Contextual, lexical, and sublexical effects on Braille reading

Introduction. Tactile reading of Braille — a primary modality through which blind individuals access written material — holds unique promise for the study of language processing (e.g., Millar, 2003). As in reading of print, and unlike ordinary comprehension of speech or sign, Braille reading involves (implicit) control over the order and rate at which linguistic material enters peripheral processing. This allows reading time (RT) to serve as a dependent measure of processing operations and costs, playing the same role for tactile reading that it does for eye tracking and self-paced reading of print. However, the fingers move smoothly over the Braille page, often touching each character of a word, rather than making discrete saccades to a relatively small number of locations in a text. Relatedly, the tactile modality has no direct counterpart to parafoveal processing found in reading by eye: while multiple fingers on both hands may be used in Braille reading, linguistic material that has not yet been directly touched is perceptually inaccessible. In these respects, Braille reading is more similar to processing of speech or sign, where the incoming signal evolves smoothly in time and access to upcoming material is limited. Indeed, because Braille text is rendered with isolated and stereotypical cells free of anticipatory coarticulation, tactile reading could provide one of the most precise windows into predictive and minimal unit-by-unit processing of linguistic material.

We provide benchmark findings on contextual, lexical, and sublexical effects in a densely sampled data set of naturalistic Braille reading. While some of our results replicate findings of Millar (2003) and parallel studies of print reading, our low-cost and automatic method of tracking Braille reading is original and we give novel evidence bearing on character-level effects.

Data. Adult congenitally-blind individuals (*N*=9) read six passages from the Natural Stories Corpus (Futrell et al., 2020) embossed in Contracted Unified English braille (UEB). Hand movements were video recorded from above at approximately 60fps with a consumer cellphone. In each frame, the locations of fingers on both hands were identified using MediaPipe (Lugaresi et al., 2019), placed in standard text coordinates by automatic affine transformation (Thévenaz et al., 1998), and mapped to the closest Braille cells. Subsequent to this mapping, a finger-specific RT for each cell and word token was calculated by summing frames and converting to milliseconds. Figure 1 shows left (green) and right (purple) index-finger locations for a single clip (one participant's reading of a single embossed page) with squares indicating non-blank Braille cells. In total, the data set contained more than 3 million tracked index-finger locations (> 110,000 per participant hand) and RTs for approximately 178,000 cell tokens (> 19,000 per participant) and 50,000 word tokens (> 5,000 per participant).

Analysis. We first examined whether three major effects repeatedly found in eye-tracking studies of print reading — word length (here, number of Braille cells), word frequency (taken from SUBTLEX-US), and contextual word predictably (surprisals provided with the Natural Stories Corpus) — had expected effects on word RTs. Figures 2 and 3 show a strong positive relationship with length (r = 0.77) and negative relationship with frequency (r = -0.62) for word *types* averaged over participants and tokens; the relationship with surprisal for word *tokens*, averaged over participants, was also strong (r = 0.64, all ps < .001). Mixed-effects analyses were performed at the level of word *tokens* using lme4 (Bates, 2015) with centered predictors, log RT summed over index fingers as the outcome, and random intercepts for participants and words. There were significant effects of length (0.076, t = 42.84), frequency (-0.044, t = -12.32), and surprisal (0.006, t = 9.7). These were in the same direction and significant ($|t| > 2$) for all but one of the participants analyzed separately. We further analyzed the log RTs of character (Braille cell) tokens as a function of their containing word frequency, position within the word (Millar, 2003), complexity (number of raised dots), and cohort surprisal (e.g., Brodbeck, 2018). There were significant negative effects of frequency (-0.026, t = -35.82) and position (-0.012, t = -18.85), and significant positive effect of complexity (0.012, t = 7.17) and surprisal (0.001, t = 2.4; see Figure 4). These results suggest that cells are processed predictively, as information about their containing words unfold, and that detection of raised dots is a perceptual bottleneck.

Figure 1

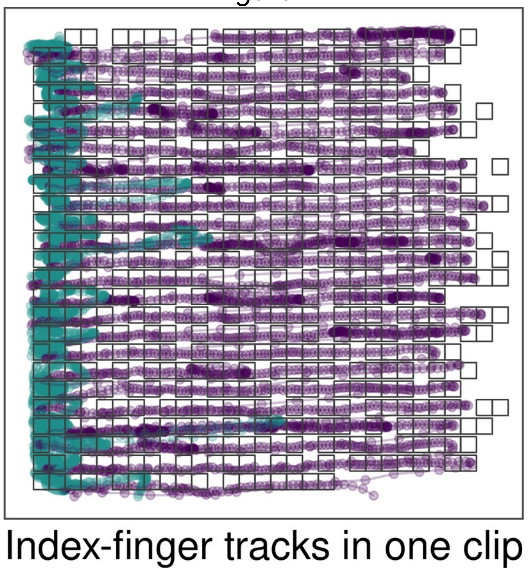


Figure 2

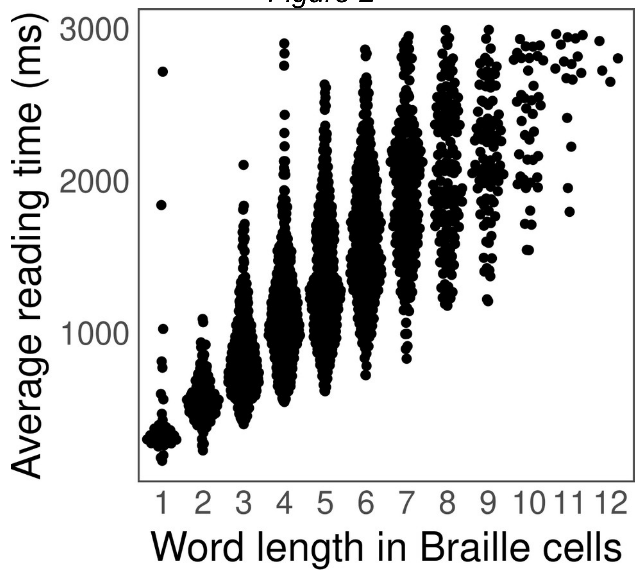


Figure 3

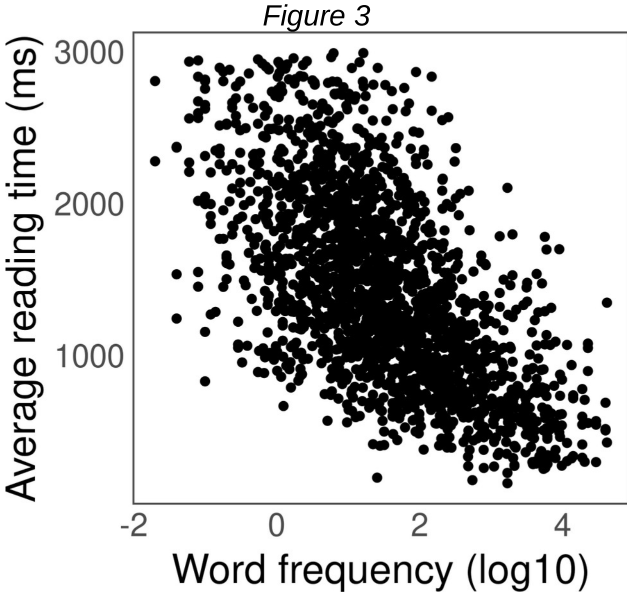
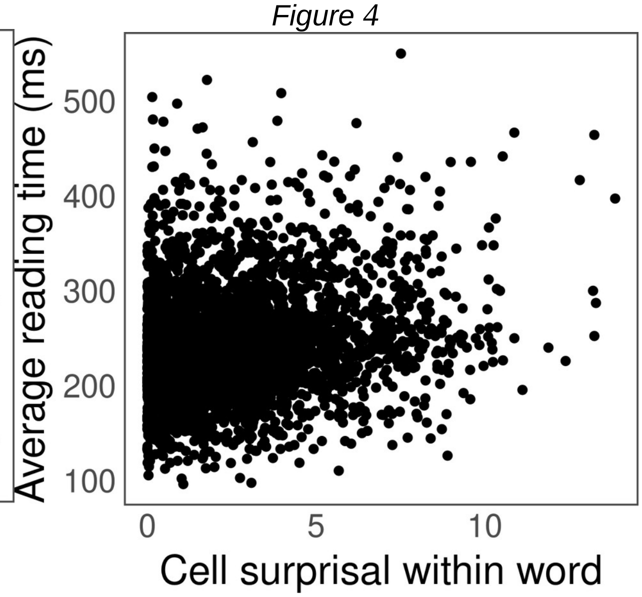


Figure 4



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