The effectiveness of the computerized visual perceptual training program on individuals with Down syndrome: An fMRI study

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ABSTRACT

This study investigated the effectiveness of the Computerized Visual Perception Training (CVPT) program on individuals with Down syndrome (DS, mean age = 13.17 ± 4.35 years, age range: 6.54–20.75 years). All participants have mild intellectual disability classified by the standard IQ measures (mean = 61.2, ranges from 55 to 68). Both the Test of Visual Perceptual Skill-Third Edition (TVPS-3) and functional magnetic resonance imaging (fMRI) were used to evaluate the training outcomes. Results of TVPS-3 and fMRI showed that DS group had visual perceptual deficits and abnormal neural networks related to visual organization. The results showed that DS intervention group had significant improvements on TVPS-3 after intervention. The fMRI results indicated more activation in superior and inferior parietal lobes (spatial manipulation), as well as precentral gyrus and dorsal premotor cortex (motor imagery) in DS intervention group. The CVPT program was effective in improving visual perceptual functions and enhancing associated cortical activations in DS.

What this paper adds

A Computerized Visual Perception Training (CVPT) program was developed for individuals with Down syndrome (DS). The program proved effective for improving visual perceptual functions and neural plasticity in DS. The duration (60 min per session, once a week, for 52 weeks) of this CVPT program and its training strategies provide a useful reference for clinical professions during program development and implementation. In-depth understanding of the underlying neuroanatomical correlates of visual perception in DS was discussed as well.

1. Introduction

Down syndrome (DS) is the most common genetic cause of intellectual disabilities (ID); with prevalence of 1 in 737 live births (Parker et al., 2010). In the past, numerous researchers have stressed that the neuropsychological profile with DS is characterized by a remarkable deficit in language abilities solely (Abbeduto, Warren, & Conners, 2007; Daunhauer & Fidler, 2011). Much of the research that established visuo-spatial ability as a relative strength in DS, however, contrasted it with verbal and other cognitive abilities (Klein & Mervis, 1999; Wang, Doherty, Rourke, & Bellugi, 1995). Recent study also confirmed deficits in visuo-spatial working memory in DS, the deficit particular relates to the spatial-simultaneous component (Carretti, Lafranchi, & Mammarella, 2013). The...
spatial-sequential component was rather intact in DS (Carretti & Lanfranchi, 2010). Therefore, visual perceptual functions are rarely discussed or even treated in DS compared to other groups of ID such as Williams syndrome (WS) or fragile X syndrome (FXS). Recent studies from different labs have demonstrated a more complex cluster of neuropsychological features in this population, with deficits in visual perceptual functions such as visual organization (Wuang & Su, 2011), visual discrimination (Wang et al., 1995), form constancy, position in space (Ikeda et al., 2013), figure ground (Vicari, Bellucci, & Carlesimo, 2006) and visual closure (Cornish, Munir, & Cross, 1999).

Given that occupational therapists focus on individual’s participation in activities of daily living, school, work and leisure, the intervention emphasis on visual perception and its effects on performance skills can be crucial (Ted Brown, Rodger, & Davis, 2003). Visual perceptual intervention can be categorized into traditional visual perceptual training programs or computerized visual perceptual training programs in clinical settings. Examples of traditional visual perceptual training programs were copying figures, matching shapes, block constructions (Nadkarni & Ashok, 2012), puzzles (Levine, Ratliff, Huttenlocher, & Cannon, 2012), paper-and-pencil activities (Chen, Lin, Wei, Liu, & Wang, 2013), and origami (Jaušovec & Jaušovec, 2012). Although the individuals with visual perceptual dysfunctions could benefit from the above-mentioned programs, traditional programs are repetitive and offer very little to keep individuals motivated (Adamovitch, Fluet, Tunik, & Merians, 2009). Particularly, children with disabilities tend to show difficulty in repeated practice of functional activities due to the very nature of their disabilities (i.e. short attention span, cognitive impairments).

Use of computer-based interventions can simultaneously provide multiple sensory stimulations and immediate feedback to promote intrinsic motivation and enhance automatic learning of children (Chen et al., 2013; Perzov & Kozminsly, 1990). Computer-based visual perceptual training programs have been previously applied in individuals with attention-deficit/hyperactivity disorder, learning disabilities, and developmental delay; the study results demonstrate their effectiveness in improving general visual perceptual functions (Cardona, Martinez, & Hinojosa, 2000; Chen et al., 2013; Klingberg et al., 2005; Poon, Li-Tsang, Weiss, & Rosenblum, 2010). Previous studies also had shown that computer-based program can be used effectively to improve the visuospatial short-term and simultaneous working memory in DS (Bennett, Holmes, & Buckley, 2013; Pulina, Carretti, Lanfranchi, & Mammarella, 2015). Computerized programs can be implemented outside the clinical settings by parents or teachers in the natural context; therefore, training effect can be sustained and the labor resource of therapists can be saved as well. Nowadays, many computerized software programs such as Tetris (De Lisi & Wolford, 2002), and 3-D Antz© Extreme Racing computer game (Cherney, 2008) are claimed to be effective in increasing visual perceptual functions of individuals. However, these commercial programs are not appropriate for the DS group since the DS individuals have profound difficulties on computer usage due to their limitations in cognitive, language, and motor skills (Feng, Lazar, Kumin, & Ozok, 2010). They might also feel frustrated and less motivated since they cannot gain successful experience from such, indeed most, commercial computer programs (Feng et al., 2010). Therefore, there is a need to develop a customized computerized training program according to the specific neuropsychological profile of DS that is free from their cognitive and motor limitations.

The aims of this study were to: (1) develop and implement an one-year Computerized Visual Perceptual Training (CVPT) program for DS, (2) use standardized visual perception assessment to evaluate the effectiveness on CVPT program, and (3) examine the changes of cortical activation patterns of DS after one-year of CVPT intervention by utilizing the functional magnetic resonance imaging (fMRI) technique.

2. Methods

2.1. Participants

DS and typically developing (TD) individuals participated in this study. Inclusion criteria for DS group were: (1) a diagnosis of DS defined by board-certified physicians with a full-scale IQ of 55–70 on Wechsler Intelligence Scale for Children- Fourth Edition (WISC-IV) (Wechsler, 2003) or Wechsler Adult Intelligence Scale- Third Edition (WAIS-III) (Wechsler, 1997); (2) between 6 and 21 years of age; (3) without serious behavioral or emotional disturbances; (4) not receiving any visual perceptual training program in the preceding year of the present study; and (5) being right-handed. Those who carried coexisting cerebral palsy, autism, blindness and deafness were excluded. Also excluded were individuals with known etiologies of ID (e.g., FXS, WS, etc.) or previous history of neurological disorders. Participants in the TD group were excluded if school medical records revealed any history of diagnosis of intellectual, developmental, physical, or psychiatric disabilities. The TD and DS groups were matched for age and gender. Thirty eight TD (27 males and 11 females, mean age 13.07 ± 4.20 years, age range 6.63–20.56 years) and 38 DS (27 males and 11 females, mean age 13.17 ± 4.35 years, age range 6.54–21.00 years) were recruited from relevant educational and clinical institutions/resources. These 76 participants were all assessed by the TVPS-3 to evaluate their current visual perceptual skills. Thirty-eight DS participants were further divided into two groups: the DS intervention group (n = 18, 11 males and 7 females, mean age = 14.09 ± 4.65 years, age range 6.54–20.75 years) participated in an one-year CVPT program, and the DS control group (n = 20, 16 males and 4 females, mean age = 12.35 ± 4.00 years, age range 8–21 years) that received no visual perception treatment. Nineteen of 38 children who had initially agreed to participate in the intervention found that they could not attend because of practical reasons (e.g., time of the sessions) before it started and were assigned to the control group. Although not chosen at random, parents of control children had initially wished to join the therapy group, so, presumably, they formed a satisfactory control group.
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