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Cognitive compensations for blindness in children: An investigation using odour naming

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Abstract. Historically, blindness has been associated with compensation for the loss of vision by the other senses. However, research to date has focused on perceptual compensations, largely ignoring possible cognitive compensations. We explored the notion that cognitive skills of blind children may facilitate performance in apparently perceptual tasks, by investigating the cognitive factors related to naming a familiar odour. Eighty-three children participated in olfactory and cognitive tasks (thirty-two early-blind, five late-blind, fourteen low-vision, and thirty-two sighted). In the olfactory tasks, the early-blind children performed significantly better than the sighted children on the odour-naming task but not on the odour-sensitivity task. From the cognitive tasks, scores on a nonvisualisable word-pairs task and a sound – word-pairs task were significantly higher for early-blind children and were highly correlated with odour-naming score. The early-blind children outperformed the sighted controls on a task of directed attention. The groups did not differ on memory for a story or for visualisable word pairs. The results suggest that blind children enjoy an advantage in tasks that assess nonvisual memory for paired associates and directed attention, and that superiority on these tasks facilitates performance in the odour-naming task. Other data suggest that sighted children rely on visualisation as a strategy to aid their performance on the cognitive tasks, and are disadvantaged when these strategies cannot be utilised.

1 Introduction

The notion that blind individuals develop remarkable sensory abilities as compensation for their loss of vision is an old one. James (1890; cited in Gibson 1953) described two deaf – blind women, Laura Bridgman and Julia Brace. Laura apparently had such an acute sense of touch as to recognise, after a year, the hand of a person who had once shaken hers. Julia was employed at the Hartford lunatic asylum to sort the clean laundry of the inmates with "her wonderfully educated sense of smell" (James 1890, page 509; cited in Gibson 1953).

Few workers have examined any role of higher-level cognitive skills that may underlie such apparent sensory feats. It is difficult to conduct methodologically sound research in this area because of the frequent co-occurrence of blindness with other handicaps, and marked heterogeneity in vision-impaired populations in aetiology, age of onset, and amount of useful vision. Recently, Rosenbluth et al (2000) reported that children who became blind at an early age were significantly better than controls at naming 25 familiar odours. They concluded that the advantage of the blind children arose from a difference in the ability to self-generate the names of the odours. There is support for this hypothesis in the literature. Murphy and Cain (1986) reported that blind subjects (7/20 early blind) named 31% more familiar odours when the task was to retrieve the name from memory. In contrast, Smith et al (1993) found no difference between the performance of fifty-six blind (thirty-one early blind) and seventy-five sighted adults on an odour-recognition task. In the odour-recognition task alternative names were provided for each of the familiar odours and so the ability to retrieve a label from memory was not measured.

Our research is an extension of that of Rosenbluth et al (2000): their proposal that the advantage of blind children on odour-naming tasks reflects a cognitive compensation

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for blindness is here examined. Possible mechanisms involve developing superior cognitive skills in areas such as attention, memory, and vocabulary.

Bradley-Johnson (1986) proposed that: "Visually impaired students are not more sensitive than sighted students in terms of their ability to discriminate using hearing, taste, touch, and smell. Instead, they attend better when receiving information via these senses and are thus better able to interpret this information" (page 21). There is some evidence for this proposal. The superior performance of blind adults on tactual-discrimination tasks disappears when the sighted subjects are taught to use the same strategy that the blind subjects use (Davidson and Whitson 1974) or when the significantly longer time blind subjects use to explore the objects is taken into account (Cronin et al 1983). Blind adults also consistently demonstrate enhanced language comprehension in situations with degraded input or a noisy background (Muchnik et al 1991). These tasks require directed attention—a cognitive skill—rather than sensory ability. Thus, evidence from other modalities suggests that improved attention by the blind to sensory cues may underlie superior performance on some tasks.

Better performance by blind adults has been reported on several memory tasks. Vertes (1920, cited in Juurmaa 1967) first showed an advantage for blind adults in a memory-for-word-pairs task, although the study was conducted in a very small, heterogeneous sample. In more recent studies of short-term memory capacity in early-blind, higher capacities for the blind have been found (Hull and Mason 1995) and the effect of the visualisability of the to-be-remembered pairs has been examined. Like sighted adults, the blind remember items with high imagery ratings better than those with low ratings, although not if the imagery available is based solely on visual properties (De Beni and Cornoldi 1988; Marchant and Malloy 1984; Zimler and Keenan 1983). Paivio and Okovita (1971) investigated paired-associate learning in the blind using high visual imagery (eg rainbow – shadow) and high auditory imagery (eg music – gong) word pairs. The found that the blind subjects recalled more high auditory imagery pairs than the sighted, while the reverse pattern held for the highly visualisable word pairs.

Eichenbaum (1998) proposed that learning the association between an odour and its name is a paired-associate task similar to a word-pairs task, because both require learning an association between arbitrarily paired stimuli. Indeed, Juurmaa (1967) suggested that it is *practice* at creating auditory-paired associations which underlies superior memory skills in blind children, without their memory per se being better. However, Wyver and Markham (1998) did not find that children with vision impairments used more advanced memory strategies to enhance their memory performance. Most of the nineteen subjects had some useful vision, so the findings may not generalise to the blind. Taken together, there is evidence of enhanced verbal memory in blind individuals, particularly memory for paired associates, although no research to date has been reported on paired-associate learning across nonverbal modalities.

We compared the performance of three groups of children with vision impairments with that of sighted children on two olfactory tasks (odour naming, sensitivity and novel odour – word learning), and explored cognitive abilities (paired-associate learning, attention and strategy choice) which may underlie any advantage of the blind. Data collected concurrently from a number of personality measures and a verbal fluency task will be reported elsewhere (Wakefield et al, submitted).

It was hypothesised that blind and sighted children would be equally sensitive to odours, but that blind children would perform significantly better than sighted on the odour-naming task. Second, blind children's paired-associate memory scores (odour learning and memory for word pairs) were predicted to be significantly higher than sighted children's scores. Finally, it was hypothesised that odour-naming and paired-associate memory scores would be significant predictors of group (blind versus sighted).

2 Subjects

Subjects were recruited by an advertisement placed in the newsletter of a national organisation for the blind and from participants in two short residential camps for children with vision impairments. One of these was for children who play a musical instrument at any skill level. Demographic details of the subjects are contained in table 1.

Table 1. Demographic details of subjects.

	Early blind	Late blind	Low vision	Sighted controls
n	32	5	14	32
Mean age/years (SD)	14.00 (2.92)	16.00 (3.74)	12.21 (2.97)	13.59 (2.72)
Age range/years (median)	8 – 18 (15)	11 – 18 (18)	8 – 17 (11)	8 – 18 (13.5)
Female : male	19 : 13	2 : 3	7 : 7	17 : 15

Children were assigned to the early-blind group if they became legally blind before their first birthday. 'Legally blind' is a term used by the Australian government to define the conditions for which a person is eligible for special benefits and services, and includes someone who cannot see at 6 m what a person with normal vision can see at 60 m (6/60 vision) and/or whose field of vision is between 5 and 20 deg.

Of the thirty-two children in the early-blind group, twenty-eight were blind from birth and the remainder became blind before their first birthday. Eleven had no light perception, sixteen light perception only, and five were legally blind (visual acuity less than 6/60). All children began to learn Braille before the age of six years.

There were five children in the late-blind group. The mean age of onset of blindness was 7.2 years (SD = 5.26). The fourteen children in the low-vision group had a congenital mild to moderate vision impairment (visual acuity less than 6/24, or a field of vision less than 20 deg).

The controls were the sighted siblings of the children in the three vision-impaired samples and children drawn from the community: matched on age, gender, number of years of musical experience, and average number of hours of music played per week.

All children were reported by their parents to have normal olfaction and hearing and were in the mainstream school system. Parent or teacher report was used to exclude children with moderate to severe cognitive or physical impairments. Children with mild cognitive impairments, as evident by placement in special-needs class at school, were included to increase the representativeness of the sample to the blind population as a whole. Informed consent was obtained from both the child and the primary care giver, who provided a short medical and educational history. To reduce the demand on children, all the children completed only the core components of the study (the olfactory and memory for word-pairs tasks). Children who attended camp 1 and their matched controls, completed the 'memory for stories' task and children from camp 2 (and controls) completed the sound-based task and strategy-use tasks. Table 2 presents the demographic details of the participants by camp.

2.1 *Olfactory tasks*

The odour-naming and odour-sensitivity tasks were similar to those used by Rosenbluth et al (2000), and were completed by all children.

2.1.1 *Odour-naming task.* This required subjects to name 16 familiar odours, 6 of which were used in the Rosenbluth et al (2000) study. Odour names are listed in table 3. Odours were presented in identical, opaque, polyethylene bottles with a protruding spout.

Table 2. Demographic details of subjects by camp they attended.

	Age/years (SD)	*n*	Gender female : male	Mild cognitive impairment/%
Camp 1				
blind	12.57 (3.32)	14	9 : 5	50.0
low vision	12.21 (2.97)	14	7 : 7	21.4
sighted	12.21 (2.75)	14	7 : 7	0.0
Camp 2				
blind	15.11 (2.17)	18	10 : 8	0.0
late blind	16.00 (3.74)	5	2 : 3	0.0
sighted	14.67 (2.22)	18	10 : 8	0.0

Table 3. Names of odours used in odour-naming task. Odours better named by blind children in Rosenbluth et al (2000) are marked by *. Odours better named by sighted children are marked **.

Odour	Other possible correct responses
Chocolate *	other chocolate flavoured items eg chocolate milk
Vanilla essence *	vanilla
Coffee *	–
Vinegar **	salt and vinegar flavoured chips
Strawberry bubble gum **	bubblegum, strawberry flavoured sweets
Honey **	–
Vegemite	Promite, Marmite
Burnt toast	burnt bread, damper from the fire
Grass	plants
Potato chips	chips, salted chips
Antiseptic	Dettol, medical cream, disinfectant
Eucalyptus oil	cough lollies, chest cream
Parmesan cheese	cheese, Parmesan
Lemon juice	lemons, lemon flavoured juices
Insect repellent	brand names of mosquito/fly spray
Licorice	–

Order of presentations was randomised with the proviso that it was matched between control and vision-impaired samples. Subjects held the bottle approximately 1 cm below their nose and gently squeezed the bottle. They were asked: "What do you think is in the bottle?". Ratings of the familiarity and pleasantness of the odours were collected from the first fourteen subjects in the early-blind and control groups.

2.1.2 *Odour-sensitivity task.* The 2-alternative, forced-choice, staircase procedure to assess odour sensitivity was derived from Cain (1989). Subjects were required to decide, for a series of 12 pairs of bottles, which bottle contained an odour and which contained only water, with the concentration of the target odour increasing across the series. A 36-bottle set of odours was prepared in identical bottles, as above. The 'target' bottles consisted of two sets of a 12-bottle dilution series filled with 60 ml of liquid containing increasing concentrations of N-butyl alcohol (ranging from 2.3×10^{-5}% to 4%). Presentation of the two sets of target odours was alternated so that the same target bottle was not presented on consecutive trials. The 'blank' series included 12 bottles with 60 ml of tap water from the same source as the diluent used in the target bottles. The child's odour-detection threshold was defined as the lowest concentration (measured as the bottle number) that could be correctly discriminated from the blank bottles for 4 consecutive trials with their left nostril. The odour set was replaced every five days and refrigerated between tests.

2.2 *Paired-associate memory tasks*

Paired-associate memory tasks were administered in three modalities: odour – word, word – word, and sound – word. All subjects completed the odour – word and memory-for-word-pairs (word – word) tasks. Eighteen early-blind children at the music camp and eighteen controls, matched on musical experience, completed the sound – word task.

2.2.1 *Odour – word task.* This task was similar to that used in the selective-reminding paradigm of Davis (1975), where subjects learned to pair an unfamiliar odour with a label. Pilot testing with five sighted children established that it was necessary to modify Davis's method of using numbers as labels, as the children confused the numeral labels with order of presentation. Nonsense syllables, as used by Annett and Leslie (1995), proved too difficult to remember. The labels chosen reflected these constraints, and were four-letter, single-syllable, English words with similar frequencies. The task was presented as a game involving naming new perfumes.

For camp 1, 2 pleasant and 2 unpleasant odours were chosen. Unfortunately, many children reported that the unpleasant odours were *very* unpleasant and one blind child refused to finish the task. For camp 2, 2 new pleasant odours matched as far as possible for pleasantness and intensity in a previous study were used (see table 4).

Table 4. Concentrations, intensity, and pleasantness ratings of odourants (Memhet 2001).

Odourant	Camp	Concentration/g per 100 ml water	Mean intensity	Mean pleasantness
Oolong tea	1	1.0	4.1	1.9
Acetyl methyl carbimol	1	0.075	3.4	1.9
Mandarin aldehyde	1, 2	0.0447	3.1	3.7
Beta demascone	1, 2	0.073	3.6	3.1
Angelica oil	2	0.0213	3.1	3.0
Sage oil	2	0.0365	4.1	4.1

2.2.2 *Word – word task.* For this task, learning was assessed with a standard instrument, the 'memory-for-word-pairs' task in the Children's Memory Scale (CMS; Cohen 1997). The task required children to recall a list of 14 paired associates over 3 cued learning trials and 2 free-recall trials (one of which had a 15 min delay). Half of the to-be-remembered pairs were visualisable (eg apple – cloud and nurse – fire), while the other half were nonvisualisable (eg near – copy and listen – magic).

2.2.3 *Sound – word task.* In this task, 4 unfamiliar, digital sounds were used, with the task design being identical to that of the odour-learning task. Auditory acuity was not assessed, as differences in acuity were unlikely between groups of children with musical experience.

2.3 *Story recall*

The CMS 'memory for stories' task assessed a child's ability to listen to two short stories, and retell them immediately and after a 10 min delay (Cohen 1997).

2.4 *Directed attention*

Directed attention was assessed by using a sound-naming task with eighteen early-blind and eighteen control subjects. The task required subjects to name 32 recordings of familiar sounds presented on a Toshiba Satellite 4000CDS IBM laptop (the sounds are listed in table 5 and are available via e-mail on request to the corresponding author). Two recordings of each sound were stored on the laptop. Half of the sounds were presented as recorded, and half were presented mixed with digital background (white) noise. Order of presentations was randomised and the white noise was randomly assigned to different sounds for each subject, with the proviso that it was matched between the blind and sighted samples.

Table 5. Sounds used in the sound-naming task.

Sound			
Biting into an apple	Coil dropping	Horse galloping	Mosquito buzzing
Wind howling	Dentist drill	Ice clinking in glass	Sandshoes squeaking
Budgie tweeting	Dog barking	Page of a book turning	Water pouring
Camera taking a photo	Church bells	Footsteps	Aerosol spray can
Soft drink can opening	Drawer opening	Wine cork being pulled out	Stapler
Car driving by	Fire crackling	Water dripping	Stone dragging against stone
Car door shutting	Lion growling	Windscreen wipers	Tennis ball being hit
Chickens	Person swallowing	Jackhammer drilling	Train

2.5 *Strategy choice*

Strategy choice for the paired-associate tasks was assessed by asking: "How did you remember which smell/sound/word went with which word?" after each task. Recall strategies were categorised into: no strategy, visualisation, word association, and remembering the order of presentation of the stimuli (similar to Velayo and Quirk 2000). If necessary, subjects were asked how they remembered two specific visualisable and nonvisualisable word pairs in order to assess their strategy use in both types of word pairs. The 'no strategy' category may have included children who could not recall or describe the strategy they used.

3 Procedure

The consent form described the study to parents and children as 'research into our sense of smell'. Testing was conducted by one of the authors (CW) in two 40 min sessions, separated by a 40 min break. To maintain the motivation of the child, similar types of tasks were separated by different tasks, and wherever possible the tasks were presented as games. A small reward (a bath bomb) was presented to the child to thank it for participation. Each odour presentation in the odour-naming and odour-sensitivity tasks was followed by a 60 s interstimulus interval to eliminate the effects of olfactory adaptation. Each olfactory and sound task was preceded by a 'practice attempt', with unrelated odours or sounds as stimuli. The cognitive tasks were administered according to the manual's instructions. The order of administration of the test items is outlined in table 6.

Table 6. Order of presentation of test items.

Camp 1	Camp 2
Odour sensitivity	Odour sensitivity
Memory for stories, immediate recall	Sound naming
Odour naming	Odour naming
Memory for stories, delayed recall	Sound–word task
Personality measures	Verbal fluency
Verbal fluency	40 min break
40 min break	Odour–word task
Odour–word task	Memory for word pairs (word–word task)
Memory for word pairs (word–word task)	Odour–word task, delayed recall
Odour–word task, delayed recall	Memory for word pairs, delayed recall
Memory for word pairs, delayed recall	

4 Results

Because of the small numbers in the low-vision and late-blind groups, group means without statistical tests are presented for these two groups. The only demographic variable on which the groups differed was 'presence of a mild cognitive impairment', with seven early-blind and no sighted children having a mild impairment ($\chi^2 = 7.86$, $p = 0.005$). Three low-vision and no late-blind children were classified with a mild cognitive impairment. For all the analyses reported below, excluding data from children classified as having a mild cognitive impairment did not change the pattern of results. There were no significant differences in scores on any tasks between children who participated in the first camp compared with the second.

Detailed results of the verbal-fluency tasks are presented elsewhere (Wakefield et al, submitted). Briefly, independent samples t-tests revealed no significant difference between blind and sighted children's average semantic-fluency scores ($t_{1,32} = -1.934$, $p = 0.062$), while the blind children were significantly more phonemically fluent than the sighted children ($t_{1,32} = 3.509$, $p = 0.005$). The fluency task × visual-status interaction was also significant ($F_{1,32} = 19.89$, $p < 0.0005$).

4.1 *Multivariate analysis of variance of core model*

A multivariate analysis of variance was conducted on the data in order to account for the correlation between the 5 dependent variables (odour-naming, odour-sensitivity, odour-learning, visualisable word-pairs, and nonvisualisable word-pairs scores). As age was significantly correlated with odour-naming scores ($r = 0.37$, $p = 0.003$), odour-learning scores ($r = 0.27$, $p = 0.035$), visualisable word-pairs scores ($r = 0.27$, $p = 0.031$) and nonvisualisable word-pairs scores ($r = 0.36$, $p = 0.004$), it was included in the analysis as a covariate. The age × visual-status interaction for odour-naming score was not significant ($F_{1,60} = 1.81$, $p = 0.184$). Indeed, there was a significant association between age and the dependent variables (Wilks lambda = 0.790; $F_{5,56}$, $p = 0.019$).

The multivariate model was a significant predictor of group (blind versus sighted), demonstrating that the dependent variables were significant predictors of group, adjusted for age (Wilks lambda = 0.783; $F_{5,56}$, $p = 0.002$). Results for individual dependent variables adjusted for age are listed below, with an $\alpha = 0.01$ correction to allow for multiple statistical tests.

4.1.1 *Olfactory tasks.* Mean scores of early-blind and sighted subjects in the olfactory tasks are presented in table 7. On adjusting for age, univariate F-tests revealed a significant advantage for the early-blind children on the odour-naming task ($F_{1,60} = 10.55$, $p = 0.002$). The multivariate analysis revealed that odour-naming score was a significant predictor of visual status (blind versus sighted), explaining 33.6% of the total variance. No significant between-groups difference emerged in the odour-sensitivity task ($F_{1,60} = 0.43$, $p = 0.512$). Odour-sensitivity score was not a significant predictor of visual status.

4.1.2 *Paired-associate tasks.* Mean scores of early-blind and sighted subjects in the paired-associate tasks are presented in table 8. Univariate F-tests demonstrated marginally superior performance by blind children in the odour-learning task ($F_{1,60} = 4.13$,

Table 7. Mean scores of sighted, early-blind, late-blind, and low-vision subjects (with standard deviations in parentheses) on 2 olfactory tasks (***$p \leqslant 0.005$).

Subjects	n	Odour-sensitivity task		Odour-naming task	
Sighted	32	5.75 (4.9)	$p = 0.512$	6.28*** (2.4)	$p = 0.002$
Early blind	32	6.5 (1.5)		9.34*** (2.5)	
Late blind	5	5.6 (2.14)		4.0 (1.58)	
Low vision	14	5.43 (2.10)		7.57 (3.08)	

Table 8. Mean scores of early-blind and sighted subjects (with standard deviations in parentheses) on core paired-associate tasks (*** $p \leqslant 0.005$).

Subjects	Odour-learning score (max = 24)	Visualisable word-pairs score (max = 35)	Nonvisualisable word-pairs score (max = 35)
Sighted, $n = 32$	14.5 (4.2)	25.75 (4.9)	14.91*** (6.3)
Early blind	17.19 (5.7)[a]	27 (4.4)[b]	23.81*** (7.0)[c]
Late blind, $n = 5$	10.6 (1.95)	24.5 (0.71)	16.5 (0.71)
Low vision, $n = 14$	14.17 (4.63)	25.14 (4.45)	14.29 (6.34)

[a] $n = 31$, $p = 0.046$; [b] $n = 32$, $p = 0.048$; [c] $n = 32$, $p = 0.002$.

$p = 0.046$); adjusted for age, however, this cannot be considered significant, given the alpha level of 0.01. There was no significant between-groups difference in the memory for visualisable word-pairs scores ($F_{1,60} = 4.07$, $p = 0.048$), while there was a significant difference between groups in memory for nonvisualisable word-pairs scores ($F_{1,60} = 9.97$, $p = 0.002$).

Figure 1 demonstrates a significant interaction between visual status and visualisability of the word pairs ($F_{1,62} = 26.28$, $p < 0.0005$), such that there was no evidence of a difference between blind and sighted children's recall of visualisable word pairs, while blind children remembered significantly more nonvisualisable word pairs than sighted children. This interaction was significant for the immediate free-recall trial ($F_{1,62} = 7.97$, $p = 0.006$), and for the 15 min delay condition ($F_{1,62} = 12.84$, $p = 0.001$), although the 3-way (visual status × visualisability × time) interaction was not significant ($F_{1,62} = 1.12$, $p = 0.293$).

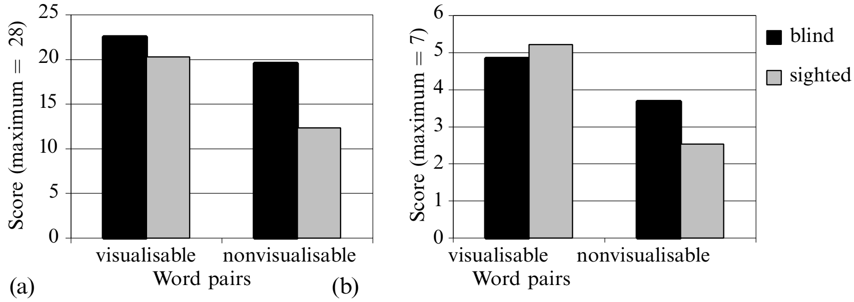

Figure 1. Performance on immediate (a) and 15 min delay (b) word-pairs trials for visualisable and nonvisualisable word pairs.

4.2 *Exploratory tasks*

Results from the exploratory tasks are listed below. Table 6 shows whether vision-impaired children from camp 1, camp 2, or both completed the tasks. The conventional level of statistical significance has been used in the statistical analyses.

4.2.1 *Odours.* To determine if there was any early-blind-group advantage for particular odours, the percentage of blind minus the percentage of sighted children who correctly labelled each odour was calculated (see figure 2). Of the 16 odours, 7 were named correctly by significantly more blind than sighted children including the 3 odours better named in Rosenbluth et al (2000). No odours were correctly named by significantly more sighted than early-blind children. Chocolate and coffee were the most frequently named odours, and vanilla essence was the least named odour. There was no difference in familiarity or pleasantness ratings between blind and sighted children ($t_{26} = 0.3$, $p = 0.767$; $t_{26} = 1.64$, $p = 0.113$, respectively). Eucalyptus had the highest familiarity rating, while lemon juice was the most unfamiliar. Chocolate was rated as the most pleasant odour, and Parmesan cheese was rated as the least pleasant.

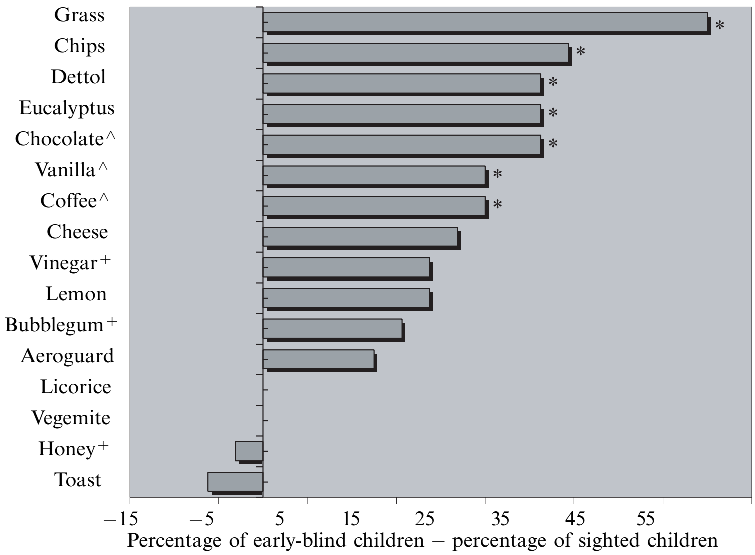

Figure 2. Percentage of early-blind children minus percentage of sighted children who correctly labelled each odour in the odour-naming task (* $p < 0.05$). Odours better named by blind children in the Rosenbluth et al (2000) study are marked with ^; those better named by sighted children are marked with +.

Age was significantly correlated with familiarity rating ($r = 0.64$, $p < 0.0005$): older children on average rated the odour-naming odours more familiar than younger children. Age was not correlated with pleasantness ratings.

4.2.2 *Sound–word task scores.* Mean scores of early-blind and sighted subjects in the sound–word task are presented in table 9. Independent samples t-tests revealed that the blind children attained significantly higher scores than the sighted children ($t_{34} = 3.82$, $p = 0.001$).

Table 9. Early-blind and sighted subjects' mean scores (with standard deviations in parentheses) on sound-learning task ($n = 18$; ** $p \leqslant 0.01$).

Subjects	Sound–word score (maximum score = 24)
Sighted	18.22** (5.1)
Early blind	22.89** (1.1)

4.2.3 *Story recall.* There were no significant differences between blind children and their sighted controls in immediate and delayed story-recall scores ($t_{26} = 0.61$, $p = 0.545$; $t_{26} = 0.41$, $p = 0.689$, respectively). The correlation between immediate and delayed scores was $r = 0.906$ ($p < 0.0005$).

4.2.4 *Directed attention.* Mean scores of early-blind and sighted subjects in the sound-naming task are presented in table 10. Total sound-naming scores and undistorted sound-naming scores were not different between the groups ($t_{34} = 1.36$, $p = 0.183$; $t_{34} = 0$, $p = 1$, respectively). Blind children, however, named significantly more sounds mixed with white noise than did the sighted children ($t_{34} = 2.42$, $p = 0.027$), and this was revealed as a significant visual status × task interaction ($F_{1,34} = 4.27$, $p = 0.047$; see figure 3).

4.2.5 *Strategy choice.* Table 11 lists the number of blind and sighted children who chose each strategy type. There was a significant difference between blind and sighted children's strategy choice in the odour–word task ($\chi^2 = 6.75$, $p = 0.034$): sighted children

Table 10. Mean scores for early-blind ($n = 18$) and control subjects ($n = 18$) in the sound-naming task ($*p \leqslant 0.05$).

Subjects	Sound-naming task: total score (max = 32)	Sound-naming task: undistorted (max = 16)	Sound-naming task: white noise (max = 16)
Sighted	12.06 (4.21)	6.94 (2.98)	5.11* (2.22)
Early blind	14.06 (4.62)	6.94 (2.60)	7.11* (2.72)
Total	13.06 (4.47)	6.94 (2.76)	6.11 (2.65)

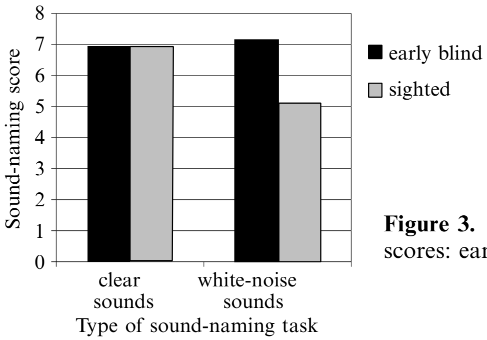

Figure 3. Mean undistorted and white-noise sound-naming scores: early-blind children versus sighted.

Table 11. Number of blind ($n = 16$) and sighted ($n = 18$) subjects who used each strategy type on 4 paired-associate learning tasks ($*p \leqslant 0.05$).

Task	Subjects	No strategy	Visualisation	Presentation order	Word association
Odour – word	early blind	4	0	0*	12
	sighted	2	0	6*	10
Sound – word	early blind	8	0	1	7*
	sighted	6	2	7	3*
Visualisable word pairs	early blind	3	0*	0	13*
	sighted	3	10*	0	5*
Nonvisualisable word pairs	early blind	3	0	0	13
	sighted	7	0	3	8

were more likely to use order of presentation, and blind children were more likely to use either no strategy or word association. No children used visualisation as a strategy on this task. On the sound – word task, reported strategies were also significantly different between the groups ($\chi^2 = 8.3$, $p = 0.04$), with blind children being more likely to use no strategy or word association than sighted children. Sighted children used visualisation and presentation order more often than blind children. Strategy choice was also significantly different between blind and sighted children in the visualisable word-pairs task ($\chi^2 = 19.06$, $p < 0.0005$), with ten out of eighteen sighted children using visualisation. No blind child used visualisation. For nonvisualisable word pairs, there was no significant difference between the strategy chosen by blind children and by sighted children ($\chi^2 = 1.66$, $p = 0.198$). Those sighted children who had used visualisation for the visualisable word pairs, resorted fairly evenly to one of the other three strategies. All blind children reported having used the same strategy for visualisable and nonvisualisable word pairs.

4.3 *Bivariate results*

The plots of odour-naming score against each predictor revealed positive, linear relationships. Significant ($p < 0.01$) Pearson's product – moment correlation coefficients are listed in table 12. There was no suggestion of multicollinearity, as no correlations exceeded 0.7. The strongest correlations with odour-naming score were with nonvisualisable word pairs, followed by odour – word learning. The odour – word correlation was significant for the blind group only ($r = 0.64$, $p < 0.0005$), with a sighted group correlation of $r = 0.29$ ($p = 0.105$). The within-groups scatter plots revealed no unusual data points, and a visually similar relationship between the two variables within each group. The difference between the correlations approached significance ($z = 1.72$, $p = 0.085$), as did the interaction between visual status and odour-learning score ($F_{1,55} = 3.01$, $p = 0.088$). The only significant camp 1 task-score correlation with odour-naming score was with familiarity rating: higher average familiarity ratings for the odour-naming odours were associated with higher odour-naming scores. When split into groups, this correlation remained significant for the blind group only ($r = 0.76$, $p = 0.002$). The sighted group correlation was $r = 0.26$ ($p = 0.379$).

Table 12. Significant correlations between task scores, $p < 0.01$.

Variable 1	Variable 2	Correlation coefficient	p
Odour naming	Nonvisualisable word pairs	0.618	<0.0005
Odour naming	Odour – word	0.542	<0.0005
Odour naming	Familiarity rating	0.528	0.004
Odour naming	Sound – word	0.495	0.002
Odour naming	White-noise sound naming	0.473	0.004
Odour naming	Phonemic fluency	0.537	<0.0005
Nonvisualisable word pairs	Sound – word	0.552	0.001
Visualisable word pairs	Nonvisualisable word pairs	0.474	<0.0005
Odour – word task	Nonvisualisable word pairs	0.400	0.001

5 Discussion

We aimed to extend the findings of Rosenbluth et al (2000) by examining the role of cognitive factors in any superior performance by blind children on an odour-naming task. Parallel to the findings of Rosenbluth et al (2000), in the present study we found that blind and sighted children were equally sensitive to odours, and the blind children outperformed the sighted children on the odour-naming task, naming, on average, almost 20% more familiar odours. The data point to a particular advantage of blind children on tasks that assess memory for nonvisualisable stimuli. The exploratory tasks described above indicated that directed attention and strategy use are two variables that may also play a role in blind children's superior performance at odour-naming tasks. The absence of differences between groups in odour sensitivity, and on ratings of pleasantness and familiarity make it difficult to attribute the superior performance to alterations in odour perception.

Word – word, odour – word, and sound – word paired-associate learning tasks have in common the ability to recognise a stimulus, recall a label, and remember the associative link between them (Engen 1987). Blind children demonstrated a significant advantage on the word – word and sound – word pairings and a marginal superiority in the odour – word task. All except memory for visualisable word pairs were significantly correlated with odour-naming scores. Each is discussed in turn.

The blind children recalled significantly more word pairs than the sighted children. However, when the word pairs were divided into visualisable and nonvisualisable pairs, only the sighted controls showed the expected pattern of better performance on the visualisable word pairs (Paivio 1971), while the blind children remembered both types equally. This created an unexpected second-order interaction with no difference between the groups on visualisable word pairs and significantly better performance of the blind children on nonvisualisable word pairs. The blind children recalled, on average, 25.4% more nonvisualisable word pairs than did the sighted children. This interaction may have arisen because the blind children treated visualisable and nonvisualisable stimuli in the same way, while sighted children were unable to apply the strategy they used to remember the visualisable pairs to the nonvisualisable ones.

Data from the strategy-choice questionnaire support this assertion. All the blind children reported that they used the same strategy for both tasks. Ten of the eighteen sighted children reported that they used visualisation to aid their performance on the visualisable word pairs. These children resorted evenly to the three remaining strategies for the nonvisualisable task. The eight sighted children who did not report having used visualisation also showed superior performance on the visualisation task. Informal discussions revealed that, although they did not recognise the visualisability distinction, they reported that the nonvisualisable pairs were simply "harder to remember".

Despite the traditional view that visual language is meaningless to the blind (Millar 1994), the performance of blind children on the visualisable word pairs was equivalent to that of the sighted. It is possible that the visualisable word pairs evoked a nonvisual as well as visual image, and that the blind children utilised this nonvisual image. For example, the visualisable words 'fire', 'wind', and 'apple' might have evoked tactile, auditory, and olfactory imagery, respectively, although the existence of olfactory imagery is hotly debated (Stevenson and Boakes 2003).

In line with the results reported by Murphy and Cain (1986), in this study the blind children performed marginally better on learning to associate 4 unfamiliar odours with familiar labels. The early-blind children scored significantly higher than the sighted on learning to associate 4 unfamiliar digital sounds with familiar labels, demonstrating an almost 20% advantage in performance. Table 12 shows the very high correlations between odour-naming scores and these 3 paired-associate task scores. These relationships are impressive because of the many differences between learning odour – name pairings in the real world and paired-associate learning in a laboratory setting, including differences in the total number of pairings of the stimuli and the effect of massed versus spaced trials. The advantage of early-blind children across paired-associate tasks in different modalities suggests that the superiority lies in nonvisual associative learning per se, rather than in a modality-specific skill.

The early-blind and sighted children named an equivalent total number of sounds in the sound-naming task. There was, however, a significant interaction between visual status and the type of sound presented (undistorted versus white noise), with sighted children's performance being disrupted by the white noise, while blind-children's performance remaining stable. This result is consistent with Muchnik et al's (1991) finding that blind adults perform better than sighted adults at discriminating speech in a noisy context. The significant correlation between white-noise sound naming, and the absence of a relationship between clear sound naming, with odour naming, implies that the ability to filter irrelevant information and focus on the critical elements of a stimulus may also play a role in odour-naming skill.

We did not obtain estimates of intelligence for our subjects, so the classification of having a mild cognitive impairment is based on the only available data, that is if the children were placed in a special-education class in their mainstream school. Taking this classification at face value, we found this pattern of superior performance in an early-blind group where 23% of subjects had a mild cognitive impairment.

In contrast to this pattern of positive findings on paired-associate tasks, scores on the memory-for-stories task from the CMS did not discriminate between the blind and sighted groups. In the CMS, story-recall and word-pairs scores are averaged to form a total score for verbal memory because these tasks measure the same construct in sighted subjects. As almost all storybooks include pictures, stories are typically very visual for sighted children. In contrast, auditory presentation of stories is more familiar to blind children. It is possible that the absence of differences arose because the sighted children used visualisation as a memory strategy for the story-recall task, as 10/18 reported doing on the visualisable word-pairs task and the blind children remembered the nonvisualisable components of the tasks.

Scores on all tasks except odour sensitivity improved with age, in accordance with previous findings (Jehl and Murphy 1998; Lehrner et al 1999). There was no interaction between age and visual status in the olfactory or cognitive tasks, showing that the differences between groups do not change through adolescence, further supporting the conclusion that perceptual factors such as familiarity do not underlie blind children's odour-naming superiority.

Pylyshyn (1999, page 342) concluded that "vision is continuous with and indistinguishable from cognition, except that part of its input comes from the senses". This relationship has been studied extensively from the direction of the effect of cognition on visual perception and to a lesser extent in the other direction. In this study, the performance of blind and sighted children did not differ on tasks where visualisation could be used as a strategy, despite the proposed indistinguishableness of vision with cognition. The debate regarding the link between visual perception and cognition would greatly benefit by including investigations of blind individuals.

We were able to test here only a small number of children who became blind relatively late in childhood (on average at 7 years of age) and a larger group of children who had some useful vision but had a congenital mild or moderate visual impairment of heterogenous aetiology. We presented their scores on the tasks they completed without statistical comparison to the early-blind or the sighted controls. It can be noted that on the data of principal interest—scores on tasks that are hard to accomplish with visual imagery—the means of these two groups resemble more closely the mean scores of the sighted than those of the early-blind group. While it is not possible to make a definitive statement, these data support an assertion that the cognitive compensations we have observed in our early-blind subjects arise because of the absence of useful vision from very early in life.

To summarise, our findings concur with the suggestion of Rosenbluth et al (2000) that specific, superior cognitive skills underlie the enhanced performance of blind children on odour-naming tasks. There was no evidence of sensory compensation for loss of vision. The results suggested that early-blind children perform better than sighted children on cognitive tasks where visualisation cannot be used as a performance-enhancing strategy. Early-blind children performed significantly better than sighted children on nonvisual paired-associate tasks (nonvisualisable word–word and sound–word pairs) and on a task that assessed the ability to name sounds against a background of white noise. Performance on these tasks was significantly correlated with odour-naming ability. A multivariate analysis of variance revealed that odour-naming and nonvisualisable word-pairs scores were significant predictors of visual status. Further research into the possible roles of attention, strategy use, short-term memory, associative memory, and verbal ability in the performance of blind children in tasks such as those described above is warranted.

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