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A new look at "the hard problem" of bilingual lexical access: evidence for language-switch costs with univalent stimuli

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ABSTRACT
Considerable work has used language-switching tasks to investigate how bilinguals manage competition between languages. Language-switching costs have been argued to reflect persisting inhibition or persisting activation of a non-target language. However, these costs might instead reflect the use of bivalent stimuli (i.e. pictures or digits that can be responded to in either language). That is, language-switching costs may simply reflect a cost of selecting the task-appropriate response for a given item and so may not be reflective of bilingual lexical access [Finkbeiner, M., Almeida, J., Janssen, N., & Carramaza, A. (2006). Lexical selection in bilingual speech production does not involve language suppression. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 32(5), 1075–1089]. The present study addresses this concern by having Chinese/English bilinguals switch between languages in response to inherently univalent stimuli (English words and Chinese Characters) as well as lexically univalent, but orthographically bivalent, stimuli (English words and Chinese Pinyin). Speakers showed switch costs when naming both univalent and orthographically bivalent stimuli, showing that switch costs can be found even with inherently univalent stimuli.

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For bilingual speakers, lexical representations in both languages become activated even when they are only intending to read, speak, or listen in one language (e.g. Hoshino & Kroll, 2008). Because of this, a bilingual speaker presumably needs to overcome competition from words in the non-target language in order to select a lexical item from the appropriate language (what Finkbeiner, Gollan, and Caramazza (2006) have called "the hard problem"). Much of the work investigating how bilinguals solve the "hard problem" relies on language-switching paradigms, which build on the well-studied task-switching paradigm (see Kiesel et al., 2010, for a review). In these tasks, bilingual participants are required to switch between naming digits, pictures, or words in their first and second languages, and typically take longer to respond on language switch than on language-repetition trials (Meuter & Allport, 1999; *inter alia*).

One explanation for these language-switch costs, and of how bilinguals might solve the "hard problem" more generally, relies on domain-general inhibitory control mechanisms (e.g. Green & Abutalebi, 2013). That is, bilingual speakers may need to inhibit their non-target language(s) in order to successfully speak in the language they intend. One type of evidence that inhibitory control is involved in language switching is that language-switch costs are often larger when switching from the non-dominant to dominant language (L2 to L1) than when switching from the dominant to non-dominant language (L1 to L2) (e.g. Macizo, Bajo, & Paolieri, 2012; Meuter & Allport, 1999). By an inhibitory control account, these asymmetric switch costs arise because the dominant language (L1) has a greater baseline activation than the less dominant language (L2), and thus requires more inhibition to allow naming in the L2, thereby resulting in greater lingering inhibition of the L1 and correspondingly larger switch costs on subsequent trials. An alternative possibility is that language-switch costs and the switch cost asymmetry do not

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reflect language inhibition, but rather result from persisting *activation* of a given language (Philipp, Gade, & Koch, 2007). By this account, switch costs reflect the time required for the target task to surpass residual activation of the non-target task on a switch trial (cf. the task set inertia hypothesis in the non-linguistic task-switching literature; e.g. Wylie & Allport, 2000). This leads to switch cost asymmetries because L2 naming requires higher activation, and therefore produces higher residual activation, than L1 naming. The relatively high residual L2 activation requires more time to surpass when switching into L1 than the relatively low residual L1 activation does when switching into L2.

However, a third possibility is that language-switch costs reflect neither language inhibition nor persisting activation, but instead simply reflect characteristics of language-switching *tasks*. In a review of the literature on language switching, Bobb and Wodniecka (2013) noted that task design elements can have important effects on the cognitive processes that purportedly underlie switch costs. For example, switching tasks typically employ artificial language-cuing procedures (e.g. flag icons or screen colours cue the target language on each trial), which is a quite different situation than typical bilingual language use. Indeed, switch costs and asymmetries are reduced or eliminated when speakers switch languages voluntarily (e.g. Gollan, Kleinman, & Wierenga, 2014), suggesting that findings from "standard" language-switching tasks may have little relationship to everyday bilingual language processing. Specifically, switch costs in these tasks may not reflect language inhibition, but instead reflect a cost in selecting the appropriate response for a given item (Finkbeiner, Almeida, Janssen, & Caramazza, 2006). This *response-selection hypothesis* is based on the fact that most language-switching paradigms use *bivalent* stimuli such as pictures or numbers, which afford responses in either language. If responses in both L1 and L2 are automatically prepared in a bivalent context, then slower responses on switch trials may not reflect language switching, but instead switching between the criteria used to select the trial-appropriate response. To test this hypothesis, Finkbeiner, Almeida, et al. compared switch costs elicited by *bivalent* digit stimuli (which could be named in either L1 or L2) and *univalent* picture stimuli (or, in a second experiment, dot-diagrams) that, in the context of the task, were always named in L1. Bivalent stimuli produced a typical asymmetric pattern of switch costs; however, there was no evidence for switch costs when naming univalent picture stimuli. That is, L1 picture naming latencies were no slower when the previous digit was named in L2 than when it was named in L1, suggesting that switch costs in previous studies do not reflect language control, but rather reflect the demands of selecting between two responses afforded by a given item.

However, other evidence suggests that switch costs can arise in response to univalent stimuli. Using a similar task, Peeters, Runnqvist, Bertrand, and Grainger (2014) compared switch costs on picture stimuli that were univalent in the context of a block (i.e. pictures were always named in L1 in one block and L2 in the other) after reading (and categorising) words in either the L1 or L2. Participants in this task did show switch costs and a switch cost asymmetry on the univalent trials. In addition, these costs emerged across modalities – from reading a word in one language to naming a picture in the other language – suggesting whatever process is involved is not specific to selecting lexical items for production. Although it is not entirely clear why costs differed for univalent stimuli across these two studies, it is worth noting that language switching was confounded with a task switch in both studies (switching between picture naming and either digit naming or word categorisation), and with a modality switch in Peeters et al. (switching from word categorisation to picture naming). In addition, the univalent picture stimuli used in these tasks were only univalent within the context of the task or block; it is certainly still the case that pictures can afford naming responses in multiple languages.

Little work has investigated language switching with intrinsically univalent stimuli (although see Orfanidou and Sumner (2005) for evidence for switching costs in a lexical decision task using Greek and English words with language-specific orthography). In production, there is evidence for asymmetric language-switch costs between word reading in Spanish and English (Macizo et al., 2012) and in Italian and English (Filippi, Karaminis, & Thomas, 2014). Spanish, Italian, and English words are univalent at the lexical level (excepting cognates and interlingual homographs) – one can presumably only access a lexical item for *gorrión* in Spanish, for *passero* in Italian, and for *sparrow* in English – thus these effects show that lexical bivalency is not required to observe switch costs. However, even this is equivocal: while *gorrión*, *passero*, and *sparrow* are lexically univalent, their shared orthography still affords a mapping to phonemes in either language. Assuming an orthography-to-phonology pathway for word naming, these could still be bivalent stimuli in the context of a word-naming task – that is, the stimuli may not unequivocally cue only one language. Thus, the response-selection hypothesis (Finkbeiner, Almeida, et al., 2006) may still be able to account for these language-switch costs, leaving open the possibility that evidence from language-switching paradigms may not reflect *language* control.

The aim of the current experiment is to investigate whether language-switch costs are observed in a situation with stimuli that are inherently univalent both lexically and orthographically, and whether this differs for stimuli only lexically univalent (but orthographically bivalent). To do this, we relied on two languages that have very different orthographic systems: Chinese and English. For Chinese/English bilinguals, Chinese characters are inherently univalent stimuli both lexically and orthographically because they unambiguously cue only one language by virtue of their different script (e.g. 麻雀 cannot cue a response in English). However, the Romanised *Pinyin* Chinese writing system represents Chinese words with Roman characters and therefore words in the Roman alphabet are orthographically bivalent (e.g. the orthographic strings *máquè* or *sparrow* could be mapped to a set of phonemes in Chinese or English). We thus conducted a language-switching experiment in which Mandarin Chinese/English bilinguals switched between naming aloud words in Chinese or English. In the orthographically univalent block, stimuli were words in English and in Chinese Characters (hereafter, Characters); in the orthographically bivalent block, stimuli were words in English and in Pinyin. If language-switch costs in a word-naming task (Filippi et al., 2014; Macizo et al., 2012) reflect response selection issues due to the use of orthographically bivalent stimuli rather than due to language control (cf. Finkbeiner, Almeida, et al., 2006), we should observe significant switching costs in the orthographically bivalent English–Pinyin block, but not in the univalent English–Character block. In contrast, if switching costs do reflect processes of language control (be it via lingering inhibition or persisting activation), we should observe reliable switching costs in both blocks regardless of whether stimuli are orthographically bivalent or univalent. In addition, we included a third control block at the end of the experiment where participants switched between reading Pinyin and Characters to examine if any switching costs observed in the language-switching blocks might be attributable to switching between orthographic systems in the absence of language switching (cf. Shafiullah & Monsell, 1999).

Method

Participants

Fifty Chinese dominant Mandarin Chinese–English bilinguals (62% female; all from mainland China) were recruited from the University of Maryland community via flyers and email lists and were compensated $10 for participating. Participants were prescreened to ensure proficiency in both English and Chinese. One participant was excluded for failing to follow the instructions and translating some words rather than reading aloud in the language of presentation. Most participants were in their mid-twenties (mean = 24.2, $SD = 3.1$), had started learning English in their teens (mean = 13.57, $SD = 4.12$), and were more proficient in Chinese than English (self-ratings of proficiency on a ten-point Likert scale were 9.41 ($SD = 0.86$) for Chinese and 6.91 ($SD = 1.38$) for English). (Note that three participants did not provide data on their language background.)

Materials

Stimuli for the switching task were 66 words, each in English, Characters, and Pinyin (see Appendix). Words were selected such that translations were matched on number of syllables, number of letters in Pinyin and English spelling, and as closely as possible on lexical frequency in American English and Chinese (from the SUBTLEX-US and SUBTLEX-CH corpora; Cai & Brysbaert, 2010).

Procedure

The language-switching task consisted of five blocks: two single-language naming blocks (first and last) and three language-switching blocks.

Naming blocks. Blocks 1 and 5 were identical; participants were asked to read aloud all of the words used in the experiment, presented once in Pinyin, once in Characters, and once in English, always in that order. The first block was included to familiarise participants with the stimuli and to informally assess participants' abilities to read in each script, and the final block was used to evaluate mixing costs (see e.g. Kiesel et al., 2010). Participants were instructed to read each word aloud as soon as it appeared. Each trial consisted of a 250 ms presentation of a fixation cross, followed by a word that remained on the screen until the participant began speaking. As soon as an automated VoiceKey detected the participant's speech onset, the word disappeared and, following a 500 ms blank interval, the next trial started.

Switching blocks. Blocks 2 and 3 required participants to switch back and forth between languages, and Block 4 required participants to switch between scripts. Blocks 2 and 3 were counterbalanced in order between participants: half completed the Character–English block first and half completed the Pinyin–English block first. Block 4 always consisted of switching between Character and Pinyin naming. Trials followed an alternating runs paradigm: two trials in one language/script followed by two trials in the other language/script, throughout the whole block. Each trial started with a 250 ms fixation cross followed by a word to be named, which remained on the screen until a vocal response triggered the VoiceKey, and then a 500 ms response interval before the next trial began. Each switching block contained 11 practice trials and 240 experimental trials, with one short break after the 120th trial. Words used in practice trials were not used on experimental trials. Trial 121 was excluded from the analysis for Blocks 2, 3, and 4 as it was neither a switch nor stay trial.[1] Participants were allowed to take a short break in between each block.

Data analysis and modelling procedure

Mixed effects models were fit to the data using the lme4 package (version 1.1–7) within the R statistical platform (R version 3.1.1). Contrast coding was used for all factors as indicated below, and random effects were included at both the Subject and Item levels. We began all model building with the maximal random effects structure appropriate for the analysis (Barr, Levy, Scheepers, & Tily, 2013). If the model failed to converge, we simplified the random effects structure until a model converged using the following steps: we first removed all correlations between random effects, then removed random effects for higher-order interaction terms. Finally, we removed random effects parameters that were perfectly or near-perfectly correlated with others (suggesting overfitting; see Bates, Kliegl, Vasishth, & Baayen, under review), so long as those removals did not reduce model fit (i.e. did not notably increase AIC, and BIC fit indices). The final converged, best-fitting models are reported below and, in the interest of transparency, results from alternative models are reported in supplemental material (available online: http://hdl.handle.net/1903/17152).

Results

Participant responses were audio-recorded and later transcribed to ensure only trials where the participant correctly pronounced the word without hesitation or stuttering were included in the analysis. For the reaction time analysis, all trials involving stuttering, hesitations, mispronunciations, inappropriate translation, incorrect/unrelated words, coughing, or other background noise were excluded from the analysis, resulting in the exclusion of 2.4% of trials. Data points that were greater or less than 2.5 SD away from each participant's mean response time (calculated separately for naming and switching blocks) were also discarded, resulting in the exclusion of an additional 2.8% of trials. The data for one participant were dropped due to an excessively high error rate (more than 70% incorrect trials in the Character–Pinyin mixed block), leaving a final sample size of 48 participants. An analysis of $\log_{10}$ transformed (non-trimmed) response times revealed the same pattern of results as the 2.5 SD trimmed data described below. Naming accuracy was also analysed using generalised logistic mixed effects models; few effects emerged, however, perhaps due to near-ceiling performance (see Table 2). Therefore, we report the full results of the RT analyses in the text below, but only describe the patterns of results for the corresponding accuracy analyses.

Main analysis of language switching

Mean RTs and percent accuracy (with standard errors) for the Character/English and Pinyin/

[1]The first experimental trial in each block was included as a stay trial as it occurred directly after (and in the same condition as) the final practice trial.

Table 1. Mixed-language word-naming mean latencies and accuracy with standard errors (computed across subjects) and switch costs, by block, language, and switch condition.

	Character/English (univalent) block		Pinyin/English (bivalent) block	
Switching condition	Characters	English	Pinyin	English
Response latencies				
Switch	631 (11)	735 (15)	934 (35)	788 (19)
Stay	616 (10)	721 (14)	933 (34)	761 (18)
Switch costs	15	13	1	27
Accuracy				
Switch	99.9 (0.1)	100 (0)	99.5 (0.2)	99.8 (0.1)
Stay	99.8 (0.1)	99.9 (0.1)	99.7 (0.1)	99.8 (0.1)
Switch costs	−0.1	−0.1	0.2	0

English mixed-language blocks are reported in Table 1. To analyse our two main blocks of interest, we first performed an omnibus analysis of RTs by fitting a linear mixed effects model with the fixed factors of block (univalent vs. bivalent), switch condition (repeat vs. switch), and spoken language (Chinese vs. English), and their full factorial combination. The final best-fitting model (see Table 2a) included uncorrelated random slopes for the main effects only (i.e. only fixed effects for higher-order interactions) varying by both subjects and items. Participants were faster in the Character/English than in the Pinyin/English block (a main effect of *block*), and Chinese naming was considerably (over 300 ms) slower in response to Pinyin than to Characters (resulting in a *block* × *language* interaction). Importantly, participants experienced switch costs (a main effect of *switch condition*), although the exact pattern of switch costs varied as a function of both block and language of naming (a *block* × *switch condition* × *language* interaction).

To better understand this three-way interaction and to more directly address the central hypothesis of this study, we conducted follow-up analyses to examine the language and switch condition effects separately for the Character/English (orthographically univalent) and Pinyin/English (orthographically bivalent) blocks. For the Character/English block, the final best-fitting model included uncorrelated random intercepts and language slopes varying by both subjects and items (Table 2b). The fixed effects indicated that participants named pictures faster in Chinese than in English (a main effect of *language*) and experienced switch costs (a main effect of *switch condition*). Critically, switch condition did not interact with language, indicating that similar switch costs were experienced in both languages even when using inherently univalent stimuli. This finding goes against the claims of the response-selection hypothesis because these switching costs cannot be due to choosing the task-appropriate response (language) to name, for example, 麻雀. In the Pinyin/English block, the final best-fitting model included uncorrelated random intercepts and slopes for language and switch condition varying by both subjects and items (Table 2c). The fixed effects indicated that participants named English faster than Pinyin (a main effect of *language*) and experienced marginal switch costs (a marginally significant main effect of *switch condition*). Although switch costs on English trials were numerically larger than those on Pinyin trials when computed on the aggregate across

Table 2. (a) Mixed effects model omnibus analysis examining the effects of valence, language, and switch condition, and individual mixed effects analyses for (b) Character/English, and (c) Pinyin/English blocks.

	Fixed effects			Random effects	
				By subjects	By items
Parameters	Estimate	*SE*	*t*	*SD*	*SD*
(a) Omnibus analysis[a]					
Intercept	759.9	18.5	41.0*	115.4	63.5
Block	182.3	18.8	9.7*	119.6	53.9
Switch condition	14.7	5.7	2.6*	9.2	37.8
Language	−24.9	16.2	−1.5	88.7	75.1
Block × switch condition	8.5	5.5	1.6	–	–
Block × language	−272.5	4.9	−55.6*	–	–
Switch condition × language	4.2	5.5	0.8	–	–
Block × switch condition × language	22.7	9.6	2.4*	–	–
(b) Character/English (univalent) block[b]					
Intercept	676.8	12.8	52.9*	77.3	47.6
Switch condition	8.1	3.1	2.6*	–	–
Language	107.6	15.6	6.9*	74.6	84.8
Switch condition × language	3.7	6.2	0.6	–	–
(c) Pinyin/English (bivalent) block[c]					
Intercept	845.2	27.6	30.6*	173.2	89.2
Switch condition	19.0	10.3	1.9	15.3	70.3
Language	−164.5	28.9	−5.7*	176.2	103.1
Switch condition × language	6.3	8.4	0.8	–	–

Note: Factors were contrast coded as follows: block (−.5 = Character/English, .5 = Pinyin/English), switch condition (−.5 = repeat, .5 = switch), language (−.5 = Chinese, .5 = English).

[a]Residual *SD* was estimated at 175.6. Model formula for uncorrelated random effects model: rt ∼ Block × Switch condition × Language + (1 + Block + Switch condition + Language || Subject) + (1 + Block + Switch condition + Language || Item).

[b]Residual *SD* was estimated at 145.3. Model formula for uncorrelated random effects model: rt ∼ Switch condition × Language + (1 + Language || Subject) + (1 + Language Item).

[c]Residual *SD* was estimated at 186.4. Model formula for uncorrelated random effects model: rt ∼ Switch condition × Language + (1 + Switch condition + Language || Subject) + (1 + Switch condition + Language Item).

*$|t| > 2.0$, indicating a significant effect (Gelman & Hill, 2007).

Table 3. Mixed effects model examining the effects of valence and switch condition on English word-naming trials only.

	Fixed effects			Random effects					
				By subjects				By items	
Parameters	Estimate	*SE*	*t*	*SD*	Block	Switch condition	Block × switch condition	*SD*	Block
Intercept	753.3	19.6	38.40*	109.8	.51	.29	.18	88.7	−.36
Block	46.8	9.08	5.15*	59.2		.06	.48	–	
Switch condition	15.1	4.6	3.27*	17.6			.84	11.9	
Block × switch condition	13.7	6.7	2.05*	18.9				–	

Note: Factors were contrast coded as follows: block (−.5 = Character/English, .5 = Pinyin/English), switch condition (−.5 = repeat, .5 = switch). Under random effects, values to the right of the SD columns indicate estimated correlations between random effects. Residual *SD* was estimated at 161.0. Model formula for correlated random effects model: rt ~ valence × trial_type + (valence × trial_type | subj) + (trial_type | item).
*$|t| > 2.0$, indicating a significant effect (Gelman & Hill, 2007).

subjects, no reliable interaction was detected in the mixed effects analysis.[2]

However, it should be noted that English switching costs differed numerically across blocks (Table 1), and it is possible that this effect was obscured when combined with the Pinyin and Character trials (leading to no *block* by *switch condition* interaction; Table 2a). To circumvent this issue, we analysed the effect of block (univalent vs. bivalent) and switch condition (repeat vs. switch) *only* on English naming times – i.e. to the same set of English words in different contexts.[3] (Note that we did not perform a similar analysis of only Chinese naming times because that would confound effects of block with script; i.e. all univalent trials would be in Pinyin script and all bivalent trials in Characters.) The response-selection hypothesis predicts that naming times for English words should be influenced by language switches only in a bivalent context (when switching from naming words in Pinyin) but not in a univalent context (when switching from naming Chinese Characters). English switching costs were, in fact, significantly smaller in the orthographically univalent Character context compared to the bivalent Pinyin context (a significant *block* by *switch condition* interaction; see Table 3).[4] However, English word naming still showed a significant language-switching cost even in the orthographically univalent Character context ($b = 10.08$, $t = 2.04$). Thus, while bivalent stimuli may lead to increased switching costs, language switching induces a cost even in an orthographically univalent context, contra the response-selection hypothesis.

Another way to address the role of bivalency in language switching is via *mixing costs*, where responses are typically slower in contexts with mixed languages than in single-language contexts (see e.g. Kiesel et al., 2010). Although this experiment was not specifically designed to evaluate mixing costs, they can be calculated by comparing the mixed blocks to the final single-language naming blocks (Table 4). (Note that these analyses were carried out separately for orthographically univalent and bivalent conditions, as there was only one single-language block for English to compare to both mixed blocks.) Participants showed robust mixing costs (a main effect of *mixing*), which interacted with language: in particular, mixing costs for Pinyin naming were considerably larger than for any other language condition (Table 5). Follow-up models testing mixing costs separately in each of the four language-by-valence conditions revealed significant mixing costs in all cases: for Chinese-univalent (characters; $b = 55.03$, $t = 6.12$), English-univalent ($b = 36.46$, $t = 3.22$), Chinese-bivalent (Pinyin; $b = 133.40$, $t = 6.38$), and English-bivalent ($b = 83.39$, $t = 6.27$) stimuli. Thus, mirroring the switching cost results above, mixing costs emerged for both orthographically bivalent and univalent stimuli.

Participants were highly accurate in performing the task (see the bottom section of Table 1): The

[2]Although this interaction was not significant, it was the case that the simple effect of switch condition within the Pinyin/English block was significant for English (estimate = 19.3, $SE = 7.7$, $t = 2.50$) and non-significant for Pinyin (estimate = 18.0, $SE = 15.1$, $t = 1.20$). Although this is not problematic for our primary conclusion that switch costs emerge even in the bivalent Character/English block, it is nevertheless somewhat surprising. The lack of an interaction effect in this block likely reflects, at least in part, the high variability in Pinyin naming times by items. That is, the by-item random variance was much larger for Pinyin than for English naming (*SD*s of 104 vs. 32, respectively); this, combined with small switch costs overall, likely makes it difficult to observe reliable switch cost asymmetries.

[3]We thank Dan Kleinman for this suggestion.

[4]Note that this interaction was not significant in a model with a maximal random effects structure ($b = 12.38$, $t = 1.67$); however, this more complex model does not appear to be justified as it had slightly higher AIC and BIC values than the simplified model reported here (for details, please see supplemental material at http://hdl.handle.net/1903/17152).

Table 4. Word-naming mean latencies, with standard errors (computed across subjects), in blocked (single-language) contexts and in mixed (switching) contexts (on "stay" trials) by block and language.

	Character/English (univalent) block		Pinyin/English (bivalent) block	
Naming context	Characters	English	Pinyin	English
Response latencies				
Mixed languages	623 (10)	728 (14)	933 (34)	775 (18)
Single-language	568 (9)	694 (13)	807 (24)	694 (13)
Mixing costs	56	34	127	81

Note: Single-language naming times for English come from the same post-experiment naming block for comparisons both to the univalent and the bivalent mixed-language conditions.

omnibus accuracy analysis only revealed a main effect of block ($z = -1.98$, $p = .047$), with no main effects or interactions involving switch condition.

Within-language script-switching

To assess whether switching orthographic systems incurs a cost in the absence of a language switch, we also analysed the Pinyin/Character block. We fit a mixed effects model with the fixed factors of switch condition (repeat vs. switch) and script (Characters vs. Pinyin), and their factorial combination. The final best-fitting model included correlated random intercepts and slopes for all factors, varying by both subjects and items (see Table 6). Results indicated that participants were significantly slower to name Pinyin words than Characters (a main effect of *script*). There was no evidence of reliable switch costs in either condition. RTs and accuracy by condition are reported in Table 7.

Participants performed this block task with high levels of accuracy as well (Table 7): the accuracy analysis found no main or interaction effects when switching between scripts.

Discussion

The present study investigated the concern that previous demonstrations of language-switching costs do not actually reflect language control, but rather reflect response selection costs due to the bivalent nature of task stimuli (Finkbeiner, Almeida, et al., 2006). Previous work on this question used stimuli that were univalent only in the context of the task (Finkbeiner, Almeida, et al., 2006; Peeters et al., 2014) or that were lexically, but not orthographically, univalent (Filippi et al., 2014; Macizo et al., 2012). This experiment extends that previous work by investigating language switching in response to Chinese Characters and English words, which are inherently both lexically and orthographically univalent (in the context of word naming), and by separating effects of language- and task-switching. Although switch costs were larger in bivalent contexts (for English words), speakers in this experiment nevertheless showed significant switch costs in the univalent (English/Character) condition, providing evidence against the claim that switch costs result entirely from response selection difficulties induced by bivalent stimuli.

The switch costs observed here were considerably smaller than those typically observed in the language-switching literature (e.g. Meuter &

Table 5. Mixed effects model examining mixing costs for the (a) Character/English and (b) Pinyin/English blocks.

	Fixed effects			Random effects							
				By subjects				By items			
					Correlations				Correlations		
Parameters	Estimate	*SE*	*t*	*SD*	Type	Language	Type × language	*SD*	Type	Lang	Type × language
(a) Character/English (univalent) block[a]											
Intercept	658.8	11.7	56.4*	70.0	.12	.50	−.33	44.9	.38	.91	.39
Type	36.6	7.9	4.7*	50.5		.02	.01	14.4		.08	−.67
Language	127.0	15.0	8.5*	76.2			−.19	76.7			.68
Type × language	−36.6	7.2	−5.1*	32.8				23.1			
(b) Pinyin/English (bivalent) block[b]											
Intercept	810.0	22.2	36.5*	136.6	.55	−.61	−.24	78.3	.71	−.19	−.35
Type	99.17	14.4	6.9*	96.0		−.54	−.76	20.2		.01	−.62
Language	−130.3	24.7	−5.3*	148.0			.41	93.4			.70
Type × language	−68.5	16.7	−4.1*	104.7				29.8			

Note. Factors were contrast coded as follows: Type (−.5 = single-language, .5 = mixed-language) and Language (−.5 = Chinese, .5 = English). Model formula for both correlated random effects models: rt ∼ mixed × spoken lang + (mixed × spoken lang | Subj) + (mixed × spoken lang | Item).

[a]Residual *SD* was estimated at 138.4.

[b]Residual *SD* was estimated at 181.8.

*$|t| > 2.0$, indicating a significant effect (Gelman & Hill, 2007).

Table 6. Mixed effects model analysis of the Character/Pinyin mixed block examining the effects of switch condition and script.

	Fixed effects			Random effects							
				By subjects				By items			
					Correlations				Correlations		
Parameters	Estimate	*SE*	*t*	*SD*	Switch	Script	Switch × script	*SD*	Switch	Script	Switch × script
Intercept	712.7	17.4	41.0*	112.3	−.61	.84	−.64	46.5	−.16	.92	.06
Switch condition	−1.7	6.9	−0.3	20.9		−.59	1.00	39.1		−.03	.95
Script	214.8	25.0	8.6*	149.4			−.58	95.2			.24
Switch condition × script	−14.4	10.5	−1.4	31.5				46.6			

Note: Factors were contrast coded as follows: Switch condition (−.5 = repeat, .5 = switch), Script (−.5 = Character, .5 = Pinyin). Residual *SD* was estimated at 167.2. The model was fit using the following formula: rt ~ Switch condition × Script + (1 + Switch condition × Script | Subject) + (1 + Switch condition × Script | Item).
*$|t| > 2.0$, indicating a significant effect (Gelman & Hill, 2007)

Allport, 1999). This may reflect the relatively smaller costs of lexical competition on word naming than on picture naming (e.g. Damian, Vigliocco, & Levelt, 2001), and/or the involvement of different processing stages in word and picture naming (Declerck & Philipp, 2015). Indeed, these data provide additional support to the idea that language-switch costs can emerge in word-naming tasks (Filippi et al., 2014; Macizo et al., 2012) and indicate that reading aloud involves at least some degree of lexical access and therefore is sensitive to lexical competition (cf. Rodd, Gaskell, & Marslen-Wilson, 2002). The magnitude of switch costs in this experiment could have also been affected by the predictable nature of trials in the alternating runs paradigm, which may have allowed participants to prepare what language to use in advance of stimulus presentation (e.g. Fink & Goldrick, 2015), and/or to the fact that switch and stay trials occurred equally often, which can lead to smaller switch costs and lack of switch cost asymmetries compared to unbalanced L1/L2 contexts (e.g. Filippi et al., 2014; Olson, in press). However, it is also possible that these small effects indicate that response selection does, in fact, contribute to switching effects observed in previous studies. Even if so, these data show that language-switching costs are not entirely reducible to response selection difficulties.

Table 7. Means (standard errors) for response latencies and accuracy (computed across subjects) in the Pinyin and Character switching block.

Switch condition	Characters	Pinyin
Response latencies		
Switch	608 (9)	815 (24)
Stay	608 (10)	839 (28)
Switch costs	0	−24
Accuracy		
Switch	99.9 (0.1)	99.7 (0.1)
Stay	99.9 (0.0)	99.8 (0.1)
Switch costs	0.1	0.1

Results from the single-language Pinyin/Character script-switching block reinforce our interpretation of the switch costs found in the primary language-switching blocks. This task involved no language switch so it serves as a control to identify effects specific to switching orthographies. In contrast to the language-switching blocks, no reliable switch costs were found in this script-switching block. This differs from previous findings showing small but reliable costs associated with switching between reading in Japanese scripts (Kanji and Hiragana; Shafiullah & Monsell, 1999). It is not clear what explains the different pattern found here. One possibility is that it is related to a discrepancy between our participants' proficiency with character and Pinyin reading. In contrast to Japanese readers, who routinely read in multiple scripts, most Chinese speakers do not regularly use Pinyin following their primary education and so our adult participants are likely to be less practised at reading Pinyin than characters. This proficiency difference was evident throughout the experiment: naming times were nearly two times slower for Pinyin than characters in the initial naming block, and were still over 200 ms slower in the *final* naming block, after these items had been seen several times. However, this proficiency difference does not obviously explain a lack of switch costs; instead one might expect to observe a robust switch cost asymmetry (of which there was no evidence here).

In fact, we found no evidence of a switch cost asymmetry in any of our experimental conditions, even though such asymmetries have often (though not always) been found with unbalanced bilinguals (e.g. Meuter & Allport, 1999). Although it is not yet clear exactly when and why switch cost symmetries emerge (for discussion, see Declerck & Philipp, 2015), the unbalanced nature of our participants (especially regarding their low proficiency in Pinyin reading) makes the lack of asymmetry surprising. Because within-language orthography switching and switch cost asymmetries are not central to our main question, we leave these aspects of the results for future investigation. In any case, the lack of a script-switching cost in this final block suggests that the costs observed in the language-switching blocks are unlikely to only reflect costs of switching between orthographic systems.

Conclusions

Language-switching costs have been argued to reflect response selection difficulties induced by the use of bivalent stimuli rather than processes of language control (cf. Finkbeiner, Almeida, et al., 2006); however, this study found reliable switching costs when naming inherently univalent stimuli (English words and Chinese characters). These results are inconsistent with the response selection account of switch costs and lend further support to the utility of language-switching paradigms as a way to investigate mechanisms of bilingual language control.

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Appendix Words used in the experiment with lexical statistics

Character	Pinyin	English	Chinese frequency[a]	English frequency[a]	Frequency difference
概念	gàiniàn	concept	2.4742	2.6454	0.1712
尿布	niàobù	diaper	2.3766	2.2068	0.1698
头盔	tóukuī	helmet	2.3201	2.4829	0.1628
投资者	tóuzīzhě	investor	1.8633	1.6990	0.1643
前奏	qiánzòu	prelude	1.3617	1.3424	0.0193
潮	cháo	tide	2.1271	2.4472	0.3201
大人	dàren	adult	2.8739	2.7589	0.1150
机场	jīchǎng	airport	2.9069	2.9926	0.0857
民谣	mínyáo	ballad	1.7782	1.7482	0.0300
鸟笼	niǎolóng	birdcage	1.3222	1.3424	0.0202
服装	fúzhuāng	clothing	2.6875	2.6335	0.0540
颜色	yánsè	color	3.0561	3.1358	0.0797
钻石	zuànshí	diamond	2.5441	2.6758	0.1317
独裁者	dúcáizhě	dictator	1.7924	1.8633	0.0709
狗	gǒu	dog	3.4195	3.4843	0.0648
胚胎	pēitāi	embryo	1.5911	1.4314	0.1597
费用	fèiyòng	expense	2.6580	2.5145	0.1435
寓言	yùyán	fable	1.3010	1.3010	0.0000
因素	yīnsù	factor	2.5302	2.4579	0.0723
森林	sēnlín	forest	2.6385	2.6998	0.0613
胶	jiāo	glue	2.3692	2.3440	0.0248
鹰	yīng	hawk	2.2765	2.3979	0.1214
胰岛素	yídǎosù	insulin	1.6532	1.7559	0.1027
女士	nǚshì	lady	3.5362	3.6160	0.0798
房东	fángdōng	landlord	2.2330	2.2742	0.0412
腿	tuǐ	leg	3.2725	3.2011	0.0714
龙虾	lóngxiā	lobster	2.1903	2.3054	0.1151
概念	luóji	logic	2.4425	2.4232	0.0193
人	rén	man	3.7951	3.9061	0.1110
油	yóu	oil	2.9440	3.0253	0.0813
兰花	lánhuā	orchid	1.7782	1.6812	0.0970
鹦鹉	yīngwǔ	parrot	1.9590	1.9823	0.0233
农民	nóngmín	peasant	2.2148	2.0899	0.1249
猪	zhū	pig	2.9365	3.0241	0.0876
海盗	hǎidào	pirate	2.2945	2.2148	0.0797
活塞	huósāi	piston	1.3979	1.3979	0.0000
钳子	qiánzi	pliers	1.8388	1.6990	0.1398
花粉	huāfěn	pollen	1.6128	1.6435	0.0307
海报	hǎibào	poster	2.2788	2.3404	0.0616
邮差	yóuchāi	postman	1.7482	1.8261	0.0779
草原	cǎoyuán	prairie	1.8865	1.9294	0.0429
监狱	jiānyù	prison	3.2492	3.1841	0.0651
产品	chǎnpǐn	product	2.6776	2.6532	0.0244
丙烷	bǐngwán	propane	1.3424	1.4150	0.0726
先知	xiānzhī	prophet	2.1584	2.0334	0.1250
金字塔	jīnzìtǎ	pyramid	1.8976	2.0000	0.1024
研究员	yánjiūyuán	researcher	1.5441	1.5315	0.0126
帆船	fānchuán	sailboat	1.8195	1.6902	0.1293
丑闻	chǒuwén	scandal	2.3324	2.4886	0.1562
海鲜	hǎixiān	seafood	1.9138	1.9191	0.0053
污水	wūshuǐ	sewage	1.7559	1.6532	0.1027
士兵	shìbīng	soldier	2.7853	2.9196	0.1343
蜘蛛	zhīzhū	spider	2.3444	2.3655	0.0211

(*Continued*)

Appendix Continued.

Character	Pinyin	English	Chinese frequency[a]	English frequency[a]	Frequency difference
店	diàn	store	3.2676	3.3316	0.0597
房客	fángkè	tenant	2.0128	2.0086	0.0042
商标	shāngbiāo	trademark	1.9243	1.8573	0.0670
三部曲	sānbùqǚ	trilogy	1.3424	1.3424	0.0000
台风	táifēng	typhoon	1.6812	1.5441	0.1371
暴君	bàojūn	tyrant	1.9395	1.9031	0.0364
毒蛇	dúshé	viper	2.0000	1.8338	0.1612
智慧	zhìhuì	wisdom	2.6955	2.6522	0.0433
狼	láng	wolf	2.6551	2.5763	0.0788
女人	nǚrén	woman	3.6167	3.7728	0.1561
啄木鸟	zhuómùniǎo	woodpecker	1.2553	1.3617	0.1064
斑马	bānmǎ	zebra	1.6335	1.7709	0.1374
拉链	lāliàn	zipper	2.1614	2.0755	0.0859
Average (excluding practice words):[b]			2.263	2.267	0.004

Note: The first six words (shaded) were used for practice trials only.
[a]Frequency measured in $\log_{10}$-CD scores from Cai and Brysbaert (2010).
[b]Chinese and English word frequencies did not differ significantly for the 60 critical items (excluding the first six words used only in the practice trials; $t(59) = 0.34$) or for the full set of 66 words ($t(65) = 0.64$).