Visuospatial Working Memory in Individuals with Intellectual Disabilities under Simultaneous and Sequential Presentation

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Visuospatial working memory in individuals with non-specific intellectual disabilities (NSID) was investigated under different modes of presentation. Individuals with NSID and mental-age-matched controls were asked to remember locations presented either simultaneously or sequentially. Results showed that individuals with NSID outperformed mental-age-matched controls in the simultaneous task. Their performance in the sequential task was comparable. Furthermore, the advantage of simultaneous over sequential presentation was greater in individuals with NSID than in the mental-age-matched controls. On the whole, the results suggest that visuospatial working memory in individuals with NSID is preserved. Furthermore, simultaneous and sequential processes in visuospatial working memory are not developed homogeneously. Further evidence for visuospatial working memory in individuals with NSID and the benefits of distinguishing between simultaneous and sequential processes in visuospatial working memory was revealed.

Key Words: short-term memory, simultaneous processing, sequential processing, visual working memory, spatial working memory

Introduction

Deficits in memory have been well-documented in individuals with intellectual disabilities; furthermore, increasing attention has been devoted to the area of working memory. Working memory, which is defined as a set of cognitive processes that maintain information temporarily for use in ongoing mental operations (Baddeley, 2007; Conway, Jarrold, Kane, Miyake, & Towse, 2007), plays an important role in numerous everyday situations (Shah & Miyake, 1999). The original Baddeley model (Baddeley, 1986) postulates that working memory comprises an attentional system, a central executive, and two modality-specific storage systems: the phonological loop, which retains auditory-verbal information, that is, verbal working memory; and the visuospatial sketchpad, which retains visuospatial information, that is, visuospatial working memory. A large body of evidence has indicated that visuospatial working memory is not a unitary system (Logie, 1995; Repovš & Baddeley, 2006). For example, Logie (1995) distinguished between a visual component, the visual cache, which stores visual information such as color, shape, and static patterns, and a spatial component, the inner scribe, which stores spatial information such as sequential locations and movements. This multicomponent view of working memory raises the question of whether individuals with intellectual disabilities exhibit general deficits across all the components of working memory.

Numerous studies have examined verbal working memory in individuals with non-specific intellectual disabilities (NSID); findings have revealed that individuals with NSID have deficits in verbal working memory relative to mental-age-matched controls (Bayliss, Jarrold, Baddeley, & Leigh, 2005; Henry & Winfield, 2010; Schuchardt, Gebhardt, & Mäehler, 2010). In contrast, only a paucity of studies has explored visuospatial working memory in individuals with NSID. However, some results have
shown that visuospatial working memory might be preserved in individuals with NSID. For example, Henry and Winfield (2010) found that children with NSID performed equally well in comparison to mental-age-matched controls in the Visual Patterns Test (VPT; Della Sala, Gray, Baddeley, & Wilson, 1997) and the Corsi blocks task (CBT; Milner, 1971); both are widely used measures of visuospatial working memory. Other studies have also found children with NSID achieve comparable or even superior performance in the VPT and the CBT (Henry & MacLean, 2002; Schuchardt et al., 2010), thus, suggesting preserved visuospatial working memory in individuals with NSID. However, contradictory results have indicated that individuals with NSID have deficits in visuospatial working memory. One report revealed that children with NSID performed equally well in the VPT, but worse in the CBT when compared to mental-age-matched controls (Van der Molen, Van Luit, Jongmans, & Van der Molen, 2009). Other studies have revealed impairment in the CBT in children and adults with NSID (Bayliss et al., 2005; Numminen, Service, & Ruoppi, 2002).

Although studies have yielded contradictory results, they generally suggest that individuals with NSID perform better in the VPT than the CBT. It is noteworthy that the VPT and the CBT are assumed to depend on different components of visuospatial working memory. The VPT, which requires participants to remember a matrix pattern with some filled cells, is designed as a purer measure of visual working memory than the CBT (Della Sala et al., 1997). The CBT, for which participants are asked to observe a sequence of blocks tapped by the examiner and are asked to recall the locations in the correct order, is employed primarily to measure spatial working memory (Fischer, 2001). Given this assumption, earlier results have suggested that visual working memory is possibly preserved more than spatial working memory in individuals with NSID. However, this interpretation is not definite because the VPT and the CBT do not differ in modality alone. For example, unlike the VPT, the CBT involves memory for order information, which is confounded by memory for spatial information (Berch, Krikorian, & Huha, 1998; Jones, Farrand, Stuart, & Morris, 1995). Furthermore, the configuration of a pattern or path characteristics of a sequence affect performance on the VPT and the CBT, respectively (Parmentier, Elford, & Maybery, 2005; Riby & Orme, 2013). Therefore, it is difficult to compare the results in the VPT and the CBT directly.

An important difference between the VPT and the CBT is the mode of presentation. The VPT involves a simultaneous presentation of cells that form a matrix pattern, whereas the CBT involves a sequential presentation of block locations. Previous studies have demonstrated that the manipulation of a simultaneous-sequential presentation is an important variable when examining visuospatial working memory (Lecerf & de Ribaupierre, 2005; Pickering, Gathercole, Hall, & Lloyd, 2001). For example, Pickering et al. (2001) found that performance in tasks involving a simultaneous presentation of stimuli was superior to that in tasks involving a sequential presentation of stimuli. This difference increased more markedly with age, thus, indicating a distinction between simultaneous and sequential processes in visuospatial working memory. Several arguments in relation to simultaneous and sequential processes in visuospatial working memory have arisen: simultaneous and sequential processes might be regarded as indicators of visual and spatial working memory, respectively (Oosterman, Morel, Meijer, Buvens, Kessels, & Postma, 2011); alternatively, simultaneous and sequential processes might be distinguished in spatial working memory (Pazzaglia & Cornoldi, 1999). Nevertheless, a range of experimental (Della Sala, Gray, Baddeley, Allamano, & Wilson, 1999; Frick, 1985), developmental (Hamilton, Coates, & Heffernan, 2003; Logie & Pearson, 1997), and deficit studies (Mammarella, Cornoldi, Pazzaglia, Toso, Grimoldi, & Vio, 2006; Wansard, Bartolomeo, Bastin, Segovia, Gillet, Duret, & Meulemans, 2015) have found evidence for the distinction between simultaneous and sequential processes in visuospatial working memory.

However, no studies that have examined simultaneous and sequential processes in visuospatial working memory in individuals with NSID have been found in the relevant literature. Recently, however, Carretti and colleagues reported a series of interesting findings related to individuals with Down syndrome and Williams syndrome (Carretti & Lanfranchi, 2010; Carretti, Lanfranchi, De Mori, Mammarella, & Vianello, 2015; Carretti, Lanfranchi, & Mammarella, 2013; Lanfranchi, Carretti, Spanò, & Cornoldi, 2009; Lanfranchi, De Mori, Mammarella, Carretti, & Vianello, 2015).
and Carretti et al. (2015) investigated visuospatial working memory in children with Down syndrome and those with Williams syndrome by using tasks in which locations that had to be remembered were presented simultaneously or sequentially within a matrix. The children with Down syndrome and those with Williams syndrome were both impaired in the simultaneous tasks, but not in the sequential tasks even though the results of earlier studies had suggested that individuals with Down syndrome have preserved visuospatial working memory (Jarrold & Baddeley, 1997; Laws, 2002) while those with Williams syndrome have impaired visuospatial working memory (O’Hearn, Courtney, Street, & Landau, 2009; Rhodes, Riba, Park, Fraser, & Campbell, 2010). These new findings have suggested that the distinction between simultaneous and sequential processes might be valuable for a better understanding of visuospatial working memory; however, this has not been examined in individuals with NSID. Given the earlier results obtained using the VPT and the CBT, it was expected that individuals with NSID would not be impaired in a visuospatial simultaneous task, and that they would exhibit better performance in the simultaneous task than in the sequential task.

The purpose of the present study was to investigate visuospatial working memory in individuals with NSID based on the distinction between simultaneous and sequential processes. We administered visuospatial working memory tasks with a simultaneous and sequential presentation to individuals with NSID. By adapting the procedure of Carretti et al. (2015), we also sought to elucidate possible differences in results for individuals with Down syndrome and those with Williams syndrome.

**Method**

**Participants**

The participants included 28 adults (22 men and six women; mean age 39.0 years, SD 12.9 years) with mild to severe NSID. All were recruited from social welfare facilities in Japan. All met the following criteria: 18–60 years of age; diagnosis of intellectual disability; no genetic syndromes such as Down syndrome and Williams syndrome, and/or developmental disabilities such as attention-deficit/hyperactivity disorder and autism spectrum disorder; no report of mental and/or physical health problems; and capable of following instructions.

The NSID group was matched for nonverbal mental age as assessed using the Block Design subtest of the Japanese version of the Wechsler Intelligence Scale for Children 4th Edition (WISC-IV; Wechsler, 2003; Wechsler & Japanese WISC-IV Publication Committee, 2010) and gender administered to a control group of 28 typically developing children (16 boys and 12 girls; mean age 5.7 years, SD 0.4 years) who were recruited from a kindergarten in Japan. The control group had to more than five years of age and have no report of behavioral and/or educational problems. In Table 1, the characteristics of the two groups are presented. All participants had normal or corrected-to-normal vision.

Before testing, informed consent for participation was obtained from a guardian of each participant. This study was approved by the Ethical Review Board at Tokyo Gakugei University.

**Tasks and Procedure**

All the participants were administered two visuospatial working memory tasks individually: a simultaneous task and a sequential task that corresponded to measures of simultaneous and sequential processes in visuospatial working memory, respectively.

| Table 1 Characteristics of Participants |
|----------------------------------------|
| NSID group (N=28) | Control group (N=28) | Statistics | p |
|-------------------|---------------------|------------|---|
| Chronological age (year) | 38.99±12.90 | 5.71±4.3 | $\chi^2=2.95$ | 0.09 |
| Male: Female | 22:6 | 16:12 | | |
| Block Design | | | |
| Raw score | 18.43±11.26 | 17.82±7.46 | $F_{1.54}=0.06$ | 0.81 |
| Mental age (year) | 6.29±1.43 | 5.96±1.02 | $F_{1.54}=0.93$ | 0.34 |

Note. NSID=non-specific intellectual disabilities; mean±standard deviation.
These tasks were based on those used in Carretti et al. (2015). For both tasks, a matrix in which some cells were filled in red was presented on a 15-inch monitor screen. Each cell in the matrix was 3 cm × 3 cm. The participants were required to memorize the filled cell locations and recall the locations after a short period. The task presentation and data collection were controlled by employing software (SuperLab; Cedrus Corp., San Pedro, CA, USA).

An illustration of a trial sequence is depicted in Fig. 1. Trials began with a fixation cross for 2000 ms, followed by a presentation of items that had to be recalled. In the simultaneous task, all the filled cells appeared at once for 5000 ms, preceded and followed by a blank matrix for 500 ms. After viewing a black screen mask for 1000 ms, the participants were asked to recall the locations of the filled cells by touching a blank matrix. In the sequential task, each filled cell appeared on its own for 1000 ms (ISI 500 ms) in a particular manner, namely, from left to right and top to bottom. Subsequently, the participants recalled the locations in any order they wished. The locations of the filled cells were selected randomly and were common between the tasks.

The number of the filled cells increased progressively from two to eight. The matrix size varied with the increase of the filled cells: 3 × 4 matrices for two, three and four filled cells; 4 × 4 for five, six and seven; and 4 × 5 for eight. Two trials were used for each number of the filled cells; in other words, the participants had 14 trials in each task. The order of tasks was counterbalanced across participants.

**Analysis**

Task performance was measured by the number of correct trials for each task. A trial was scored as correct if all the filled cells were recalled correctly.

To obtain a better understanding of the effects of the mode of presentation, the simultaneous-sequential index was calculated using the following formula:

\[ \text{Simultaneous-sequential index} = \frac{(\text{number of correct trials for the simultaneous task} - \text{number of correct trials for the sequential task})}{(\text{number of correct trials for the simultaneous task} + \text{number of correct trials for the sequential task})}. \]

The values of this measure range from −1 to +1, with a negative value indicating that the subject performed better in the sequential task relative to his/her performance on the simultaneous task, and vice versa for a positive value. These data were analyzed using analysis of variance (ANOVA) with an alpha level of 0.05. All statistical tests were conducted by employing software (R for Windows ver. 3.3.1 and R package anovakun ver. 4.8.0; R Development Core Team, 2016).

**Results**

**Task Performance**

In Fig. 2, the number of correct trials for each
group is presented. A 2 (group: NSID vs. control)×2 (task: simultaneous vs. sequential) repeated measures ANOVA applied to the number of correct trials showed a significant main effect of task ($F_{1, 54}=113.26$, $p=.000$, $\eta^2=.23$) and a significant interaction of group by task ($F_{1, 54}=13.78$, $p=.001$, $\eta^2=.03$). The main effect of group was not significant ($F_{1, 54}=0.85$, $p=.360$, $\eta^2=.01$). Post hoc analysis showed that both groups recalled more in the simultaneous task than in the sequential task (NSID group: $F_{1, 27}=92.77$, $p=.000$, $\eta^2=.29$; control group: $F_{1, 27}=27.00$, $p=.000$, $\eta^2=.17$). Furthermore, in the simultaneous task, the NSID group outperformed the control group ($F_{1, 54}=4.69$, $p=.035$, $\eta^2=.08$). The group difference in the sequential task was not significant ($F_{1, 54}=0.36$, $p=.551$, $\eta^2=.01$).

**Effects of the Presentation Mode**

The simultaneous-sequential index showed positive values for both groups (see Fig. 3), indicating again that both groups recalled more in the simultaneous task than in the sequential task. A one-way ANOVA on the simultaneous–sequential index with group (NSID vs. control) as the between-subjects variable was conducted. The analysis showed that the score was significantly larger in the NSID group than in the control group ($F_{1, 54}=11.61$, $p=.001$, $\eta^2=.18$).

**Discussion**

The purpose of this study was to investigate visuospatial working memory in individuals with NSID; in particular, the distinction between simultaneous and sequential processes was examined. Previous studies have suggested that visuospatial working memory in individuals with NSID is preserved. Furthermore, findings have revealed that results are task-dependent with better performance in visuospatial working memory tasks that require simultaneous rather than sequential processing. In this study, the simultaneous and sequential processes in visuospatial working memory in individuals with NSID were compared directly by using identical tasks, which differed only in the mode of presentation.

Our results demonstrated that in comparison to mental-age-matched controls, individuals with NSID were not impaired in both simultaneous and sequential tasks. Individuals with NSID performed as well as mental-age-matched controls in the sequential task. Furthermore, their performance in the simultaneous task was superior to that of mental-age-matched controls. These results, which suggest preserved visuospatial working memory in individuals with NSID, were in accordance with various results obtained from earlier studies that employed the VPT and the CBT (Henry & MacLean, 2002; Henry & Winfield, 2010; Schuchardt et al., 2010). By using more con-
trolled tasks, the study provides further evidence and in particular, addressed the distinction between simultaneous and sequential processes.

In relation to the effects of the mode of presentation, individuals with NSID and mental-age-matched controls performed better in the simultaneous task than in the sequential task. As observed in typical development (Lecerf & de Ribaupierre, 2005; Logie & Pearson, 1997; Pickering et al., 2001), the advantage of simultaneous instead of sequential presentation was also observed in individuals with NSID. However, individuals with NSID benefited more from simultaneous presentation relative to the mental-age-matched controls. From a theoretical perspective, the different degrees of beneficial effects of simultaneous presentation between individuals with NSID and mental-age-matched controls further supports the dissociation between simultaneous and sequential processes in visuospatial working memory.

In essence, visuospatial working memory in individuals with NSID was preserved overall, but details show that the development of their sequential process kept pace with mental age whereas the development of their simultaneous process exceeded the expectations for participants according to their mental age. This profile of individuals with NSID is distinct from those of individuals with Down syndrome and Williams syndrome in whom a specific deficit of simultaneous process in visuospatial working memory is found (Carretti et al., 2015; Lanfranchi et al., 2009; Lanfranchi et al., 2015). Therefore, this profile might be characteristic of individuals with NSID.

Although this study did not investigate factors underlying the visuospatial working memory performance observed in individuals with NSID, various speculations can be made. Earlier reports have described that performance in simultaneous visuospatial tasks increases more markedly with age than in sequential visuospatial tasks (Logie & Pearson, 1997; Pickering et al., 2001). When considered together, the fact that the individuals in the NSID group in this study were much older chronologically than the control group, their superior performance in the simultaneous task might have been strongly influenced by chronological-age-related development. It is recommended that future studies include children with NSID as a sample so as to examine the effects of age on simultaneous processes related to visuospatial working memory.

If the age effect on simultaneous processes is the reason, one may ask: why did the performance of individuals with NSID in the sequential task not exceed the mental age expectations, as they did in the simultaneous task? One explanation is that, as suggested by Rudkin, Pearson, and Logie (2007), sequential visuospatial working memory tasks involve executive resources to a greater degree than simultaneous visuospatial working memory tasks do. In the sequential task, participants were asked to encode a series of items while remaining cognizant of previously presented items. They might also be required to chunk them into a single visual pattern. Individuals with NSID are known to have difficulty with executive processes (Carretti, Belacchi, & Cornoldi, 2010; Willner, Bailey, Parry, & Dymond, 2010). For that reason, performance in the sequential task might not have increased as much as in the simultaneous task.

Finally, one may ask whether the results of this study can be interpreted as evidence that visual working memory is more preserved than spatial working memory in individuals with NSID. This is unknown because the nature of visuospatial working memory related to simultaneous and sequential processes remains controversial. As noted in the Introduction, Oosterman et al. (2011) used simultaneous and sequential presentations as indicators of visual and spatial working memory, respectively. Pazzaglia and Cornoldi (1999) distinguished simultaneous and sequential processes in spatial working memory. One argument also holds that visuospatial working memory is well dissociated into visual and spatial working memory based on a distinction between the appearance and location of stimuli rather than between a simultaneous and sequential presentation (Darling, Della Sala, & Logie, 2009). Therefore, further evidence by employing various visuospatial working memory tasks is needed to elucidate whether visual working memory is more preserved than spatial working memory in individuals with NSID.

In conclusion, on the whole, this study demonstrated that visuospatial working memory in individuals with NSID is preserved, but simultaneous and sequential processes in visuospatial working memory do not develop homogeneously. Our results suggest that visuospatial working memory among the components of working memory is a strength of individuals with NSID. Furthermore, the benefits of distinguishing between simultaneous and sequen-
tial processes in visuospatial working memory were revealed. These findings have some practical implications for supporting individuals with NSID. For example, it would be beneficial to increase the use of visuospatial materials when intervention programs are provided for individuals with NSID. Furthermore, simultaneous presentation of them might be preferred. To support evidence-based practice, future investigations should clarify the underlying mechanisms of the possible strengths and weaknesses in the visuospatial working memory of individuals with NSID.

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