The tactile Eriksen flanker effect: A time course analysis

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Abstract

In the present paper, we explore the temporal dynamics of the flanker effect in the tactile modality and compare it with findings in the visual modality. We created a tactile version of the flanker task in which we presented groups of dots oriented either vertically or horizontally to a participant's fingertips. The target stimulus was presented to the middle finger, while the flanker stimuli were presented to the index and the ring fingers. Distributional analyses of the latency data show a tactile flanker effect: an overall facilitation for congruent target-flanker trials relative to incongruent trials, and a higher effect size for slower correct responses (higher quantiles) than for faster correct responses (lower quantiles). While this congruency effect may resemble the one typically reported in the visual modality, there are differences between these two modalities as well, mainly related to the relative speed of error and correct responses. These differences suggest that some of the mechanisms responsible for the flanker effect differ across sensory modalities.

Keywords Eriksen flanker · Tactile attention · Touch

In our daily lives, we are exposed to large amounts of complex stimulation through our senses. To successfully navigate the world, we select the relevant information and disregard the potentially irrelevant information from our environment. Notably, our perception not only depends on the information we selectively attend to but also upon the context that surrounds it. *Context effects* (also called congruency effects, or interference effects) demonstrate the influence of irrelevant contextual information on our perception of the attended stimuli. In laboratory settings, these effects are commonly evidenced in tasks in which participants are asked to respond to target stimulus while ignoring distracting stimuli irrelevant to the task, known as conflict paradigms.

While most research on the influence of distractors on the perception of the target has been conducted in the visual and auditory modalities (see Driver, 2001, for a review), the interest on the sense of touch has significantly grown

during the last two decades (see Gallace & Spence, 2014). The study of tactile selective attention is important for both applied and theoretical reasons. Understanding how we perceive and recognize tactile information, as well as the circumstances that facilitate or hinder such perception, is needed for the development and optimization of devices that give tactile feedback; for example, those providing tactile warning signals to drivers (see Meng & Spence, 2015). In addition, determining which aspects of the processing of attended stimuli are modality-independent and which are modality-dependent (e.g., Katus & Eimer, 2018; Murphy et al., 2017) is crucial for theory development.

In this paper, we examined how tactile contextual-irrelevant information affects the discrimination of attended stimuli. To do so, we created a tactile version of a well-known conflict paradigm, the Eriksen flanker task, in which we asked participants to indicate whether the pattern of dots presented to the middle finger of their dominant hand was

horizontally oriented (i.e., ••) or vertically oriented (i.e., ∴) while ignoring the distractors presented simultaneously in the index and ring fingers of the same hand. Such distractors were either congruent or incongruent with the target. We analyzed how attended and unattended stimuli are processed as a function of time, and compared our data with results found in the visual modality with the aim of exploring the similarities and differences between the time course of tactile and visual flanker effects.

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Before diving into the details of our study, we first describe conflict paradigms and briefly review previous experiments on the processing of unattended stimuli in non-visual settings.

Conflict tasks

Conflict tasks present stimuli that have both task-relevant and task-irrelevant features. One of the most common conflict paradigms is the Eriksen flanker task (Eriksen & Eriksen, 1974), which was initially designed for the visual modality (see Stroop, 1935; or Simon (1969), for other conflict tasks). In the flanker task, participants perform a classification of a target stimulus that is flanked by either congruent non-target stimuli (i.e., linked to the same response as the target), or incongruent non-target stimuli (i.e., linked to the opposite response as the target). Therefore, for this task, the relevant information is the identity of the target, whereas the irrelevant information is the identity of the stimuli that surrounds it. Critically, the classification of the target is more difficult when the flanking stimuli are incongruent than when they are congruent with the target, as shown by longer reaction times (RTs) and lower accuracy in the incongruent condition than in the congruent condition.

The flanker effect has been reported mainly in the visual modality. However, flanker-like effects have also been shown with tactile stimulation. For example, Evans and Craig (1991) asked subjects to identify the direction in which a pattern of vibrating dots moved across one fingertip while ignoring the pattern of vibrating dots presented to an adjacent fingertip, which could move in the same or opposite direction (i.e., congruent vs. incongruent conditions). To present the stimuli, the authors used two 6×24 electromechanical tactile matrices of dots (one per fingerpad). Those dot grids were a component of a technology no longer manufactured (i.e., Optacon; Linnell & Bliss 1966). To create the movement sensation, different arrays of dots were activated in either a row-by-row or a column-by-column manner to create the vertical or horizontal movement, respectively. They reported slower and less accurate responses when non-targets were incongruent than when they were congruent with the target. In a subsequent study using the same apparatus, Evans, Craig, and Rinker (1992) found the same effect when the non-target stimulus was presented to non-adjacent fingers of the same hand, when presented across hands even when increasing the distance between them, and when the vibratory dots were stationary (i.e., only one row of dots was activated), and participants were asked to make a judgement about the location of the vibration.

Similarly, Driver and Grossenbacher (1996) presented participants with either one or two vibratory pulses simultaneously in both hands and were asked to report the number of pulses in one hand while ignoring the other; they found a congruency effect that, interestingly, decreased as the distance between the hands increased (see also Soto-Faraco et al., 2004). The dissimilarity in results regarding the influence of distance on the congruency effect size has been attributed to differences in methodology because the maximum hand distance, the task instructions, and the nature of the stimuli were different across studies (see Soto-Faraco et al., 2004). Regardless of the specific mechanism in play, these experiments suggest that unattended tactile stimuli affect the processing of the attended stimuli. Moreover, although these studies are not set up as a classic flanker task, because the target was not surrounded by irrelevant information, they suggest that flanker-like effects can appear in the tactile modality. Notably, single distractor setups are not uncommon in the visual modality (e.g., Stuart et al., 2003).

In spite of the results shown by the studies described above, there would be two reasons to doubt that a flanker effect exists in the tactile modality. The first one is that for most tactile stimuli, we do not have an automatized classification; keep in mind that in the visual flanker task common symbols such as “<” or letters are often used. The other reason is that there is some existing literature on lack of effects in the tactile modality that are extremely robust in the visual modality like the transposed-letter effect (Perea, Garcia-Chamorro, Martin-Suesta, & Gomez, 2012). Hence, the first question in this research was if there is indeed a tactile flanker effect; cutting to the chase, yes, there is a flanker effect.

In addition, none of the previous studies have examined the time course of the conflict. Time course analyses are crucial to understand the mechanisms underlying an effect. Indeed, in the visual modality, fine-grained analyses that go beyond average-level comparisons have revealed that the flanker effect is not constant over time (e.g., Gratton et al., 1992). The time course of a tactile effect might help us discriminate between different hypotheses on the trajectory of the conflict—ideas discussed in the following paragraphs. Thus, the second question in the present paper was whether the time-course of the tactile flanker effect resembled the time-course of the visual flanker effect shown in the literature.

Beyond mean RTs

While comparing the performance across conditions using mean RTs is an appropriate method to establish the

presence of an effect, central tendency measurements are somewhat coarse if the goal is to uncover the temporal dynamics of cognitive function. Time-course analyses are very useful in examining the mechanisms that underlie cognitive phenomena. Indeed, such analyses have revealed differences among seemingly equivalent conflict tasks in the visual modality (e.g., Pratte et al., 2010), and these results have led to new, more sophisticated versions of visual selective attention tasks (e.g., Burle et al., 2014; Hübner & Töbel, 2019). In this paper, we use, in addition to mean RT and mean accuracy, three methods to explore the time course of the tactile flanker effects: delta plots, quantile probability functions, and conditional accuracy functions (see Fig. 1 for an example).

Delta plots are residual quantile plots. They display, on the y-axis, the RT difference for correct responses between two conditions and, on the x-axis, the mean RT for a specific quantile. Thus, they offer a visual representation of the effect size over time. In the visual flanker task, delta plots have a positive slope, showing an increase of the flanker effect as RT increases (e.g., Gratton et al., 1992; Hübner & Töbel, 2019).

Quantile Probability Functions (QPFs) provide a rich summary of the whole dataset. For each condition, they show the probabilities of correct and error responses as well as the RT distributions for correct and error responses. A point in the y-axis indicates the mean RT at a specific quantile (.1, .3, .5, .7, and .9, from lowest to highest), and a column on the x-axis indicates the probability of a response for a specific condition, with correct responses on the right and errors on the left. This way, one can compare the relative speed of error and correct responses for each condition. In the visual flanker task, QPFs show that 1) the proportion of correct responses is higher for congruent trials than for incongruent trials; 2) for incongruent trials, error responses are faster than correct responses, and 3) correct responses

to incongruent trials are slower than correct responses to congruent trials, (e.g., White et al., 2011).

Conditional Accuracy Function (CAF) displays the relationship between accuracy and RT for each condition. In the visual flanker task, CAFs have revealed that accuracy for congruent trials is high and constant across RT quantiles, but for incongruent trials is relatively low for fast responses and increases as RT increases, approaching the level of the congruent condition for slow responses (e.g., Gratton et al., 1988; Hübner & Töbel 2019; Stins et al., 2007).

The three exploratory data analysis methods described above, together with measures of central tendency, allow us to examine whether a tactile flanker effect emerges when two distractors surround the target, as well as the way our dependent variables (i.e., RT and accuracy) are influenced by the congruency of the flankers. Particularly, we can assess when in the trial distractors generate more error responses, and the costs associated with incongruent distractors for correct responses. In the visual modality, information about the time course of the flanker effect has been used to create theories and models that explain the processing underlying performance in the flanker task. These theories generally assume that attention is a dynamic process, suggesting that visual selectivity increases over time (see Eriksen & Schultz, 1979; Eriksen & James, 1986; Heitz & Engle, 2007, for continuous selectivity accounts; and Hübner, Steinhauser, & Lehle, 2010; and Ridderinkhof, 1997, for discrete selectivity accounts). Here, we explore whether this is the case in the tactile modality.

Given our focus on distributional features and the time course of the effects on the data, we believe it is *useful* (Box, 1976) to think about the flanker task in terms of evidence accumulation models. While there are many versions of such models, they all share a common assumption: sensory stimulation is encoded into tokens of information that are accumulated until a decision criterion is reached. In

Fig. 1 Response time and accuracy methods used in this paper. The data used to generate this example were simulated, following the typical figures reported in research on flanker effects in the visual modality. The code is available in the [Online Appendix](#)

many implementations, this accumulation of evidence is stochastic (meaning that it has an average rate, but also a variability). The advantage of this line of thought is that there is a robust tradition of evidence accumulation modeling in the visual modality (e.g., Brown & Heathcote, 2008; Ratcliff, 1978; Stone, 1960). Indeed, models that explain how the congruency effects are generated in the flanker task in the visual modality have also been implemented within this framework (see Hübner & Töbel, 2012; Ulrich et al., 2015; White et al., 2012; White et al., 2011); hence, the third and final question in this paper is if the time course data can be explained within evidence accumulation models.

We find thinking about the tactile flanker task in terms of evidence accumulation modeling useful because we can implement different hypotheses of the tactile flanker effect. Specifically, we can think of three possible hypotheses of

the tactile flanker effect that correspond to implementations of the evidence accumulation model (a process model) that, in turn, correspond to a statistical model (a model of the data): (1) Hypothesis₀: there is no tactile flanker effect; (2) Hypothesis_S: there is a tactile flanker effect and the noise of the distractors is constant over time, so the rate of evidence accumulation is stationary (hence the *S* subscript); (3) Hypothesis_N: there is a tactile flanker effect, and the noise of the distractors is not constant over time, affecting the rate of evidence accumulation early in a trial, but then attention can focus on the target only; (i.e., the effect of the evidence accumulation is non-stationary; hence the *N* subscript). Figure 2 shows (from left to right columns) the verbal hypotheses, the process model that explicitly implements the corresponding hypotheses, and the results of three analytical methods explained above that would offer evidence supporting such hypothesis (see White et al.,

Fig. 2 Our mapping from hypotheses to process models to data models (i.e., central tendency measures, delta plots, and CAFs)

2012 for a discussion of these three implementations in the context of the visual flanker.)

It is worth noting that there are many possible ways to implement the hypotheses under consideration, we chose to think about them as evidence accumulation processes given the recent interest in that form of modeling; other researchers might prefer different architectures. This many-to-many relationship between verbal hypotheses, process models, and statistical models is not unique to the flanker task, and in fact, it is quite ubiquitous in science (see McElreath (2018), for a discussion of this issue in the context of statistical inference; and Gillespie (1977), for a classic example from evolutionary biology). Our choice to think about the tactile flanker as the models presented in Fig. 2 is indeed subjective, but not unprincipled, and we prefer to make this subjective call explicit rather than to hide it under the rug.

In sum, we conducted an experiment using a tactile version of the Eriksen flanker task to shed some light on how this conflict effect develops over time through the sense of touch, as well as on the domain specificity/generalizability of dynamic attention. Particularly, we examined whether the influence of distractors on participant's responses changes as a function of response time, and whether such change resembles findings in the visual modality.

Method

Participants

Thirty-three students from DePaul University participated for course-credit in an introductory psychology course. Also, the three authors participated in this study. None of the participants were braille readers.

Apparatus

A refreshable braille display was used to present stimuli (Focus 40 Blue, Freedom Scientific). The display was placed in the pull-out keyboard tray of a desk to avoid participants seeing it, while the keyboard used to make the responses was placed on top of the desk. To present stimuli on the braille display and record participant's responses, we created a shell script using bash syntax that displays the stimuli in the computer's terminal and utilized the OS-X's VoiceOver accessibility feature to present the items in the terminal on the braille display.¹

¹The online repository, available at <https://osf.io/89p3c/>, provides the bash code and the stimuli lists we utilized to carry out this experiment along with the data collected, data analyses, and data wrangling scripts.

Material

We used two braille characters as stimuli: braille pattern dots-123 (⠠), and pattern dots-25 (⠡); from now on we refer to them as the vertical and the horizontal stimulus, respectively. These characters were combined in arrays of three, where the first and last (the flankers) always matched and were either congruent or incongruent with the character in the middle (the target). As can be seen in Fig. 3, congruent stimuli were ⠠⠠⠠ and ⠡⠡⠡, and incongruent stimuli were ⠠⠡⠠ and ⠡⠠⠡. These stimuli were presented on the refreshable braille display. Each participant perceived 168 trials, 50% congruent, presented in random order.

Procedure

We asked participants to place their index, middle, and ring fingers of their dominant hand on three specific braille cells separated 1.8 cm (there was an empty cell in the braille display between each of the used cells; see Fig. 3). Participants were told that a pattern of dots would appear underneath each of those fingertips. We asked them to report as fast and as accurately as possible, whether the pattern presented to the middle finger was a vertical or a horizontal line of dots. They did so by pressing the keys labeled “|” or “_”, with their non-dominant hand, while ignoring the patterns presented on the other fingertips. Both the target and the flanker stimuli were presented on the braille display until a response was made, and the inter-trial interval (ITI) was 1 s. RTs and accuracy were recorded in each trial. The experimental session lasted approximately 15 min.

Results

Mean RTs and accuracy

The data files and scripts for data wrangling and analyses are available at <https://osf.io/89p3c/>. Participants who performed below 55% ($n = 3$), and trials in which responses were either faster than 100 ms or slower than 2000 ms were excluded from the analysis. Overall, 5271 trials were analyzed (6048—trials from low accuracy participants—timeouts). Because we used braille cells (i.e., horizontal lines ⠡⠡ use two dots and vertical lines ⠠⠠ use three dots), the horizontal and vertical stimuli used in the experiment were different in their structure, which could influence

Fig. 3 A diagram of a congruent trial and an incongruent trial of the tactile flanker task

their perceptual identifiability and discriminability.² We analyzed accuracy and RTs by congruency condition (i.e., congruent vs. incongruent) and by target type (i.e., horizontal vs. vertical). Table 1 shows the means for accuracy, and RTs for correct and error responses for each of those variables.

For RTs, we analyzed the data of correct responses using a linear mixed effects model (lmer function: lme4 and lmerTest packages in R; Bates, Mächler, Bolker, and Walker (2015) and Kuznetsova et al. (2017), respectively) with congruency condition and target type as fixed factors and subject as random factor (see Appendix for the code and complete output). Results evidenced main effects of congruency ($B = -0.065$, $SE = 0.007$, $t = -8.940$, $p < 0.001$) and target type ($B = -0.06$, $SE = 0.007$, $t = -8.165$, $p < 0.001$), as well as an interaction between them ($B = 0.07$, $SE = 0.015$, $t = 4.752$, $p < 0.001$). To further analyze whether the congruency effect exists for both types of stimuli, we analyzed separately horizontal and vertical stimuli using the same model described above. Results revealed a congruency effect for both horizontal ($t(32) = -9.563$, $p < 0.001$, $d = .357$) and vertical ($t(32) = -3.219$, $p = 0.001$, $d = .112$) target types, larger for the former.³

²We thank an anonymous reviewer for noticing this difference between the horizontal and vertical stimuli, and for suggesting these analyses.

³We calculated effect sizes for mixed-effects models following Brysbaert and Stevens (2018) suggestions, taking into account the random effects. In these models, effects sizes are smaller than those obtained in t tests or ANOVAS (e.g., a big effect size in an ANOVA [i.e., $> .8$] may become less than 0.1 when using mixed-effects models; see Brysbaert and Stevens (2018) for discussion)

For accuracy, we analyzed the data using a generalized linear mixed effects model (glmer function: lme4 package in R, Bates et al., 2015), again with congruency condition and target type as fixed factors and Subject as random factor. Results revealed main effects of congruency ($B = 1.486$, $SE = 0.097$, $z = 15.310$, $p < 0.001$, $d = 1.641$) and target type ($B = 0.484$, $SE = 0.096$, $z = 5.015$, $p < 0.001$, $d = .534$), but there were no signs of an interaction between the two factors ($B = 0.144$, $SE = 0.193$, $z = 0.746$, $p = 0.456$).

Therefore, the task used in the present experiment produced a substantial flanker effect: responses to congruent trials were more accurate and faster than to incongruent trials. This effect is present in horizontal and vertical target stimuli. However, for horizontal stimuli, responses were slower and the congruency effect larger than for vertical stimuli. This indicates the horizontal target (••) was more difficult to recognize than the vertical target (•); (see Fig. 4).

Time-course analyses

For the analysis of the effect size over time, we used the delta plot technique. This is a quantile by quantile residual plot that displays distributional differences across conditions (De Jong et al., 1994). RTs per condition and participant at the .1, .3, .5, .7, and .9 quantiles were calculated, then, the difference between conditions for every quantile was computed per subject and averaged across subjects (see Fig. 5). The delta plot describing the mean effect size across quantiles has a positive slope and an intercept above zero. In other words, the flanker effect

Table 1 Mean accuracy, correct RTs, and error RTs (in ms) per congruency condition (TRUE = congruent, FALSE = incongruent) and target type (H = horizontal, V = vertical)

Congruency	Target	Accuracy	Mean RTcorrect	Mean RTerror
FALSE	H	0.76	1061	933
FALSE	V	0.82	958	969
TRUE	H	0.92	957	895
TRUE	V	0.95	927	1021

is present across all quantiles and increases for higher quantiles (slower responses). We submitted the data per

participant to a linear mixed effects model (lme4 package in R, Bates et al., 2015) with linear and quadratic fixed effects,

Fig. 4 Mean RT (*left*) and accuracy (*right*) per target type and congruency conditions. Each soft-colored shape represent the mean of a subject in that particular condition while the means per condition across subjects are shown in hard-colored shapes **Fig. 5** Delta plot: effect over time. Each dot represents the mean RT at the .1, .3, .5, .7 and .9 quantiles

Table 2 Likelihood ratio test results between linear and linear-quadratic models

Model	AIC	BIC	logLik	deviance	Chisq	Df	Pr(Chisq)
Linear	1,920.706	1,933.130	−956.353	1,912.706	NA	NA	NA
Linear-quadratic	1,921.418	1,936.948	−955.709	1,911.418	1.288	1.000	0.256

$\text{delta} \sim \text{mean RT} + I(\text{mean RT})^2 + (1|\text{Subject})$, showing evidence of a positive slope (linear component: $B = 0.317$, $SE = 0.155$, $t = 2.05$, $p < 0.05$, quadratic component: $B = -7.957 \times 10^{-5}$, $SE = 6.988 \times 10^{-5}$, $t = -1.139$, $p = 0.257$). Indeed, a likelihood ratio test between linear and linear-quadratic models showed that adding the quadratic component does not improve model fit (see Table 2).

For the analysis of the accuracy data over time, we used quantile probability functions (QPFs) and conditional accuracy functions (CAFs). As explained earlier, the QPFs inform about the distributions of response times for correct and error responses per condition (i.e., RT distributions for error-congruent, error-incongruent, correct-incongruent, and correct-congruent). The CAFs reveal how accuracy per condition changes as a function of time (i.e., mean accuracy per RT quantile for congruent and for incongruent trials).

To create the QPF, we calculated the proportion of errors and correct responses for the congruent and the incongruent trials and averaged them across participants. Then, for each response (i.e., error and correct responses to congruent trials, and error and correct responses to incongruent trials), we computed the mean RTs at the .1, .3, .5, .7, and .9 quantiles and average them across subjects (these averaged quantiles are also known as Vincentiles).

Because there were few error responses to congruent trials, only the median for that condition was calculated (see White et al., 2011). Thus, each column provides a summary of the distribution of RT for errors and correct responses per condition. The QPF plot can be seen in Fig. 6. It shows the typical flanker effect: for correct responses (the two columns on the right-hand end of the x -axis), congruent trials yielded more accurate and faster responses than the incongruent trials, as statistically evidenced by the linear mixed effects models. Moreover, the difference in response times between congruent and incongruent trials increases slightly as responses get slower (i.e., higher quantiles), as was also shown in the delta plot. Interestingly, for incongruent trials (white squares) error responses were not faster than correct responses to incongruent trials, unlike findings in the visual modality (see, White et al., 2011). QPFs are visual exploratory data analysis methods (Tukey, 1977) for which there are no established inferential statistical analyses. Nonetheless, they are a great tool to visualize data, providing a big picture of the relationships between conditions.

To create the conditional accuracy functions (CAFs), we calculated the mean accuracy per condition within the five time-bands with an equal number of responses

Fig. 6 Quantile probability functions: Distribution of RTs to *congruent* (black squares) and *incongruent* (white squares) trials. The two right columns are correct responses. The two left columns are error responses

Fig. 7 Conditional accuracy function: Mean accuracy for *congruent* (black squares) and *incongruent* (white squares) trials as a function of response time

(i.e., .1, .3, .5, .7, and .9 quantiles). As can be seen in Fig. 7, accuracy for the congruent condition was higher than for the incongruent condition across all RT quantiles and this difference is approximately constant over time. Indeed, a Bayesian analysis of variance⁴ showed a lack of an interaction between condition and quantile when explaining accuracy ($BF_{10} = 0.001$). This CAF differs from those found in the visual flanker task, where accuracy for incongruent trials is below chance for the first quantile and increases for slower responses up to the accuracy level of incongruent trials (e.g., Gratton et al., 1988).

Discussion

We created a tactile flanker task to examine the flanker congruency effect in the tactile modality when presenting two distractors surrounding the target, and to explore the temporal dynamics of the responses. To do so, we asked participants to focus their attention on the middle finger of their dominant hand, where we presented the target braille pattern (either $\bullet\bullet$ or $\begin{smallmatrix} \bullet \\ \bullet \end{smallmatrix}$), and, simultaneously, two distractors were presented to the adjacent ring and index fingers, which could be congruent (i.e., $\bullet\bullet$ $\begin{smallmatrix} \bullet & \bullet \\ \bullet & \bullet \end{smallmatrix}$ or $\begin{smallmatrix} \bullet & \bullet \\ \bullet & \bullet \end{smallmatrix}$) or incongruent (i.e., $\bullet\bullet$ $\begin{smallmatrix} \bullet & \bullet \\ \bullet & \bullet \end{smallmatrix}$ or $\begin{smallmatrix} \bullet & \bullet \\ \bullet & \bullet \end{smallmatrix}$) with the target. Participants had to

identify the target by pressing one of the two response keys (i.e., “|” or “-”).

Results showed a robust tactile flanker effect: responses to congruent trials were faster and more accurate than responses to incongruent trials (latency: 942 vs. 995 ms; accuracy: 93.5 vs. 78.7%). Hence, we extended previous research on tactile congruency effects (Driver & Grossenbacher, 1996; Evans & Craig, 1991; Evans et al., 1992; Soto-Faraco et al., 2004), this time using two distractors that surrounded the target (i.e., a scenario more similar to the demonstrations of the flanker effect in the visual modality). Although this effect was significant for both vertical and horizontal targets, it was greater for the former, indicating that the horizontal braille pattern was more difficult to detect than the vertical one. Further research is needed to clarify whether those results are a product of the orientation of the stimuli, or of the larger sensory field activated by the vertical stimuli (three dots) in comparison the horizontal one (two dots).

We further analyzed the data to explore the temporal dynamics of the tactile flanker effect, finding some similarities and differences with the standard results in the visual modality. It is worth noting that given the numerous differences between tactile and visual processing, as well as the differences in methodology, we cannot interpret equally the results found in the present study to those found in the visual modality. However, we can compare the qualitative features of results that may be modulated by modality.

As shown by the delta plot, the difference in RT between congruent and incongruent trials increases as RT increases. Thus, tactile contextual information (irrelevant to the task) influences participant’s response decision more for slow

⁴We used a Bayesian approach because it shows in a clearer manner a lack of an interaction. We include in the [Appendix](#) both frequentist and Bayesian analyses.

responses than for fast responses. Consistent with our results, delta plots in the visual modality also show an increase of the congruency effect as responses get slower (e.g., Gratton et al., 1992; Hübner & Töbel, 2019). From these results, we cannot conclude that the tactile and visual flanker effects are equivalent, since positive-going delta plots are common to many cognitive tasks (in fact, they are the most common pattern of results across many manipulations). The results reveal that the time course of the flanker effect shown by delta plots in the tactile modality is not qualitatively different from the one described in the visual modality. That is, the basic features of delta plots do not seem sensitive to the modality differences (which does not mean that there is none).

Interestingly, the QPF and CAF obtained from our experiment do not mimic those reported in the visual modality literature. In the visual flanker task, QPFs show that error responses to incongruent trials are faster than correct responses to both congruent and incongruent trials (e.g., White et al., 2011), and CAFs show that for incongruent trials accuracy shows an increase over time (it is very low for fast responses, increasing to nearly perfect levels as responses get slower), but for congruent trials accuracy is nearly perfect across all response times (Gratton, Coles, & Donchin, 1992; Hübner & Töbel, 2019; Stins, Polderman, Boomsma, & de Geus, 2007). These results suggest a greater influence of the distractors early on in the trial, in line with Hypothesis_N (third row in Fig. 2), and with models that explain congruency effects as a result of dynamic attention (e.g., Heitz & Engle, 2007; Hübner et al., 2010). However, the QPF found in our experiment shows that correct responses to congruent trials are faster than both correct and error responses to incongruent trials, with not much difference between the distributions of incongruent-correct and incongruent-error responses. In addition, the CAFs plot shows that accuracy is higher for congruent trials than for incongruent trials over time, and that the difference between does not decrease for higher RT quantiles. These results indicate the influence of the distractors was constant over time, in line with Hypothesis_S (second row in Fig. 2), which suggests the relevant information to make a decision was accumulated in a stationary manner. That is, in our tactile task, attentional selectivity does not improve during the course of processing. Hence, it seems that attentional control has some aspects that are specific to modality.

In sum, we found a tactile flanker effect that has both similarities and differences with the visual flanker effect. This is taken as evidence to support that cognitive processes underlying the response decision in the tactile flanker task, from the sensory input to the motor response, are not totally equivalent to those in the visual flanker task. We believe these results offer a start point to further research in different modalities to explore which aspects of the mechanisms

underlying the effect are domain-specific and which are domain-general. Further research is needed to understand whether the differences between visual and tactile flanker effect are caused by the specific characteristics of our perceptual systems. Moreover, such investigation has real applied implications for the growing haptic technology field. Technological developments that focus on a specific sensory modality can be optimized using knowledge about both the modality-specific and the modality-independent cognitive processes that underlie perception.

Open Practices

The online repository, available at <https://osf.io/89p3c/>, provides the bash code and the stimuli lists we utilized to carry out this experiment, along with the data analyses and data wrangling scripts.

The experiment was not pre-registered.

Author Contributions AB contributed to the original idea, carried out the data analysis, and was the primary writer of the manuscript. IU ran participants and contributed to the analysis and the preparation of the manuscript. PG developed the original idea for the experiment and the analyses and contributed to the preparation of the manuscript.

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