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Effects of sensory deprivation on cognitive degeneration: Evidence from ageing individuals with blindness

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ABSTRACT

Cognitive functioning is based on sensory information. Both sensory deprivation and ageing cause cognitive deterioration. The aim of this study was to evaluate the effects of these two factors upon one another. The present study was cross sectional, comparing 137 blind and 124 normal vision participants using the Weschler memory scale (WMS-III), the mini mental state examination (MMSE) and the verbal fluency task (VFT). These scales measure cognitive abilities such as attention and calculation, auditory memory, working memory, associative learning, orientation, registration, attention, recall, language and phonemic and semantic verbal fluency. Findings indicated that normal vision participants performed significantly better in cognitive tasks compared to blind individuals. Both groups showed a similar pattern of decline in scores of cognitive ability with increase in age. Results suggested that sensory deprivation alone may not be considered as a detrimental factor in cognitive degeneration over the life span.

1. Introduction

Sensory deprivationleads to changes in the organization of the brain and the deafferented cortices occupied with other remaining sensory inputs and the subsequent processing related to them (de Heering et al., 2016; Litovsky & Gordon, 2016; Stronks, Nau, Ibbotson, & Barnes, 2015). Cortical areas that are related to the deprived sensory modality, as usual, are involved with other remaining sensory afferent pathways and this reorganization has been defined as "cross- modal plasticity". The cross- modal plasticity may not necessarily be associated with the improvement of the remained sensory functions (Lee et al., 2014).

The problem of a sensory deprived individual is not limited to the sensation. The sensory information is used for subsequent perceptual and cognitive functions and the paucity of these sensory inputs may affect the subsequent cognitive functioning. There are two approaches to explain the interaction between sensory information and cognitive functioning. In a bottom-up approach, cognitive functions are rooted in the sensory information and the lack of sensory experience may leads to an impairment in subsequent cognitive functioning (Valentijn et al., 2005). In a top- down approach, cognitive functioning modulates the sensory processing (Kamiyama, Fujita, & Kashimori – Biosystems, 2016; Näätänen, Tervaniemi, Sussman, Paavilainen, & Winkler, 2001) and the brain can compensate the lack of sensory information and interpolate the information loss based on the remained parts (Baltes & Lindenberger, 1997). Furthermore, there are two variations for the interaction between these approaches that may be considered as two alternative perspectives. The former considers a horizontal relationship between the bottom- up and the top- down systems and states that both of them may be related to the same source (Christensen et al., 2001). The latter considers a parallel relationship between these two systems in a way that both of them work along as "perceptual reversals". For example, in the matter of visual perception, the bottom-up visual process scans the visual field on the basis of saliency and similarity, and the top-down process tries to achieve the goal (Kornmeier, Maira Hein, & Bach, 2009).

The visual information engages more than 35 centers and 50 percent of the brain for processing (Kandel & Showartz, 2002). The loss of this information in blindness provides an opportunity for the evaluation of the effects of visual deprivation on cognitive performance. Both perceptual and cognitive abilities of individuals with blindness could be explained by two controversial mechanisms including the compensation and the general loss. In the compensation approach, individuals with blindness show a preference to the remaining healthy tactile (Goldreich & Kanics, 2003), auditory (Vercillo, Milne, Gori, & Goodale, 2015), and olfactory systems (Zhou, Fang, Pan, Liu, & Ji, 2017), as well as the subsequent cognitive functioning such as auditory skill (Fieger, Röder, Teder-Sälejärvi, Hillyard, & Neville, 2006), arithmetic and working memory (Dormal, Crollen, Baumans, Lepore, & Collignon, 2016), and semantic and episodic memory (Pasqualotto, Lam, & Proulx, 2013). This compensatory phenomenon is apparent in the cortical level

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Table 1
Cognitive Measures performance in different age decades in both groups.

Age Groups	20s	30s	40s	50s	60s	Age Effect	Sight Effect	Age and Sight Effect
Number of Blind- Sighted	10–12	32–27	77–69	12–12	4–4	F (Sig.)	F (Sig.)	F (Sig.)
Cognitive Measures	[Mean](SD)	[Mean](SD)	[Mean](SD)	[Mean](SD)	[Mean](SD)	[Etta]	[Etta]	[Etta]
Weschler Memory Scale III								
General Knowledge	[5] 91(0.28)	[5] 85(0.36)	[5] 86(0.49)	[5] 72(0.46)	[5] 50(0.70)	[0] 92(0.450)	[4] 75(0.006)	[0] 371(0.829)
Sighted Blind	[5] 40(0.51)	[5] 38(0.71)	[5] 32(1.19)	[5] 08(0.51)	[5] (0)	[.127]	[.017]	[.038]
Attention and Calculation	[337.] (1.77)	[836.] (1.64)	[6] 50(1.73)	[5] 18(2.40)	[6] (2.82)	[5] 44(0.000)	[55] 06(0.000)	[0] 232(0.920)
Sighted Blind	[905.] (1.72)	[511.] (1.87)	[5] 24(2.09)	[5] 41(2.06)	[332.] (2.30)	[.980]	[.087]	[.014]
Auditory Memory (Recall Story)	[36] 6(5.8)	[34] 7(6.1)	[36.1] (5.1)	[34.9] (4)	[35] (5.6)	[1] 29(0.273)	[84] 11(0.000)	[1] 14(0.335)
Sighted Blind	[16] 6(5.89)	[22] 3(35.5)	[13.9] (5.2)	[10.8] (5.5)	[2.6] (3)	[.770]	[.012]	[.058]
Working Memory (Digit Span)	[12] 8(2.2)	[11] 7(2.2)	[11] 8(1.9)	[10] (2.5)	[9] 3(2.3)	[5] 21(0.000)	[180] 82(0.000)	[2] 52(0.42)
Sighted Blind	[11] 5(1.9)	[10] 3(2)	[9] 4(2.2)	[8] 8(2.6)	[7] 3(0.5)	[.152]	[.070]	[.028]
Associative Learning(Word Recall)	[16] 1(2.7)	[14] 4(2.8)	[14] 3(2.3)	[10] (2.5)	[11] 5(0.7)	[10] 18(0.000)	[810.] (0.800)	[1] 75(0.138)
Sighted Blind	[19] 3(1.7)	[15] 8(4.6)	[15] 8(4)	[10] 7(5.5)	[7] 6(5.6)	[0.016]	[.090]	[.107]
Mini Mental State Examination								
Orientation	[919.] (0.28)	[889.] (0.32)	[769.] (0.58)	[909.] (0.30)	[10] (0)	[0] 654(0.625)	[0] 440(0.508)	[0] 114(0.997)
Sighted Blind	[10] (0)	[939.] (0.25)	[899.] (0.38)	[809.] (0.44)	[10] (0)	[.019]	[0.045]	[.003]
Registration	[3] (0)	[3] (0)	[3] (0)	[3] (0)	[3] (0)	[5] 552(0.000)	[4] 391(0.038)	[5] 552(0.000)
Sighted Blind	[3] (0)	[3] (0)	[3] (0)	[802.] (0.04)	[3] (0)	[.058]	[0.014]	[.108]
Attention	[834.] (0.38)	[514.] (0.80)	[364.] (0.89)	[813.] (1.07)	[4] (2)	[7] 595(0.000)	[0] 541(0.463)	[0] 831(0.507)
Sighted Blind	[5] (0)	[754.] (1)	[334.] (1.55)	[403.] (1.67)	[502.] (2.38)	[.117]	[0.010]	[.033]
Recall	[3] (0)	[3] (0)	[3] (0)	[902.] (0.30)	[3] (0)	[3] 263(0.013)	[32] 618(0.000)	[2] 640(0.035)
Sighted Blind	[832.] (0.40)	[432.] (089)	[642.] (0.77)	[801.] (1.30)	[501.] (1.29)	[.063]	[0.188]	[.067]
Language	[6] (0)	[6] (0)	[6] (0)	[6] (0)	[6] (0)	[1] 504(0.203)	[2] 99(0.085)	[1] 504(0.203)
Sighted Blind	[6] (0)	[5] 93(0.05)	[875.] (0.05)	[5] 40(0.09)	[6] (0)	[.017]	[0.033]	[.033]
Verbal Fluency Test	[30.1] (4.1)	[25.8] (3.3)	[25.8] (4.1)	[25.6] (3.5)	[18.6] (3.1)	[4] 531(0.002)	[146] 614(0.000)	[1] 482(0.209)
Phonemic Verbal Fluency	[13] 8(5)	[13.7] (5)	[12] (4)	[10] (3.6)	[9.1] (7.6)	[.062]	[.496]	[.100]
Sighted Blind								
Semantic Verbal Fluency	[29.7] (3.7)	[27.1] (2.5)	[27.6] (3.4)	[25.4] (4.5)	[26.5] (3.1)	[4] 301(0.002)	[119] 941(0.000)	[1] 514(0.199)
Sighted Blind	[16.9] (3.4)	[18] (4.2)	[17.3] (4.2)	[12.5] (3.1)	[16.8] (3.4)	[.039]	[.334]	[.041]

as the occipital lobe is activated by auditory and tactile stimuli (Reich, Maidenbaum, & Amedi, 2012; Stronks et al., 2015).

On the other hand, the general loss approach states that individuals with complete blindness show significant impairment in different cognitive tasks such as tactile spatial memory (Vecchi & Girelli, 1998), tactile spatial attention (Forster, Eardley, & Eimer, 2007), selective and divided spatial attention (Collignon, Renier, Bruyer, Tranduy, & Veraart, 2006), semantic and phonemic verbal fluency (Nejati & Asadi, 2010), and general cognitive skills (Nejati, 2008).

Aging is another life experience that influences sensory and cognitive functioning. The process of ageing has a degenerative effect on sensory impairment such as age-related hearing loss (Roth, Hanebuth, & Probst, 2011) and visual impairment (Sachdev et al., 2013) as well as the cognitive degeneration including focused and divided attention (Getzmann, Golob, & Wascher, 2016), learning (Nejati, Ashayeri, Garusi, & Aghdasi, 2008a, 2008b), working memory (Carryl & Ivan, 2011), and inhibitory control (Kleerekooper et al., 2016). Some studies found the dependence of cognitive performance on the sensory inputs increases with age (Ghisletta & Lindenberger, 2003; Li & Lindenberger, 2002). Indeed, some studies have shown that sensory impairment, especially visual information, causes deficit in a number of cognitive functions. For example, Anstey, Luszcz, Giles et al., 2001 showed that diminished visual acuity, but not auditory acuity, is associated with a decline in memory functioning. The more dependency on visual versus auditory information older adults have, the more general functioning and well- being were observed (Liu et al., 2016).

Age related cognitive and perceptual decline can be investigated through three theories. The first one, the common-cause hypothesis, postulates that ageing as an underlying phenomenon deteriorates both cognitive and perceptual functioning (Baltes & Lindenberger, 1997); the second one, the sensory deprivation hypothesis, considers sensory decline as the origin of cognitive degeneration (Salthouse, 2000), and the third theory is the cognitive degeneration hypothesis which postulates that cognitive decline decreases the capacity for the sensory acuity and the perceptual processing (Raz et al., 2005).

The reorganized brain after sensory deprivation is more dependent on the remaining senses and should perform the cognitive functioning in the absence of the deprived sense. This may empower them more or make them more sensitive to normal life-related threat situation such as ageing. To date, interaction between ageing and blindness as an example of sensory deprivation has not been clearly understood. The present study aims to evaluate the interaction between the ageing process in the individuals suffering from complete acquired blindness. The evaluation of the main effect of age and sensory deprivation in this population, will reveal the most significant factor in cognitive degeneration, that it to say ageing or visual deprivation.

In the present study, some of these hypotheses are tested by comparing the performance of blind and normal vision participants of different age groups in certain cognitive tasks. If blind individuals have higher rates of cognitive decline, the first hypothesis is confirmed that sensory deprivation causes neural and cognitive degeneration. If blind and normal vision participants have similar rates of cognitive decline, the evidence confirms the “common cause hypothesis” and it can be concluded that ageing plays a significantly more important role in cognitive decline than sensory deprivation (blindness). Finally, if blind individuals have lower rates of cognitive decline, resource allocation hypothesis is confirmed which entails that higher engagement of cognitive functions to remediate impaired sensory input is considered to be the main factor responsible for cognitive performance.

In sum, we hypothesized that the different hypotheses of age and deprivation related cognitive degeneration could be studied in the study of ageing in individuals with blindness.

2. Material and method

2.1. Participants

137 male individuals suffering from acquired full blindness in both