bilinguals vs. 172 ms for late bilinguals).

Recent findings by Zachau et al. (2014) are also consistent with this result. They conducted an ERP study with early and late hearing bimodal bilinguals comparing semantic priming effects within modalities (spoken primes and targets) and across modalities (spoken primes and signed targets). Whereas the early bilinguals revealed a clear N400 effect for cross-modality semantic priming, the ERP signal for the late bilinguals did not yield a N400 component, and instead showed later effects more consistent with post-lexical processing, suggesting that only the early bilinguals automatically integrated the meanings of words and signs presented in rapid succession.

As in the present study, the late bilinguals in Zachau et al. (2014) were sign language interpreters, who might be more experienced in recoding signed information into the spoken modality. Although the relatively small samples and unbalanced distribution of interpreters across the two bilingual groups in the present study does not allow us to further address this possibility, interpreting experience did not impact the outcomes in the study by Emmorey et al. (2012). Alternatively, the late bilinguals may not have been sufficiently proficient in their L2 to directly access semantic information in ASL. This seems unlikely, however, given their professional status as interpreters in all three studies. Also, although the late bilinguals rated their ASL proficiency slightly lower than the early bilinguals (5.8 and 6.3, respectively), there is evidence that even moderately proficient L2 learners of a spoken language can directly access L2 word meanings (see e.g., Kroll, Van Hell, Tokowicz, & Green, 2010, for discussion).

Importantly, our findings demonstrated that facilitation effects in code-blend processing likely cannot be explained by an independent “horse race” between the two languages, according to which lexical access to each language proceeds independently and either the word or sign in the code-blend can be recognized first (see Dijkstra, 2005, for discussion of a parallel effect with interlingual homographs for spoken language bilinguals). Critically, this account would predict that bimodal bilinguals should also exhibit facilitation effects for code-blends in a lexical decision task. Although the lexical decision task yielded code-blend facilitation compared to ASL signs alone for both bilingual groups, facilitation compared to their dominant language English was not observed and did not interact with bilingual group. One possible explanation for the absence of code-blend facilitation compared to English words alone for lexical decisions,

as opposed to semantic decisions, is that redundant information from words and signs is mainly, or even exclusively, combined and co-activated at the semantic level and that words and signs are not yet integrated at the phonological level. When task responses were mainly based on semantic processing, as in the semantic decision task, the activation of redundant semantic information in both language modalities facilitated participants' decisions. In contrast, when task responses were mainly based on phonological processing, as in the lexical decision task, the presentation of code-blends did not lead to combined activation of semantic information across the spoken and signed modality and did not facilitate participants' decisions.

An important role for semantic integration of spoken words and signs in code-blend processing is consistent with the findings by Weisberg et al. (2015), who reported reduced neural activation for code-blends compared to ASL signs alone in frontal brain regions associated with semantic processing. Furthermore, the semantic level as the main locus of the integration of words and signs in code-blend processing fits well with recent behavioral and neuroimaging findings that co-speech gestures are automatically integrated with the accompanying spoken information during language processing and can facilitate language comprehension (i.e., the integrated-systems hypothesis; e.g., Habets et al., 2010; Kelly, Ozyurek, & Maris, 2010; Özyürek et al., 2007; Skipper, Goldin-Meadow, Nusbaum, & Small, 2009; Willems, Özyürek, & Hagoort, 2007). For example, Wu and Coulson (2007) found smaller N300 and N400 effects when presenting pictures that were related to both the (iconic) gesture and the speech of a preceding gesture-speech utterance than when the picture was only related to the speech of the preceding utterance, suggesting that co-speech gestures can facilitate subsequent

interpretation of the pictures. Furthermore, Özyurek et al. (2007) found identical N400 effects for words and gestures that were incongruent with a preceding sentence, demonstrating important similarities in the integration of co-speech gestures and lexical meaning with previous context (also see Willems et al., 2007).

In conclusion, the present study provides further evidence for processing advantages in code-blend comprehension for bimodal bilinguals, and for the hypothesis that the simultaneous retrieval of lexical representations in two languages is less effortful than the suppression of translation equivalents in a non-selected language. Furthermore, our results provide important insight into the underlying cognitive mechanisms of facilitation effects in the comprehension of code-blends by bimodal bilinguals. By demonstrating that code-blends facilitate semantic decisions, but not lexical decisions, the present study suggests that lexical integration of words and signs in code-blends occurs at the semantic level and likely reflects the combined activation of redundant semantic information in the two modalities. Furthermore, in line with previous research, early bilinguals exhibit larger processing advantages compared to their dominant (spoken) language than late bilinguals. We suggest that age of acquisition effects in code-blend processing might be related to differences in early and late bilinguals' ability to access early visual phonological cues for sign recognition.

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