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Graphesthesia on human fingernails

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ABSTRACT

The fingernails have been considered passive support structures that enhance tactile sensitivity by providing a rigid background, preventing the fingertips from slipping when interacting with objects. Recent studies have provided evidence that the people can perform basic tactile judgments of stimuli applied to the fingernails. In this study, we investigate whether fingernails also contribute to more complex, higher-order spatial processing. Specifically, we examine graphesthesia – the ability to recognise shapes or letters traced onto the skin – and assess whether this tactile capacity extends to the fingernail. Participants were asked to discriminate between the letters b, d, p, and q drawn either on the left middle fingertip or fingernail. Results showed that graphesthetic performance was lower on the fingernail compared to the fingertip. However, participants were still able to classify letters drawn on the fingernail at levels significantly above chance. These findings align with theoretical claims that the fingernail plays a role in perception and expand the growing body of evidence supporting its perceptual functions highlighting the fingernail as an active contributor to complex spatial processing in touch perception.

The presence of nails, rather than claws, on the digits is an adaptation specific to the primates (Hamrick, 2001; Le Gros Clark, 1959; Spearman, 1985; Wood Jones, 1916). The evolutionary emergence of nails is believed to be linked to the high levels of manual dexterity in primates, as suggested both by fossil evidence from early primates (Bloch & Boyer, 2002) and by comparative studies in existing primates (Le Gros Clark, 1936; Spearman, 1985). In humans, evidence consistent with a sensorimotor role of fingernails comes from evidence showing that manual dexterity is impaired in nail conditions such as psoriasis (Baran, 2010), fungal infections (Lubeck et al., 1993), traumatic nail injury (Dumontier, 2003; Zook et al., 1984), and congenital nail malformation (Prandi & Caccialanza, 1977). Nevertheless, the exact role of nails in sensorimotor function remains unclear.

The fingernails have traditionally been considered to be largely passive support structures which enhance tactile sensitivity on the fingertips by providing a rigid background to prevent the fingers from slipping when touching objects (Kleinert et al., 1967; Zook, 2003). Evidence supporting this function comes from a study showing that moistening the fingernails, which reduces rigidity, impairs perceptual discrimination on the fingertip (Brothers & Hollins, 2014). Tanaka et al. (2008) developed a tactile device that applied mechanical loads to the nail root while delivering tactile stimuli to the fingertip pad. Without applying these forces to the nail, the participant's detection on the fingertip was worse, meaning that the load on the nail lowered tactile detection thresholds on the pad, suggesting that the nail plays a mechanical role in enhancing sensitivity on the fingertip.

Other authors have suggested that the fingernails might have more active perceptual functions (e.g., Gibson, 1966; Katz, 1925). Katz, for example, claimed that people can recognise textures they touch only with the fingernails and not with the skin. Gibson groups perception with fingernails with phenomena like the ability of animals to perceive things happening on their horns or antlers and the use of canes by blind people: "the man has only to scrape a surface with his fingernail to realize that he is aware of what happens at the end of the nail, not at the root, where the mechanoreceptive neurons are and where the sensations should theoretically be felt" (pg. 100). Despite such claims, little research has actually measured the perception of tactile stimuli applied directly to the nails.

Seah et al. (2013) measured pressure detection thresholds and both static and moving two-point discrimination thresholds (2PDT) for stimuli applied to the fingernails. Static 2PDT was about twice as high on the fingernails as on the fingertips, while moving 2PDT was similar on both surfaces. In another recent study, Longo (2024) measured the ability of participants to localise tactile stimuli applied to the fingernails,

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finding that performance was very high and similar to that on the fingertips. These results show that the fingernail can provide spatial information which can be used for simple perceptual judgments.

It remains unclear whether this ability is limited to basic aspects of tactile perception or whether more complex spatial information can also be obtained through fingernails. Complex tactile perception is known to depend on complex patterns of skin stretch and strain (Delhaye et al., 2016), which are likely to be fundamentally altered when a rigid plate like the fingernail intervenes between the stimulus and the mechanoreceptors. Indeed, studies which have investigated haptic object recognition when the skin is covered by a rigid plastic sheath (Lederman & Klatzky, 2004) or a thick glove (Phillips et al., 1997) have found dramatic reductions in performance. Such effects might disproportionately affect more complex spatial judgments. For example, Gibson and Craig (2002) found that wearing a surgical glove produced only modest decreases in a basic task of spatial acuity, but much more dramatic decreases in a more complex task involving recognising grooves. In this study, we explore whether fingernails can also support more complex spatial processing. Specifically, we examine graphesthesia – the ability to recognise shapes or letters traced onto the skin - assessing the extent to which this tactile capacity extends to the fingernail.

Evidence that graphesthesia is a distinct, higher-level somatosensory function comes from a condition known as *agraphesthesia*, which is linked clinically more closely to deficits in haptic object recognition than to basic deficits in somatosensory processing, such as tactile acuity or localization (Baumard et al., 2023; Bender et al., 1982; Sakurai et al., 2020). Agraphesthesia has been reported in a wide range of clinical conditions, including schizophrenia (Martin et al., 1995), Alzheimer's disease (Davis et al., 2010; Galasko et al., 1990), cortico-basal degeneration (Bensaïdane et al., 2014; Riley et al., 1990), posterior cortical atrophy (Baumard et al., 2023), callosal disconnection syndrome (Bachoud-Lévi et al., 2000), and obsessive-compulsive disorder (Hollander et al., 1990; Thienemann & Koran, 1995), as well as following focal damage to several brain areas, including the parietal lobe (Fukatsu et al., 1998; Talmasov & Ropper, 2016), the thalamus (Teraoka et al., 2023), the corpus callosum (Falchook et al., 2016), and occipito-temporal regions (Sakurai et al., 2020).

Here we used a widely-used graphesthesia task in which participants discriminate between the letters *b*, *d*, *p*, and *q* which are drawn onto the skin (Ferrè et al., 2014; Natsoulas & Dubanoski, 1964; Sekiyama, 1991). We compared performance on this task for stimuli drawn either on the left middle fingertip or fingernail. If the fingernail supports high-level spatial perception, then classification performance for stimuli on the fingernails should be above chance levels (i.e., 25 %). We hypothesised that graphesthetic performance on the fingernail would be higher than chance, but lower than performance on the fingertip.

1. Method

1.1. Participants

Thirty members of the [REDACTED] community (17 women, 13 men) between 18 and 54 years of age (*M*: 27.2, *SD*: 8.8) participated after giving written informed consent. Twenty-eight participants were right-handed and two left-handed, as measured using the Edinburgh Inventory (Oldfield, 1971) (*M*: 70.0, *SD*: 42.2). Procedures were approved by [REDACTED]. The data were collected in 2024.

We determined our sample size in an a priori power analysis. Mørch et al. (2010) performed a graphesthesia test on the forearm, either using touch or an infrared laser to produce nociceptive stimuli. A number (0–9) was drawn, and the participant had to recognise it. From the reported mean accuracy and 95 % confidence intervals, we estimated Cohen's *d* for one-sample *t*-tests comparing mean accuracy to chance (i.e., 10 %). This produced estimates of Cohen's *d* of 7.88 for touch and 1.84 for nociceptive heat. A power analysis using G*Power 3.1 (Faul et al., 2007) with a one-tailed one-sample *t*-test comparing performance to chance, alpha of 0.05, and power of 0.95, indicated that 3 participants were needed using the effect size from touch, and 5 were needed using the effect size for heat. Even for an effect size 1/10th the size of that found for touch on the forearm (i.e., $d = 0.788$), 19 participants were needed for 95 % power. Given that the effect size on the fingernail was unknown, we decided to test a somewhat larger sample. Our sample size of $N = 30$ is therefore well powered to detect an effect substantially smaller than that found for touch on the skin of the forearm.

1.2. Stimuli

Stimuli were applied using a wooden cuticle stick (Superdrug, London) which tapered to a point of approximately 1 mm in diameter. This was used as a stimulus in our recent study of tactile localisation on the fingernail (Longo, 2024) as well as in numerous studies in our lab of tactile perception on the skin (e.g., Calzolari et al., 2017; Fiori & Longo, 2018; Longo & Sadibolova, 2013). On each trial, one of the four lowercase letters *b*, *d*, *p*, or *q* was drawn on either the fingertip (i.e., the glabrous skin of the distal phalanx) or the fingernail of the left middle finger. These four letters have been widely used in previous studies of graphesthesia as they differ only in terms of reflection about the horizontal or vertical planes (Ferrè et al., 2014; Natsoulas & Dubanoski, 1964; Sekiyama, 1991). Consistent with the procedures of Ferrè et al. (2014), the letters were drawn starting with the stem and ending with the circular loop.

1.3. Procedures

The experimental setup is shown in Fig. 1. Participants sat at a table with their left middle finger resting in an apparatus made from Lego blocks which supported the finger on the two proximal phalanges, with the stimulated distal phalanx hanging off the end. Depending on the condition, the hand rested with the palmar (fingertip condition, Fig. 1, left panel) or dorsal (fingernail condition, Fig. 1, right panel) surface facing upwards. A vertical board aligned approximately with the participant's body midline prevented them from seeing their stimulated left hand.

Letters were drawn approximately 8 mm tall and consistently centred on the distal phalanx, regardless of individual differences in finger or nail size. Each letter was traced over approximately 2 s, beginning with the vertical stroke and following a standardised motion. The experimenter practiced so as to attempt to perform all drawings with approximately consistent size, pressure, and speed across trials and conditions. On the fingertip, letters were drawn over the rounded pad of the distal pulp, while on the nail, they were traced over the flat central surface of the nail plate. To maintain this consistency, the drawing speed on the nail was slightly reduced. For precision, the experimenter rested their little finger lightly on the table next to the participant's hand. The wooden stick was moved in a light, controlled motion more akin to painting a shape than pressing it into the surface, to ensure minimal variation across trials.

There were four blocks of trials, two each on the fingernail and the fingertip. The blocks were counterbalanced using an ABBA design, with the first condition counterbalanced across participants. Each block consisted of 12 repetitions of each of the 4 letters presented in a random order. This resulted in 48 trials per block and 192 trials in total. Participants were allowed to take a short break between blocks. Inclusive of informed consent, the Edinburgh Inventory, instructions, testing, and debriefing, the study took about 30 min to complete.

1.4. Analysis

To assess overall levels of performance, we calculate the proportion of trials for each body part on which the participant was correct in their classification. As there are four options, chance performance if the participant was guessing would be 1 in 4, or 0.25. We therefore used

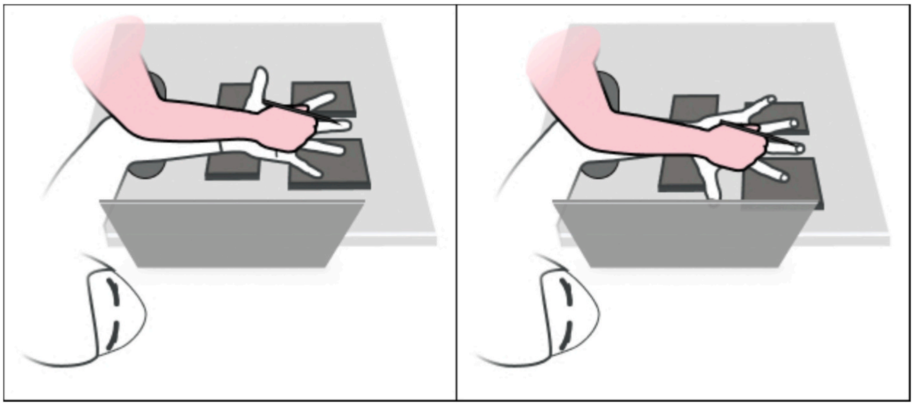

Fig. 1. Experimental setup. *Left panel*: the fingertip condition. *Right panel*: the fingernail condition. The participant's hand rested on a support structure, leaving only the middle finger suspended in air and not in contact with any surface. The pink hand represents the experimenter's hand, tracing the letter on the fingertip and on the nail, using a wooden stick. The experimenter was positioned next to the participant and drew each letter in a single, continuous movement, beginning with the vertical stroke and following a consistent trajectory across trials. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

one-sample *t*-tests to compare mean accuracy for each body part to 0.25. As we predicted that performance would be above (rather than below) chance, we used one-tailed tests, consistent with our a priori power analyses (see above). We also compared performance on the two body parts using a paired *t*-test. As measures of effect size, we used Cohen's *d* for one-sample *t*-tests and Cohen's d_z for paired t-tests.

As the four letters differ from each other only in terms of reflections about the horizontal and vertical axes, there are three types of error that a participant can make on any given trial: (1) *left-right errors* (e.g., responding 'd' when 'b' is presented), (2) proximo-distal errors (e.g., responding 'p' when 'b' is presented), and (3) *other errors* (e.g., responding 'q' when 'b' is presented). We therefore used repeated-measures analysis of variance (ANOVA) to assess differences in the frequency of error types. Where Mauchley's test indicated a violation of the sphericity assumption, the Greenhouse-Geisser correction was applied. As a measure of effect size for F-tests, we report partial eta-squared.

Raw data are available on the Open Science Framework: https://osf.io/7fyw4/

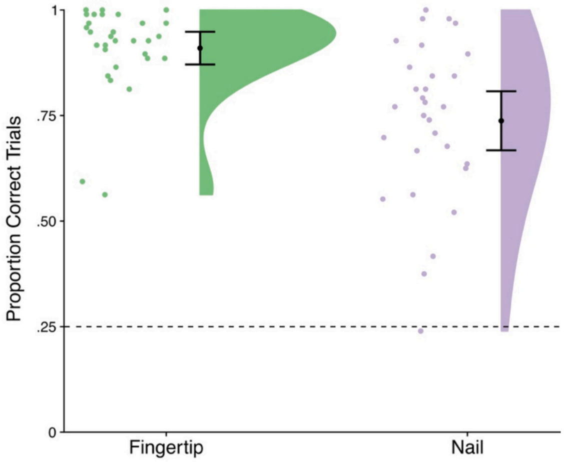

Fig. 2. Classification accuracy on the fingertip and nail, shown using raincloud plots (Allen et al., 2021). The horizontal dashed line indicates chance performance (i.e., 0.25 accuracy). Black circles indicate the mean and error bars indicate the 95 % confidence interval. Accuracy was substantially above chance on both body parts, but was significantly lower on the nail than on the fingertip.

2. Results

Overall accuracy is shown in Fig. 2. On the fingertip, classification accuracy was high (*M*: 0.910, *SD*: 0.104), and substantially above chance (i.e., 0.25), $t(29) = 34.95$, $p < .0001$, Cohen's $d = 6.363$. Accuracy was also substantially higher than chance on the nail (*M*: 0.738, *SD*: 0.187), $t(29) = 14.25$, $p < .0001$, Cohen's $d = 2.602$. Accuracy was above chance level for all 30 participants on the fingertip and for 29 of 30 on the nail. Despite high levels of performance in both conditions, accuracy was significantly lower on the nail than on the fingertip, $t(29) = 7.17$, $p < .0001$, Cohen's $d_z = 1.310$.

As accuracy scores are bounded between 0 and 1 and several participants performed near ceiling, we replicated these analyses using Wilcoxon signed-rank tests to validate the results non-parametrically, and found the same pattern of significance. Accuracy was significantly above chance on both the fingertip ($V = 465$, $p < .0001$) and nail ($V = 464$, $p < .0001$), and was significantly higher on the fingertip than on the nail ($V = 429.5$, $p < .0001$).

The top panel of Fig. 3 shows confusion matrices, while the bottom panel shows the frequency of each error type. A repeated-measures ANOVA with factors *body part* (fingertip, nail) and *error type* (left-right, proximo-distal, other) revealed a significant main effect of body part, $F(1, 29) = 51.46$, $p < .0001$, $\eta_p^2 = 0.640$, consistent with the analysis of accuracy above. There was also a significant main effect of error type, $F(1.55, 45.02) = 18.64$, $p < .0001$, $\eta_p^2 = 0.391$, which was modulated by a significant interaction between the two factors, $F(2, 58) = 9.78$, $p < .001$, $\eta_p^2 = 0.252$.

To explore this significant interaction, we conducted follow-up *t*-tests with Holm-Bonferroni correction for multiple comparisons to compare the frequency of each error type between the two conditions. There were more errors on the nail than the fingertip for L-R errors, $t(29) = 6.71$, $p < .0001$, $d_z = 1.224$, P—D errors, $t(29) = 4.19$, $p < .001$, $d_z = 0.764$, and other errors, $t(29) = 5.38$, $p < .0001$, $d_z = 0.982$. We next compared the magnitude of this difference between body parts between the three different types of error. This difference was significantly larger for L-R errors than for either P—D errors, $t(29) = 3.58$, $p < .005$, $d_z = 0.654$, or Other errors, $t(29) = 3.50$, $p < .005$, $d_z = 0.639$. There was no difference between P—D errors and Other errors, $t(29) = -0.36$, $p = .722$, $d_z = 0.066$.

3. Discussion

The results of this study provide clear evidence for graphesthesia on the human fingernail. Participants were able to classify letters drawn on

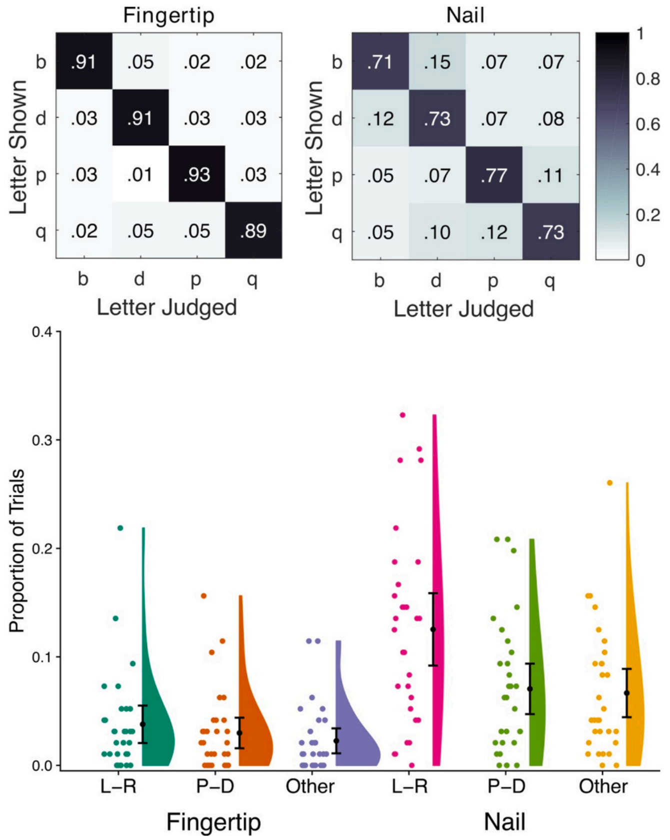

Fig. 3. *Top panel:* Confusion matrices. *Bottom panel*: Frequency of different types of classification errors on the fingertip and nail.

the fingernail at levels substantially above chance. This ability, however, was less precise than that found on the fingertip. These results are consistent with theoretical claims that the fingernail supports perceptual functions (Gibson, 1966; Katz, 1925), and add to the growing list of perceptual abilities the nails have been shown to have, including discriminating one from two touches (Seah et al., 2013), localising where on the nail a touch was applied (Longo, 2024), and graphesthetic recognition of drawn shapes (this study).

Despite their familiarity, the status of fingernails has a certain ambiguity. On the one hand, nails are clearly natural parts of our body. On the other hand, nails are rigid plates of dead tissue extending outwards from the body. The ability to perceive spatial properties of touch applied to the fingernails is likely closely related to the ability to perceive tactile stimuli applied to held objects, such as tools. The ability of blind people to use canes to obtain rich spatial information about objects at the end of the cane is well known, and has been widely discussed by philosophers and psychologists for centuries (e.g., Descartes, 1637; Gibson, 1966; James, 1890; Longo, 2025; Lotze, 1885). More recently, a series of studies by Miller and colleagues (Miller et al., 2018, 2019; Miller & Farnè, 2024) has provided striking evidence that we do not obtain information only from the tips of tools, but can precisely localise tactile stimuli applied anywhere along the length of a held rod. The ability to perceive touch applied to fingernails is similar in that both nails and tools are rigid surfaces which lack mechanoreceptors. The ability to localise touches applied to hairs (Longo & Sakka, 2026), which like fingernails are bits of dead tissue extending outwards from the body, is likely related. In each case, however, the sensory receptors in the hand can code spatial information about events occurring on the nail/tool.

In the case of tools, Miller et al. (2018) argue that the ability to localise touch along the length of a held rod is based on Pacinian corpuscles and the RA-II afferent system. The same may be true of tactile perception on fingernails. It is interesting to note, however, that the papillary ridges forming the fingerprint are known to act as a spectral filter, amplifying vibrations to be optimal for Pacinian receptors (Scheibert et al., 2009), and these ridges are naturally absent on both tools and nails. The rich spatial object recognition required for graphesthesia in the present study suggests that slowly adapting (SA) units may be involved as well. The fingernails appear to be well-equipped with such SA units, both in the fingernail bed and along the base and edges of the nails, including both Merkel cells linked with SA-I fibres (Cameli et al., 1998; Moll & Moll, 1993) and Ruffini corpuscles linked with SA-II fibres (Paré et al., 2003). These SA receptors have been shown to respond to pressure applied to the nails (Johansson, 1978), to the fingertips (Birznieks et al., 2009), and also to movements of the fingers (Knibestöl, 1975). In one recent study, electrical stimulation of SA-II units in the fingernails evoked subjective experiences of pressure being applied to the fingernails (Watkins et al., 2022).

While both tools and fingernails are rigid structures, fingernails are not passive transmitters of touch. While there are no mechanoreceptors in the nail itself, the nail bed and the skin around the edges of the nails contain a rich variety of mechanoreceptors, allowing for spatially precise tactile perception. Yet, it is unlikely that a tool with similar rigidity and thickness, placed on the finger's skin, would enable similar accuracy in detecting letters traced on it, as it would lack activation of slowly adapting mechanoreceptors. Our results suggest that the fingernail is an active sensory surface from which humans can detect complex tactile information. Future research could explore whether similar spatial discrimination is possible with tools that mimic the structural and mechanical properties of the nail.

Our findings of higher left-right errors on the nail than on the fingertip might relate to the fact that the nail itself is curved in the left-right axis, although the implications of this curvature for activation of mechanoreceptors in the nail bed and edges of the nail is unclear. Alternatively, this difference may be due to a postural remapping of tactile input into a canonical palm-up reference frame. As humans typically perceive complex spatial information on the palmar surface (we do not usually grab or manipulate objects with the hand dorsal), participants may have interpreted dorsal input on the nail as if it originated from the palm. This remapping would predict mirror confusions as if the letter is switching between the left and right sides, for example, interpreting a "p" drawn on the nail as a "q" on the palm. This is aligned with Romano et al.' (2019) theory of the *standard posture of the hand*, which suggests that the brain represents the hand in a canonical position: palm-up with fingers pointing forward. Given the increased receptor density and frequent use of the palmar surface for identifying shapes and processing complex tactile information, ambiguous inputs may be remapped to this canonical hand and fingers' posture (Romano et al., 2017, 2019), in the same way that we mislocalise touch to the canonical location of the hand, when our hands are crossed (Badde et al., 2016). Since we typically manipulate objects and surfaces with the palmar side of the hand, it is plausible that complex shapes felt on the hand dorsal are switched as if they were traced on the palm.

The high number of left-right errors may explain why there is a lower tactile accuracy on the fingernail in this study (although still very significantly above chance), compared to findings of Longo (2024) demonstrating that humans can localise tactile stimuli on the fingernail with remarkable high precision. At the same time, our task likely involved greater cognitive demands: identifying a letter from a continuous motion is more complex than localising a single touch on the nail, since it requires an integration of spatial and temporal information over time. As the experimenter traces the letter, the tactile information is held until the full letter shape is identified. This identification of a letter involves higher-order cortical processing, engaging the somatosensory 'what' pathway (Reed et al., 2005) to recognise the shape as the letter p, q, d or b.

This study shows that the human fingernail can support graphesthesia. Participants were able to identify letters traced on the nail with accuracy well above chance, though lower than on the fingertip, showing that fingernails are a part of the body from which humans can recognise complex tactile patterns. Our findings suggest that this ability is not only based on indirect cues, such as pressure transferred to the fingertip, but may reflect direct tactile encoding through mechanoreceptors embedded in and around the nail.

CRediT authorship contribution statement

Daniel Oluwaseyi Olawole: Writing – review & editing, Methodology, Investigation, Formal analysis, Conceptualization. **Denise Cadete:** Writing – review & editing, Methodology, Conceptualization. **Milena Da Silva Baiao:** Writing – review & editing, Investigation. **Sonima Sharma:** Formal analysis, Writing – review & editing. **Elisa R. Ferrè:** Conceptualization, Writing – review & editing, Methodology. **Matthew R. Longo:** Writing – original draft, Visualization, Supervision, Project administration, Methodology, Formal analysis, Conceptualization.

Data availability

We include a link to the raw data.

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