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Research paper

The role of sound-to-symbol literacy in phonological awareness: Evidence from Cantonese

Tamara Rathcke*, Hiu Yan Wong, Massimiliano Canzi

Department of Linguistics, University of Konstanz, Germany

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ABSTRACT

Phonological awareness reflects linguistic knowledge related to the sound system of a language. Individual development of phonological awareness is known to progress from larger to smaller sized units and is promoted by the acquisition of literacy, especially in alphabet-based writing systems that are built around sound-to-symbol correspondences. The present study addressed the nature of phonological awareness in speakers of a logographically scripted language. It investigated phonological awareness in adult speakers of Cantonese hailing from Hong Kong who (compared to speakers of other logographically scripted languages) traditionally received little sound-based assistance from tools like Pinyin or Zhu-yin-Fu-Hao when they acquired orthography. The study adopted an individual difference approach, quantifying individually variable levels of experience with a sound-to-symbol writing system and their relationship to phonological awareness. Fifty-seven Hong-Kong speakers of Cantonese took part online, completing rhyme judgment and phoneme monitoring tasks, alongside an extensive background questionnaire. The main prediction that Cantonese speakers who had a relatively high level of experience with sound-to-symbol writing would show an advantage in phonological awareness at the subsyllabic level was largely borne out by the data. The findings of the present study suggest that phonological awareness is a complex set of dissociable skills, shaped by the linguistic and orthographic experience of individual speakers.

1. Introduction

Phonological awareness represents individual knowledge of the sound system of one's native language(s) (Castles and Coltheart, 2004; Leong and Goswami, 2014). It is considered key to successful language processing (Snowling, 2001) and involves efficient encoding of the entire phonological system, measured as the ability to identify, discriminate, retain, and manipulate sound structures of one's native language(s) (Leong and Goswami, 2014; Ziegler and Goswami, 2005). Partly implicitly acquired, the knowledge of the sound system is frequently made explicit at the onset of schooling (Ziegler and Goswami, 2005). To examine the development of phonological awareness, there exists a large array of tests, many of them specifically targeting the ability to segment a continuous speech stream into smaller constituents. For example, distinguishing between onsets and rimes or onsets, nuclei, and codas within a syllabic unit forms a foundational aspect of phonological awareness (Chen et al., 2004; Ho & Bryant, 1997; Huang & Hanley, 1995; Shu et al., 2008; Siok & Fletcher, 2001). Similarly, awareness of the number of constituents contained within a larger unit and awareness of the hierarchical structure of words and phrases are part of this linguistic knowledge (Høien et al., 1995; Lenchner, Gerber, and Routh, 1990; Ziegler and Goswami, 2005). It has been suggested that phonological awareness, along with phonological recoding in lexical access and phonetic encoding in working memory, constitutes one of the three main building blocks of phonological processing in general (Wagner and Torgesen, 1987).

The development of phonological awareness closely follows the acquisition of literacy (Anthony and Francis, 2005; Carroll et al., 2003; Ziegler and Goswami, 2005). Pre-schoolers tend to be able to identify larger linguistic units before smaller ones, progressing from word-level to syllable-level, then to onset/rime-level, and lastly to phoneme-level awareness (Anthony & Francis, 2005; Carrillo, 1994; Carroll et al., 2003; Ho & Bryant, 1997; Ziegler & Goswami, 2005). While onset/rime awareness can be well-developed in kindergarteners, phoneme awareness (i.e., the ability to isolate, manipulate, and delete syllable-medial and −final phonemes) does not appear before the onset of schooling, with typically-developing children reaching full competence by the age of eight (Cooper et al., 2002). The tight connection between

* Corresponding author.
E-mail address: tamara.rathcke@uni-konstanz.de (T. Rathcke).

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phonological skill and the acquisition of literacy is further documented by impairments in the acquisition of literacy such as developmental dyslexia. Dyslexic individuals tend to have a reduced ability to segment lexical items into discrete phonological units (Peterson and Pennington, 2015; Vellutino et al., 2004), show poor performance in phoneme awareness tasks (Caravolas et al., 2012), display a reduced short-term memory capacity for verbal information, and exhibit slower phonological recoding (Ramus and Szenkovits, 2008; Wagner and Torgesen, 1987). Indices of a well-developing phonological awareness at an early age have been seen as a reliable indicator of reading ability later in life (e.g., Hulme et al., 2002), though such links between phonology and orthography seem to exist primarily in languages that use an alphabetic writing system based on phoneme-to-grapheme correspondences (Anthony and Francis, 2005; Jevtović et al., 2022; Ziegler and Goswami, 2005).

Not all languages are scripted using the alphabetic principle of phoneme-to-grapheme correspondences Verhoeven et al., 2017. In languages like Chinese, Taiwanese, or Japanese, the writing system does not (or does not fully) reflect phonological representations, with the mapping between scripts and sounds varying arbitrarily. For example, varieties and languages united under the umbrella of the Chinese language can profoundly differ in their phonological representations of morphemes or words that are, however, at the same time uniformly scripted as holistic symbols (Sampson, 1985). These symbols – also referred to as characters or logograms – have a squared shape and consist of a semantic radical (denoting meaning), and a phonetic radical (indicating some aspects of pronunciation, Siok & Fletcher, 2001). In contrast to alphabet-based languages, however, phonetic radicals provide only partial cues for the phonological representations of the characters, and the sound(s) resulting from one phonetic radical can vary depending on the semantic radical it occurs with (Siok & Fletcher, 2001). In other words, correspondences between characters (i.e., graphemes) and pronunciations (i.e., phonemes) are mostly highly irregular. Overall, such writing systems prioritise the represention of units of meaning over units of phonology as alphabet-based languages do. Given that Chinese characters are monomorphemic and monosyllabic Verhoeven et al., 2017, Chinese orthography has sometimes been referred to as morphosyllabic (e.g. Tolchinsky et al., 2012).

Previous research has found that reading ability in languages like Chinese is not as strongly connected to the development of phonological awareness as it is in English (Huang and Hanley, 1995; McBride-Chang et al., 2004), though evidence is mixed (Ho & Bryant, 1997; Hu & Catts, 1998; Huang & Hanley, 1997; Tolchinsky et al., 2012). Cross-linguistic studies assessing phonological awareness in beginning readers of Chinese, compared to children of the same age acquiring alphabet-based orthography, have shown that they had a similar (or an even superior) performance for syllable-level units but a poor performance for any subsyllabic units (McBride-Chang et al., 2005; Shu et al., 2008; Tolchinsky et al., 2012). Researchers argue that syllable-level awareness may be primarily promoted by the morphosyllabic nature of the language itself and somewhat less influenced by its writing system (cf. Ruan et al., 2018). Older Chinese children demonstrate subsyllabic unit awareness at the onset/rime level by the age of seven, with awareness at the phoneme level lagging behind (Siok & Fletcher, 2001; Shu et al., 2008). Ho and Bryant (1997) suggest that the patterns of development of phonological awareness (i.e., larger units first, smaller units last) are consistent across learners of different orthographies, though the temporal trajectories are delayed in children acquiring logographic orthography such as the Chinese writing system.

However, weaker phonological awareness at the phoneme level may persist into adulthood, at least in some varieties of Chinese (Holm and Dodd, 1996; McDowell and Lorch, 2008). For example, the performance of Mandarin Chinese speakers compares well to the performance of speakers who had successfully acquired alphabet-based literacy across a number of phonological awareness tasks, while Cantonese speakers from Hong Kong usually tend to underperform, even in comparison to other speakers of Chinese (Holm and Dodd, 1996; McDowell and Lorch, 2008). This finding is generally attributed to the differences in language teaching approaches adopted in Hong Kong and mainland China. When schoolers in Hong Kong start to learn Chinese orthography, no or very little phonetic assistance is offered. In contrast, orthographic acquisition of Mandarin Chinese in mainland China is supported by Pinyin, a romanised alphabetic script that can be used to transparently transcribe spoken language. Pinyin uses the Latin alphabet and consists of 21 onsets, 35 rimes, and special signs for four lexical tones (Ding et al., 2018). Notably, Pinyin primarily emphasises the onset-rime boundary, not the individual phonemes of the rime, when transcribing the pronunciation of a character; though, it is otherwise reported to be even more transparent than, for example, English orthography (Ding et al., 2018). Another system for representing sounds in a logographically scripted language is Zhu-Yin-Fu-Hao, used primarily in Taiwan. Principles of Zhu-Yin-Fu-Hao closely follow Pinyin, with the same number and content of symbols differing only in their orthographic representations (Huang and Hanley, 1997). Similar to mainland China, Taiwanese children are taught Zhu-Yin-Fu-Hao at the very beginning of reading instruction, to help them access the pronunciation of the characters. Neither of these systems is an integral part of the educational process in Hong Kong.

The present study investigates phonological awareness in adult speakers of Cantonese who were born and raised in Hong Kong. Compared to Chinese speakers from mainland China or Taiwanese speakers whose literacy acquisition of a morphosyllabic writing system traditionally involves the assistance of a sound-to-symbol script like Pinyin or Zhu-yin-Fu-Hao, respectively, Cantonese speakers in Hong Kong do not use any sound-to-symbol tools when they acquire Chinese orthography. These learners tend to start reading in kindergarten and also learn English at some point during their education, with both language orthographies being acquired through a whole-word approach (Ho & Bryant, 1997). They may take Mandarin classes and get some experience with Pinyin at school, though it is never as prolonged and extensive as it is in mainland China. The first research question of the present study asks if the development of phonological awareness in these speakers may be influenced by individual familiarity with any writing system(s) based on phonemic segmentation of syllable units in accordance with the sound-to-symbol principle. Alongside Pinyin and Zhu-yin-Fu-Hao, some Cantonese speakers may have also had exposure to alphabet-based literacy related to foreign and second language acquisition (e.g., English, French) as well as to the International Phonetic Alphabet (IPA, cf. McDowell & Lorch, 2008).

We were further interested in testing the universal phonological principle in speakers of Cantonese. This principle postulates that readers – irrespective of the writing system they have acquired – activate phonological representations when presented with printed words (Perfetti and Zhang, 1995; Perfetti, Zhang, and Berent, 1992). Accordingly, phonological activation during reading holds across writing systems, elements of a writing system, and individual readers regardless of their literacy attainment. However, Lin et al. (2010) suggest that the logographic nature of Chinese characters is unlikely to require phoneme-level processing. Existing evidence for Mandarin Chinese speakers from mainland China and Taiwanese speakers supports the universal phonological principle (Ding et al., 2018; Huang and Hanley, 1997), though as outlined above, the use of Pinyin or Zhu-Yin-Fu-Hao during the acquisition of literacy is likely to increase the involvement of phonological processes during reading in these participants. The second research question of the present study therefore asks if phonological representations of words are activated as an integral part of the reading process in Cantonese readers with variable exposure to sound-to-symbol writing systems.

Based on previous research documenting a connection between sound-to-symbol literacy and phonological awareness (Anthony and Francis, 2005; Carroll et al., 2003; Ziegler and Goswami, 2005), we predicted that Cantonese speakers who had a relatively high level of experience with sound-to-symbol writing would show an advantage in phonological awareness, specifically at the subsyllabic level that involves segmentation of the syllable rime in its constituent phonemes (Hypothesis 1). Examining the universal phonological principle (Perfetti and Zhang, 1995; Perfetti et al., 1992), we further hypothesised phonological activation during an orthographic stimulus presentation to be stronger in readers who were more familiar with sound-to-symbol writing (Hypothesis 2).

To test these hypotheses, we created a rhyming task that could be administered online auditorily as well as orthographically. Previous research deployed a similar task to test the universal phonological principle in bilingual Mandarin-Cantonese speakers (Lam, Perfetti, and Bell, 1991). Moreover, recognition of rhymes forms part of test batteries that investigate phonological awareness, along with phoneme or syllable counting tasks and phoneme or syllable substitution and deletion tasks (e.g., Høien et al., 1995; Leong & Goswami, 2014; Ziegler & Goswami, 2005). It targets the ability to segment onsets and rimes and can also be used to test the ability to segment vowels and codas. In addition, we used a phoneme monitoring task testing participants' ability to segment a continuous speech stream that did not contain any lexical information and to identify phoneme-sized units in onset and coda positions (cf. Rathcke & Lin, 2021). The demands of this task lay at the intersection of acoustic and phonological processing given that nonsense strings without real word embeddings could not facilitate phoneme access via lexical boost (Frauenfelder, Segui, and Dijkstra, 1990), meaning that listeners had to attend to acoustic cues to consonants constrained by syllable phonology. While the results of the rhyming task could provide an answer to both research questions in the present study, the phoneme monitoring task was expected to primarily inform the first research question. We expected participants to be better at both tasks if they had more experience with sound-to-symbol writing.

2. Methods

2.1. Participants

58 adult Cantonese speakers (38 female; age range 19–70, mean age: 25) born and raised in Hong Kong volunteered to take part in the current study. All participants gave informed written consent prior to taking part in the experiment and reported normal hearing and normal or corrected-to-normal vision. One participant disclosed a diagnosis of developmental dyslexia and was excluded from the analyses. Among the remaining participants (N = 57), four were multilinguals, i.e., native speakers of Cantonese and at least one other language, predominantly English, that had been acquired prior to age 10. 33 participants had learned one further language, typically Mandarin or English, at a later age.

The participants were recruited via researchers' networks and social media platforms. As an incentive for participation, a prize draw was advertised during recruitment, with five winners receiving an Amazon voucher worth 15€ upon completion of the data collection. Participants could select whether or not they wanted to be considered for the prize draw by providing their contact details after submitting their responses. The prize draw information and the experimental data were treated separately.

2.2. Materials

The experiment included two tasks, a rhyming task that required participants to judge pairs of words as either rhyming or not rhyming, and a phoneme monitoring task that required participants to respond to a specified phoneme embedded in nonsense strings.

Sixteen minimal pairs were selected for the rhyming task. Each minimal pair consisted of two Cantonese characters representing real words with a CVC syllable structure (e.g. /tyn^{6}/ 段 "paragraph") and differed in one phonemic feature: onset consonant, coda consonant, vowel, or tone. Examples are given in Table 1. In the experiment, the pairs were presented orthographically and auditorily, in two separate, counterbalanced blocks. For the auditory presentation, 32 Cantonese words were recorded by a native speaker of Cantonese (the second author), concatenated with a 500-ms silence between the two target words of each minimal pair, and saved as a mp3-file.

Forty-eight nonsense strings were created for the phoneme monitoring task. Each string consisted of three to four syllables with a variable syllable structure (CVC, CV, or V). The target phonemes to be monitored in a block were either /t/ or /n/. The phonemes could occur either in onset (e.g., [lu^{2}.**tʰ**ɔn^{1}.hɛ^{3}], [mam^{1}.ŋu^{3}.**n**yt^{2}.fɐp^{4}]) or in coda (e.g., [fam^{2}.hɛ^{4}.wɔ**t**^{5}.nœ^{6}], [pʰap^{2}.tʰɛ^{3}.my**n**^{4}.ju^{5}]) position of CVC-syllables (Bauer, 2016). Please note that /t/ was aspirated in onsets and unaspirated in codas, meaning that the phonetic realisation (and potentially the perceptual salience, cf. Law, Fung, and Bauer, 2001) of /t/ – in contrast to /n/ – differed between the two syllable positions. A syllable containing a target could occur in the second or the third position of a nonsense string but never the first or the last. Half of the nonsense string contained a target (12 strings contained /t/ and 12 strings contained /n/), and half served as distractors. Half of the targets occurred in the onset position (n = 12) and the other half occurred in the coda position (n = 12). A native speaker of Cantonese (the second author) recorded the nonsense strings and prepared 48 mp3-files, each containing one nonsense string. All materials used in the present study are available on OSF (https://osf.io/7z8nq/).

2.3. Questionnaire

A questionnaire was created to screen for exclusion criteria (here, speech, language, or orthography disorders and hearing issues) and to gather comprehensive information about participants' language background, including questions on multilingualism and proficiency in second or foreign language(s). The special focus of the questionnaire was on participants' familiarity with any sound-based writing system, including Pinyin, Zhu-yin-Fu-Hao, the Latin alphabet, the Yale romanisation of Cantonese, and the alphabet of the International Phonetic Association (IPA), as well as the frequency of using these sound-to-symbol systems. Thirty-three participants reported no knowledge of Pinyin or Zhu-yin-Fu-Hao, and 17 participants were completely unfamiliar with the alphabet-based spelling of English or other alphabet-scripted languages. Only two participants had experience with both IPA and the Yale romanisation of Cantonese. Answers to the question about participants' individual familiarity with a sound-to-symbol writing system were collected on a scale from 1 (not familiar at all) to 10 (highly familiar). Answers to the question about their individual frequency of using a sound-to-symbol writing system were collected on a scale from 1 (never) to 5 (daily). In addition, the questionnaire asked about the frequency of individual habits, such as listening to Cantonese songs or reading modern and traditional Chinese poetry. These answers were collected on a scale from 1 (never) to 5 (daily) and were entered as control factors in the statistical modelling of the rhyming task responses. A summary of the questionnaire questions used in the present study can be found on OSF (https://osf.io/7z8nq/).

Table 1
Examples of minimal pairs used in the rhyming task. Superscript numbers indicate tone.

Experimental condition	Minimal pairs	
Onset	葉 /jip^{6}/ "leaf"	蝶 /tip^{6}/ "butterfly"
Coda	北 /pɐk^{1}/ "north"	崩 /pɐŋ^{1}/ "to collapse"
Vowel	扇 /sin^{3}/ "fan"	傘 /san^{3}/ "umbrella"
Tone	餅 /pɛŋ^{2}/ "biscuit"	病 /pɛŋ^{6}/ "ill"

2.4. Procedure

The experiment was set up and conducted online using the research platform Gorilla (Anwyl-Irvine et al., 2020). It started with a brief introduction of the aims of the study, eligibility criteria, and technical requirements, followed by experimental instructions and consent forms. Participants were asked to set aside an undisturbed period of around 20 minutes in a quiet room with no external noise. They were required to use a mobile device with a built-in speaker and a touch screen (e.g., a mobile phone or a tablet) and to join the study from any browser except Safari (the latter was blocked due to technical issues with sound playback that had been identified during piloting). Finally, participants were instructed to use the built-in speaker of their device for the playback, and a test sound was given for setting the volume to an individually comfortable level. Once a participant consented to taking part, they were directed to the first block of the rhyming task (in the auditory or orthographic condition, counterbalanced across participants), followed by the phoneme monitoring task, then the second block of the rhyming task (in the orthographic or auditory condition, depending on the first rhyming task), and finally the background questionnaire.

The rhyming task started with extended experimental instructions which contained a traditional Chinese poem as an example of rhyming words by way of explaining rhymes and rhyming. As part of the instructions, participants were reminded that there was no correct or wrong answer to the rhyming questions and what mattered was their spontaneous and intuitive response. The experimental task started after a series of practice trials given for familiarization with the procedure. Participants either had to listen to or read minimal pairs (differing in vowel, tone, onset or coda consonant) and had to respond as quickly as possible, judging whether or not the two words rhymed with each other. Responses were collected using two buttons placed on the touch screen, green indicating a positive response and red indicating a negative response. Each trial started with a fixation cross displayed on the screen for 250 milliseconds. This was followed by the presentation of either orthographic or auditory stimuli separated by a 500-ms pause. In the orthographic presentation mode, one character was displayed for 1 second (cf. Zhou et al., 2014; Wang et al., 2021). Attention was paid to the fonts of the orthographic stimuli. Given potential variability on the type of device participants may have used, the font size was not fixed but set to 50 % of the device screen size. On both types of stimulus presentation, one second was given for responses before the experiment proceeded to the next trial. The sixteen minimal pairs were presented in a randomised order, blocked by stimulus modality. After a presentation of a minimal pair, participants had to indicate their response by pressing one of the two buttons (rhyming/not rhyming) on the touch screen of their device as soon as possible. Both responses and reaction times were collected and analysed.

The phoneme monitoring task intervened between the two (orthographic/auditory) blocks of the rhyming task. At the beginning of the phoneme monitoring task, participants were instructed to click on a green button given in the centre of the touch screen as soon as they heard a specific phoneme contained in a nonsense string and to do nothing but wait for the next trial if they did not hear the phoneme. The experiment progressed to the next trial automatically after a one-second time-out. Four practice trials were provided as part of the instructions, with the task to monitor for the phoneme /m/. In the main part of the experiment, each target phoneme (/t/ and /n/) was described by a Chinese character containing the target in the onset (here, 他 "he", pronounced as [$t^h a^1$] and 南 "south", pronounced as [nam^4]). The 48 items in the phoneme monitoring task were grouped into four blocks of 12 stimuli, each containing three targets in the onset position, three targets in the coda position, and six distractors. Each target phoneme was monitored in two consecutive blocks. The order of blocks was counterbalanced while the order of nonsense-strings within a block was randomised.

Upon completion of all experimental tasks, participants were requested to fill in the questionnaire. The average duration of the rhyming task was five minutes, the phoneme monitoring task took about three minutes, while the questionnaire could be completed in five to ten minutes (depending on the individual circumstances of the participant). The study received ethical approval from the institutional review board (Ethics Committee) of the University of Konstanz (IRB statement 05/2021, dated 04/02/2021).

2.5. Data pre-processing and analyses

Raw data from all tasks were preprocessed and analysed using R (R Core Team, 2022). First, individual background data were analysed. Using factor analysis implemented in the library *psych* (Revelle, 2010), we examined covariance among participants' responses to the four key questions of the questionnaire: (1) whether (coded as 1) or not (coded as 0) participants learned a phonetic support tool such as Pinyin or Zhuyin-Fu-Hao; (2) whether (coded as 1) or not (coded as 0) participants acquired any sound-to-letter systems such as the Latin alphabet, Yale romanisation, or the IPA; (3) the degree of their familiarity with these sound-to-symbol systems (on a scale from 1 to 10); and (4) the frequency of their using these sound-to-symbol systems (on a scale from 1 to 5). To account for the combination of ordinal and binary factors in these data, we deployed polychoric correlations and maximum-likelihood factor analysis, and derived the Bartlett weighted least-squares scores which were then used as a metric of individual experience with sound-to-symbol writing systems based on these four factors. Even though the method accounts for the varied nature of the present data, it may arguably give higher weight to the scaled variables and lower weight to the binary variables entering the factor analyses, thus retaining more information from two out of four variables used in the present study (cf. Schiel and Shaw, 1992).

Responses made to orthographic/auditory stimuli in the rhyming task were categorised as 0 (not rhyming) or 1 (rhyming). These responses were modelled as the dependent variable using mixed-effects logistic regression implemented in the *lme4*-package in R (Bates et al., 2015). A change of the default optimiser to "bobiqa" helped to combat the model convergence issues. Log-transformed response times (RTs) were analysed using a mixed-effects linear regression from the same R package *lme4*. Both models tested for an interaction of individual experience with sound-to-symbol writing system (here, the Bartlett factor score scaled and centred around group mean) and experimental condition (onset, vowel, coda, tone) as well as presentation mode (orthographic/auditory). In these models, we further checked for the contribution of the individually variable frequency of listening to Cantonese songs, and/or reading modern and traditional Chinese poetry (from 1 to 5, scaled and centred around group mean). Random intercepts were assigned to experimental participant and stimulus, and participant was fitted with a random slope for experimental condition. Since the experiment was conducted online and attracted participants of different ages, reaction time models further included participant age as a covariate (Fozard et al., 1994) and checked for a potential effect of browser and device type (Semmelmann and Weigelt, 2017) by fitting each unique combination of browser and device ($n = 41$) as a random intercept. Model fit and predictors' contribution were examined using χ^2 tests implemented in the function *Anova()* from the R-package *car* (Fox et al., 2022). Model estimates (**β**) and standard errors (SE) were obtained from the summary() function (R Core Team, 2022).

To analyse the phoneme monitoring data, timings of targets embedded in the nonsense strings were manually annotated by a native speaker of Cantonese (the second author) and checked by an expert phonetician (the first author). Reaction times were measured from the onset of the stimulus until the button-click or the time-out. Subsequently, response times (RTs) were calculated by subtracting the time-point of the target offset from the reaction time measured in a nonsense string. Missed targets were coded as 0, correctly identified targets as 1. The binary accuracy score was used as the dependent variable in a logistic mixed-effects model testing for an interaction of individual experience with sound-to-symbol writing systems (here, the Bartlett factor score scaled and centred around group mean) and experimental condition (target location in syllable onset vs. coda). Given that /t/ (unlike /n/) had slightly different acoustic realisations in the onset vs. coda position, target type was also entered as a predictor in the analyses. Log-transformed response times to correctly identified targets were analysed in a linear mixed-effects model testing for an interaction of individual experience with sound-to-symbol writing systems, experimental condition (onset vs. coda), and target (/t/, /n/). Random intercepts were assigned to participant and stimulus, with a random slope for experimental condition by participant. Response time models additionally included participant age as a covariate and the combination of browser and device type as a random intercept. Model fit and predictors' contribution were again calculated by means of χ^2 tests of the function *Anova()* from the R-package *car* (Fox et al., 2022).

3. Results

3.1. Individual-level analyses

The factor analysis indicated that responses to the questions about familiarity with a sound-based writing system and the frequency of its use were strongly correlated ($R^2 = 0.86$, $t(54) = 12.63$, $p < 0.001$), with high factor loadings (familiarity: 0.997; frequency: 0.866). In contrast, knowledge of an alphabet or a phonetic support tool did not substantially contribute to the results of the factor analysis (phonetic tools: 0.184; alphabet: −0.143). Overall, more participants were familiar with an alphabet (Latin, IPA, the Yale romanisation of Cantonese – 69.5 % of participants) than with a phonetic support tool used during the acquisition of Chinese writing (Pinyin or Zhu-yin-Fu-Hao – 41.1 % of participants).

The covariance matrix of the four factors is plotted in Fig. 1. The distribution of the derived metric of individual experience with sound-to-symbol writing systems (the Bartlett factor score) is plotted in Fig. 2 (the higher the score, the higher the experience with sound-to-symbol writing of a given participant).

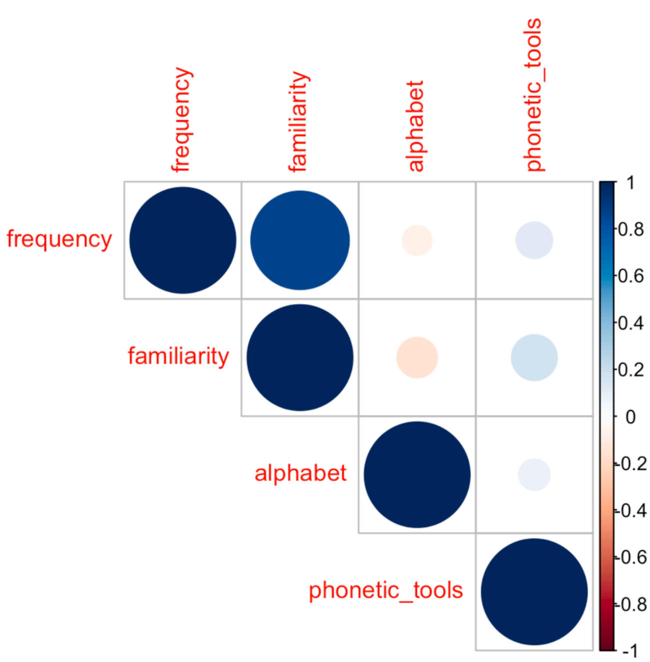

Fig. 1. Covariance among four individual factors describing experience with a sound-based writing system (including the knowledge of an *alphabet*, *phonetic tools*, self-assessed *familiarity* with a sound-to-symbol system, and *frequency* of its use).

3.2. The rhyming task

The best-fitting model of the rhyming data retained a two-way interaction between the experimental condition and individual experience with sound-based writing systems ($\chi^2 = 15.36$, df = 3, p = 0.001). The presentation mode, whether auditory or orthographic, did not yield a significant improvement to the model fit, and there was no interaction with the individual metric. Individual engagement with Cantonese songs, and/or modern or traditional Chinese poetry also did not contribute to the model fit.

The interaction between the experimental condition and experience with sound-to-symbol writing is plotted in Fig. 3, displaying marginal means. Accordingly, participants' performance with the onset-manipulated stimuli was almost at ceiling, with all participants, regardless of their experience with sound-to-symbol writing systems ($\beta = 0.41$, SE=0.22, z = 1.82, p = 0.069), accepting onset-stimulus pairs as rhyming. A similar result was found for tone-manipulated stimuli ($\beta = 0.27$, SE=0.48, z = 0.55, p = 0.582), though there was slightly more variability among the study participants in response to these word pairs. Word pairs manipulating vocalic nuclei were generally rated as not rhyming, though a small effect of familiarity with sound-based writing systems could be observed ($\beta = 1.17$, SE = 0.42, z = 2.80, p = 0.005), indicating that participants with less sound-to-symbol experience (occasionally) rated vowel-manipulated stimuli as rhyming. Finally, acceptance of coda-manipulated stimulus pairs as rhyming was strongly shaped by individual experience with sound-based writing systems ($\beta = 1.23$, SE=0.37, z = 3.35, p < 0.001).

As far as response times are concerned, the speed of the ability to make a rhyming judgment was not influenced by individual experience with sound-to-symbol writing systems, neither as a main effect nor in interaction with mode of presentation (auditory/orthographic) or experimental condition (onset, tone, vowel, coda). However, mode of presentation helped to improve the model fit ($\chi^2 = 75.54$, df = 1, p < 0.001), with the orthographically presented word pairs being judged as rhyming or not approximately 200 ms faster than their auditorily presented counterparts ($\beta = 0.36$, SE = 0.04, t = 8.69, p < 0.001, see Fig. 4A). Additionally, age of the participant significantly influenced response times ($\chi^2 = 7.67$, df = 1, p = 0.005), with younger participants making faster responses than older participants ($\beta = 0.02$, SE=0.01, t = 2.77, p = 0.007), see Fig. 4B).

3.3. The phoneme monitoring task

The best-fitting model of the accuracy data collected in the phoneme monitoring task retained a three-way interaction of individual experience with sound-to-symbol writing, experimental condition, and target ($\chi^2 = 6.86$, df = 1, p = 0.009). The interaction is plotted in Fig. 5, displaying marginal means. Accordingly, the predicted effect of individual experience with sound-to-symbol writing was limited to the identification of /t/ in the onset position ($\beta = 0.73$, SE=0.29, z = 2.48, p = 0.012). The individual factor did not significantly moderate the identification of /t/ in the coda position ($\beta = 0.20$, SE=0.24, z = 0.85, p = 0.396) or the identification of /n/ in either position (onset: $\beta = 0.19$, SE = 0.24, z = 0.80, p = 0.423; coda: $\beta = 0.18$, SE = 0.20, z = 0.88, p = 0.381). Overall, participants' performance in the task differed depending on the position of a target embedding, with significantly higher accuracy in the onset than in the coda position of a CVC-syllable ($\beta = 5.05$, SE = 0.48, z = 10.57, p < 0.001).

Variance in response times measured for correctly identified targets was best predicted by consonant target (/t/ vs. /n/, $\chi^2 = 36.93$, df = 1, p < 0.001, plotted in Fig. 6A) and participant age ($\chi^2 = 4.10$, df = 1, p = 0.042, plotted in Fig. 6B). These effects show that /t/ was responded to faster than /n/, regardless of the target position in the syllable ($\beta = 0.21$, SE = 0.04, t = 6.08, p < 0.001). Older participants took longer to respond than younger participants in this task ($\beta = 0.007$, SE = 0.004, t = 2.02, p = 0.048, cf. Fozard et al. 1994).

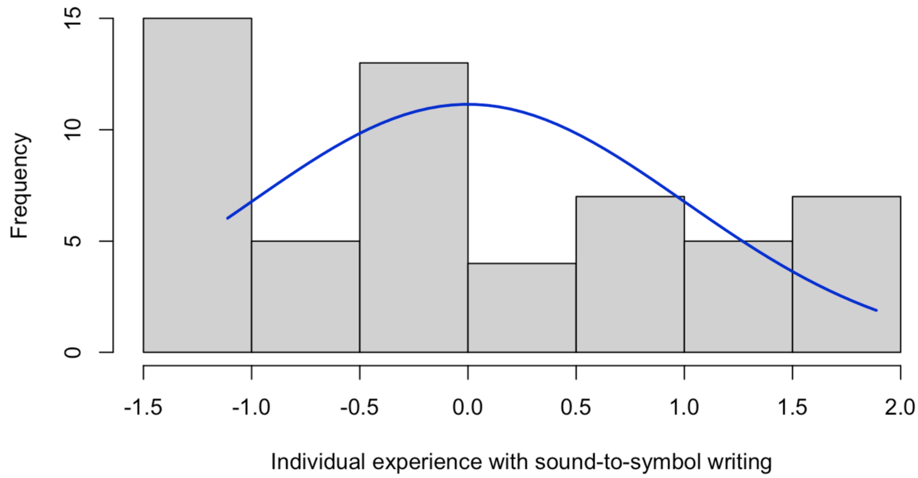

Fig. 2. Distribution of the Bartlett factor scores derived from the factor analyses, reflecting individual experience with sound-to-symbol writing in the present sample. The x-axis represents the range of scores from −1.5 (lower than average experience) to 2.0 (higher than average experience). The y-axis shows the number of individuals at each experience level. The over-imposed blue line reflects the density function of the distribution.

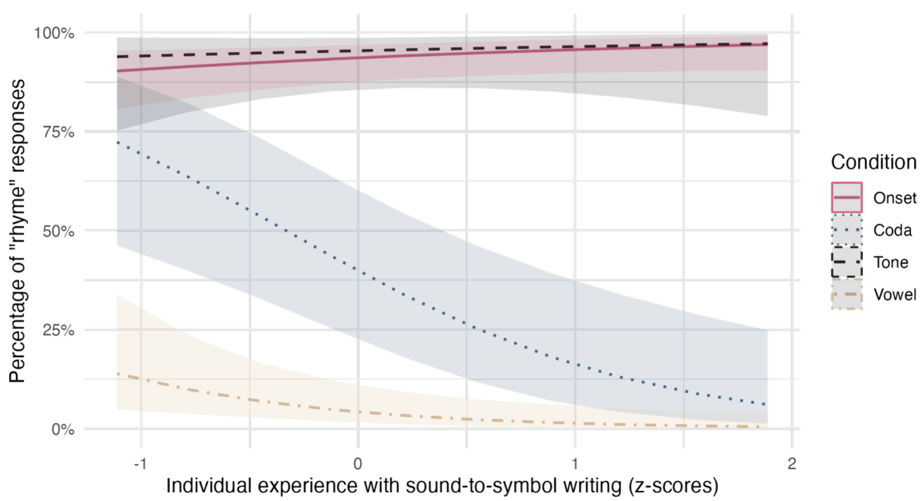

Fig. 3. Model estimates for the two-way interaction between familiarity with sound-based writing systems (z-scores) and experimental condition (minimal pairs differing in onset, vowel, coda, or tone).

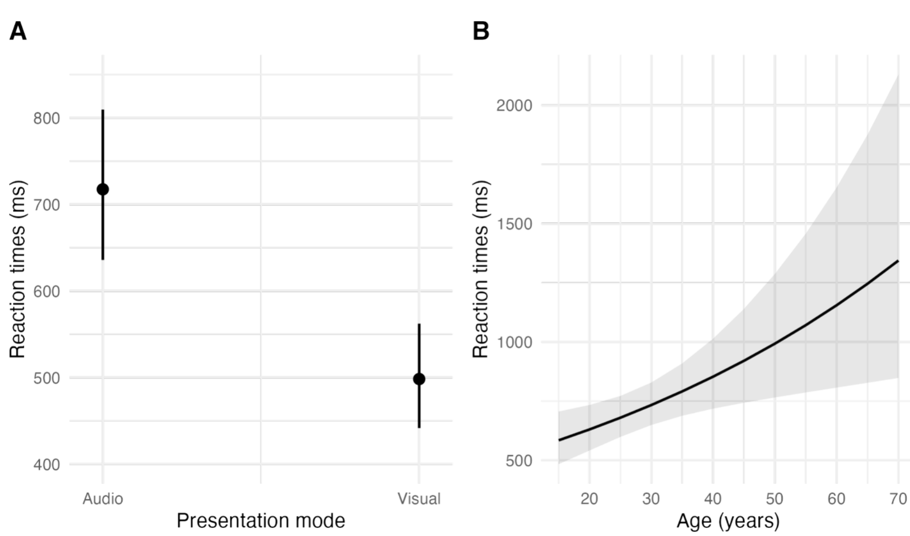

Fig. 4. Model estimates for response times measured across two presentation modes (auditory vs. visual, panel A) and in participants of different ages (panel B).

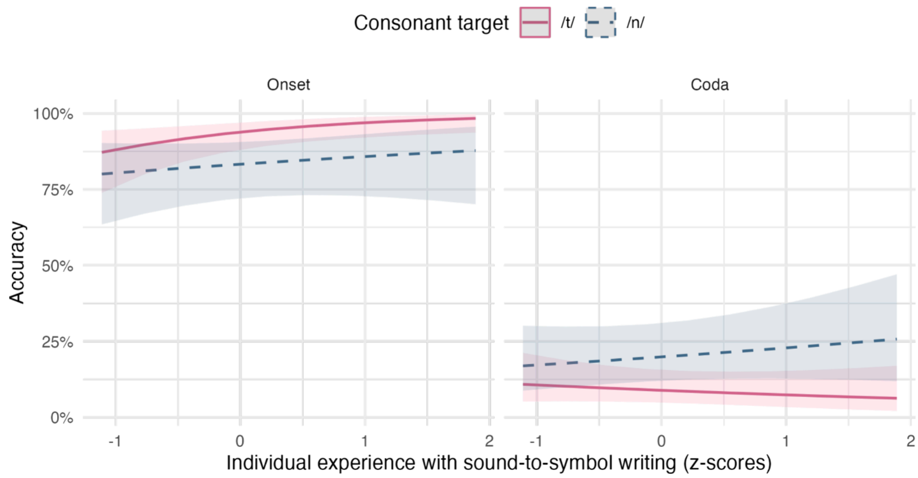

Fig. 5. Model estimates of participants' accuracy in the phoneme monitoring task, showing the three-way interaction between familiarity with sound-based writing (z-scores), experimental condition (onset vs. coda position of a CVC-syllable), and target (/t/ vs. /n/).

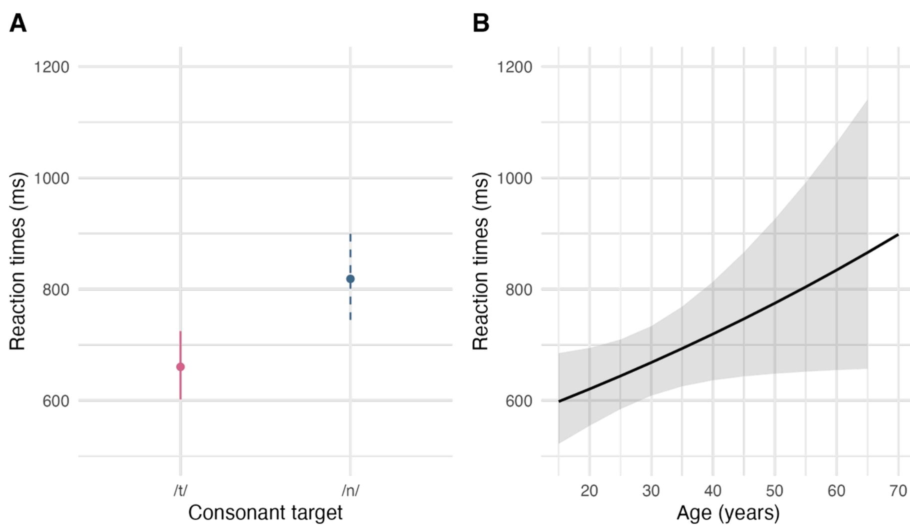

Fig. 6. Model estimates for response times measured for the two consonant targets (/t/ vs. /n/, panel A) and in participants of different ages (panel B).

4. Discussion

The present study aimed to investigate the role of individual experience with sound-to-symbol writing on the phonological awareness of adult speakers of Cantonese who were born and raised in Hong Kong, with a special focus on the subsyllabic level of phoneme-sized units (cf. Høien et al., 1995). Given that Hong-Kong speakers of Cantonese are not traditionally taught any sound-to-symbol script while acquiring Cantonese orthography (e.g. Ho & Bryant 1997, McDowell & Lorch, 2008), we expected – and found – much variability in the individual levels of familiarity and use of different sound-to-symbol scripts like Pinyin, Zhu-yin-Fu-Hao, and the Latin alphabet, along with other sound-based writing tools. About a quarter of the study's participants reported low familiarity with sound-based writing systems and having never used Pinyin or Zhu-yin-Fu-Hao (see Fig. 2). The rest of the participants had at least some experience with sound-based writing systems, with only a few highly experienced participants. We examined how the level of the individually variable experience affected the participants' performance in rhyming and phoneme monitoring tasks, documenting a strong effect of experience with sound-to-symbol writing systems in the former and a weak effect in the latter task.

The ability to recognise rhymes is integral to phonological awareness (e.g., Høien et al., 1995; Leong & Goswami, 2014; Ziegler & Goswami, 2005). In the present study, the rhyming task consisted of an auditory and orthographic presentation of monosyllabic word pairs differing in one phonological feature – onset or coda consonant, vowel, or tone. We were specifically interested in the ability to segment syllable rhymes and to reject word pairs differing in either vowels or coda consonants as rhyming. Hypothesis 1 predicted that Cantonese speakers with a relatively high level of experience with sound-to-symbol writing systems would perform better on this task, showing an advantage in phonological awareness at the subsyllabic level (Høien et al., 1995). This hypothesis was borne out by the data as we found a strong effect of individual experience with sound-based writing systems on rhyming judgements of vowel- and coda-manipulated stimulus pairs. Especially the ability to reject coda-manipulated word pairs as rhyming depended on individual experience with sound-based writing systems: the higher the experience level, the better the ability to segment coda and reject coda-manipulated word pairs as not rhyming.

As part of the task, Hypothesis 2 tested the universal phonological principle, proposing that readers activated phonological representations of printed words as a necessary part of the reading process (Perfetti and Zhang, 1995; Perfetti et al., 1992). A similar task has been used in previous research to investigate the universal phonological principle in bilingual Mandarin-Cantonese speakers from mainland China (Lam et al., 1991). Even though phonology has sometimes been argued to play a marginal role, and to certainly not constitute an automatic process during the reading of a logographic script (Lin et al., 2010), we expected phonological activation to be present in readers of Cantonese (Ding et al., 2018; Huang and Hanley, 1995, 1997); however, we hypothesised it to be stronger in readers who had more experience with sound-to-symbol writing systems. We failed to support this idea comparing participants' performance in the rhyming task in response to an orthographic vs. auditory stimulus presentation. While rhyming judgements were comparable in the two types of stimuli, response times for the orthographically presented stimulus pairs were faster than those for their auditory counterparts. This finding is unlikely to provide evidence in support of phonological activation during the reading of a logographic script. Rather, it may be reflecting an advantage that the longer presentation times implemented in the present experiment provide for orthographic pairs of characters (chosen upon extensive piloting of experimental settings to satisfy the requirements of an online study). More work is required to test the hypothesis of whether or not the strength and the automaticity of phonological activation differ across individuals with variable experience with a sound-based writing system. Arguably, rhyming judgements may not be best suited to detect automatic activation of phonology due to their *meta*-phonological nature. That is, the task of judging a rhyme can only be performed well if phonological representations of the orthographic characters are activated, suggesting a strategic top-down process rather than automatic, bottom-up processing (Dijkstra, Grainger, and Van Heuven, 1999; Goswami, 2002). Future research might therefore benefit from other tasks tapping more automatic processes, such as, for example, the phonetic recoding of print paradigm (Frost, 1991; Frost, Repp, and Katz, 1988).

The phoneme monitoring task further tested the role of individual experience with sound-based writing systems on participants' ability to segment a continuous speech stream that did not contain any lexical information and to identify phoneme-sized units in onset and coda positions (cf. Rathcke & Lin, 2021). We used nonsense strings without lexical embeddings, in order to avoid lexical facilitation effects on phonological processing (Frauenfelder et al., 1990). A successful task performance therefore hinged on an interplay of acoustic and phonological processing, meaning that listeners had to attend to acoustic cues to consonants constrained by syllable phonology. A rather subtle influence of individually variable writing experience was found in the present experiment. Only onset /t/ showed higher accuracy in participants who had more extensive experience with sound-to-symbol writing systems, providing further support for Hypothesis 1. However, the effect was absent for coda /t/ and /n/ in both syllabic positions. This discrepancy cannot be attributed to a purely acoustic effect of salience on onset vs. coda positions (Stevens, 2002), given that, in the present dataset, only /t/ (not /n/) had distinct allophones in onsets vs. coda (cf. Wright, 2001).

Overall, both tasks demonstrated an onset-advantage in subsyllabic unit awareness, meaning that onset targets were generally easier for Cantonese participants to segment than coda targets. Existing theoretical accounts (e.g. Blevins and Goldsmith, 1995) and empirical findings (e.g. Bradley and Bryant, 1983; Treiman, 1985; Uhry and Ehri, 1999) suggest that onsets and rimes may be the cross-linguistically preferred subsyllabic segmentation units, leading to a higher awareness of onset as compared to coda consonants. Onset advantage is, however, not a language universal as speakers of some languages (notably Korean, Dutch, Hebrew, and Arabic) display a coda advantage at the level of subsyllabic segmentation, treating onset and vowel as one unit of a syllable body (Geudens and Sandra, 2003; Kim, 2007; Saiegh-Haddad, 2007). Notably, speakers of Mandarin Chinese also seem to have a body-coda segmentation preference (Chen, 2011), contrasting with the results of the present study for Cantonese speakers.

No unified clear-cut explanations of the subsyllabic segmentation preference across different languages exist (Chen, 2011). Lexical restructuring models of phonological acquisition propose that phonology develops from holistic representations of lexical items to phonemic representations with an increasing vocabulary size during linguistic development (e.g., Metsala et al., 1998). A vocabulary growth poses new discrimination demands among similar-sounding words, leading to a restructuring of phonological representations and segmentation at the subsyllabic level. This is assumed to start with words in dense phonological neighbourhoods (i.e., words with many phonological neighbours) and to extend across the entire lexicon later in life (Storkel, 2002). Restructuring is further suggested to apply at the onset–rime boundary in languages with complex syllable structures, such as English (De Cara and Goswami, 2002; Storkel, 2002). Analyses of English monosyllabic words in the Celex corpus (De Cara and Goswami, 2002) found that phonological neighbours in dense neighbourhoods tend to consist of words sharing rimes while phonological neighbours in sparse neighbourhood tend to mainly contain words sharing syllable bodies (i.e., onset and vowel). These statistical tendencies of the lexicon have been suggested to support the onset–rime segmentation tendency observed in English (De Cara and Goswami, 2002). While these ideas seem plausible, the lexical restructuring hypothesis does not account for the fact that a strong relationship exists between the development of phonological awareness at the subsyllabic level and the acquisition of alphabet-based literacy that starts after children may have learned a large number of similar-sounding words (Anthony and Francis, 2005; Carroll et al., 2003; Ziegler and Goswami, 2005). Moreover, syllable complexity cannot be the only factor driving the subsyllabic awareness, given that the syllable structure of Dutch is even more complex than that of English, yet Dutch speakers show a body-coda segmentation preference while English speakers tend to segment at the onset-rime boundary (Chen, 2011). Cantonese has more restricted syllable phonotactics than English, yet speakers of both languages show an onset advantage and an onset-rime segmentation tendency. Future work involving cross-linguistic comparisons may help to provide an empirically grounded explanation of subsyllabic phonological awareness and its determinants.

To summarise, the present study adopted an individual difference approach to shed new light on the connection between sound-to-symbol literacy and phonological awareness (Anthony and Francis, 2005; Carroll et al., 2003; Ziegler and Goswami, 2005), focussing on adult speakers of a logographically scripted language. The main prediction that Cantonese speakers who had a relatively high level of experience with sound-to-symbol writing would show advantage in phonological awareness at the subsyllabic level was partially borne out by the data collected in two experimental tasks. Critically, the results of this research are based on a comparatively small sample of 57 participants that may be viewed as relatively low-powered in the context of an individual-difference study (Brysbaert, 2019). To make reliable conclusions about the relationship between speakers' individual experience with sound-to-symbol writing and phonological awareness in Hong Kong Cantonese, the results of this study require a replication with a larger number of participants. Taken together, our (preliminary) findings suggest that phonological awareness constitutes a complex set of dissociable skills (Høien et al., 1995) which develop into adulthood and are shaped by the linguistic and orthographic experience of individual speakers (and listeners).

Research ethics statement

All procedures were performed in compliance with relevant laws and institutional guidelines and have been approved by the appropriate institutional committee(s). The study received ethical approval from the institutional review board (Ethics Committee) of the University of Konstanz (IRB statement 05/2021, dated 04/02/2021).

CRediT authorship contribution statement

Tamara Rathcke: Writing – review & editing, Writing – original draft, Visualization, Supervision, Project administration, Methodology, Data curation, Conceptualization. **Hiu Yan Wong:** Software, Resources, Methodology, Investigation, Data curation. **Massimilano Canzi:** Visualization, Formal analysis, Data curation.

Data availability

Data will be made available on request.

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