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Predictors of lexical retrieval in Hindi–English bilingual speakers

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Abstract

When bilinguals name pictures while in 'monolingual mode', we expect that under conditions of language-constraint and no cognate facilitation, factors influencing lexical retrieval in monolinguals ought to exert similar effects on bilinguals. To this end, we carried out a L1-only naming task on early Hindi–English bilinguals. Results of linear mixed effects analysis reveal AoA, Familiarity, Image Agreement and Codability (availability of alternate names) to be the most significant predictors of lexical retrieval speed for early bilinguals, confirming our expectations. However, we report, for the first time, a by-subject variation in Codability for bilinguals. Implications of the results are discussed in the context of current theories of bilingual lexical access and competition. In preparation for this study, Hindi norms from bilinguals for items in the Snodgrass and Vanderwart set have been established, which will be of use for stimuli selection in experimental studies involving bilinguals.

Introduction

The process of picture naming can be divided into at least three discrete stages (Glaser, 1992; Johnson, Paivio & Clark, 1996): i) visual recognition and object identification where stimulus features (size, shape, colour, texture etc.) are extracted and matched with a concept stored in semantic memory; ii) lexical retrieval/selection i.e., accessing word 'lemmas' (lexical representations of words with syntactical properties specified; Levelt, 1999) and their phonological forms, and finally iii) response generation – where phonological knowledge guides articulation of the stimulus name. Psycholinguistic properties such as the concept depicted (e.g., image agreement, familiarity, name agreement) and the rated age of acquisition (AoA), word frequency and length of stimulus names are typically assumed to impact independent stages of picture naming (Johnson et al., 1996; Paivio, Clark, Digdon & Bons, 1989). Studies in a wide variety of languages – like Arabic (Boukadi, Zouaidi & Wilson, 2016), Chinese (Bates, D'Amico, Jacobsen, Székely, Andonova, Devescovi, Herron, Lu, Pechmann & Pléh, 2003; Weekes, Shu, Hao, Liu & Tan, 2007), English (Barry, Morrison & Ellis, 1997; Ellis & Morrison, 1998), Modern Greek (Dimitropoulou, Duñabeitia, Blitsas & Carreiras, 2009), Japanese (Nishimoto, Miyawaki, Ueda, Une & Takahashi, 2005), Persian (Bakhtiar, Nilipour & Weekes, 2013) and Spanish (Álvarez & Cuetos, 2007), to name a few – have consistently confirmed the influence of such psycholinguistic variables on the speed of lexical retrieval during picture naming. In a first, Bates and colleagues (2003) carried out a cross-linguistic study that examined factors influencing lexical access during picture naming across seven languages (belonging to different language families) and concluded that variables such as the number of alternate names (which we refer to as 'codability') and word frequency significantly influenced speed of lexical retrieval across all seven languages examined. Word frequency and rated AoA along with other measures of name agreement have also been consistently reported as significant predictors of naming by various other studies preceding and following the Bates et al. (2003) study (e.g., Bakhtiar et al., 2013; Barry et al., 1997; Cuetos, Ellis & Alvarez, 1999; Nishimoto et al., 2005; Weekes et al., 2007).

However, all the above-mentioned studies have examined lexical access via picture naming only in monolingual speakers. The cognitive steps of picture naming apply just as equally to bilinguals, but a direct comparison with monolinguals shows a consistent difference: bilinguals are slower and more error-prone during naming than their monolingual counterparts (e.g., Gollan, Montoya, Fennema-Notestine & Morris, 2005; Ivanova & Costa, 2008; Roberts, Garcia, Desrochers & Hernandez, 2002). One explanation has been that bilinguals use each of their languages less frequently than monolingual speakers of either language. The time-share between their two languages leads to weaker links between semantics and phonology in each language's lexicon that results in slower retrieval. This is the WEAKER LINKS HYPOTHESIS (Gollan, Montoya, Cera & Sandoval, 2008). Another explanation for bilingual's slower performance in picture naming tasks is that competition between lexical representations in L1 and L2 (for examples see Costa, Miozzo & Caramazza, 1999; Marian & Spivey, 2003; Martin et al., 2009) and the control processes that manage such inter-linguistic competition, slow down lexical access (Abutalebi & Green, 2008). As per the Inhibitory Control (IC) model (Green, 1998), cognitive control processes bring about the inhibition of non-target lemmas that compete for selection along with the target language ones. In either case, under the assumption (e.g., Pavelenko, 2009; Finkbeiner, Gollan & Caramazza, 2006) that lexical representations are linked to shared semantic concepts – i.e., objects are nameable in L1 and in L2 – we ask how would psycholinguistic factors influence speed of lexical access in bilinguals?

Linguistic codability is a robust predictor of naming speed in monolinguals. In studies of picture naming, this variable has been operationalized to reflect either the number of referential connections between an object and its names (captured by measures such as the "H-statistic"; Snodgrass & Vanderwart, 1980) or the dominance of individual connections (reflected in measures such as Percentage Name Agreement for an object's name; Johnson et al., 1996). Pictures with high codability – i.e., those having an unambiguous and dominant name and consequently low uncertainty (e.g., banana) – are consistently named faster than objects with low codability – i.e., those having multiple alternative names (e.g., blossom, rose, flower) – by monolingual speakers in all languages tested so far (Alario, Ferrand, Laganaro, New, Frauenfelder & Segui, 2004; Bates et al., 2003). In monolinguals, concepts that have lower codability will trigger competition between several intra-language alternatives; the competition in turn contributes to increased latency during name selection (Alario et al., 2004). In bilinguals, each concept is already associated with at least one name in each of their languages (e.g., "banana" in English, "*kElA*" in Hindi). Therefore, most concepts naturally have a lower codability for bilinguals than for monolinguals. As per the Weaker Links hypothesis we might expect codability to have a dominant effect during picture naming because the more distributed links between alternative names for any one concept (which is always more than one for bilingual speakers), the slower is name production for bilingual and for monolingual speakers. The IC model generates the same predictions but for different reasons. Codability should dominate timed picture naming because the more alternative names, the more competition for production and thus the longer the naming latency. In sum, both the Weaker Links hypothesis and the IC model allow for an effect of codability when bilinguals name pictures in 'monolingual mode'.

To test these predictions and to examine which psycholinguistic variables of picture naming (previously examined only on monolinguals) would influence speed of lexical access and retrieval in bilinguals we asked bilingual speakers to name pictures while they were in 'monolingual mode'. We adopt this term from Grosjean (2001) to refer to a mental state wherein activation of one language is maintained while the non-target language is inhibited. Our expectation was that codability would be a dominant predictor of timed picture naming speed in bilinguals.

It should be noted that co-activation of target and non-target lemmas need not always slow down naming in bilinguals. Several studies have demonstrated that cognates (characterized by high phonological similarity) speed up naming in bilinguals (e.g., Costa, Caramazza & Sebatstian-Galles, 2000; Gollan & Acenas, 2004; Hoshino & Kroll, 2008). To assess the influence of codability on language-restricted lexical retrieval in bilinguals, we carried out a simple language-constrained picture naming study on early Hindi(L1)–English(L2) bilinguals from India who named pictures exclusively in one language (Hindi L1), in the absence of cognates. Under the assumption that there is always INTER-language competition for the concepts presented (i.e., concepts are nameable in BOTH languages, as was the case in this study) but no cognate facilitation, we specifically predict that decrease in L1 codability of the object ought to increase L1 naming latency in bilinguals just as it does for monolinguals.

Materials and methods

Preparatory study

The preparatory study involved collecting ratings and responses for 158 items selected from the colour version of the S&V pictures (Rossion & Pourtois, 2004). To aid item selection, an informal poll of 20 Hindi–English speakers was performed with all 260 pictures of the colourized S&V set. Poll participants were first asked to determine (1) if objects/concepts depicted were culturally familiar and (2) had a distinctive, non-descriptive Hindi name. Culturally unfamiliar objects (e.g., asparagus, raccoon) and concepts whose visual depictions deemed uncommon in the Hindi context (e.g., football helmet, French horn) were removed. Objects referred to by their English loan-names (although now a routine part of Hindi vocabulary, e.g., shirt, guitar, strawberry) were also removed. Finally, for object pairs with the same Hindi name (e.g., *ju:ṯa* = shoe/boot) one picture from each pair was removed.

Ratings for an agreed set of 158 items were collected via online self-paced survey from 59 early Hindi (L1)–English(L2) bilingual students (males: 33, females: 26; Mean Age = 22.58, SD = 3.03) at the University of Allahabad, India. All raters completed a language background questionnaire and provided subjective estimates of their Hindi comprehension and speaking proficiencies on a scale of 1–10. Despite studying in English-medium schools, all reported studying Hindi formally for at least 10 years and using both languages daily. For details of survey participant language profile and self-rated Hindi proficiency scores see Table S1 in Supplementary Materials (Supplementary Materials).

Following previous studies (see Bakhtiar et al., 2013; Weekes et al., 2007) the raters were asked to provide the following responses for each picture in the survey: (1) the Hindi name of the object or one of the following responses – *don't know the Hindi name* or *don't know the object,* followed by subjective ratings for the following features on a 5-point scale; (2) Image Agreement (ImAg), defined as how closely a picture matched their own mental representations, with 1 being *very poorly* and 5 being *very well*; (3) Concept Familiarity (Fam), defined as the extent to which they were familiar with the object depicted, with 1 indicating *not at all familiar* and 5 indicating *very familiar*; (4) Visual Complexity (VC), explained as the level of complexity of the pictorial representation and not the real object itself (Rossion and Pourtois, 2004), with 1 *quite simple* and 5 *quite complex*; and finally indicate their approximate (5) Age of Acquisition (AoA) in years for the object's Hindi name on a scale where 1 was *less than 2 years*, 2 was *2 years* and so on till 11, *11 years or older*.

From the survey responses, average ratings of image agreement, concept familiarity, visual complexity and AoA for each picture were obtained (see Appendix 1 in Supplementary Materials). Additionally, the following psycholinguistic variables were derived for each picture: (1) picture name – the Hindi name having the highest count (after excluding erroneous/*don't* *know Hindi name* responses); three measures of codability, which are: (2) Nameability (NmAbl) – an index of the pre-existing prevalence of the *Hindi* name of an object in the community of Hindi–English bilingual speakers, calculated as 1 minus the proportion of raters selecting *Don't know Hindi name* (the highest value is 1); (3) Percentage of Name Agreement or PNA in Hindi – the percentage of raters who produced the dominant name, the highest being 100%. This captures the level of agreement for an object name in Hindi from within the sample of Hindi–English speakers and is a measure of the dominance of a specific object-name association in Hindi; (4) H-statistic (Snodgrass & Vanderwart, 1980), an indirect measure of name uncertainty that reflects the number of connections between an object and its alternative names in a language. The H-Statistic (H-Val) was calculated using the formula recommended by Snodgrass and Vanderwart (1980)

$$\mathrm{H} = \sum_{i=1}^{k} P_i \log_2\left(\frac{1}{P_i}\right),$$

where k is the number of nominal alternatives for each item and P_i is the proportion of raters providing each alternative name. An object is assigned an H-value of zero when all raters providing a name provide the *same name*. Increasing positive deviation from zero indicates that an object is referred to by more than one name and suggests a greater extent of name uncertainty is associated with it. The H-statistic is a suitable measure of codability as it captures the level of uncertainty/ambiguity regarding an object's name due to the presence of one or more nominal alternatives available in the language. (5) a Frequency index which is a combination of written and spoken word frequency estimates (WFreq) for the most dominant Hindi names taken from Hindi EMILLE/ CIIL corpora (approximate word count: 13 million), calculated as Log_{10}(Counts per Million) +1; and (6) word length calculated as the number of phonemes (Phon), alpha-syllables (ASyll)[1] and syllables (Syll) in each dominant name. The mean descriptive statistics for rated and computed variables are provided in Table 1. The norms for each item are reported in Appendix 1 of Supplementary Materials (Supplementary Materials).

Experiment: timed picture naming in monolingual mode

Participants

40 Hindi(L1)–English(L2) bilinguals (Indian nationals studying at the University of Hong Kong) volunteered to take part in this part of the study. None had participated in the ratings study. All participants completed a language background questionnaire. Before moving to study in Hong Kong, all participants had lived for at least 10 years in a Hindi-dominant region of India and, like the raters from Allahabad, had formally learnt Hindi for at least 10 years and reported using both languages regularly in India and in Hong Kong (see Table 2).

To ensure that inter-language competition was being consistently overcome more than half the time in favour of L1 and cross linguistic errors were minimised (these were common in a pilot study conducted with similar participants), an accuracy level of at least 64% (providing a permissible Hindi name for 100 out of 154 stimuli) was set as the inclusion criterion. 10 participants did not meet this criterion and were therefore excluded. Data from the remaining 30 participants (males: 19, females: 11; Mean age (SD) = 20.27yrs (2.49)) were used. For these participants, average L1 (Hindi) AoA was 1.37 (SD = 0.61) and L2 (English) AoA was 3.8 (SD = 0.8).

Procedure

154 pictures were used for the experimental study. Four pictures whose dominant names were English cognates[2] were excluded for the naming experiment. Thus, only pictures with distinctive Hindi names were used. The experimental procedure was similar to previous studies (Cuetos et al., 1999; Bakhtiar et al., 2013; Weekes et al., 2007). DMDX (Forster & Forster, 2003) was used to present stimuli and record latencies. Stimuli presentation was designed in blocks of five (about 30 items per block) with a rest period of five minutes between blocks. Item order within block was randomized and block order was pseudorandomized for all participants. Objects sharing phonologically similar Hindi names (e.g., potato=/a:lu:/ & bear=/bʰa:lu:/) were placed in different blocks to prevent any phonological facilitation. Vocal responses were captured by a microphone placed 5cm away from the mouth. The input threshold level for the voice key trigger was adjusted to match the natural intensity and volume of the participants' voice. Prior to the experiment, participants were familiarised with the experiment format first and then given instructions to name pictures as quickly and accurately as possible in Hindi (L1), while avoiding prefacing responses with utterances like "umm", "err" etc. Naming latencies were recorded from stimulus onset to naming onset with a timeout of 2000ms, after which the picture disappeared and replaced by a '+' for 500ms. Complete vocal responses (for accuracy analysis) were also recorded simultaneously. For RTs per item see Appendix 1 in Supplementary Materials (Supplementary Materials).

Data preparation

Participants who failed to reach 65% accuracy (n = 10) were first excluded. From the remaining data 11.4% responses (providing an English name, wrong Hindi name, blank responses, prefacing responses with meaningless vocal fillers and voice key errors) were removed. A further 1.9% of data that were more than two standard deviations from the mean were removed. RT was log transformed to reduce skew.

Data analysis

A linear mixed effects analysis with subjects and items as crossed random effects (Baayen, Davidson & Bates, 2008) was performed on latency (dependent variable) in R (version 3.2.1; R Core Team, 2015) using the *lme4* package (Bates, Maechler, Bolker & Walker, 2014; R package version 1.1-9). Satterthwaite-approximation-derived *p*-values for the coefficients of fixed effects were computed using the *lmerTest* package (Kuznetsova, Brockhoff & Christensen, 2015; R package version 2.0-29). The predictor variables considered were: (1) H Value (H_Val); (2) Percentage Name Agreement (PNA); (3) Nameability (NmAbl); (4) rated Image Agreement (Im_Ag); (5)

[1]English–Hindi cognates (excluded) for the stimuli used in the present study were: Glass = "gilaas" [gIla:s]; Bottle = "botal" [bo:t̪ələ]; Cycle = "saikil" [sa:IkIlə]; Kangaroo = "kangaaroo" [kə̃ga:ru:].

[2]Hindi is an alphasyllabic language whose writing system shares some features with alphabetic (e.g., English) and syllabic (e.g., Japanese) systems. Like alphabetic system, vowel and consonant sounds are represented by discreet visual symbols. Like syllabic systems, consonant-vowels (CV) combinations are grouped into "syllabic bundles" (Vaid & Gupta, 2002). However, unlike in either system, the consonant is graphically represented by its symbol while the vowel modifiers are represented as distinct vowel markers. This combination of the consonant symbol + vowel marker represents a single alphasyllabic unit in Hindi writing.

Table 1. Descriptive statistics for rated and derived psycholinguistics variables

	N	*Min*	*Max*	*Mean*	*SD*	*Skewness*
H_VAL	158	0.00	2.05	0.24	0.42	2.00
PNA	158	0.35	1.00	0.94	0.12	−2.50
NmAbl	158	0.15	1.00	0.90	0.17	−2.28
Im_Ag	158	3.93	4.94	4.72	0.15	−1.82
Fam	158	4.00	4.98	4.81	0.15	−2.04
VC	158	1.53	4.94	4.18	1.11	−1.58
AoA	158	2.76	7.78	4.68	1.07	0.58
WFreq (log + 1)	158	0.00	2.66	0.77	0.57	0.96
ASyll	158	2.00	6.00	3.01	1.02	1.16

Table 2. Picture naming participant language profile and self-rated Hindi proficiency scores an ascending scale of 1-10 (n = 30)

No. of years spent in a Hindi dominant region	*Highest Academic Qualification*	*No. of years of Formal Hindi study*	*Mean self-rated proficiency scores*
5-10 yrs.: 0%	*High School*: 0%	*<10 yrs.*: 0%	*Comprehension:* 9.17 (0.59)
10-15 yrs.: 30%	*Bachelors*: 90%	*10 yrs.*: 83.33%	*Speaking:* 9.34 (0.80)
15-20 yrs.: 63.33%	*Masters*: 10%	*>10 yrs.*: 16.67%	*Reading:* 8.5 (1.11)
>20 yrs.: 6.67%			*Writing:* 8.3 (0.91)

SD indicated in parenthesis

rated Concept Familiarity (Fam); (6) rated Visual Complexity (VC); (7) rated AoA; (8) Word Frequency (WFreq); and (9) number of Alpha-syllables (ASyll). Pearson's correlations between latency and each of the predictor variables are reported in Table 3.

The analysis strategy implemented in this study is as follows:

(1) Testing for effects of initial phoneme on RT

First, the effect of initial phoneme on latency was tested since the initial phoneme is known to affect acoustic onset of naming, i.e., voice key measures of latency (Rastle & Davis, 2002; Kessler, Treiman & Mullennix, 2002). The initial phoneme of each picture name was coded as one of eleven types of phonemes based on manner of articulation[3]. When entered as fixed effects, none of the 11 initial phoneme types had a significant effect on latency ($p > .05$) and were not considered for further analysis.

(2) Testing for multicollinearity

Multicollinearity between predictor variables is problematic for mixed effect models as it reduces the contribution of each correlated variable towards the dependent variable (Zuur, Ieno & Elphick, 2010). A test for multicollinearity among the 9 predictor variables revealed a Variance Inflation Factor (VIF) value of over 15 for two measures of codability – H-value and PNA – indicating a high level of collinearity. H-Value was retained as the measure for name agreement, as it is more indicative of the uncertainty in name selection due to the availability of L1 and L2 alternatives than PNA. When PNA was omitted, the VIF values for the remaining 8 variables did not cross 2, a value well under the generic cut-off points of 5–10 (Craney & Surles, 2002).

(3) Model evaluation using Likelihood Ratio Test (LRT)

Model fitting began by using the 8 predictor variables as fixed effects and subject and items entered as random intercepts. To arrive at the simplest, best-fit model a series of pair-wise comparisons between models lacking one or more fixed effects was carried out and their utility was determined using a log Likelihood Ratio Test (LRT) following the method outlined in Baayen et al. (2008). To determine if there was significant variation WITHIN the sample for each of the 8 predictor variables, pairwise comparisons between models both with and without random slopes for each predictor variable were also performed (Barr, Levy, Scheepers & Tily, 2013; Davies, Barbón & Cuetos, 2013).

Results

The mean naming latency for items with a consistent response rate of more than 50% (n = 106) was 1083.75ms (*SD* = 113.18). A full model with 8 predictors as fixed effects and subjects and items as random effects was fitted. The Best Linear Unbiased Predictors (BLUPS), *t*-values and Satterthwaite-approximation-derived *p*-values for each of the 8 fixed effects in the full model are shown in Table 4.

A summary of this original full model indicated that AoA ($t = 3.556$, $p < .001$) and Familiarity ($t = -2.932$, $p < .01$) significantly predict naming latency followed by H-Value ($t = 2.258$, $p < .05$) and Image Agreement ($t = -2.181$, $p < .05$) with word frequency showing a trend ($t = -1.984$, $p = .049$).

The LRT statistic was significant for comparisons between models that differed in inclusion of AoA (χ^2 (1) = 12.85,

[3]Initial phonemes were coded as follows: consonants as unvoiced-unaspirated, unvoiced-aspirated, unvoiced-fricative, voiced-unaspirated, voiced-aspirated, voiced-fricative, nasal and approximants/semi-vowels; vowels as short monophthongs and long monophthongs (no item name began with a diphthong).

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Table 3. Pearson's correlations for RT & 9 major predictor variables

	RT	H_VAL	PNA	NmAbl	Im_Ag	Fam	VC	AoA	WFreq
H_VAL	0.072								
PNA	−0.071	−.972*							
NmAbl	−0.134	−0.125	0.142						
Im_Ag	−.425*	−0.098	0.121	.383*					
Fam	−.473*	−0.091	0.120	.465*	.474*				
VC	−0.022	−0.063	0.064	−0.017	0.043	0.014			
AoA	.386*	0.035	−0.050	−.568*	−.259*	−.555*	0.110		
WFreq	−0.151	0.013	0.043	.194	.223*	.251*	0.060	−.405*	
ASyll	0.163	−0.034	0.027	−.299*	−.185	−.179	−0.058	.313*	−0.103

* Significant correlations ($p < .01$, 2-tailed)

Table 4. Summary of the full model with *t* values and their corresponding *p* values

	Estimate	*Std.Error*	*df*	*t-value*	*Pr(>|t|)*
(Intercept)	3.8330	0.1818	163.20	21.0900	< 2e-16
H_VAL	0.0189	0.0084	153.30	2.2580 *	0.0253
NmAbl	−0.0501	0.0315	224.00	−1.5900	0.1132
Im_Ag	−0.0643	0.0295	153.90	−2.1810 *	0.0307
Fam	−0.1086	0.0371	145.80	−2.9320 *	0.0039
VC	0.0001	0.0030	124.40	0.0380	0.9701
AoA	0.0169	0.0047	142.80	3.5560 *	0.0005
WFreq	−0.0123	0.0062	126.70	−1.9840	0.0494
ASyll	0.0041	0.0035	137.40	1.1920	0.2354

* $p < .05$

$p = .0003$), Familiarity (χ^2 (1) = 8.81, $p = 0.003$), H-Value (χ^2 (1) = 5.28, $p = .02$) and Image Agreement (χ^2 (1) = 4.97, $p = .025$) with addition of word frequency (χ^2 (1) = 4.09, $p = .04$) showing a trend. The LRT statistic did not reach significance for comparisons where either Number of Alphasyllables, Visual Complexity or Nameability were added. Omission of these non-significant variables from the model did not change the direction or significance of effect of the other 5 variables.

In LRT comparisons among models that differed in inclusion of one of the remaining 5 variables (AoA, Familiarity, H-value, Image Agreement and Word Frequency) the LRT was significant when AoA, Familiarity, H-Value and Image Agreement were included ($p < .01$ for all four comparisons), indicating that models with these predictors fit the data better. The LRT failed to reach significance when Word Frequency was added, confirming that the influence of Word Frequency was weaker than expected and could be excluded. A final comparison between the simplest model with 4 predictors (AoA, Familiarity, H-Value and Image Agreement) and the original full model with non-significant variables included yielded a non-significant LRT, indicating the simpler model to be a better fit.

Finally, when comparisons between models with or without a random slope were carried out, an improved fit was seen only when H-Value was added as the random slope term (χ^2 (2) = 11.35, $p = .003$), but not for any other predictor. Overall a model with AoA, Familiarity, H-Value and Image Agreement as fixed effects and by-subject random slope for H-Value had a better fit (χ^2 (2) = 11.66, $p = .003$) than a model with the same 4 fixed effects and no by-subject slope for H-Value.

Since Hindi is an alphasyllabic language (see Vaid & Gupta, 2002, p.680-682), "Number of Alphasyllables" was used as one of the predictor variables. However, since its orthographic units map onto both syllables and phonemes depending on context (Nag, 2014) additional models, either with phoneme and syllable count were fitted (in Appendix 2, Supplementary Materials). The BLUPS, *t*-values for the fixed effects in alternate models (one with number of syllables and one with number of phonemes as a predictor variable) was nearly identical to one with alphasyllables (see Appendix 2). The results of systematic model comparisons for these alternate models with phonemes and syllables had an identical pattern of results to the one with alphasyllables with these variables also becoming non-significant.

Discussion

In this study, we set out to determine if linguistic codability would influence bilinguals performing a task of lexical access and retrieval in 'monolingual mode'. We imposed a language-constraint on our bilingual participants so that final lexical SELECTION is limited to one lexicon. By removing any cognates, we ensured no inter-language facilitation. As predicted, lower codability increased naming latency in Hindi–English speakers. Critically, the by-subject random slope for H-Value also had an independent effect on timed picture naming.

In the modelling, we found rated AoA, Concept Familiarity, Image Agreement and H-Value to be significant predictors of lexical access in L1 for bilinguals. The findings resonate with studies of monolingual speakers in several other languages as previously mentioned. By implementing an LME analysis, the results allow generalizability beyond the limited sample of items and participants used in this study, while also partly circumventing some issues inherent to chronometric data such as noise, non-sphericity and heteroscedasticity (see Baayen et al., 2008).

AoA emerged as a significant predictor of naming in L1 as is the case for other bilingual speakers (see Izura & Ellis, 2002). Notably, it was one of the most stable predictors that withstood multiple rounds of model evaluation. Our result once again confirms that lexical access and retrieval in monolingual mode (i.e., Hindi) is constrained by subjective estimates of when a word is acquired in the L1. This finding has been replicated in studies with monolingual speakers (Alario et al., 2004; Bates et al., 2003; Cuetos et al., 1999; Severens, Van Lommel, Ratinckx & Hartsuiker, 2005), including speakers of less-studied languages like Persian (Bakhtiar et al., 2013), Turkish (Raman, Raman & Mertan, 2014; Raman, Raman, İkier, Kilecioğlu, Uzun Eroğlu & Zeyveli, 2018) and Russian (Volkovyskaya, Raman & Baluch, 2017). The robustness of the AoA effect across such a diverse spectrum of speakers highlights the universality of AoA in lexical retrieval. Additionally, in the present study AoA showed no variation in the shape of the effect, which means that this variable had a uniform effect on speed of lexical retrieval. By contrast, we found no evidence for independent effects of word frequency on naming performance.

Word frequency, although significantly correlated with AoA, was only marginally significant in the LME model and ultimately did not survive model reduction. In this regard, our findings are similar to studies that report no independent effect of word frequency on picture naming (Bonin, Chalard, Méot & Fayol, 2002; Morrison, Ellis & Quinlan, 1992; Nishimoto et al., 2005; Weekes et al., 2007). Our results, however, contrast with studies that do report a significant independent effect of frequency (e.g., Alario et al., 2004; Barry et al., 1997; Bates et al., 2003). A speculative explanation for the lack of frequency effect in our study is that corpora derived frequency measures for Hindi do not capture frequency trajectory – i.e., distribution of word use over time (Zevin & Seidenberg, 2002) – but only index word use in adulthood assuming monolingual speech production. It is possible for different words with the same cumulative frequency to have different frequency trajectories, as their patterns of use over a lifetime can vary due to changing language contexts. This is most relevant in the bilingual context. We do not have reliable frequency estimates for the spoken use of a word in the native language for bilingual or multilingual speakers. If bilinguals like our Hindi–English speakers divide their resources between two languages, usage patterns of each language will affect word frequency trajectories differently in either language, e.g., constant usage of an L2 name to denote an object could result in faster retrieval than an earlier acquired but infrequently used L1 name. We therefore do not rule out an effect of frequency on monolingual mode picture naming in bilinguals if more reliable estimates of Hindi word frequency become available. Given a lack of such frequency measures for Hindi words, rated AoA appears to be a reliable proxy.

Rated Concept Familiarity and Image Agreement emerged as significant predictors with neither variable exhibiting any within-subject variation. Only a couple studies on monolinguals (Cuetos et al., 1999; Liu, Hao, Li & Shu, 2011) report significant effects of both variables. Most studies reported significant effects of either Familiarity (e.g., Nishimoto et al., 2005; Snodgrass & Yuditsky, 1996; Weekes et al., 2007) or Image Agreement (e.g., Bakhtiar et al., 2013; Barry et al., 1997; Bonin et al., 2002). One speculation is that Concept Familiarity (which represents the level of prior sensory and motoric experience with an object) and Image Agreement (which reflects the level of similarity between a depicted object and its mental representation) influence lexical access at a level of non-linguistic conceptual identification by affecting the strengths of semantic representations and the ease with which they are accessed. We observed these effects despite filtering experimental stimuli for objects with low cultural familiarity in the Hindi context. We speculate this might be a cultural effect as sociocultural factors influence mental representations. We also note that many objects/concepts common in the Hindi-speaking culture (e.g., mango, crow, North Indian musical instruments) are absent in the Snodgrass and Vanderwart set.

Finally, word length measured in three dimensions (number of phonemes, alphasyllables and syllables) did not seem to influence naming latency. We contend this confirms the validity of the picture naming task as a reliable measure of lexicalization rather than articulation of Hindi words in speech production.

Codability was operationalized as the H-Statistic for Hindi names in our study. All items had names in English (L2) that were known to our participants and English names (cross-linguistic intrusions) were removed from analysis. This means that when non-target (English) lemmas are inhibited, the NUMBER of available Hindi (target language) lemmas for an object still has a significant influence on the speed of lemma selection, thus influencing naming time. However, we uncovered a by-subject variation in the shape of the effect suggesting that codability might not have a uniform effect on 'monolingual' naming speed for bilinguals. In other words, for an object with a given level of Hindi linguistic codability, there is an effect of participant variability with speakers varying in the speed of lexical selection in Hindi. Although this finding is novel in studies of timed picture naming, it is probably not surprising. Even if multiple alternatives are available in a language, individual speakers within a population will differ in their knowledge of alternate names for concepts (Johnson et al., 1996). Indeed, for a language like Hindi that is spoken by over 260 million people (Ethnologue, 19th Ed., 2016) spanning a widespread geographical area, sociolinguistic factors and regional linguistic variations are very likely to influence their L1 and L2 vocabulary size and their usage patterns. Therefore, the NUMBER of language lemmas that are activated and available for selection will vary between speakers. Consequently, the EXTENT OF COMPETITION between co-activated lemmas will vary in bilinguals affecting time taken to select and retrieve a response.

Of all the predictor variables measured, only the H-statistic (codability) showed within-subject variation even after inherent subject-related individual variation was taken into account by modelling it as a random intercept term in the LME model. This reveals a significant dimension of codability in L1 for bilingual speakers. The key point is that codability is not simply a property of the stimulus presented, it is also a characteristic of the participant which, although highly relevant to studies of bilingual speakers, is not limited to studies of bilingual speakers. As in all samples, participants will vary in their 'proficiency' in their native language as well as any other language spoken. It is incumbent on models of bilingual and monolingual speech production to explain the effects.

We obtained Nameability data in Hindi for pictures and modelled possible effects of this variable on timed picture naming. Although Nameability was significantly correlated with AoA, Familiarity, and Image Agreement (see Table 3), it did not emerge as a unique predictor of naming latency. One reason for this, we believe, is the operationalization of this variable in this study. In bilingual communities, different objects are often referred to in one language or in the other language but rarely both languages. For example, in a socio-linguistic scenario such as in India, everyday objects (e.g., television = "TV", telephone = "phone") are referred to exclusively by their English names (borrowed words) rather than their Hindi names, some by names in both languages (e.g., ball, spoon) and some only in Hindi (e.g., rolling pin, bowl) rather than in English. If one population tends to prefer using one language or the other to code an object, then, given a constrained naming task, the strongest candidate for selection would be the more prevalent name of the object in that population. The stimuli used in our study could be named in either language, making lemmas in L1 and L2 equally competitive. Selecting one lemma over another requires suppression of a non-target language lemma, adding a delay to name retrieval. Nameability in the present study was operationalized to index the prevalence of Hindi name(s) and does not take English (L2) names into consideration. Nameability is therefore suggestive of whether Hindi lemmas would become active and compete for selection, but it does not reflect the number of English lemmas that could co-compete. We do not have normative data for English name prevalence in Hindi–English bilinguals. Therefore, we cannot test any putative effects that such a factor might have on naming latency, and our reasoning remains speculative.

Both the Weaker Links hypothesis and the IC model predict an effect of codability on name production in bilingual speakers. However, we reasoned that if the activation between concepts, lemmas and lexemes is reduced for a bilingual speaker due to sharing of resources for language production, then the factors that predict timed picture naming in monolinguals might be different for bilinguals. However, lexical variables such as rated AoA and familiarity were both significant predictors when correlated variables were controlled. However, we also found that codability had a dominant effect in item and participant level analyses. Our reasoning was that distribution of the links between alternative names for a concept is greater for a bilingual speaker and this could be a constraint of name production specifically for bilinguals. We also argued the IC model makes the same prediction because, the more alternative names, the greater is competition for production and thus the longer is naming latency. We did not compare effects across groups of bilingual and monolingual speakers directly. This was not feasible because monolingualism, although widespread in rural areas of India, frequently coincides with lower literacy, socio-economic status and older age (see Freedman, Alladi, Chertkow, Bialystok, Craik, Phillips, Duggirala, Raju & Bak, 2014, p5–6 and Bialystok & Vishwanathan, 2009 for similar reports), making comparisons between bilingual and monolingual speakers experimentally difficult. We do not consider our results to be limited to the naming of pictures in the native language of Hindi–English speakers, however. Codability is very reliably found to predict timed picture naming in all languages tested. What is not known is whether codability has a dominant effect on participants as well as items in the languages tested to date. This would require analysis of existing data using LME and is recommended in future studies of timed picture naming.

Cognitive processes are not typically incorporated in models of picture naming beyond descriptive accounts of competition, exclusion, inhibition and selection (Hall, 2011). This seems at odds with the well-known effects of codability on timed picture naming in all studies reported. Some languages have more synonyms and/or specific names than other languages. Therefore, it is not surprising that codability has a robust effect across studies. A conceptual link between the codability of a concept and timed picture naming is articulated in models of bilingual language production but these insights have not transferred to studies of monolingual picture naming. One outcome of this study is to highlight possible intra-individual variability in codability in studies.

In sum, several factors that influence speed of lexical access in monolingual speakers also influence lexical access in Hindi–English bilinguals. It is remarkable that effects were observed despite (possibly) weaker links, greater competition and selection in lexical access for bilinguals. We expect similar results if the bilinguals were to name objects exclusively in L2, and expect our results to be replicated across bilinguals speaking other languages. However, as normative data from Indian populations for Indian English are not available, such cross-linguistic comparisons are not feasible. We will take this opportunity to emphasize the need to establish psycholinguistic norms for studies of Indian bilinguals who are amongst the largest NON-WESTERN multilingual population in the world. Languages such as Hindi, Tamil, Telugu and Bengali, are large by number of speakers with at least 60 million native speakers each (Ethnologue, 19th Ed, 2016). Due to the history of India and present socio-economic factors (Clingingsmith, 2014), 'Indian Language – English' bilingualism is the norm (Sahgal, 1991), especially with urban adults aged between 18–35 years. The present results facilitate cross-linguistic comparisons, and aid assessment of bilinguals.

Supplementary material. For supplementary material accompanying this paper, visit https://doi.org/10.1017/S1366728918001177

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