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Research report

Enhanced heat discrimination in congenital blindness

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HIGHLIGHTS

- Congenitally blind subjects outperform sighted controls in thermal sensory-discrimination.
- Congenitally blind subjects are more susceptible to spatial summation of heat than the sighted.
- Enhanced thermal discriminability of the blind may help in object recognition.

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ABSTRACT

There is substantial evidence that congenitally blind individuals perform better than normally sighted controls in a variety of auditory, tactile and olfactory discrimination tasks. However, little is known about the capacity of blind individuals to make fine discriminatory judgments in the thermal domain. We therefore compared the capacity to detect small temperature increases in innocuous heat in a group of 12 congenitally blind and 12 age and sex-matched normally sighted participants. In addition, we also tested for group differences in the effects of spatial summation on temperature discrimination. Thermal stimuli were delivered with either a 2.56 or 9 cm^2 Peltier-based thermode. We applied for 5–8 s lasting non-painful thermal stimuli to the forearm and asked participants to detect small increments in temperature (ΔT = 0.4, 0.8, 1.2 or 1.6 °C) that occurred at random time intervals. Blank trials (ΔT = 0 °C) were also included to test for false positive responses. We used signal detection theory model to analyze the data. Our data revealed that blind participants have a higher accuracy than the sighted (d': Blind = 2.4 ± 1.0, Sighted = 1.8 ± 0.7, p = 0.025), regardless of the size of the stimulated skin surface or magnitude of the temperature shift. Increasing the size of the stimulated skin area increased the response criterion in the blind (p = 0.022) but not in the sighted. Together, these findings show that congenitally blind individuals have enhanced temperature discrimination accuracy and are more susceptible to spatial summation of heat

1. Introduction

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There is growing evidence that congenitally blind individuals outperform age-and sex-matched normally sighted individuals in various sensory tasks [1]. Indeed, congenitally blind individuals have supra-normal discrimination skills in tactile [2–4], auditory [5–7] and olfactory [8–10] modalities. In a previous study, we measured warmth and cold detection thresholds as well as heat and cold pain thresholds and responses to supra-thresholds heat stimulation in congenital blind subjects [18]. Although blind individuals showed increased responses to pain stimulation, thresholds for innocuous warmth and cold were not different from normal sighted controls. These results do not imply, however, that blind individuals perform would not perform any better than sighted controls in more complex temperature discrimination tasks. To date, nothing is known about the blind's ability to discriminate thermal stimuli. Based on anecdotal accounts from blind individuals about their use of thermal cues in daily-life activities, e.g. the difference in temperature gradient caused by sunlight hitting the forehead for purposes of spatial navigation, we hypothesized that they would have better heat discrimination skills.

It has been shown that people can discriminate between a broad range of materials by relying solely on thermal diffusivity proprieties [11–13]. Because of their lack of vision, blind individuals might

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rely more strongly on these thermal cues for object recognition, possibly leading to an enhanced sensitivity to detect subtle differences in thermal properties. Furthermore, thermoception also plays a role in avoiding thermal injury [14]. Indeed, nociceptive heat is encoded by the combined activity of thermoceptors and nociceptors, suggesting that warm fibers contribute to the experience of pain [14–17]. Therefore, a rapid increase in temperature, even within the innocuous range, can be encoded as dangerous. Since CB has lower heat pain thresholds compared to sighted individuals [18,19], they may be more attentive to temperature shifts that may be indicative for an impeding painful stimulus.

Thermal perception is not only dependent on stimulus intensity but also on spatial summation [12,20,21]. Indeed, changing the size of a thermal stimulus drastically affects the perceived intensity. This property is especially important in warmth perception in which intensity and spatial extent of the stimulus have equal influence on the perceived intensity [12,22]. Unpublished preliminary data from our lab suggested that the spatial extent of thermal stimulation more strongly affects perceptual decision making in blind compared to sighted participants. Therefore, we investigated here in a more systematic manner whether congenitally blind differ from normal controls with respect to spatial summation of heat.

2. Methods

Participants were recruited from our database of congenitally blind subjects or by advertisement. Our study population consisted of 12 congenitally blind (5F; mean age: 39.0 ± 12.2 years; range: 24–61) and 12 normally sighted (5F; mean age: 38.8 ± 14.7 years; range: 21–66) participants. One blind participant and her matched control were excluded from the data analysis due to non-completion of the experiment. All blind participants suffered from blindness due to peripheral origin. Blindness due to diabetic neuropathy was an exclusion criterion [23]. None of the participants suffered from known neurological or psychiatric disorders that might interfere with the experiment's results. Demographic details on the blind participants are provided in Table 1. All participants, including the blind, provided their written informed consent to participate in this study. The ethics committee for the city of Copenhagen and Frederiksberg, Denmark approved the study and the consent procedure.

We used a Peltier-based thermotest (TSA-II, Medoc, Haifa, Israel) to deliver innocuous heat stimuli. The device was gently strapped to the dominant volar forearm, thereby avoiding too much pressure as this may affect skin temperature [24]. Participants were first familiarized with the procedure and underwent a number of practice trials. All participants, including the blind, were blindfolded during data acquisition. The baseline temperature of the probe was kept at 32 °C. At the beginning of each trial, the skin temperature was brought to a conditioning temperature of 38 °C, a temperature that was clearly above the baseline skin temperature for all participants, using a ramp rate of 5 °C/s. Skin temperature was maintained at this level for 3 to 6 s; following a second sound cue, temperature increased by a ΔT of 0.4, 0.8, 1.2 or 1.6 °C at a rate of 3 °C/s and was maintained at this temperature for 2.5 s, after which a third sound cue announced the end of the trial (Fig. 1). Participants were instructed to press a response key as soon as they detected the second temperature increase. Each temperature shift was presented 20 times. We also included 20 blank trials in which the temperature was maintained at 38° C (ΔT = 0.0 °C). Stimuli were presented in a pseudo-randomized order to avoid the same temperature shift to be delivered more than twice in a row. The inter-stimulus interval was set at 10 s.

To investigate the effect of spatial summation, we used a small (2.56 cm^2) and a large (9 cm^2) thermode. Half of the blind participants and their matched sighted controls were assigned to the small thermode first, the other half to the large one first. There was a minimum time interval of 1 week between the two sessions.

We evaluated task performance using a signal detection theory model of analysis. The probability of a "hit" (P(H)) was calculated for each level of stimulation (ΔT = 0.4, 0.8, 1.2 or 1.6 °C) by dividing the number of correct detections of a temperature increase (hit) by the number of stimulus presentations. Next, the probability of a "false alarm" (P(FA)) was calculated as the proportion of trials in which the subject responded detecting a temperature shift during a blank trial (ΔT = 0.0 °C). Thereafter, we calculated the discrimination accuracy (d') for each stimulus intensity by subtracting a z-score calculated from P(FA) from a z-score calculated for P(H). Finally, the decision criterion (c), a value that indicates the participant's response bias, was calculated by subtracting z(H) from d'. We used Levene's test for assessing equality of variances of the data distributions for d' and c assessments (factor = "group" and dependent variable = "d'"/"c"). We then compared groups for d' by conducting a repeated measures ANOVA with the factors "group", "size" and "temperature shift" as independent variables and "d'" as dependent variable. In order to compare groups for c, we also performed a repeated measures ANOVA with the factors "group" and "size" as independent variables and "c" as dependent variable. Two-tailed Student t-tests were used for single comparisons of the different variables listed above. Correction for multiple comparisons was done using Bonferroni (α = 0.05).

3. Results

Levene's tests indicated equality of variance for all data distributions, as illustrated in Table 2. The first ANOVA showed that congenitally blind (CB) participants had a higher accuracy in

Table 1
Q5 Demographic data of blind participants.

ID	Age	Sex	Blindness Onset	Etiology	Residual vision
CB1	39	M	0	Retinopathy of prematurity	Bright light
CB2	26	M	0	Retinopathy of prematurity	–
CB3	57	M	0	Retinopathy of prematurity	–
CB4	37	M	0	Optic nerve atrophy	Bright light
CB5	25	M	0	Retinopathy of prematurity	–
CB6	42	F	0	Retinopathy of prematurity	–
CB7	24	F	0	Retinopathy of prematurity	–
CB8	50	M	0	Retinopathy of prematurity	–
CB9*	36	F	0	Retinopathy of prematurity	–
CB10	29	F	0	Retinopathy of prematurity	–
CB11	61	F	0	Retinopathy of prematurity	–
CB12	42	M	1	Meningitis	Bright light

* This participant was excluded due to the non-completion of the experiment.

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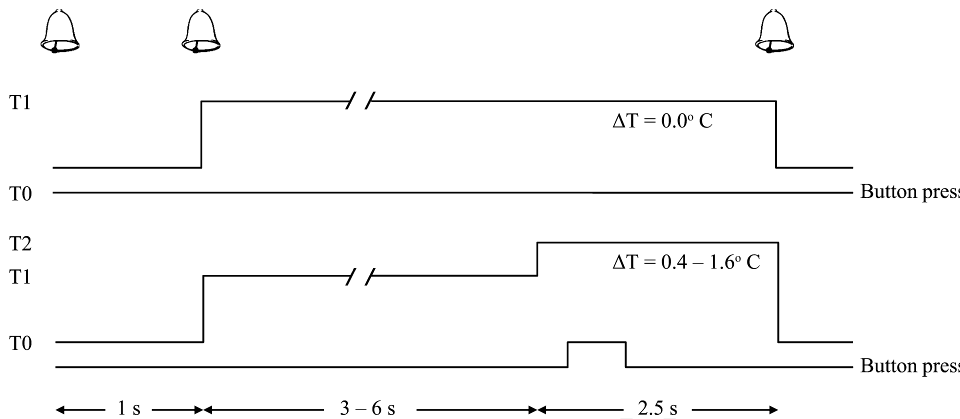

Fig. 1. Experimental procedure. We used a baseline temperature of 32 °C prior to each trial. Following a first sound cue, the skin was heated up at a rate of 5 °C/s. The second sound cue announced the stabilization of skin temperature at 38 °C. This first temperature was maintained for a time varying randomly between 3 and 6 s. Thereafter, the temperature increased by ΔT = 0.4, 0.8, 1.2 or 1.6 °C at a rate of 3 °C/s and was maintained for 2.5 s. Participants had to click on a response key as soon as they detected the temperature increase. A third sound cue indicated the end of the trial. The inter-stimulus interval was set at 10 s. Each temperature shift was presented 20 times. We also included 20 blank trials in which the temperature was maintained at 38 °C (ΔT = 0.0° C). Stimuli were presented in a pseudo-randomized order to avoid the same temperature shift to be delivered more than twice in a row.

Table 2
Levene tests of normality.

Device	Variable	df1	df2	*F*	*p*
2.56 cm^2	*d'* (0.4 °C)	1	20	0.117	0.735
	d' (0.8 °C)	1	20	4.318	0.051
	d' (1.2 °C)	1	20	0.702	0.412
	d' (1.6 °C)	1	20	0.038	0.848
	c	1	20	0.383	0.543
9.00 cm^2	*d'* (0.4 °C)	1	20	0.274	0.606
	d' (0.8 °C)	1	20	2.579	0.124
	d' (1.2 °C)	1	20	0.499	0.488
	d' (1.6 °C)	1	20	0.061	0.807
	c	1	20	0.427	0.521

detecting temperature changes than the normally sighted (NS) (d': CB = 2.4 ± 1.0, NS = 1.8 ± 0.7; F = 5.903, df = 1, p = 0.025).

Further comparisons indicated that all participants–regardless of the group–performed better when using the large 9 cm^2 thermode (d': 2.56 cm^2 = 1.8 ± 0.7, 9 cm^2 = 2.5 ± 0.7; F = 7.636, df = 3, p < 0.001). Interestingly, we found a significant "size" × "temperature shift" interaction (p < 0.001), indicating that spatial summation only influenced performance for the temperature shifts that were larger than 0.4 °C (Table 3). Fig. 2A illustrates the detailed performance of each group.

The ANOVA performed on the decision making component of our data showed that, on average, blind and sighted participants have similar response criteria (c: CB = 1.2 ± 0.7, NS = 1.3 ± 0.5, df = 1, F = 0.217, p = 0.647). Comparisons of c specific to each stimulus size also failed to show significant group differences (2.56 cm^2: CB = 0.95 ± 0.5, NS = 1.2 ± 0.4; df = 1, F = 1.889, p = 0.185; 9 cm^2: CB = 1.5 ± 0.7, NS = 1.4 ± 0.7; df = 1, F = 0.073, p = 0.790). Importantly, spatial summation affected decision making in the blind but not in the sighted group (Fig. 2B). Indeed, there was a significant increase in c when increasing the area of stimulation from 2.56 cm^2 to 9 cm^2 in blind (CB: df1 = 1, df2 = 20, F = 6.158, p = 0.022), but not in sighted participants (NS: df1 = 1, df2 = 20, F = 0.778, p = 0.388).

4. Discussion

The aims of this study were to test whether congenitally blind individuals (1) are better in discriminating small increases in innocuous warmth and (2) are more prone to spatial summation effects of heat. In accordance with our hypothesis, results showed that congenitally blind participants are better than the normally sighted at discriminating temperature changes, regardless of the amplitude of the temperature increase or the spatial extent of the stimulated area. Our findings further indicated that the effect of spatial summation on performance accuracy did not differ for blind and sighted subjects, whereas it exerted a differential effect on the response criterion. Indeed, increasing the spatial extent of stimulation lead to an enhanced performance in both groups, but to a reduction in false positives in the blind only.

There is strong evidence that congenitally blind individuals outperform their sighted peers in discrimination tasks involving auditory, tactile and olfactory sensory modalities [1], but few data are available for thermal perception. Here we present the first demonstration that visual deprivation from birth is associated with enhanced temperature discrimination accuracy. This adds new evidence on cross-modal compensatory plasticity in congenital blindness.

Two hypotheses have been put forward to explain increased sensory sensitivity in congenital blindness. According to the sensory deprivation hypothesis, blind individuals perform better in non-visual sensory tasks because the mere absence of vision leads to compensatory changes in the other sensory modalities.

Table 3
Influence of stimulation size on performance.

Temperature increase (°C)	Size of stimulation (cm^2)	*d'*	*t*	df	*p*
0.4	2.56	1.0 ± 0.6	1.7	21	p = 0.113
	9.00	1.2 ± 0.6			
0.8	2.56	1.6 ± 0.8	4.8	21	p < 0.001
	9.00	2.4 ± 0.9			
1.2	2.56	2.0 ± 0.9	4.2	21	p < 0.001
	9.00	2.9 ± 1.0			
1.6	2.56	2.5 ± 0.7	4.6	21	p < 0.001
	9.00	3.5 ± 0.7			

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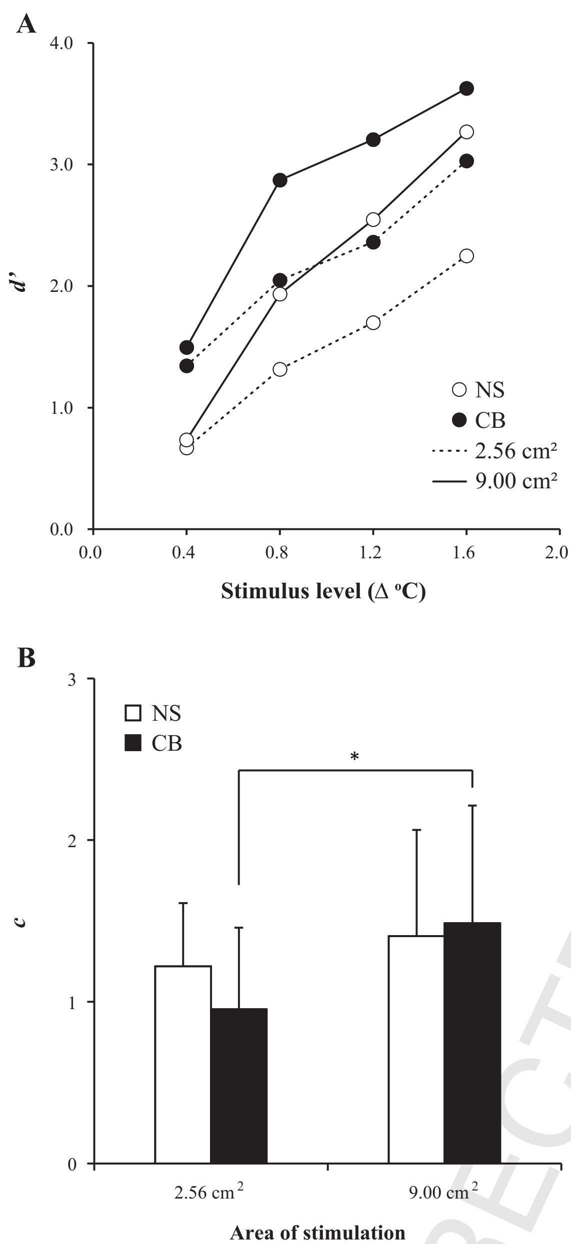

Fig. 2. Performance of congenitally blind (CB) and normally sighted (NS) participants in the temperature discrimination task. A – Overall, CB had a better performance (d') than NS in detecting small changes in temperature ($p = 0.025$). Increasing the area of stimulation from 2.56 cm^2 (dashed lines) to 9 cm^2 (solid lines) enhanced both groups' accuracy in all temperature shifts ($p < 0.001$), but $\Delta T = 0.4°$ C ($p = 0.113$). B – CB and NS had a similar response criterion (c), regardless to stimulus size ($p = 0.647$). A significant increase in criterion was observed when increasing the area of stimulation ($p = 0.027$). Error bars represent the standard deviation.

According to the training-induced hypothesis, it is not the absence of vision per se that drives hypersensitivity but training-induced plasticity. For instance, for the tactile domain, superior grating orientation discrimination was shown for the fingertips but not for the facial area, and improved performance correlated with the amount of Braille reading, which was interpreted as supporting the training-induced plasticity hypothesis [4]. Since we tested the volar forearm, a body region that is unlikely being used extensively by the blind in temperature discrimination tasks, it seems rather unlikely that our results are due to training-induced plasticity. Alternatively, the increased thermal sensitivity in congenital blindness might be explained by their hypersensitivity to nociceptive stimulation [18,19]. Indeed, a more efficient computing of rapid temperature raises, will help in avoiding possible encounters with noxious thermal stimuli. In general, most thermally harmless objects of the environment are colder than the skin, whereas the dangerous ones are warmer [12]. Therefore, the activation of heat-sensitive C-fibers of the skin when touching an object can indicate impeding danger.

We propose that blind individuals have learned to better use these thermal cues in order to prevent thermal injuries. This is supported by our recent findings that congenitally blind individuals are hypersensitive to thermal pain [18,19]. The same studies, however, indicated that thresholds for innocuous thermal perception in congenitally blind and sighted participants were not different. This, of course, does not preclude the possibility that the blind are better at tasks that require higher order perceptual skills such as fine temperature discrimination. Indeed, it is now well documented that congenitally blind individuals show sensory compensation in discrimination and identification tasks rather than simple detection thresholds [1,25,26].

A recent study from Wong et al. [4] showed that temporarily light depriving sighted participants worsens their performance on a tactile spatial task. One could therefore argue that blindfolding the sighted participants in the present study would worsen their performance. Nonetheless, we decided to blindfold our sighted participants because it has been shown that there is an important effect of vision on thermal perception [27]. A subsequent experiment could measure discrimination thresholds in normal sighted subjects with and without blindfold to address this issue.

We also studied the effects of spatial summation of heat on temperature discriminability. Increasing the stimulation surface from 2.56 to 9 cm^2 enhanced stimulus discriminability in both groups, whereas it affected the response criterion only in the blind group. Indeed, blind participants showed a larger increase in response criterion when increasing the size of the thermode, and hence became less prone to false positive responses. Previous studies have attributed the increased performance in various non-visual sensory tasks in congenitally blind subjects to the recruitment of the occipital cortex [1]. In addition, congenitally blind subjects also show increased occipital activity at rest [28]. If we assume that the increased performance in thermal discriminability is due to a similar mechanism of occipital recruitment, we propose that stimulating a small skin area is insufficient to bring neuronal activity within the occipital cortex above the physiological noise level. In contrast, stimulating a larger skin area will, through spatial summation, clearly raise the signal above the physiological noise levels.

5. Conclusions

Altogether, our findings indicate that congenitally blind individuals' hypersensitivity to nociceptive thermal stimuli extends to innocuous warmth and add to a growing literature on cross-modal compensatory plasticity in congenitally blind individuals [1]. An improved capacity for thermal information processing may help blind individuals in object recognition based upon thermal diffusivity characteristics of materials [11,12]. Our data therefore suggest that when sight is absent since birth in man, dormant mechanisms of sensory information processing regain a more relevant functional role.

Competing interests

The authors declare that they have no competing interests.

Authors' contributions

HS, MP and RK conceived and designed the experiments. RK and MP contributed with experimental equipment and analysis tools. HS performed the experiments and the data analysis. HS, MP and RK wrote and edited the manuscript. All authors read and approved the final manuscript.

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