

Rhythmic constraints in handwriting. A review of Pagliarini et al. (2017)

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Elena Pagliarini, Lisa Scocchia, Mirta Vernice, Marina Zoppello, Umberto Balottin, Sana Bouamama, Maria Teresa Guasti & Natale Stucchi. (2017) Children's first handwriting productions show a rhythmic structure. *Scientific Reports*, Vol. 7. DOI: 10.1038/s41598-017-05105-6

Writing involves several interacting types of processes. However, surprisingly, researchers have focused either on the spelling level or on motor production. The interaction between the two has hardly received attention. Specifically, linguistic research on the time course of handwriting and typing investigates language-related factors that modulate it (e.g. Kandel et al. 2006, 2009, Nottbusch et al. 2005, Nottbusch 2008, Pinet et al. 2016). Among the constraints imposed by language structure on the temporal dimension of writing that have been studied experimentally are lexical frequency, grapheme-phoneme consistency and syllable structure. By contrast, psychologists and neuroscientists are mainly interested in the time course of motor programs in writing. This is also the research rationale of the study carried out by an international team of researchers and published in the prestigious "Scientific Reports" of "Nature" with Elena Pagliarini as a first author.

In this study, 298 children of five age groups, from first to fifth grade of primary school, wrote the Italian word "burle" ('jokes') under different conditions: bigger and smaller, faster and slower, in all-capital block and in cursive script as well as spontaneously. The children wrote the word on a digital tablet using an electronic pen. This method allowed recording the coordinates of the trace and calculate the geometry and kinematics of movement in writing. The aim of the study was to provide evidence that Homothety and Isochrony – two domain independent rhythmic principles that govern motor actions in our brain – guide handwriting from the first year of primary school with no developmental variation. The experimental results showed that children comply with Homothety since

the first grade of primary school, both when writing in all-capital block script and when writing in cursive script. Deviations from Homothety occurred but were marginal. In sum, the duration of each single letter relative to the duration of the word was very similar despite major changes in size and speed in compliance with Homothety. In addition, when children were required to write bigger, they increased their writing speed in order to minimize changes in the global movement duration, in line with Isochrony. The overall results at the group level showed that all age groups complied equally well with Isochrony and – with minor deviations – also with Homothety. The authors conclude that these results also shed new light on studies related to dyslexia and dysgraphia. A previous study conducted by the same authors (Pagliarini et al. 2015) revealed that children with dyslexia and dysgraphia are not able to satisfy the two constraints on the rhythmic organization of handwriting.

Pagliarini and colleagues assume that their results specifically hold for handwriting. They repeatedly claim that, despite being a cultural acquisition, handwriting appears to be shaped by general constraints on timing in movements (Pagliarini et al. 2017, pp. 1–2).

In the present review, we do not aim to call into doubt Homothety and Isochrony. Instead, we want to draw attention to possible limitations of the study that are related to the fact that the authors disregard both language-related factors that have been shown to modulate the time course of handwriting in children as well as the close correspondence between letters and sounds in transparent alphabetic writing systems such as Italian.

Let us begin with our concerns about the target word *burle* and some of its pertinent linguistic properties. Pagliarini and colleagues give no reason for its selection beyond the fact that “it is usually written in a smooth, continuous line when writing in cursive script.” (Pagliarini et al. 2017, p. 2). The linguistic properties of the target word that we want to discuss are related to syllable structure, which has been shown to affect the time course of handwriting in children in other languages (e.g. Kandel et al. 2006, 2009 for French; Nottbusch 2008 for German).

According to Kandel et al. (2006, 2009), French children program the words they write by hand syllable by syllable. The results on letter stroke duration and fluency yielded significant peaks at the syllable boundary within words, indicating that the children use syllables as processing units to program the words they write. Specifically, a systematic duration peak at the first letter of the items’ second syllable was observed.

These results are pertinent to the study of Pagliarini and colleagues. The Italian word *burle* corresponds to two syllables *bur-le*. One deviation from Homothety in cursive script mentioned by Pagliarini and colleagues is due to the longer duration of <l> in the youngest age group. This is exactly the letter at the onset of the

second syllable of *burle*. This suggests that the Italian children of this age group might have used syllables as motor units well in accordance with the findings of the above-mentioned experimental studies for French and German. The fact that a significant longer duration for <l> occurred only in the youngest age group is also in line with previous studies. As noted by Kandel et al. (2009), the syllable structure effect becomes weaker with age when handwriting becomes more fluid.

But why did the youngest Italian children delay the production of <l> only in cursive script? One of the conspicuous differences between block capitals and cursive letters is that only the latter have ascenders or descenders. The letters of *burle* written in cursive script differ in length: and <l> are long letters with ascenders, <u>, <r> and <e> are short letters without ascender or descender. According to Primus (2004) and Fuhrhop et al. (2011) letter length is a cue to syllable structure. This difference is neutralized in block capital letters. This might explain why deviations from Homothety were attested in the study of Pagliarini and colleagues only in cursive script for <l>.

In sum, Homothety – and perhaps also Isochrony – seem to be modulated by the structural properties of the target. Boundaries between structural sub-units cause rhythmic disfluencies. It seems that the motor program in writing and speech is determined both by domain independent constraints such as Homothety and Isochrony and domain specific constraints imposed by language structure.

Another conspicuous property of the target word *burle* is the close correspondence between letters and sounds. The five letters of the Italian word *burle* correspond to five different sounds in a systematic, transparent way. By contrast, there are more opaque writing systems such as English and French. In these languages a word final <e>, for instance, may be silent having no sound correspondent, as in French *mule* ‘mule’ and *belle* ‘beautiful’ and English *hole* and *birle*. We would like to show that using a fully transparent word like *burle* casts some doubt on a major claim of Pagliarini and colleagues that their results specifically hold for handwriting. As mentioned, the authors repeatedly claim that, despite being a cultural acquisition, handwriting is determined by Homothety and Isochrony.

The starting point of our endeavor is the traditional dual-route model of reading and spelling, in which there are two routes between orthography and semantics – a direct route and an indirect route (Rapcsak et al. 2007, Grainger & Ziegler 2011). The direct route makes direct contact between letters with whole-word orthographic form, which then provide access to whole-word phonology and meaning. Along the so-called indirect route, letters and phonemes are connected directly before making contact to whole-word phonology and meaning (Grainger & Ziegler 2011). Both routes involve access to phonology, i.e. sound structure. For instance, the two routes share processing components at the phoneme and letter level. Furthermore, it is assumed that all written and spoken input is processed

obligatorily by both routes in parallel, with cooperative or competitive interactions taking place (Rapcsak et al. 2007). The model applies equally well to spelling and to reading silently or aloud. According to this standard model, the participants in the study of Pagliarini and colleagues activated their phonological knowledge when writing *burle*.

Activating phonological knowledge includes activation of the speech motor system. In compliance with the motor theory of speech perception, people perceive spoken words by mirroring the vocal tract gestures with which they are pronounced rather than by identifying the sound patterns that speech generates. Thus, the role of the speech motor system is not only to produce speech articulations but also to detect them. The appeal of this hypothesis has increased particularly since the discovery of mirror neurons that link the production and perception of motor movements, including those made by the vocal tract (Galantucci et al. 2006). Emerging neurophysiologic evidence also indicates that motor programs are activated during the perception of speech (Wilson et al. 2004). According to this standard theory, the participants in the study of Pagliarini and colleagues activated corresponding articulatory motor gestures in their brain when writing *burle*.

Pagliarini and colleagues assume that Homothety and Isochrony are not restricted to specific types of motor activity. They mention wrist circling, weight lifting and drawing as actions that have been shown to be determined by these constraints. Therefore it is reasonable to assume that they also constrain the motor system involved in sound articulation and perception. According to the above-mentioned dual-route model, the orthographic processing of *burle* will activate silent sound processing. This in turn involves activation of the sound motor program, which might be constrained by Homothety and Isochrony.

Homothety and Isochrony are not in the center of attention in phonetics and phonology, but the phenomenon captured by Homothety has been detected in several experimental studies (e.g. Hirata 2004, Hirata & Whiton 2005, Amano & Hirata 2015). They explored the question whether an absolute or relative duration value can be found to reliably classify short against long vowels as well as single stop consonants against geminate ones, such as /k/ versus /k:/ in Japanese, where both distinctions are used to convey different meanings. For example, /i/ with a short vowel means 'stomach' while the corresponding word with the long vowel /i:/ means 'good.' It is well known that the absolute durations of short and long phonemes vary considerably with speech rate and that their absolute durations tend to overlap in fast speech. However, across three speech rates (slow, normal, fast), the ratio of the duration of stop consonant closure to word duration best classified all single versus geminate stop tokens with 95.7%–98% accuracy (Hirata & Whiton 2005). Likewise, the proportion of the vowel duration to the total word duration was found to distinguish the two vowel length categories across the three speech

rates most accurately (Hirata 2004). Both types of data are in line with Homothety (called “relative acoustic invariance hypothesis” by Hirata and colleagues). We suspect that Homothety is a powerful (yet neglected) constraint in sound production and perception.

Since handwriting and sound processing in a word like *burle* go hand in hand, it is possible that the results of the study of Pagliarini and colleagues pertain to the motor program of sound production, which closely accompanies letter production in *burle*. A possible alternative explanation for the results of their study would be that Homothety and Isochrony do not guide handwiring directly, as assumed by the authors. They rather determine the motor program of silent sound production. The influence of Homothety and Isochrony in the handwriting productions of the participants would be indirect, mediated by silent sound production.

Teasing apart sound and letter motor programs in an alphabetic writing system is challenging and would require an additional study with materials where sounds and letters do not match. Silent letters are appropriate for this aim. We want to mention just one experimental study that is specifically devoted to disentangle sound structure from orthographic structure (cf. also Evertz & Primus 2013). According to Kandel et al. (2009), a study we mentioned before, French children program the words they write syllable by syllable. The authors examined whether the syllable the children use to segment words is determined phonologically (i.e., is derived from speech production processes) or orthographically. Third, fourth and fifth graders wrote on a digitiser words that were mono-syllables phonologically, e.g. *barque*, pronounced [bark], but bi-syllables orthographically. These words were matched to words that were bi-syllables both phonologically and orthographically, e.g. *balcon*, pronounced [bal-kō]. The results on letter stroke duration and fluency yielded significant peaks at the boundary of the second syllable for both types of words, indicating that the children use orthographic rather than phonological syllables as processing units to program the words they write.

Let us return to the study of Pagliarini and colleagues. A test item such as *burle*, where sounds and letters match perfectly, would be inappropriate for the task of settling the issue whether Homothety and Isochrony guide handwriting or silent sound production. As a consequence, the claim of the authors that Homothety and Isochrony determine the time course of handwriting has to be taken with caution and further experimental studies are needed to consolidate it.

Let us sum up our review. One main open question is the way domain independent rhythmic principles such as Homothety and Isochrony are modulated by linguistic rhythmic constraints. We have illustrated this point with reference to syllable structure and its potential confounding effect on Homothety. Another issue is the dissociation between orthographic and phonological form and, correspondingly, between handwriting and sound production, which cannot be detected if

the experimental target word shows a close match between sound structure and orthographic structure. However, teasing apart timing in sound and letter production would be necessary in order to consolidate the claim of Pagliarini and colleagues that general rhythmic constraints guide timing specifically in handwriting. Admittedly, these issues cannot be settled within a single experiment. However, the authors overlooked to mention these potential limitations of their study. Despite these concerns, the study presents robust evidence that Homothety and Isochrony – perhaps indirectly, yet manifestly – determine the time course of writing even if they are not the only factors that govern it. Our review is also meant as an invitation to articulatory phonologists and writing researchers to pay more attention to these domain independent rhythmic constraints.

References

- Amano, S. & Yukari Hirata. (2015). Perception and Production of Singleton and Geminate Stops in Japanese: Implications for the Theory of Acoustic Invariance. *Phonetica* 72(1): 43–60. doi: 10.1159/000430099.
- Evertz, Martin & Beatrice Primus. (2013). The graphematic foot in English and German. *Writing Systems Research* 5(1): 1–23.
- Fuhrhop, Nanna, Franziska Buchmann & Kristian Berg. (2011). The length hierarchy and the graphematic syllable. Evidence from German and English. *Written Language & Literacy* 14(2): 275–292.
- Galantucci, Bruno, Carol A. Fowler & M. T. Turvey. (2006). The motor theory of speech perception reviewed. *Psychonomic Bulletin & Review* 13(3): 361–377.
- Grainger, Jonathan & Johannes C. Ziegler. (2011). A dual-route approach to orthographic processing. *Frontiers in Psychology*. doi: 10.3389/fpsyg.2011.00054
- Hirata, Yukari & Jacob Whiton. (2005). Effects of speaking rate on the single/geminate stop distinction in Japanese. *Journal of the Acoustical Society of America* 118: 1647–1660. doi: 10.1121/1.2000807
- Hirata, Yukari (2004). Effects of speaking rate on the vowel length distinction in Japanese. *Journal of the Acoustical Society of America* 32(4): 565–589.
- Kandel, Sonia, Carlos J. Alvarez & Natahalie Vallée. (2006). Syllables as processing units in handwriting production. *Journal of Experimental Psychology: Human Perception and Performance* 32(1): 18–31.
- Kandel, Sonia, Lucie Herault, Géraldine Grosjacques, Eric Lambert & Michel Fayol. (2009). Orthographic vs. phonologic syllables in handwriting production. *Cognition* 110(3): 440–444.
- Nottbusch, Guido, Angela Grimm, Rüdiger Weingarten & Udo Will. (2005). Syllabic structures in typing: Evidence from deaf writers. *Reading and Writing* 18(6): 497–526.
- Nottbusch, Guido (2008). *Handschriftliche Sprachproduktion. Sprachstrukturelle und ontogene-tische Aspekte*. Tübingen: Niemeyer.

- Pagliarini, Elena, Lisa Scocchia, Mirta Vernice, Marina Zoppello, Umberto Balottin, Sana Bouamama, Maria Teresa Guasti & Natale Stucchi. (2017). Children's first handwriting productions show a rhythmic structure. *Scientific Reports*. doi: 10.1038/s41598-017-05105-6
- Pagliarini, Elena, Maria Teresa Guasti, Carlo Toneatto, Elisa Granocchio, Federica Riva, Daniela Sarti, Bruna Molteni & Natale Stucchi. (2015). Dyslexic children fail to comply with the rhythmic constraints of handwriting. *Human Movement Science* 42: 161–182.
- Pinet, Svetlana, Johannes Ziegler & F.-Xavier Alario. (2016). Typing is writing: Linguistic properties modulate typing execution. *Psychonomic Bulletin and Review, Psychonomic Society* 23(6): 1898–1906.
- Primus, Beatrice (2004). A featural analysis of the Modern Roman Alphabet. *Written Language and Literacy* 7(2): 235–274.
- Rapcsak, Stephen Z., Maya L. Henry, Sommer L. Teague, Susan D. Carnahan, & Pélagie M.-Beeson. (2007). Do dual-route models accurately predict reading and spelling performance in individuals with acquired alexia and agraphia? *Neuropsychologia*, 45(11): 2519–2524. doi: 10.1016/j.neuropsychologia.2007.03.019
- Wilson, Stephen M., Ayşe P. Saygin, Martin I. Sereno, Marco Iacoboni. (2004). Listening to speech activates motor areas involved in speech production. *Nature Neuroscience* 7: 701–702.