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RESEARCH PAPER

Cross-language contributions of rapid automatized naming to reading accuracy and fluency in young adults: evidence from eight languages representing different writing systems

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Abstract Rapid automatized naming (RAN) is a strong predictor of reading across languages. However, it remains unclear if the effects of RAN in first language (L1) transfer to reading in second language (L2) and if the results vary as a function of the orthographic proximity of L1–L2. To fill this gap in the literature, we examined the role of RAN in reading accuracy and fluency in eight languages representing different writing systems. Seven hundred and thirty-five university students (85 Chinese-, 84 Japanese-, 100 Kannada-, 40 Oriya-, 115 English-, 115 Arabic-, 105 Portuguese-, and 91 Spanish-speaking) participated in our study. They were assessed on RAN (Digits and Objects) and reading (accuracy and fluency) in both L1 and L2 (English). Results of hierarchical regression analyses showed significant

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effects of L1 RAN on L2 reading accuracy in the Chinese-, Portuguese-, and Spanish-speaking groups. In addition, L2 RAN was a significant predictor of reading fluency in L1 in the same language groups. No cross-language transfer was observed in the other languages. These findings suggest first that L1 and L2 RAN capture similar processes and controlling for one does not leave unique variance for the other to explain. Second, to the extent there is cross-language transfer of RAN skills, this appears to be independent of the orthographic proximity of the languages.

Keywords Bilingual · Cross-language transfer · Rapid automatized naming · Reading · Writing system

Introduction

Rapid automatized naming (RAN), defined as the ability to name as quickly as possible highly familiar visual stimuli such as letters, digits, colors, and objects, is a strong predictor of reading ability (particularly of reading fluency) across different languages (e.g., Caravolas et al., 2013; Georgiou et al., 2016; Landerl et al., 2019) and ages (e.g., Georgiou et al., 2014; Rodríguez et al., 2015; van den Bos et al., 2002). In a meta-analysis, Araújo et al. (2015) reported an average correlation of 0.44 between RAN and reading. Research on RAN proliferated after Denckla and Rudel's (1974) study showing that dyslexic children were not significantly different from normal readers in color naming accuracy, but were significantly less proficient in color naming speed. Despite the acknowledged importance of RAN in reading, it remains unclear if the effects of RAN on reading 'transfer'[1] from an individual's native language (L1) to a second language (L2) and if there are differences across pairs of languages depending on their orthographic proximity. Thus, the purpose of this study was to examine if the effects of L1 RAN transfer to word reading accuracy and fluency in L2 (English) in several languages (Chinese, Japanese, Kannada, Oriya, Arabic, Portuguese, Spanish) representing different writing systems (e.g., logographic, alphasyllabic, and alphabetic). Examining the role of L1 RAN in L2 reading is important in our attempt to better understand what cognitive-linguistic skills are universal predictors of reading and what are language/script specific.

To date, only a few studies have examined the cross-language transfer effects of RAN skills on reading and have some important limitations.[2] First, most of the previous studies included Chinese–English bilinguals (e.g., Keung & Ho, 2009; Li et al., 2011; Yeung, 2016) and therefore, much less is known about transfer within pairs of alphabetic languages (e.g., Spanish–English) or in pairs comprising an alphasyllabic orthography (e.g., Kannada) and English. Second, all previous studies included young children who were in the process of learning to read. It remains unclear if similar results could be obtained in young adults who have mastered reading in L1 and have had adequate instruction and practice in L2 reading. This is theoretically important because one of the cross-language transfer models (i.e., the Transfer Facilitation Model; Koda, 2008) assumes that for transfer to happen the competencies to be transferred must be well rehearsed—to the point of automaticity—in the first language and we know that RAN does not reach such level before adolescence (e.g., Albuquerque & Simões, 2010; Georgiou et al., 2014; Siddaiah et al., 2016). Third, previous studies have examined if there is cross-language transfer of RAN on reading accuracy and reading comprehension and we do not know if similar results hold for reading fluency. This is important in view of the strong relations between RAN and reading fluency (e.g., Georgiou et al., 2016; Landerl et al., 2019; López-Escribano et al., 2018). Finally, in previous studies (e.g., Keung & Ho, 2009; Manis et al., 2004), RAN was entered in the regression equation along with other cognitive skills (e.g., phonological awareness) and we do not know how much of its effects on L2 reading were unique or shared with the other predictors.

[1] Transfer is defined as the use of linguistic and cognitive knowledge acquired in L1 for L2 learning (Odlin, 1989). It is assessed here only through correlations, not an actual observation of linguistic and cognitive knowledge acquired in L1.

[2] We specifically refer to studies that examined the effects of L1 RAN on L2 reading after controlling for the effects of L2 RAN. There are some studies that examined the effects of L1 RAN on L2 reading without controlling for the effects of L2 RAN (see e.g., Geva et al., 2000; Lafrance & Gottardo, 2005; Morfidi et al., 2007; Pasquarella et al., 2015; Savage et al., 2018). In this case, we cannot really claim that there was a 'transfer' of RAN effects from L1 to L2.

Theories of cross-language transfer

Two of the most prominent theoretical accounts of cross-language transfer are the contrastive-typological framework (Lado, 1957) and the linguistic interdependence framework (Cummins, 1981). In regard to the contrastive-typological framework, Lado (1957) argued that L2 learners rely heavily on their native language when they learn the L2 and that cross-linguistic differences in L2 acquisition are predictable based on a systematic analysis of the structural (e.g., phonology, syntax, semantics) similarities or differences between languages. When specific features are shared by two languages (e.g., letters or letter combinations correspond to phonemes), a "positive transfer" is expected to happen such that learning these features in L2 will be easier than when L1 does not include these features. In contrast, when the two languages are orthographically distant, then a "negative transfer" can occur. Based on this, we should expect a larger transfer among alphabetic orthographies (e.g., Spanish–English, Portuguese–English) than between languages representing different writing systems (e.g., Chinese–English, Japanese–English, Kannada–English).

In regard to the linguistic interdependence framework, Cummins (1981, 2000) argued that L1 proficiency can transfer to L2 learning and that the degree of transfer could vary as a function of quality of instruction in L1 and language proficiency in L2. Unfortunately, it is hard to make testable cross-linguistic predictions using this framework because it would require assessing and equalizing the quality of instruction in L1 across the participating languages.

Building on these theoretical accounts, Geva and Ryan (1993) proposed the 'common cognitive processes' hypothesis according to which correlations between parallel tasks in L1 and L2 (e.g., word reading) do not necessarily mean that skills acquired in L1 'transfer' to L2, but that shared cognitive processes underlie performance in both L1 and L2 reading skills, even when the orthographies vary in complexity and are distant to each other. To illustrate this, Geva (2014) used the example of RAN and argued that "RAN …. is expected to be related to reading fluency in L1 and L2 because it is an underlying cognitive process that should be relevant across languages or learning groups" (p. 6). The problem with this account is that it cannot explain existing data showing that L2 RAN accounts for unique variance in reading in L1, after controlling for L1 RAN (see below).

To date, only a handful of studies have examined the cross-language transfer of RAN skills and have produced mixed findings (e.g., Gholamain & Geva, 1999; Keung & Ho, 2009; Li et al., 2011; Manis et al., 2004; Yeung, 2016). For example, working with a group of Grade 2 children from Hong Kong, Keung and Ho (2009) found no unique effects of L1 RAN on word reading in English (L2). However, RAN in English explained 6% of unique variance in Chinese word reading, even after controlling for several cognitive processes including RAN in Chinese. Yeung (2016) also reported non-significant effects of L1 RAN on English word reading (L2) in second-year kindergarten children in Hong Kong, but in contrast to Keung and Ho, she also found non-significant effects of L2 RAN on Chinese word reading. Finally, working with a group of Grade 2, 4, and 6 Chinese–English bilinguals, Li et al. (2011) reported no significant effects of L1 RAN on English reading ability (L2) and no significant effects of L2 RAN on Chinese reading ability.

The present study

The purpose of the present study was to examine if the effects of RAN transfer from L1 to L2 reading, and if the findings vary as a function of the orthographic proximity of the languages comprising each pair. Assuming the typological-contrastive framework is correct (Lado, 1957), we should see a larger transfer among alphabetic languages that share linguistic features (i.e., Spanish–English, Portuguese–English) than between languages with different linguistic features (e.g., Chinese–English, Japanese–English, Kannada–English). In addition, within each pair of alphabetic languages, the effect should go from L1 to L2 (i.e., the less proficient one) and not the other way around. The examples presented above (e.g., Keung & Ho, 2009) challenge this hypothesis but need to be replicated with older participants who have reached automaticity in RAN in L1 at least. However, we also know that RAN in L1 correlates strongly with RAN in L2 (e.g., Li et al., 2011; Manis et al., 2004; Yeung, 2016) and that the mechanisms underlying the RAN–reading relationship are very similar across languages (e.g., Georgiou et al., 2013, 2016). This means that controlling for the effects of L2 RAN should leave little room for L1 RAN to explain unique variance in L2 word reading.

In contrast to previous studies that included only one group of bilingual participants, in our study we selected bilinguals with different L1 languages using different types of writing system. More specifically, we collected data from Chinese (representing a logographic writing system), Kannada and Oriya (representing an alphasyllabic writing system), and English, Portuguese, and Spanish (representing an alphabetic writing system).[3] The alphabetic languages were selected to lie at different points along the orthographic consistency continuum. Spanish is considered a transparent orthography, Portuguese an orthography of intermediate depth, and English an opaque orthography (Seymour et al., 2003).[4] In addition, we collected data from Japanese- and Arabic-speaking participants. The Japanese writing system is a mixed system that employs two functionally distinct subsystems: Hiragana and Kanji. Hiragana is a transparent phonetic syllabary in which each character corresponds to the same mora in all words (Taylor & Taylor, 2014). In contrast, Kanji is a morphography in which a character can represent multiple morphemes. Thus, results in Hiragana should be similar to those in other syllabaries like Kannada, and results in Kanji should be similar to those in Chinese. Finally, Arabic is a consonantal alphabetic orthography that has different orthographic features from the rest of the alphabetic orthographies and this adds an interesting angle to the notion of orthographic depth (see Share & Daniels, 2015; Tibi & Kirby, 2018, for details).

Method

Participants

Seven hundred and thirty-five university students participated in our study. More specifically, we included 85 Mandarin-speaking Chinese students (24 males, 61 females, $M_{\text{age}} = 20.82$, range 18.05–27.08 years), 84 Japanese students (29 males, 55 females, $M_{\text{age}} = 20.10$ years, range 18.0–23.0 years), 100 Kannada-speaking Indian students (31 males, 69 females, $M_{\text{age}} = 20.95$, range 19.0–23.0 years), 40 Oriya-speaking Indian students (19 males, 21 females, $M_{\text{age}} = 20.43$, range 18.0–22.0 years), 115 English-speaking Canadian students (32 males, 83 females, $M_{\text{age}} = 21.66$, range 17.12–28.10 years), 115 Arabic-speaking Palestinian students (56 males, 59 females, $M_{\text{age}} = 20.35$, range 17.04–24.02 years), 105 Portuguese-speaking Brazilian students (44 males, 61 females, $M_{\text{age}} = 23.40$, range 18.01–30.00 years), and 91 Spanish-speaking Mexican students (27 males, 64 females, $M_{\text{age}} = 21.79$, range 17.06–28.07 years). All participants were native speakers of their language, were attending an undergraduate program in their respective university (the majority of them were in their third or fourth year of their studies), and were recruited either through advertisements in their university campus or through the subject pool program. In the Chinese-, Japanese-, Arabic-, Portuguese- and Spanish-speaking groups, English was one of the school subjects and participants were also exposed to it through some university classes and media (e.g., tv series). In contrast, for the Kannada- and Oriya-speaking participants, English was the medium of instruction at school and at university.

For their participation in our study, students received either a small honorarium (less than $15 CAD) or 5% credit towards one of their courses (this applies to the students recruited through the subject pool programs). None of the participants reported experiencing any sensory or behavioral difficulties. Written consent from each participant was obtained prior to testing.

[3] For a detailed description of these languages see Joshi and Aaron (2005), Winskel and Padakannaya (2013), and Mishra and Stainthorp (2007).

[4] Even though the English-speaking participants were not tested in a second language, we included them in our study because we wanted to see how close the correlations among the L2 (English) tasks in the other languages would be to those derived from a sample of native speakers of similar age.

Materials

Rapid automatized naming (RAN)

To assess RAN, we administered Digit Naming and Object Naming in the participants' native language as well as in English (L2). In English, we adopted the tests from the RAN/RAS test battery (Wolf & Denckla, 2005). More specifically, participants were asked to name as fast as possible five digits (2, 7, 4, 9, 5) or objects (hand, book, chair, dog, star) that were repeated ten times each and arranged in a semi-random order in five rows of ten. In each of the other languages, we created a new card for digit naming by re-arranging the items from its English version. The average syllabic length of the items in each language was the following: Chinese: 1.0, Japanese: 1.2, Kannada: 1.8, Oriya: 1.8, Arabic: 2.0, Portuguese: 1.8, and Spanish: 1.8.

In Object Naming, we selected new items in each language in order to keep the syllabic length of objects as close as possible to the digits. We did not administer the same items as in English because the names of the items in the English version can be very long in the other languages, thus introducing a confound. The average syllabic length of the items in each language was the following: Chinese: 1.0, Japanese: 1.8, Kannada: 2.0, Oriya: 2.0, Arabic: 1.0, Portuguese: 1.8, and Spanish: 2.0. The objects in each language were also selected to be highly frequent. A participant's score was the time per item, which was derived by dividing the total time by the number of items. The number of naming errors was negligible and was not considered further (mean number of errors was less than 1 in each language and task). Previous studies with young adults reported test–retest reliability for RAN Digits and Objects to be 0.86 and 0.80, respectively (Georgiou et al., 2018; Tsantali, 2014).

Reading accuracy

Word reading accuracy was assessed only in Chinese, Japanese (Kanji), Kannada, Oriya, and English. Because of the transparency of the other orthographies, reading accuracy in adulthood was expected to be at ceiling and for this reason we did not assess it. In English, reading accuracy was assessed with the Word Identification task (Form H) from Woodcock Reading Mastery Tests-Revised (Woodcock, 1998). Participants were asked to read aloud and as accurately as possible a list of 106 words of increasing difficulty. Cronbach's alpha reliability in our samples ranged from 0.90 to 0.96. In Chinese, Kannada, and Oriya, we used existing word reading tasks that were adopted from Liu et al. (2017), Padakannaya (1999), and Mahapatra et al. (2010), respectively. In Japanese, participants were asked to read as accurately as possible 120 Kanji words that were selected from The Japan Kanji Aptitude Testing Foundation (2019). Cronbach's alpha reliability in these languages ranged from 0.88 to 0.94. In all languages, the task was discontinued after six consecutive errors and a participant's score was the total number correct.

Reading fluency

In English, participants were assessed with the Word Reading Efficiency (WRE) and Phonemic Decoding Efficiency (PDE) tasks from the Test of Word Reading Efficiency-Second Edition (TOWRE-2; Torgesen et al., 2012). The participants were asked to read as fast as possible a list of words (max = 108) or pseudowords (max = 66). The score was the number of correct words/pseudowords read in 45 s. Torgesen et al. (2012) reported alternate-form reliability for WRE and PDE in ages 17–24 to be 0.92. In the other languages, we either used existing word/nonword reading fluency tasks that have been used in previous studies (e.g., Inoue et al., 2017, 2020; Leong et al., 2005; Liu et al., 2013, 2017; Martinez et al., 2021; Saldanha et al., 2014; Tibi et al., 2020) or developed new ones following the structure of TOWRE-2 in English (Portuguese, Oriya).[5] Irrespective of language, the tasks followed the same format (i.e., words and nonwords were arranged in columns and in terms of increasing difficulty) and a participant's score was the total number of words/nonwords read correctly in 45 s. In Arabic, words were partially vowelized in order to eliminate different pronunciations due to the homography of some words. Because WRE correlated strongly with PDE in both L1 and L2 (*r*s were higher

[5] Notice that since this study is concerned with correlations between RAN and reading accuracy/fluency and not with comparisons of scores in reading between the different groups, we did not match the reading tasks across languages. Such endeavor would be almost impossible with the number of languages included here and the writing systems they represent.

than 0.60), we created a composite score for reading fluency in each language (L1) and English (L2) by averaging the z scores in WRE and PDE. In Japanese, we derived a reading fluency score by averaging the z scores in Hiragana real word fluency, Hiragana pseudoword fluency, and Kanji real word fluency. Alternate-form reliability for WRE and PDE in the other languages has been reported to be higher than 0.80 (e.g., Inoue et al., 2017; Liu et al., 2017; Saldanha et al., 2014; Tibi et al., 2020).

Procedure

Participants were individually tested in their respective universities by experimenters with substantial experience on test administration and scoring. The testers were native speakers of their respective language and fluent in English. L1 instructions were used for the L1 measures and both English and L1 instructions were used for the English measures to ensure participants understood what they were expected to do in L2. Testing was completed in one session lasting approximately 30 min. The order of L1 and L2 testing was counterbalanced. The protocols within each language were checked by a second rater for accuracy purposes and the interrater agreement ranged from 99 to 100%.

Results

Table 1 shows the descriptive statistics of the measures used in our study, separately for each language. RAN Objects in either L1 or L2 was slower than RAN Digits and performance in L2 RAN was generally slower than L1 RAN. The exception to this was the performance of the Kannada- and Oriya-speaking participants. Because English is the medium of instruction for these participants, they were faster in English than in their native language. This was also reflected in their performance in the L2 reading tasks. They were much closer to the performance of the native English speakers than any other group. The descriptive statistics also revealed great variability in the performance of the different language groups in L2 reading; suggesting different levels of English language proficiency among the language groups included in our study.

Prior to conducting any further analyses, we checked the distributional properties of the measures for any deviations from normality. The distributions of the RAN tasks were positively skewed in all languages except Oriya. To normalize their distribution, we winsorized the scores of the outliers (one to three outliers in each language and task) to the next non-outlier's score plus or minus 1 (Tabachnick & Fidell, 2012) and we used the winsorized scores in further analyses.

Table 2 shows the correlations between RAN Digits and Objects in L1/L2 and the reading outcomes in L1/L2, separately for each language. The correlations between RAN and reading accuracy (L1 or L2) were relatively weak and generally failed to reach significance. For example, the correlations between L1/L2 RAN and L1 reading accuracy ranged from 0.12 to − 0.30. Likewise, the correlations between L1 RAN and L2 reading accuracy ranged from 0.11 to − 0.39. In contrast, most correlations with reading fluency in both L1 and L2 were significant and strong. For example, the correlations between L1/L2 RAN and L1 reading fluency ranged from − 0.34 to − 0.72. Using Fischer's r to z transformation for correlation comparisons, we found that the correlations between L2 RAN (both Digits and Objects) and L2 reading accuracy were significantly stronger in the Arabic, Portuguese, and Spanish groups than in the group of native English speakers. Finally, RAN Digits and Objects in L1 correlated significantly and strongly with their corresponding tasks in L2 (rs ranged from 0.39 to 0.76). The highest correlations were observed in Japanese and the lowest in Spanish.

Next, we performed hierarchical regression analyses to predict reading accuracy and fluency in L2 (see Table 3). Within each language, we ran two models. First, we ran a model in which we entered RAN Digits and Objects in L2 at step 1 of the regression equation and RAN Digits and Objects in L1 at step 2 of the regression equation. Second, we ran a model in which we reversed the order of entry. Results of Table 3 (Model 1) show that after controlling for the effects of L2 RAN, L1 RAN explained 13% of unique variance in L2 reading accuracy in the Chinese group, 12% of unique variance in the Portuguese group, and 12% of unique variance in the Spanish group. These findings are likely due to suppression as none of the correlations between L1 RAN and L2 reading accuracy in Chinese, Portuguese, and Spanish were significant

Table 1 Descriptive statistics of the measures used in our study

	M	*SD*	Skewness	Kurtosis
Chinese				
RAN Digits_L1	0.20	0.03	0.781	0.241
RAN Objects_L1	0.48	0.07	0.616	− 0.221
RAN Digits_L2	0.44	0.09	0.664	0.383
RAN Objects_L2	0.53	0.08	0.369	− 0.123
Word Id_L1 (max = 100)	81.24	4.86	− 0.344	0.129
Word Id_L2 (max = 106)	68.35	10.12	0.133	0.016
WRE_L1 (max = 180)	101.61	13.66	0.259	0.141
WRE_L2 (max = 108)	75.33	7.96	− 0.074	− 0.110
PDE_L1 (max = 144)	90.98	11.94	0.293	0.838
PDE_L2 (max = 66)	42.41	7.09	− 0.291	0.200
Japanese				
RAN Digits_L1	0.28	0.06	0.384	0.408
RAN Objects_L1	0.59	0.08	0.270	− 0.799
RAN Digits_L2	0.42	0.07	0.299	− 0.374
RAN Objects_L2	0.53	0.08	0.624	0.109
Word Id_Kanji (max = 120)	91.91	4.76	0.113	− 0.483
Word Id_L2 (max = 106)	72.57	11.70	− 0.105	− 0.138
WRE_Hiragana (max = 104)	85.73	11.89	− 0.326	− 0.175
WRE_Kanji (max = 120)	80.84	12.25	0.174	0.237
WRE_L2 (max = 108)	69.48	8.57	− 0.354	− 0.275
PDE_Hiragana (max = 63)	45.53	9.75	0.261	− 0.760
PDE_L2 (max = 66)	39.96	8.80	0.150	0.241
Kannada				
RAN Digits_L1	0.43	0.06	0.488	− 0.031
RAN Objects_L1	0.59	0.09	0.822	0.450
RAN Digits_L2	0.30	0.04	0.587	− 0.038
RAN Objects_L2	0.55	0.08	0.506	− 0.533
Word Id_L1 (max = 150)	138.22	11.19	− 1.327	1.183
Word Id_L2 (max = 106)	87.87	10.99	− 0.683	0.515
WRE_L1 (max = 108)	58.94	10.15	− 0.669	0.017
WRE_L2 (max = 108)	80.39	10.72	− 0.386	0.685
PDE_L1 (max = 66)	39.45	9.62	0.321	− 0.513
PDE_L2 (max = 66)	48.74	9.33	− 0.645	0.542
Oriya				
RAN Digits_L1	0.32	0.06	− 0.439	− 0.915
RAN Objects_L1	0.52	0.08	− 0.247	0.496
RAN Digits_L2	0.24	0.05	0.174	0.448
RAN Objects_L2	0.49	0.08	0.135	0.601
Word Id_L1 (max = 100)	92.40	5.29	− 0.664	− 0.318
Word Id_L2 (max = 106)	94.57	5.13	− 0.304	− 0.577
WRE_L1 (max = 108)	64.35	7.72	− 0.576	− 0.123
WRE_L2 (max = 108)	90.67	8.09	− 0.197	0.403
PDE_L1 (max = 66)	51.85	7.33	− 0.360	− 0.460
PDE_L2 (max = 66)	49.03	7.54	− 1.131	0.983

Table 1 continued

	M	*SD*	Skewness	Kurtosis
English				
RAN Digits	0.27	0.04	0.474	0.372
RAN Objects	0.47	0.07	0.472	− 0.166
Word Id (max = 106)	96.40	4.22	− 0.865	0.437
WRE (max = 108)	96.71	6.87	− 0.768	− 0.147
PDE (max = 66)	55.46	6.02	− 1.002	0.578
Arabic				
RAN Digits_L1	0.33	0.06	0.487	0.297
RAN Objects_L1	0.53	0.08	0.117	− 0.480
RAN Digits_L2	0.42	0.09	0.422	0.539
RAN Objects_L2	0.59	0.12	0.502	0.165
Word Id_L2 (max = 106)	62.10	16.41	0.359	− 0.615
WRE_L1 (max = 86)	58.82	9.79	0.408	− 0.400
WRE_L2 (max = 108)	60.76	13.12	− 0.039	− 0.721
PDE_L1 (max = 70)	35.53	9.48	0.628	− 0.046
PDE_L2 (max = 66)	38.50	9.60	− 0.099	− 0.812
Portuguese				
RAN Digits_L1	0.35	0.07	0.757	0.341
RAN Objects_L1	0.51	0.09	0.568	− 0.279
RAN Digits_L2	0.49	0.09	0.491	0.303
RAN Objects_L2	0.60	0.10	0.794	0.284
Word Id_L2 (max = 106)	72.62	17.67	− 0.837	− 0.169
WRE_L1 (max = 108)	85.80	9.61	0.004	0.135
WRE_L2 (max = 108)	67.02	12.14	− 0.538	0.708
PDE_L1 (max = 66)	51.42	5.79	0.206	− 0.189
PDE_L2 (max = 66)	40.86	9.77	− 0.455	− 0.117
Spanish				
RAN Digits_L1	0.36	0.07	0.557	0.075
RAN Objects_L1	0.60	0.11	0.846	0.889
RAN Digits_L2	0.51	0.09	0.333	− 0.216
RAN Objects_L2	0.63	0.11	0.475	− 0.301
Word Id_L2	67.72	19.20	− 0.235	− 0.987
WRE_L1 (max = 108)	82.94	12.04	− 0.394	− 0.388
WRE_L2 (max = 108)	68.52	12.33	− 0.189	0.089
PDE_L1 (max = 66)	44.93	7.10	0.121	0.063
PDE_L2 (max = 66)	49.61	7.12	− 0.639	0.452

RAN rapid automatized naming, *Word Id* word identification, *WRE* word reading efficiency, *PDE* phonemic decoding efficiency

(see Table 2). In addition, L1 RAN explained 13% of unique variance in L2 reading fluency in the Chinese group. In all other languages, the effects of L1 RAN on L2 reading were non-significant after controlling for L2 RAN. When we reversed the order of entry (see Model 2), L2 RAN continued to predict 7–32% of unique variance in L2 reading accuracy and 17–28% of unique variance in L2 reading fluency.

Table 2 Correlations between RAN and reading in L1 and L2

	L1		L2 (English)		
	Accuracy	Fluency	RAN[a]	Accuracy	Fluency
Chinese					
RAN Digits (L1)	0.12	− 0.38**	0.39**	− 0.08	− 0.34**
RAN Objects (L1)	0.11	− 0.34**	0.51**	0.09	− 0.01
RAN Digits (L2)	0.01	− 0.35**		− 0.43**	− 0.52**
RAN Objects (L2)	− 0.12	− 0.43**		− 0.18	− 0.28**
Japanese					
RAN Digits (L1)	− 0.30**	− 0.72**	0.61**	− 0.24*	− 0.42**
RAN Objects (L1)	0.10	− 0.50**	0.76**	0.10	− 0.25*
RAN Digits (L2)	− 0.13	− 0.58**		− 0.32**	− 0.59**
RAN Objects (L2)	0.10	− 0.49**		− 0.04	− 0.29**
Kannada					
RAN Digits (L1)	− 0.14	− 0.55**	0.56**	− 0.03	− 0.40**
RAN Objects (L1)	− 0.29**	− 0.54**	0.71**	− 0.16	− 0.41**
RAN Digits (L2)	− 0.23	− 0.44**		− 0.24	− 0.67**
RAN Objects (L2)	− 0.27*	− 0.45**		− 0.19	− 0.41**
Oriya					
RAN Digits (L1)	− 0.14	− 0.65**	0.51**	− 0.27	− 0.44*
RAN Objects (L1)	− 0.27	− 0.39*	0.60**	− 0.17	− 0.35*
RAN Digits (L2)	− 0.08	− 0.50**		− 0.37*	− 0.62**
RAN Objects (L2)	− 0.19	− 0.35*		− 0.22	− 0.40*
English					
RAN Digits (L1)				− 0.22*	− 0.62**
RAN Objects (L1)				− 0.10	− 0.41**
Arabic					
RAN Digits (L1)		− 0.55**	0.50**	− 0.39**	− 0.50**
RAN Objects (L1)		− 0.38**	0.58**	− 0.24**	− 0.29**
RAN Digits (L2)		− 0.39**		− 0.46**	− 0.60**
RAN Objects (L2)		− 0.45**		− 0.55**	− 0.62**
Portuguese					
RAN Digits (L1)		− 0.70**	0.56**	− 0.12	− 0.30**
RAN Objects (L1)		− 0.45**	0.58**	− 0.03	− 0.31**
RAN Digits (L2)		− 0.57**		− 0.48**	− 0.65**
RAN Objects (L2)		− 0.50**		− 0.37**	− 0.55**
Spanish					
RAN Digits (L1)		− 0.57**	0.36**	− 0.01	− 0.41**
RAN Objects (L1)		− 0.30**	0.41**	0.11	− 0.24*
RAN Digits (L2)		− 0.48**		− 0.49**	− 0.62**
RAN Objects (L2)		− 0.48**		− 0.38**	− 0.56**

RAN rapid automatized naming

*$p < 0.05$; **$p < 0.01$

[a]The correlation is between the same type RAN task (L1 Digit Naming with L2 Digit Naming and L1 Object Naming with L2 Object Naming)

Table 3 Results of hierarchical regression analyses predicting reading scores in English (L2)

Step	Variable	Reading accuracy		Reading fluency	
		β	ΔR^2	β	ΔR^2
Chinese (Ch)					
Model 1					
1	RAN Digits E	− 0.499***	0.20***	− 0.537***	0.27***
	RAN Objects E	0.113		0.035	
2	RAN Digits Ch	0.082	0.13***	0.190*	0.13***
	RAN Objects Ch	0.418***		0.396***	
Model 2					
1	RAN Digits Ch	− 0.104	0.02	− 0.358***	0.12**
	RAN Objects Ch	0.115		0.086	
2	RAN Digits E	− 0.667***	0.30***	− 0.581***	0.27***
	RAN Objects E	− 0.018		− 0.107	
Japanese (J)					
Model 1					
1	RAN Digits E	− 0.458***	0.13**	− 0.648***	0.35***
	RAN Objects E	0.235		0.104	
2	RAN Digits J	− 0.146	0.04	− 0.106	0.01
	RAN Objects J	0.288		− 0.103	
Model 2					
1	RAN Digits J	− 0.332***	0.10*	− 0.397***	0.19***
	RAN Objects J	0.215		− 0.081	
2	RAN Digits E	− 0.353*	0.07*	− 0.597***	0.17***
	RAN Objects E	0.015		0.195	
Kannada (K)					
Model 1					
1	RAN Digits E	− 0.279**	0.10**	− 0.612***	0.46***
	RAN Objects E	− 0.065		− 0.130	
2	RAN Digits K	0.269*	0.04	0.051	0.01
	RAN Objects K	− 0.101		− 0.146	
Model 2					
1	RAN Digits K	0.063	0.03	− 0.266*	0.21***
	RAN Objects K	− 0.189		− 0.264*	
2	RAN Digits E	− 0.404**	0.11**	− 0.621***	0.26***
	RAN Objects E	− 0.045		− 0.043	
Oriya (O)					
Model 1					
1	RAN Digits E	− 0.338**	0.11**	− 0.588***	0.36***
	RAN Objects E	0.135		− 0.154	
2	RAN Digits O	− 0.138	0.03	− 0.136	0.01
	RAN Objects O	0.241		− 0.125	
Model 2					
1	RAN Digits O	− 0.300**	0.09**	− 0.351**	0.17**
	RAN Objects O	0.175		− 0.164	

Table 3 continued

Step	Variable	Reading accuracy		Reading fluency	
		β	ΔR^2	β	ΔR^2
2	RAN Digits E	− 0.223*	0.05*	− 0.475***	0.20***
	RAN Objects E	0.019		0.109	
Arabic (A)					
Model 1					
1	RAN Digits E	− 0.191	0.33***	− 0.348***	0.46***
	RAN Objects E	− 0.434***		− 0.402***	
2	RAN Digits A	− 0.086	0.01	− 0.165	0.03
	RAN Objects A	0.141		0.150	
Model 2					
1	RAN Digits A	− 0.356***	0.16***	− 0.465***	0.26***
	RAN Objects A	− 0.088		− 0.085	
2	RAN Digits E	− 0.182	0.18***	− 0.323***	0.23***
	RAN Objects E	− 0.470***		− 0.406***	
Portuguese (P)					
Model 1					
1	RAN Digits E	− 0.422***	0.21***	− 0.516***	0.40***
	RAN Objects E	− 0.043		− 0.148	
2	RAN Digits P	0.117	0.12***	0.062	0.01
	RAN Objects P	0.404***		0.102	
Model 2					
1	RAN Digits P	− 0.181	0.03	− 0.223*	0.13***
	RAN Objects P	0.070		− 0.199	
2	RAN Digits E	− 0.609***	0.30***	− 0.582***	0.28***
	RAN Objects E	− 0.204		− 0.189	
Spanish (S)					
Model 1					
1	RAN Digits E	− 0.418***	0.25***	− 0.438***	0.42***
	RAN Objects E	− 0.105		− 0.267*	
2	RAN Digits S	0.170	0.09**	− 0.167	0.03
	RAN Objects S	0.246*		− 0.019	
Model 2					
1	RAN Digits S	− 0.042	0.01	− 0.370***	0.18***
	RAN Objects S	0.124		− 0.123	
2	RAN Digits E	− 0.418***	0.32***	− 0.404***	0.27***
	RAN Objects E	− 0.268*		− 0.216	

RAN rapid automatized naming, *E* English

*$p < 0.05$; **$p < 0.01$; ***$p < 0.001$

Finally, we performed hierarchical regression analyses to predict reading accuracy and fluency in L1 (see Table 4). Results of Table 4 (Model 1) revealed that RAN in L2 predicted reading fluency in Chinese (8% of unique variance), Portuguese (3% of unique variance), and Spanish (9% of unique variance) when

Table 4 Results of hierarchical regression analyses predicting reading scores in L1

Step	Variable	Reading accuracy		Reading fluency	
		β	ΔR^2	β	ΔR^2
Chinese (Ch)					
Model 1					
1	RAN Digits Ch	0.103	0.02	− 0.313***	0.21***
	RAN Objects Ch	0.084		− 0.261*	
2	RAN Digits E	0.013	0.05	0.012	0.08*
	RAN Objects E	− 0.261		− 0.329**	
Model 2					
1	RAN Digits E	0.129	0.03	− 0.147	0.20***
	RAN Objects E	− 0.201		− 0.343***	
2	RAN Digits Ch	0.116	0.04	− 0.296**	0.09*
	RAN Objects Ch	0.208		− 0.102	
Japanese (J)					
Model 1					
1	RAN Digits J	− 0.396***	0.14**	− 0.624***	0.58***
	RAN Objects J	0.255*		− 0.248*	
2	RAN Digits E	− 0.058	0.01	− 0.148	0.01
	RAN Objects E	0.194		− 0.023	
Model 2					
1	RAN Digits E	− 0.289*	0.06	− 0.437***	0.36***
	RAN Objects E	0.268		− 0.229*	
2	RAN Digits J	− 0.391**	0.09*	− 0.542***	0.23***
	RAN Objects J	0.129		− 0.203	
Kannada (K)					
Model 1					
1	RAN Digits K	0.003	0.13***	− 0.371***	0.39***
	RAN Objects K	− 0.368***		− 0.344***	
2	RAN Digits E	− 0.140	0.01	− 0.131	0.02
	RAN Objects E	− 0.033		− 0.087	
Model 2					
1	RAN Digits E	− 0.139	0.10*	− 0.314**	0.29***
	RAN Objects E	− 0.233*		− 0.312**	
2	RAN Digits K	0.075	0.04	− 0.302**	0.12**
	RAN Objects K	− 0.325*		− 0.266*	
Oriya (O)					
Model 1					
1	RAN Digits O	0.182	0.11**	− 0.584***	0.42***
	RAN Objects O	− 0.305**		− 0.142	
2	RAN Digits E	− 0.101	0.01	− 0.060	0.02
	RAN Objects E	− 0.062		− 0.166	
Model 2					
1	RAN Digits E	− 0.089	0.04	− 0.420***	0.26***
	RAN Objects E	− 0.160		− 0.286*	

Table 4 continued

Step	Variable	Reading accuracy		Reading fluency	
		β	ΔR^2	β	ΔR^2
2	RAN Digits O	0.062	0.08*	− 0.318**	0.18**
	RAN Objects O	− 0.300*		− 0.155	
Arabic (A)					
Model 1					
1	RAN Digits A			− 0.477***	0.33***
	RAN Objects A			− 0.173	
2	RAN Digits E			− 0.088	0.01
	RAN Objects E			− 0.093	
Model 2					
1	RAN Digits E			− 0.184	0.22***
	RAN Objects E			− 0.340**	
2	RAN Digits A			− 0.403***	0.12***
	RAN Objects A			− 0.115	
Portuguese (P)					
Model 1					
1	RAN Digits P			− 0.651***	0.53***
	RAN Objects P			− 0.140	
2	RAN Digits E			− 0.066	0.03*
	RAN Objects E			− 0.195	
Model 2					
1	RAN Digits E			− 0.398**	0.33***
	RAN Objects E			− 0.214	
2	RAN Digits P			− 0.588***	0.23***
	RAN Objects P			− 0.012	
Spanish (S)					
Model 1					
1	RAN Digits S			− 0.530***	0.34***
	RAN Objects S			− 0.130	
2	RAN Digits E			− 0.213*	0.09**
	RAN Objects E			− 0.150	
Model 2					
1	RAN Digits E			− 0.291*	0.27***
	RAN Objects E			− 0.286*	
2	RAN Digits S			− 0.416***	0.16***
	RAN Objects S			− 0.060	

RAN rapid automatized naming, *E* English

*$p < 0.05$; **$p < 0.01$; ***$p < 0.001$

entered at step 2 of the regression equation. Again, no significant effects were detected in the other languages.[6] When the order of entry in the regression equation was reversed (see Model 2), results showed that L1 RAN continued to explain 9–23% of unique variance in L1 reading fluency after controlling for the effects of L2 RAN. In both Tables 3 and 4, we also see that a large proportion of RAN's predictive variance in reading fluency was shared between L1 and L2 RAN (43–59% in Table 3 and 52–69% in Table 4).[7] The only exception was Chinese in which L1 and L2 RAN shared less than 5% of their predictive variance.

Discussion

The purpose of this study was to examine if the effects of RAN on reading accuracy and fluency transfer from L1 to L2 and vice versa, and whether the transfer is influenced by the orthographic proximity of the languages. We found little evidence of cross-language transfer. There might be two explanations for this. First, as shown by Branum-Martin et al. (2012) and Melby-Lervåg and Lervåg (2011), it is not only the orthographic proximity that matters in cross-language transfer, but the task itself and the linguistic grain size of the tasks used. In the case of RAN, individuals are asked to name highly-familiar stimuli selected from a rather limited set of items (this is at least true for digits) and the dimensionality of RAN in upper grades/adulthood (alphanumeric RAN: digits and letters; non-alphanumeric RAN: objects and colors) appears to be similar in the different languages it has been examined (e.g., Närhi et al., 2005; Rodríguez et al., 2015; Siddaiah et al., 2016; van den Bos et al., 2002). In light of this, we should not expect much transfer from one language to another. Second, general processes underlying RAN, such as processing speed, eye movement control, or motor programming are accounted for after controlling for RAN in either language and thus cannot make a unique contribution to reading in either language.

However, RAN and reading require phonological production in addition to general processes, and the languages included here vary greatly in their phonological characteristics (similarity of phonemes, presence or absence of certain phonemes, use of tone, proportion of words in the word lists that are polymorphemic or polysyllabic). This may explain why L1 RAN was a unique predictor of L2 reading accuracy only among the Chinese-, Portuguese-, and Spanish-speaking individuals. The significant effect of L1 RAN on L2 reading fluency in the Chinese group was also the only significant effect on reading fluency in all the languages included here. Together, these findings cast doubt on the basic premise of the contrastive-typological framework (Lado, 1957), according to which transfer from L1 to L2 may be facilitated among languages that share similar linguistic and orthographic features. In our study, Chinese is the most typologically distant from English.

An alternative explanation for the significant effect of L1 RAN on L2 reading accuracy may be that in both Chinese- and Spanish-speaking groups we obtained the lowest correlations between the L1 and L2 RAN tasks (see Table 2). From a statistical point of view, this means that L1 RAN had less overlap with L2 RAN than in the other languages and controlling for L2 RAN in the regression analyses did not appreciably impact L1 RAN's chances to predict L2 reading. Of interest is also the fact that in Chinese, Portuguese, and Spanish, the significant predictors were L2 RAN Digits and L1 RAN Objects. These two correlated 0.19 (*ns*) with each other in Chinese, 0.38 in Portuguese, and 0.37 in Spanish, and they were the lowest correlations among the languages included in our study.

A similar pattern of findings was observed when L2 RAN was used to predict reading accuracy and fluency in L1. We obtained significant effects in Chinese, Portuguese, and Spanish, but only when the outcome

[6] In Japanese, we also ran hierarchical regression analyses with Hiragana word fluency and Kanji word fluency as the outcome measures. The results were the same as those presented in Table 4 with a composite fluency score. L2 RAN did not significantly predict Hiragana fluency or Kanji fluency when entered in the regression equation at step 2.

[7] To calculate the proportion of shared variance, we first looked at how much variance in the outcome measure the predictor explained when entered at step 1 and at step 2, and then calculated their difference. Next, we divided this difference score by the amount of variance explained by the same predictor when entered at step 1 of the regression equation. For example, in Table 4 in Japanese, L1 RAN Digits and Objects explained 58% of the variance in reading fluency when entered at step 1 and 23% of the variance when entered at step 2 (difference score = 35%). We then divided the 35 by 58 to find what percentage was shared between the two predictors (35/58 = 60.34%).

measure was reading fluency. This suggests that RAN in L2 English influences only the reading skill in L1 that continues to develop. Taken together, our findings support Geva's (2014) 'common cognitive processes' hypothesis according to which significant correlations between reading outcomes in L1 and L2 do not necessarily imply transfer, but may be a product of shared underlying cognitive processes (e.g., RAN). Indeed, irrespective of language, RAN (particularly RAN Digits) correlated strongly with reading fluency in both L1 and L2. Our findings further suggest that orthographic proximity among languages is not likely a key factor since we obtained similar results among languages that share orthographic features with English (i.e., Portuguese, Spanish) and languages that do not have much in common (i.e., Chinese).

Some limitations of the present study should be reported. First, our study is correlational and any significant effects of RAN on reading do not imply causation. In fact, there is evidence that reading may also influence RAN (e.g., Georgiou et al., 2020; Powell & Atkinson, 2021). Second, even though we included university students with sufficient exposure to English (L2), we could not obtain an accurate estimate of years of exposure to English (e.g., even though some children start learning English at a certain grade level at school, they also learn English through private tutoring which makes it hard to estimate how much exposure to English they had) and we do not know if their level of proficiency is equal across languages. In fact, the scores of the different language groups in reading accuracy and fluency in English suggest that some groups were very proficient in English (e.g., the Oriya group), whereas others were still learning English (e.g., the Arabic group). As a result, our findings should be interpreted with some caution. Third, we conducted our study with university students and our results may not generalize to young children who are in the process of learning to read a second language. In fact, it is quite possible that L1 RAN has an effect on L2 reading when the children are in the early phases of L2 reading development. Finally, we did not match the task properties across languages, even though we tried to match the syllabic length of the items in RAN Digits and Objects within each language. Matching is desirable but when you have so many diverse languages, it is an impossible task. Researchers have also shown that matching tasks across languages in one parameter may artificially introduce differences in another parameter (e.g., Caravolas, 2018; Landerl et al., 2019). For this reason, we kept the tasks in each language as is.

To conclude, our findings add to a small body of studies examining the cross-language transfer effects of RAN on reading (e.g., Keung & Ho, 2009; Li et al., 2011; Manis et al., 2004) by showing that once you control for the effects of RAN in either L1 or L2, there is very little variance to be accounted for, and this is irrespective of how close or distant the languages are. A significant effect of L1 RAN on L2 reading was observed only in languages in which the RAN tasks were not as strongly related to each other across L1 and L2. Taken together, these findings suggest that the existing theoretical frameworks of cross-language transfer (i.e., contrastive-typological framework, linguistic interdependence framework) might be too simplistic when applied to RAN to capture the conditions under which there is transfer from L1 to L2 and vice versa. As indicated by some researchers (e.g., Chung et al., 2019; Fumero & Tibi, 2020), cross-language transfer is likely influenced by multiple cognitive and linguistic factors such as L1 and L2 distance, proficiency levels in L1 and L2, and L1–L2 complexity. A future study should explore the cross-language transfer of RAN skills across several languages with both young children and adults.

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Declarations

Conflict of interest On behalf of all authors, the corresponding author states that there is no conflict of interest.

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