Exogenous cueing of visual attention using small, directional, tactile cues applied to the fingertip

de Grosbois, John; Di Luca, Max; King, Raymond; Parise, Cesare; Ziat, Mounia

DOI:
10.1109/WHC.2019.8816122

License:
Other (please specify with Rights Statement)

Document Version
Peer reviewed version

Citation for published version (Harvard):
de Grosbois, J, Di Luca, M, King, R, Parise, C & Ziat, M 2019, Exogenous cueing of visual attention using small, directional, tactile cues applied to the fingertip. in *2019 IEEE World Haptics Conference (WHC).*, 8816122, IEEE World Haptics Conference (WHC), Institute of Electrical and Electronics Engineers (IEEE), pp. 455-460, IEEE World Haptics Conference 2019, Tokyo, Japan, 9/07/19. https://doi.org/10.1109/WHC.2019.8816122

Exogenous cueing of visual attention using small, directional, tactile cues applied to the fingertip*

John de Grosbois, Massimiliano Di Luca, Raymond King, Cesare Parise, and Mounia Ziat

Abstract— **The deployment of visual spatial attention can be significantly influenced in an exogenous, presumably bottom-up manner. Traditionally, spatial cueing paradigms have been utilized to come to such conclusions. Although these paradigms have primarily made use of visual cues, spatially correspondent tactile cues have also been successfully employed. However, one property of tactile cues not thoroughly explored in this context is the influence of their specific directionality on the subsequent deployment of visual attention. Thus, the current study sought to evaluate the potential utility of small, directional tactile cues as a means to exogenously direct visual spatial attention. Tactile cues were employed by a small shearing of the fingertip's skin in either the leftward of rightward direction. A modified spatial cueing paradigm was used to compare reaction time performance across both traditional-visual and directional-tactile cues at cue-target onset asynchronies of 100, 200, 400 and 800 ms. The results indicated that both visual and tactile cues mediated the deployment of exogenous visual spatial attention. However, differences between the two modalities were observed in terms of both the magnitude and the pattern of the associated cueing effects. Further, there appeared to be a general rightward bias in performance irrespective of cue modality. Overall, the current work offers preliminary evidence that small, directional tactile stimulation may influence the allocation of attention across space in a manner at least partially distinct to traditional visual cueing tasks. Yet, further research will be required to explicitly determine the underlying mechanisms.**

I. Introduction

Although spatial attention is extremely important for the achievement of even the most simple tasks, the evaluation of stimulus features linked to the deployment of spatial attention is an ongoing challenge to researchers. Posner [1] popularized a paradigm with which to evaluate the deployment of spatial visual attention across a workspace in response to specific stimuli. Such deployment has been characterized in general as either exogenous (i.e., bottom-up or stimulus driven) or endogenous (i.e., top-down or voluntarily driven). Exogenous shifts in attention in response to a flashed placeholder typically result in early facilitation of reaction times to the presentation of a target at the cued vs an uncued location (i.e., within the first 200 ms). This period of facilitation is often followed by a period (i.e., between 200 and 600 ms) of relative inhibition at the cued location (i.e., inhibition of return; for a review, see [2]). The exogenous nature of this facilitation of reaction time can be demonstrated by utilizing non-predictive cues, which still lead to reaction time advantages. In contrast, endogenous shifts of visual attention tend to facilitate performance at relatively longer timescales (i.e., relative to the exogenous facilitation; e.g., [3]). Posner's cueing paradigm has also been successfully implemented across sensory modalities such as audition and touch (e.g., [4]). These influences on reaction time can be represented as the reaction time advantage associated with the cued relative to the uncued location or a reaction time advantage for a target when it was or was not cued (i.e., cue-target compatibility effects).

For example, if tactile stimulation is provided to the left or right hand, cueing effects have been observed at associated left or right visual locations respectively (e.g., [4]). Furthermore, vibrotactile tactile cues have been utilized in driving simulators to endogenously direct visual attention to upcoming relevant stimuli (e.g., [5]). Further, directional tactile cues have been utilized successfully to provide drivers with navigation-related information (e.g., [6,7]). Notably, however, such studies utilized tactile stimulation as a means to symbolically represent some upcoming event, and thus did not directly evaluate the direct influence of small directional tactile stimuli on the exogenous deployment of visual attention. Thus, the current study sought to evaluate short-timescale shifts in visual attention in response to small directional tactile cues.

One notable implication of such directional tactile cues is that the expected direction of the associated attentional shifts is less intuitive than one might first surmise. That is, although one may expect that a leftward shifting tactile cue would naturally cue a leftward shift in attention, one could also predict that a leftward shifting tactile cue may also/instead lead to a rightward shift in attention. This latter prediction stems from the fact that a leftward shifting tactile stimulus yields a stimulus on the fingertip consistent with a rightward-moving fingertip. According to common-coding theory (e.g., [8]; see also Theory of Event Coding, [9]), actions and their associated sensory consequences become intricately linked within the central nervous system such that sensory consequences experienced alone may prime/activate the associated action plan(s). Response-effect compatibility phenomena have provided evidence for such binding (e.g., [10,11]). Furthermore, the preparation of simple movements has been implicated in shifts of visual attention for both eye (e.g., [12]), and limb movements (e.g., [13]). Also, movement preparation has been associated with changes in the attentional set in visual search tasks (e.g., [14]), and cross modal temporal order judgements [15]. Therefore, the provision of a tactile cue that is compatible with a direction of finger movement, may bias attention in the movement-primed direction, in addition to, or instead of, the intuitive direction of tactile motion.

In the current study, participants completed two modified versions of a Posner cueing task [1] wherein they responded to the appearance of a visual target following a non-predictive, directional sensory cue. Both visual and tactile cues were utilized. It was hypothesized that at short cue-target intervals, spatially compatible visual cue-target combinations would facilitate reaction times. At longer cue-target intervals, visual cues were expected to show a reduced, or even reversed cueing

*Research supported by Facebook Reality Labs.

J. de Grosbois is with the Psychology department at Northern Michigan University. (email: jdegrosb@nmu.edu).
M. Di Luca, is with Facebook Reality Labs and the School of Psychology at the University of Birmingham (email: m.diluca@bham.ac.uk).
R. King, is with Facebook Reality Labs (email: raymond.king@oculus.com)
C. Parise is with Facebook Reality Labs (email: cesare.parise@oculus.com).
M. Ziat was with Northern Michigan University, (906-227-2948; e-mail: mziat@bentley.edu). She is now with Bentley University.

effect. Given that tactile cues have been previously reported to elicit exogenous shifts in visual attention, it was hypothesized that short cue-target intervals, spatially compatible tactile cue-target combinations would also facilitate reaction times. In contrast, due to the strong relationship between actions and their associated sensory consequences, it was hypothesized that directional tactile cues may exhibit an opposite pattern of reaction times at cue-target intervals consistent with manual reaction time (i.e., 200 to 400 ms). That is, because the tactile cues will provide sensory consequences compatible with a movement in the opposite direction, they may automatically elicit movement planning processes and their associated shifts in visual attention. Consequently, it was hypothesized that tactile cues would exhibit a decreased duration of spatially compatible cueing effects relative to the visual cues. Thus, the current study evaluated the potential for novel dynamics of exogenous visual spatial attention in response to small, directional tactile cues.

II. Experiment

A. Participants

Seventeen participants were recruited for the current study (12 females; age range = 18 to 26; 13 self-reported right handed). Participants were undergraduate students in the Psychology Department at Northern Michigan University, and were compensated with course credit. Written informed consent was provided before commencing the experiment. All experimental procedures were approved by the local institutional research ethics board.

B. Apparatus and Stimuli

The two types of stimuli employed were visual and tactile. Visual stimuli were generated from within MATLAB (Mathworks, Natick, MA, USA) using the Psychophysics Toolbox version 3 [16]. All visual stimuli were presented upon a grey background of 1920 by 1080 pixels. These stimuli consisted of a central fixation cross and two peripheral square placeholders (see *Fig.* 1A). The fixation cross was approximately 1x1 cm in size, whereas the placeholders were approximately 5x5 cm in size, and located approximately 15 cm to the left and right. Both the fixation cross and the placeholders appeared black upon the grey background. Additionally, a filled, red circular target (i.e., approximately 1 cm in diameter) could be presented within the center of either placeholder.

The tactile stimuli were created using a NanoCube linear positioning system (Model: P-611.3 Positioning System, Physik Instrumente, Karisruhe, Germany) paired with a linear servocontroller box (Model: E-664 LVZPT Linear Position Controller, Physik Instrumente, Karisruhe, Germany). The NanoCube was fitted with a 3D-printed cap, containing a tactile stimulus. The tactile stimulus was a flat, square surface (i.e., 50 by 50 mm) that spanned the top surface of the NanoCube (i.e., 44 mm squared). A finger-support structure was also utilized and positioned directly in front of the Nanocube stimulator. The support surface was positioned at a height of 58 mm (see *Fig.* 1A for an example of the experimental setup). The top surface of the support had a cylindrical-downward indentation extending approximately 8 mm with a curvature radius of 15 mm. This combination resulted in the tactile stimulus on the upper NanoCube surface sitting approximately 1 mm above the lower support surface of the finger-support.

Tactile stimulation was applied to the fingertip via the NanoCube device as 50 µm leftward or rightward displacements of the NanoCube surface as quickly as the NanoCube system was capable of delivering them (see *Fig* 2 for a depiction). The driving signals were generated in MATLAB and routed to the NanoCubes as 0 to 10 V analog signals via National Instruments 9264 cDAQ card (National Instruments, TX, USA).

Participant responses were recorded using a USB dual foot pedal device that simulated a USB keyboard button

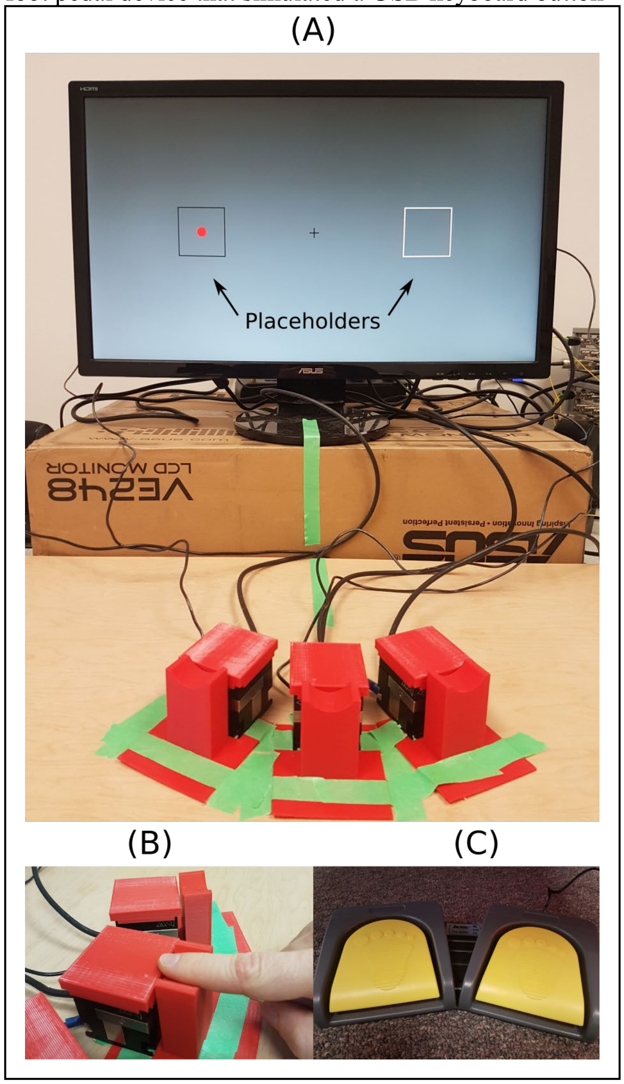

Figure 1. The experimental setup.(A) The fixation cross and the central, utilized NanoCube tactile stimulator were aligned (B) The participant placed their finger on the finger-support such that the most distal finger joint was supported and the stimulation surface was gently contacted. (C) Participants responses were recorded foot-pedals placed beneath the table.

press (Model: FS2016_USB, IKKEGOL.com, Shenzhen, China; see *Fig*. 1C).

C. Procedures

Participants were seated in front of a computer monitor at an approximate viewing distance of 50 cm. A NanoCube stimulator device with the tactile stimulus was positioned in front of the monitor and aligned with its center (see *Fig.* 1).

Participants rested their dominant hand index fingertip across the finger support and extended the upper-third of their fingerpad onto the stimulator surface. Participants rested their forearm upon the table surface in front of the stimulator. Participants feet rested upon the two foot-pedals on the floor in front of them. Instructions were delivered via an onscreen message. The primary task was to wait for the appearance of a red circle in one of the placeholders and to depress the associated foot pedal (i.e., left or right) as quickly as possible. Participants the completed two blocks of trials. Within a block of trials, participants initiated automated sequences of 25 trials at a time. After every 25 such trials, a break of a self-determined duration was provided. Each trial consisted of the following events: 1) The participant was presented with a display consisting of the fixation cross and the two placeholders. 2) Following a delay of 1 to 2 s, an audible beep indicated the initiation of a trial sequence. 3) Next, another delay of 1 to 2 seconds elapsed. 4) Either a leftward or a rightward cue was presented. Note that depending upon the current condition, the cue could be either the appearance of a white box over one of the placeholders, or the movement of the stimulator surface. Following one of 4 possible cue-target onset asynchronies (CTOA; i.e., 100, 200, 400, or 800 ms), a red visual target appeared within one of the two placeholders (see *Fig.* 2 for a depiction of a trial sequence). The participant then responded as quickly as possible with the depression of the associated foot pedal.

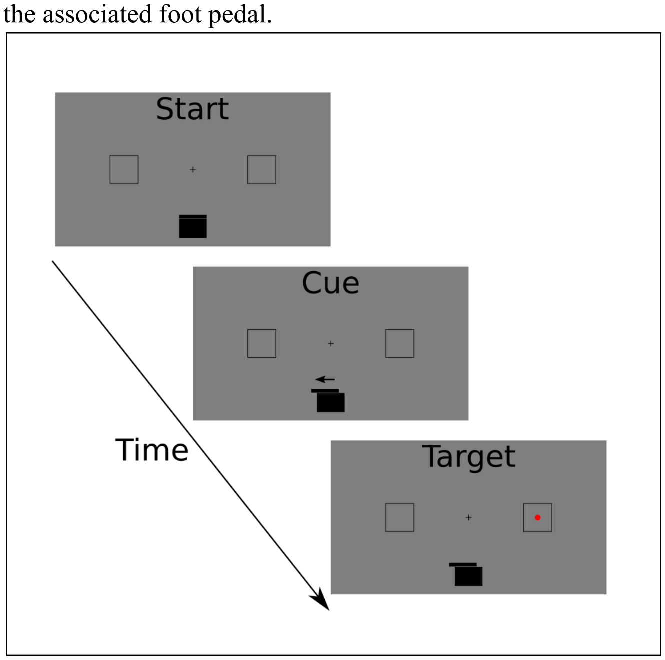

Figure 2. The a depiction of the trial sequence in the tactile stimulus block.. The three images represent a left cue followed by a right target. Note the solid black square (bottom) represents the state of the NanoCube tactile stimulator surface and did not appear on the screen.

Across the two blocks of trials, the modality of the cue (i.e., visual, tactile) was varied. Within each block, twelve trial repetitions were completed for each of the 16 combinations of: 2 Cue-Side (i.e., leftward, rightward) x 2 Target-Side (i.e., left, right) x 4 CTOA (i.e., 100, 200, 400, & 800 ms), yielding 192 trials per block (i.e., a total of 384 experimental trials). The block order (i.e., cue modality order) was counterbalanced across participant, and the two blocks of trials were separated by a mandatory 5-minute break.

D. Data Analysis

The main dependent variable was the participants' reaction time. That is, the time that elapsed between the onset of the visual target and the depression of the foot-pedal. Only correct responses contributed to group means, and incorrect trials were repeated randomly later in the block. An overall average error rate of 0.007 % was observed.

The overall statistical design was a 2 Modality (visual, tactile) x 2 Cue-Side (left, right) x 2 Target-Side (left, right) x 4 CTOA (100, 200, 400, 800 ms) repeated measures ANOVA. Post-hoc analyses were performed using a simple main effects approach with a Bonferroni correction applied on a family-wise basis. When a Bonferroni correction was applied the adjusted *p*-values have been reported as "p_{bx}" where the numerical value of 'x' indicates the number of comparisons corrected for. Lastly, when significant main effects were also involved in higher order interactions, only the interactions were directly subjected to post-hoc analyses. Additionally, given the relatively large number of means associated with the design, condition differences were also evaluated visually, using within-subjects 95 % confidence intervals (e.g., [17]). Of particular interest for these comparisons were contrasts associated with cue-target compatibility effects. That is, differences in reaction time within a modality between at a cued vs and uncued location, and differences to a particular target when it was vs when it was not cued. Note the direct evaluation of such cueing effects were imperative to evaluate the primary hypothesis.

E. Results

In the interest of brevity, only significant main effects and interactions are reported below. A summary of all ANOVA effects can be found in *Table* 1. Once again, if a significant effect was nested in a higher order interaction, only the highest-order effect was subjected to post-hoc analyses.

The omnibus ANOVA analysis yielded significant main effects of Target-Side and CTOA. Participants responded faster to targets presented to the right ($M = 413$, $SD = 45$) relative to the left ($M = 438$, $SD = 33$). Also, reaction times tended to be faster for intermediate CTOAs. Significant two-way interactions were also observed between Modality and CTOA, and between Cue-Side and Target-Side.

Post-hoc analyses of the Modality x CTOA interaction revealed that visual cues at a CTOA of 400 ms exhibited significantly shorter reaction times ($M = 412$ ms, $SD = 42$), relative to the 100 ($M = 431$ ms, $SD = 45$; $p_{b6} < .001$), 200 ($M = 423$ ms, $SD = 44$; $p_{b6} = .17$), and 800 ms ($M = 426$ ms, $SD = 47$; $p_{b6} = .022$) CTOAs.

In the omnibus ANOVA, significant three-way interactions were observed between Cue-Side, Target-Side and CTOA, and between Modality, Cue-Side, and Target-Side. Post-hoc analyses of the Cue-Side x Target-Side x CTOA interaction were completed as families of *t*-tests computed across levels of Cue-Side and Target-Side within

Table 1 ANOVA table for the main analysis.

Effect	*F*	*p*	η_G^2
Modality	$F(1,16) = 0.42$	.526	.002
Cue-Side	$F(1,16) = 0.48$	.496	< .001
Target-Side	$F(1,16) = 22.17$	* < .001	.068
CTOA	$F(3,48) = 4.50$	* .004	.006
Modality x CTOA	$F(3,48) = 4.46$	* .008	.007
Cue-Side x CTOA	$F(3,48) = 0.78$	.511	.001
Modality x Cue-Side	$F(1,16) = 0.43$	.524	< .001
Target-Side x CTOA	$F(3,48) = 1.79$	.161	.003
Modality x Target-Side	$F(1,16) = 0.17$	.683	< .001
Cue-Side x Target-Side	$F(1,16) = 19.94$	* < .001	.018
Modality x Cue-Side x CTOA	$F(3,48) = 2.16$	.105	.003
Modality x TargetSide x CTOA	$F(3,48) = 1.03$	.390	.001
CueSide x TargetSide x CTOA	$F(3,48) = 2.88$	* .045	.003
Modality x CueSide x TargetSide	$F(1,16) = 10.50$	* .005	.015
Modality x CueSide x TargetSide x CTOA	$F(3,48) = 1.33$	.276	.002

Notes. * indicates $p < .05$; η_G^2 is generalized eta squared.

each combination of the CTOA and the other factor (i.e., either Cue-Side or Target-Side). These analyses indicated that when the right side was cued, significantly shorter reaction times were observed at the cued vs. the uncued target at all levels of CTOA (p_{b4}s < .008). Also, regarding the left target, reaction times were significantly shorter when the left side was cued relative to when it was not cued at the 100 (Left-Cue: $M = 433$ ms $SD = 34$; Right-Cue: $M = 459$ ms, $SD = 38$; $p_{b4} < .001$), and the 200 ms CTOA (Left-Cue: $M = 432$ ms, $SD = 36$; Right-Cue: $M = 447$ ms, $SD = 38$; $p_{b4} = .026$). Further, reaction times to the right target exhibited a significant reduction in reaction time when cued vs uncued at the 200 ms CTOA only (Left-Cue: $M = 419$ ms, $SD = 48$; Right-Cue: $M = 407$ ms, $SD = 42$; $p_{b4} = .023$).

Post-hoc analyses of the Modality x Cue-Side x Target-interaction were completed as families of *t*-tests computed between each of the pairwise combinations of these three factors. A number of significant differences were observed. When the left side received a tactile cue, reaction times to the Left-Target were significantly longer ($M = 438$ ms, $SD = 33$) than those to the Right-Target ($M = 415$ ms, $SD = 43$; $p_{b4} = .001$). When the right side was cued with either modality, reaction times were significantly shorter for the Right-Target relative to the Left-Target (Tactile Cue: Left-Target $M = 441$ ms, $SD = 32$; Right-Target $M = 417$ ms, $SD = 48$, $p_{b4} = .006$; Visual Cue: Left-Target $M = 448$ ms, $SD = 45$; Right-Target $M = 398$ ms, $SD = 48$, $p_{b4} < .001$). Further, a reaction time advantage was observed for both the left and right targets when they were cued visually relative to when they were uncued (Left- Target: $p_{b4} = .008$; Right-Target: $p_{b4} = .008$).

Overall, post-hoc analyses of this Modality x Cue-Side x Target-Side interaction indicated that the presence of visual cues reduced reaction times within targets, and when the target appeared at a cued right location. In contrast, tactile cues showed shorter reaction times at the cued location for the right cue, but at the uncued location for left-cue.

To further evaluate the main hypotheses, within-subjects confidence interval analyses were completed both visual (*Fig.* 3) and tactile cues (*Fig.* 4). If the confidence intervals did not include an adjacent mean, one can be confident in the general ordinal pattern of those means [17].

Considering the visual cueing conditions (i.e., *Fig.* 3), the data were highly consistent with the primary analysis. That is, when the target appeared at the cued location, reaction times were facilitated for the right, but not the left cue. Further, reaction times were facilitated within each target when it was cued relative to when it was not.

Next, considering performance when tactile cues were provided, the results were also highly consistent with the main analysis with one notable exception (i.e., *Fig.* 4). That is, when a right-side tactile cue was provided, reaction times were facilitated to the right target relative to the left target. Also, as with the main analysis, a reversal of this cueing effect was found when the left side was cued, as reaction times were slower to the left target relative to the right target. The novel finding apparent through this analysis was observed for the right target at the 200 ms CTOA. That is, reaction times were shorter when the left side was cued relative to when the right side was cued.

F. Discussion and Conclusions

The primary purpose of the current experiment was to determine the feasibility of utilizing small, directional tactile cues as a means to exogenously direct visual spatial attention. To this end, a modified version of a traditional visual spatial cueing paradigm was adopted wherein small directional tactile cues were applied to the upper-third of the index fingertip in advance of the onset of a visual target in one of two visual locations (i.e., left or right targets), and at one of four CTOAs (i.e., 100, 200, 400, or 800 ms).

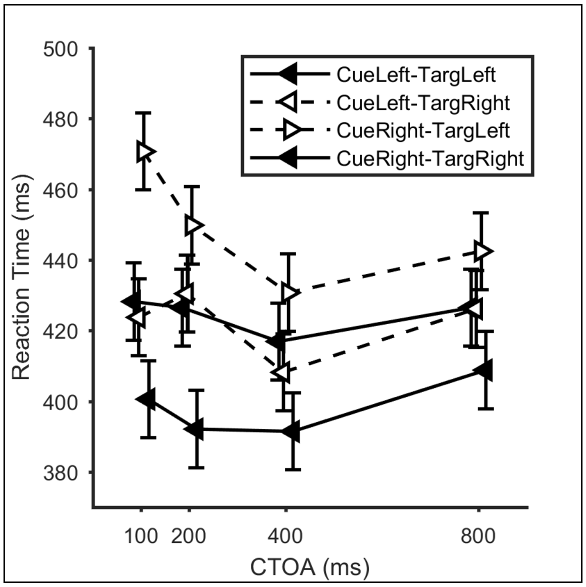

Figure 3. Reaction times across Cue-Side, Target-Side and CTOA for the visual cue conditions. Error bars represent 95 % within-subjects confidence intervals. Note. The slight horizontal offsets between condition means within each level of CTOA are for illustrative purposes only.

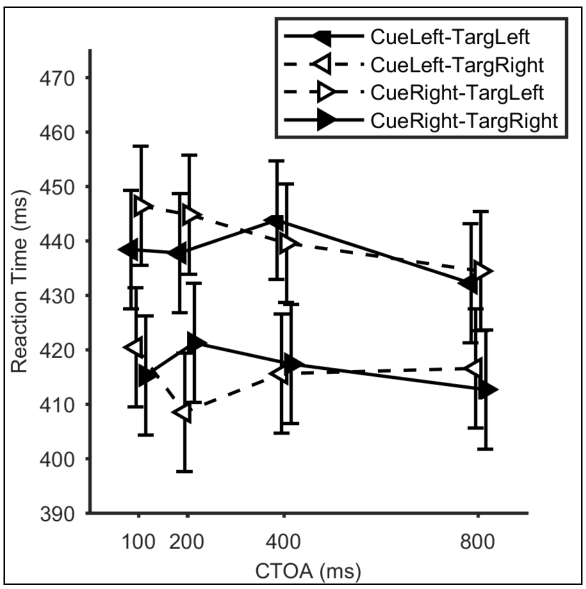

Figure 4. Reaction times across Cue-Side, Target-Side and CTOA for the tactile cue conditions. Error bars represent 95 % within-subjects confidence intervals. Note. The slight horizontal offsets between condition means within each level of CTOA are for illustrative purposes only.

To qualify the influence of these tactile cues, a traditional version of the task was also undertaken that utilized spatial visual cues. In general, the visual cues led to the expected facilitation of reaction time performance both within targets, and within cue locations [1]. That is, with the exception of the left side cue, which may have been facilitated by the experimental setup (see discussion below).

The Cue-Side x Target-Side x CTOA interaction provided evidence for common cueing effects, irrespective of cue modality, at shorter CTOAs, When performance was quantified within targets and contrasted across cue conditions, significant cue-related facilitations of reaction time were observed at early CTOAs (i.e., at 100 and 200 ms for the left target, and 200 ms for the right target). Such cueing effects at short CTOA values have been reported many times [1,2,3]. Further, crossmodal cueing between tactile and visual domains has also been demonstrated [4]. In agreement with the current results, these crossmodal effects have tended to be smaller in magnitude relative to unimodal conditions.

The first novel finding from the current experiment was the persistence of these cross-modal cueing effects in the absence of distinct, spatially correspondent cue and target locations across modalities. That is, the vast majority of studies evaluating these crossmodal effects have done so using spatially corresponding cues and targets [4]. That is, both the left and right cues in each modality were positioned correspondingly in left and right space. By contrast, the current study utilized a central tactile cueing location that provided small, directional tactile cues. Directional tactile cues have been successfully utilized to facilitate navigation performance while driving via embedded tactile stimulation devices in steering wheels, [6,7]. However, the overt decision making associated with these tasks limits the ability of the associated effects to be attributed to shifts in exogenous spatial attention. In the current study, the nonpredictive cues, combined with observed facilitation of reaction time at short CTOA values indicated that the results were likely mediated by exogenous shifts in visual attention.

In contrast, the Modality x Cue-Side x Target-Side interaction highlighted a significant differences between the compatibility effects observed across the visual and tactile cues. Visual cues on the right, but not on the left, exhibited reaction time advantages at the corresponding target. Additionally, reaction times were shorter at both targets when cued vs uncued. The tactile cues exhibited a different pattern of results. The right tactile cue exhibited shorter reaction times at the corresponding target. However, the left tactile cue exhibited a reaction time advantage at the uncued, right target. This unique cueing pattern for the leftward tactile cues were consistent with the predictions of common-coding theory [8,9,10]. That is, a leftward tactile cue provided the sensory consequences of a rightward limb movement, and could thus prime a right-target response, leading to rightward shifts in spatial attention [12,13]. However, because this uncued advantage was only observed for the right target, other factors were clearly influencing performance.

Overall, as evidenced by the significant main effect of Target-Side, participants exhibited a right target reaction time advantage. This right-side advantage may have been contributed to by a number of possible mechanisms. First, the difference in the spatial proximity of the two hands to the screen may have biased responses to the right [18]. Second, the tactile cues were only provided to a single hand, which has been shown to reduce ipsilateral foot reaction times [19]. Furthermore, through work on hemispatial neglect, it has been suggested that the right visual field may benefit from a more robust attentional control mechanism [20]. However, directional biases in visual attention have been scarcely reported given the predominance of collapsing across side of space prior to analyses [1]. Nevertheless, the biases observed in the current study likely attenuated left-target responses and contributed to the lack of target-compatibility effects for leftward visual cues (see *Fig.* 3). Importantly, despite this general rightward bias, significant evidence for the common coding theory explanation was present. That is, the confidence interval analysis indicated when only considering right target responses at a CTOA of 200 ms (i.e., consistent with a simple movement reaction time), left-cue responses still exhibited shorter reaction times compared to right-cue responses. This difference was also supported by a paired-samples t-test, $t(16) = 2.47$, $p = .025$, Cohen's d = .17. Thus, in spite of any overt directional biases, right-target responses were enhanced by small left-directional tactile stimulation, which were consistent with the sensory consequences of a rightward movement.

Ultimately, small directional tactile cues exhibited a more complicated pattern of cue-target facilitation as a function of CTOA. Consistent with previous work, similarities with traditional visual cueing were observed at short CTOA values. At slightly longer CTOA, and restricted to the right target responses, the results were best described by the predictions of common coding theory. That is these directional tactile cues appeared to have facilitated the deployment of exogenous spatial visual attention in a manner consistent with the activation of movement preparation circuits associated with experiencing compatible sensory consequences. However, it must be acknowledged that the current results are only in partial support for this conclusion. That is, a comparable effect was not observed for the left target. However, this inconsistency in cueing effects for the left target was also observed for the visual cues, therefore overall performance to the right target appeared to be more consistent with the hypothesized cueing effects. Nevertheless, the aforementioned hypothesis of tactile cue-induced movement priming effects could be evaluated in a future experiment by providing directional tactile cues and measuring their influence on the reaction times of directionally compatible or incompatible movements with the cued limb.

Overall, the current study evaluated if small, directional tactile cues could be used to exogenously influence the deployment of visual spatial attention. These cues at least partially successful in this regard. That is, cueing effects were observed when utilizing the tactile directional cues. However, the magnitude of these effects were substantially smaller relative to visual cues and the pattern was more complex. That is, reaction times associated with these small directional tactile cues were potentially also modulated by primed movement plans as predicted by common coding theory. Altogether, these findings indicate that small directional tactile cues may modulate exogenous visual attention via both common and unique mechanisms relative to traditional visual spatial cueing paradigms. Ultimately, these results are promising, but require further experiments to test the hypothesized explanations outlined above.

Acknowledgments

We would like to thank Elizabeth Makela and Katelyn Fust for the assistance and contributions to this project.

References

[1] M. I. Posner and Y. Cohen, "Components of Visual Orienting," in *Attention and Performance X: Control of Language Processing*, H. Bouma and D. G. Bouwhuis, Eds. London: Lawrence Erlbaum, 1984, pp. 531–556.

[2] R. M. Klein, "Inhibition of return," *Trends Cogn. Sci.*, vol. 4, no. 4, pp. 138–147, 2000.

[3] A. B. Chica and J. Lupiáñez, "Effects of endogenous and exogenous attention on visual processing: An Inhibition of Return study," *Brain Res.*, vol. 1278, pp. 75–85, 2009.

[4] C. Spence and J. Driver, "Cross-modal links in exogenous covert spatial orienting between touch, audition, and vision," *Percept. Psychophys.*, vol. 60, no. 4, pp. 544–557, 1998.

[5] C. Ho, H. Z. Tan, and C. Spence, "Using spatial vibrotactile cues to direct visual attention in driving scenes," *Transp. Res. Part F Traffic Psychol. Behav.*, vol. 8, no. 6, pp. 397–412, 2005.

[6] C. J. Ploch, J. H. Bae, W. Ju, and M. Cutkosky, "Haptic Skin Stretch on a Steering Wheel for Displaying Preview Information in Autonomous Cars," *IEEE/RSJ International Conference on Intelligent Robots and Systems*, pp. 60-65, 2016.

[7] C. J. Ploch, J. H. Bae, C. C. Ploch, W. Ju, and M. R. Cutkosky, "Comparing haptic and audio navigation cues on the road for distracted drivers with a skin stretch steering wheel," *2017 IEEE World Haptics Conf.*, pp. 448–453, 2017.

[8] W. Prinz, (1990). "A common coding approach to perception and action," in *Relationships between perception and action*, O. Neumann and W. Prinz, Eds. Berlin: Springer, 1990, pp. 167-201.

[9] B. Hommel, "Action control according to TEC (Theory of Event Coding)," *Psychological Research* (2009) vol. 73: pp. 512-526, 2009. https://doi.org/10.1007/s00426-009-0234-2

[10] W. Kunde, J. Hoffmann, and P. Zellmann, "The impact of anticipated action effects on action planning," *Acta Psychol. (Amst).*, vol. 109, pp. 137–155, 2002.

[11] M. Ziat, I. Frissen, G. Campion, V. Hayward, and C. Guastavino, "Plucked string stiffness affects loudness perception," in *Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)*, vol. 7989 LNCS, I. Oakley and S. Brewster, Eds. Berlin Heidelberg: Springer, 2013, pp. 79–88.

[12] G. Rizzolatti, L. Riggio, I. Dascola, and C. Umiltá, "Reorienting attention across the horizontal and vertial mreidians: Evidence in favor of a premotor theory of attention," *Neuropsychologia*, vol. 25, no. 1A, pp. 31–44, 1987.

[13] S. P. Tipper, C. Lortie, and G. C. Baylis, "Selective reaching: Evidence for action-centered attention.," *J. Exp. Psychol. Hum. Percept. Perform.*, vol. 18, no. 4, pp. 891–905, 1992.

[14] L. Craighero, L. Fadiga, G. Rizzolatti, and C. Umiltà, "Action for perception: a motor-visual attentional effect.," *J. Exp. Psychol. Hum. Percept. Perform.*, vol. 25, no. 6, pp. 1673–1692, Dec. 1999.

[15] I. Frissen, M. Ziat, G. Campion, V. Hayward, and C. Guastavino, "Acta Psychologica The effects of voluntary movements on auditory – haptic and haptic – haptic temporal order judgments," *Actpsy*, vol. 141, no. 2, pp. 140–148, 2012.

[16] Brainard, D. (1997). The psychophysics toolbox. *Spatial Vision, 10*, 433-436.

[17] G. R. Loftus and M. E. Masson, "Using confidence intervals in within-subject designs.," *Psychon. Bull. Rev.*, vol. 1, no. 4, pp. 476–490, Dec. 1994.

[18] D. M. Lloyd, E. Azañón, and E. Poliakoff, "Right hand presence modulates shifts of exogenous visuospatial attention in near perihand space," *Brain Cogn.*, vol. 73, no. 2, pp. 102–109, 2010.

[19] C. Spence and F. P. McGlone, "Reflexive spatial orienting of tactile attention," *Exp. Brain Res.*, vol. 141, pp. 324–330, 2001.

[20] J. B. Williamson, D. G. Lamb, D. B. Burtis, S. Haque, T. Kesayan, M. Harciarek, and K. M. Heilman, "Right hemispatial ipsilisional neglect with chronic right hemisphere strokes," *J Clin Exp Neuropsyc*, vol. 40, no. 4, pp. 347-356, 2018.