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SHORT COMMUNICATION

Memory for positional movements as a component of the visuospatial working memory

Stefano Sdoia[1] · **Francesco Di Nocera**[1] · **Fabio Ferlazzo**[1]

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Abstract

Though the Corsi block-tapping task (CBT) is widely used for assessing visuospatial memory, information about what exactly it measures is still debated. We investigated such issue by observing how motor, visual, and spatial secondary tasks affect the performance on three versions of the CBT. Results showed a double dissociation pattern, wherein two motor secondary tasks had larger effects when the CBT was administered by the examiner tapping on the blocks. A spatial secondary task had larger effects when the CBT was administered by automatically illuminating the blocks. Finally, a visual secondary task had larger effects on a two-dimensional, computerized version of the CBT. These findings suggest that memory for movements plays a relevant role in the CBT, and are especially relevant due to their implications for assessment of brain-damaged patients, besides providing further evidence of a fractionation of visuospatial memory into multiple subcomponents.

Keywords Corsi block-tapping task · Visuospatial memory · Memory for movements

Introduction

The Corsi block-tapping test (CBT; Milner 1971; Corsi 1972) has been widely used in cognitive psychology and clinical neuropsychology to measure visuospatial memory (e.g, Kessels et al. 2000; Vecchi and Richardson 2001; Mammarella et al. 2003; Pearson and Sahraie 2003; Zimmer et al. 2003; Chiaravalloti and Glosser 2004; Vandierendonck et al. 2004; Claessen et al. 2015; Carvalho et al. 2014; Piccardi et al. 2008; Shah et al. 2013; Stoffers et al. 2003; Brunetti et al. 2016), often within the framework provided by the working memory model (Baddeley and Hitch 1974). The standard apparatus consists of identical blocks irregularly arranged on a board. According to the standard administration procedure, but procedures vary widely among authors, the examiner taps on the blocks in randomized sequences of increasing length. The subject has to immediately reproduce each sequence, continuing until no longer accurate. Performance is measured as the longest sequence of blocks that is correctly reproduced.

Notwithstanding, Baddeley (2001) reported the CBT as the task that is most closely related to the visuospatial short term memory; it is still not completely clear what process it actually measures. For instance, Fischer (2001) found that performance at the CBT improves with prolonged encoding and maintenance time, suggesting a possible role for a limitation due to an encoding bottleneck, as well as when locations are precued, suggesting that the CBT depends on memory for both sequences and locations (see also Berch et al. 1998 for similar conclusions). Also, Kemps (2001) reported that long-term memory plays a role in the execution of the CBT, suggesting that the CBT has a more complex nature than usually accepted. Thomson and coworkers (2006), instead, found that whereas both the CBT and the visual patterns task (VPT, Della Sala et al. 1997) correlate with executive functions tasks, only the VPT correlates with a size just noticeable difference task and concluded that whereas the VPT has a distinct visual memory component, the CBT only taps on executive functions (see also Quinn 2008 for a review). However, it is worth to note that Thomson and coworkers (2006) used a two-dimensional version of the CBT and only compared the CBT with a visual memory task; thus, it is not possible to exclude that the CB has a distinct spatial memory component. Also, Cavallini et al. (2004) reported conflicting

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✉ Stefano Sdoia
stefano.sdoia@uniroma1.it

[1] Department of Psychology, University of Rome "La Sapienza", Via dei Marsi no.78, 00185 Rome, Italy

results with the notion of the CBT as a measure of visuospatial working memory, as they found that a concurrent spatial tapping task does not interfere with the CBT, while a random number generation interference, a numerical interference, and a motor interference were apparent. It is worth noting that in this study a standard, three-dimensional CBT was used.

The issue of what the CBT measures is relevant, since it is largely used for assessing visuospatial memory abilities in patients suffering from a large spectrum of neurological and psychiatric conditions (e.g, Popp et al. 2017; Bianchini et al. 2014; Piccardi et al. 2011). Also, studies of both healthy individuals and brain-damaged patients demonstrated dissociable visual and spatial memory systems in humans (e.g, Baddeley and Logie 1999; Logie 2003; Logie and Marchetti 1991; Tresch et al. 1993; Quinn and McConnell 1996; Klauer and Zhao 2004; Finke et al. 2005). Such a fractionation of the visuospatial working memory is in fair agreement with evidence in primates of separate processing streams for visual and spatial features of objects (e.g, Ungerleider and Mishkin 1982; Goodale and Milner 1992).

Interestingly, evidences for a further fractionation of the visuospatial working memory were also reported, suggesting specific components of working memory for motor and kinesthetic information (e.g, Smyth and Pendleton 1990; Woodin and Heil 1996). A close link between motor systems and visuospatial working memory was actually proposed since the very first studies about working memory (Baddeley et al. 1975; Baddeley and Lieberman 1980). However, Smyth and her coworkers (Smyth et al. 1988; Smyth and Pendleton 1989) firstly suggested that a specific kinesthetic component of working memory might be responsible for the encoding and maintenance of remembered patterned movements (those aimed to bring the body parts into a specific configuration), whereas positional movements (movements targeted toward specific external spatial stimuli) appear to be encoded and maintained within the visuospatial sketchpad.

The idea that the visuospatial working memory is composed of multiple components is empirically well supported. However, their relationship with the CBT has not been systematically investigated so far. Though, the complex administration procedure of the CBT makes a more detailed analysis of the processes underlying the CBT strongly needed (Berch et al. 1998; Fischer 2001). Especially interesting is the hypothesis that the CBT involves a memory for positional movements, since the administration procedure focuses on the movements of the examiner. Indeed, Claessen et al. (2015) compared the standard CBT and an electronic version (eCorsi) and reported a higher span in the former compared to the latter. They suggested this difference might be used to a motor priming effect, present in the standard CBT and absent in its electronic version, and argued that participants, while observing the experimenter tapping during encoding to memorize the sequence, might activate their mirror neurons network (Rizzolatti et al. 2001). According to this interpretation, the higher span they found in CBT might be caused by a motor resonance active during the observation of the examiner's motor sequence. Brunetti et al. (2016) investigated this hypothesis by including in their electronic version of the CBT (eCorsi, see Brunetti et al. 2014) information such as variations of the inter-stimulus interval between the presentations of two subsequent locations (Exp.1) and the trajectory between two subsequent locations (Exp.2). In both cases, they found that information about timing and trajectories significantly increased the participants' span compared to the standard eCorsi task. They concluded that since the movement-related information alone affects the participants' performance, it is not caused by a direct, bottom–up driven, motor resonance.

The different conclusions drawn by Claessen et al. (2015) and Brunetti et al. (2016) might be accounted for by the different experimental setup and conditions used. Thus, the contribution of a memory for positional movements in the CBT has yet to be investigated systematically. It is also worth noting that computerized, two-dimensional CBT versions have been frequently used (e.g, Fischer 2001; Pearson and Sahraie 2003; Vandierendonck et al. 2004), albeit it is not known whether the standard and the computerized versions of the task are equivalent.

The present study aims at investigating the architecture of the visuospatial working memory as measured by the CBT, through a crossed double dissociation design (Dunn and Kirsner 1988). We followed a standard dual-task procedure, using four secondary tasks aimed at interfering with the spatial, visual, and motor components of visuospatial working memory. They were crossed with three versions of the CBT: a standard version, wherein the sequences were given by the experimenter tapping on the blocks; a computer-controlled "automatic" version, wherein the sequences were given by the blocks being illuminated; a two-dimensional version, presented on a computer monitor, wherein the sequences were given by the squares on the monitor changing their color.

Method

Participants

Forty-eight healthy, right-handed individuals (mean age 22.4 years, 24 males) participated in the experiment. All the participants reported normal or corrected-to-normal vision and were naïve as to the purposes of the experiment.

Stimuli and apparatus

The apparatus used for the standard and automatic CBT administration procedures (see below) included eight

translucent white 3 × 3 × 3 cm blocks, each one containing a red light emitting diode (LED). The blocks were fixed at random positions on a 23 × 30 cm translucent white board. The two-dimensional version of the CBT (see below) was administered on a 15'' computer monitor where eight blue squares (3 × 3 cm in size) were presented on a white background at the same relative positions as the 3D apparatus described above.

Procedure

Three versions of the CBT were used. In the standard version, the to-be-remembered sequence was presented by the experimenter tapping on the blocks, with his/her index finger, at a rate of one block per second, lifting the hand straight up before moving it to the next block (Standard). In the automatic version, the to-be-remembered sequence was presented by means of an automatic sequential illumination of the red LEDs, at a rate of one block per second (Automatic). A third, two-dimensional version of the CBT was also used, as it is frequently used in the literature as a substitute of the standard version (e.g., Fischer 2001; Pearson and Sahraie 2003; Vandierendonck et al. 2004; Claessen et al. 2015; Brunetti et al., 2016; Martin et al. 2017). On each trial, the to-be-remembered sequence was indicated by the blocks changing color from blue to red and again to blue, at a rate of one block per second. The two-dimensional versions of the CBT were programmed in Visual Basic (by Microsoft; https://microsoft.com). The three versions of the CBT were administered to all the participants, in random order. Participants had to reproduce the sequence immediately after its administration, as it was presented (forward), by tapping on the blocks using their index finger.

Each participant performed each of the three versions of the CBT once alone (single-task condition), and once with one of four interference conditions (dual-task condition), in random order. In the patterned-motor interference condition, participants had to tap with their right index finger on the four corners of a mouse pad, while the to-be-remembered sequence of blocks was administered. The movement had to be performed clockwise and continuously, at a rate of about one tap per second. Whereas this task is known to interfere with the CBT (e.g, Baddeley and Lieberman 1980; Smyth and Pelky 1992), it has both spatial and motor features whose effects are difficult to disentangle. Thus, we added a motor interference condition wherein participants had to snap fingers with their right hand, while the to-be-remembered sequence of blocks was administered. The movement had to be performed continuously, in a regular manner (one snap per second, approximately). The experimenter controlled for the movement being correctly executed. In the spatial interference condition, while the to-be-remembered sequence of blocks was administered, participants were presented with a series of 1000 Hz tones at 30 Db Spl with a constant inter-stimulus interval of 2 s. Each tone was randomly presented to the participant's left or right ear through headphones. Participants were required to say aloud "sinistra (left)" or "destra (right)" to each tone according to where (left or right) it was presented. This listening task is supposed to interfere with the spatial component of the visuospatial sketchpad (e.g, Smyth and Scholey 1994). Finally, in the visual interference condition, on each trial, one of three differently colored LEDs (green, red, blue) placed at the center of the CBT board (one of three colored circles in the two-dimensional version) was continuously turned on and off at a rate of one per second, while the to-be-remembered sequence of blocks was administered. In half of the trials, the regular sequence (e.g., red, red, red, red, red, …) was violated by turning on a different colored led (on the 3D versions) or (on the 2D version) displaying a different colored circle (e.g., red, red, green, red, red, …). At the end of each trial, participants were required to say whether a violation occurred on that trial.

Six different lists of fourteen sequences from 3 to 9 blocks in length (two sequences for each length) and equated for path length were generated. For each participant, the lists were randomly associated with the three versions of the CBT for the single-task and dual-task conditions. The sequences were presented in ascending order, with two trials per length. All the fourteen sequences were administered to each participant.

Twelve participants were pseudo-randomly assigned to the patterned-motor, motor, spatial, and visual interference conditions, with the constraint that 6 male and 6 female participants were included in each group.

The participants' performance was measured as the longest sequence that was correctly reproduced at least once (memory span). Performance data were analyzed in a 3 × 2 × 4 ANOVA mixed design, with version (standard, automatic, and two dimension, within subjects), condition (single task, dual task, within subjects), and interference (patterned-motor, motor, spatial, and visual interference, between subjects) as factors.

Results and discussion

One participant in the spatial interference condition and two participants in the visual interference condition have been excluded from the following analyses because of the relatively large number of errors made on at least one of the interference tasks (errors, or mean rate slower than 2 s for the finger snapping or spatial tapping tasks, on at least four trials). The remaining participants performed all the interference tasks at optimal levels, making less than 3% of errors across visual and spatial interference tasks, and maintaining

a regular mean rate of finger snapping and spatial tapping of about 1.2 per second. Figure 1 and Table 1 show the mean memory span length for each version of the CBT and for each interference condition.

A preliminary sphericity test failed to show any significant violation of the assumptions underlying the version and the version by condition interference effects ($p > 0.05$ in all cases).

The analysis of performance data did not show interference, condition by interference, and version by condition effects ($F_{3,41} = 1.71$, $p = 0.18$; $F_{3,41}$=.83, $p = 0.48$; $F_{2,82}$=1,43, $p = 0.24$, respectively). The analysis showed significant main effects of condition ($F_{1,41} = 139.93$, MSE = 0.42, $p < 0.001$) and version ($F_{2,82} = 4.24$, MSE = 0.63, $p < 0.02$). The condition main effect was due to participants performing better in the single-task condition than in the dual-task condition, irrespective of the kind of interference and the version of the test ($p < 0.05$). The version main effect was due to the performance at the two-dimensional version of the CBT being slightly worse than at the other two versions of the task ($p < 0.05$ in both cases). While significant, though, such a difference was quite small (5.3 versus 5.6), and will not be discussed any further.

Also, the interference by version and the condition by version by interference interactions were significant ($F_{6,82} = 3.61$, MSE = 0.63, $p < 0.01$, $F_{6,82} = 4.33$, MSE = 0.63, $p < 0.01$, respectively). Newman–Keuls testing showed that the interference by version interaction was due to the individual's performance at the three versions of the CBT being dependent on the type of interference that was administered. Again, such interaction is not relevant, since it concerns the average performance of individuals across the single and dual-tasks conditions (i.e., without and with the interference). The condition by version by interference interaction is

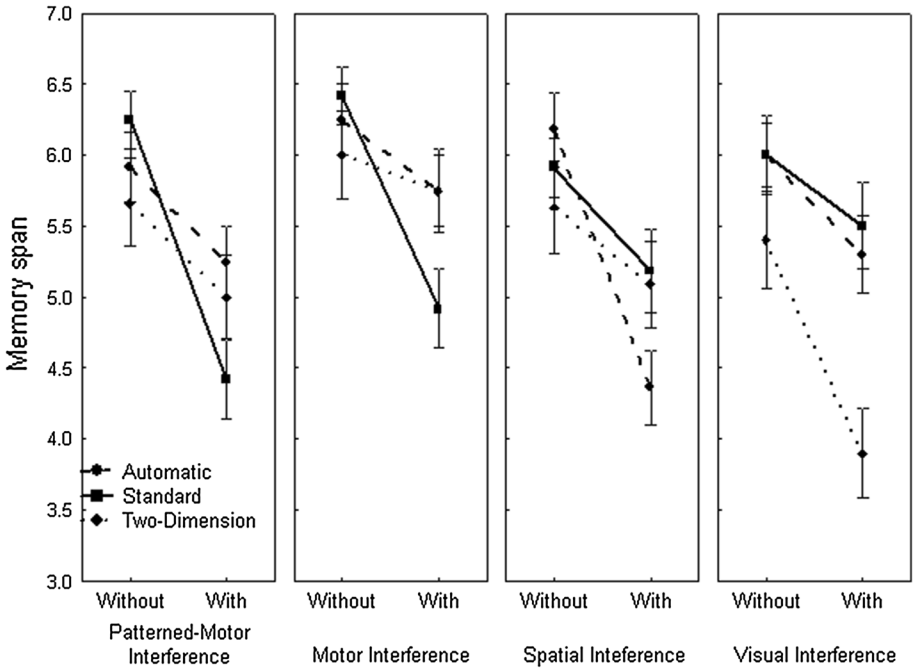

Fig. 1 Mean memory span scores as a function of the presence/absence of an interference task, the nature of the interference task (patterned-motor, motor, spatial, and visual interference), and the Corsi task version (standard, automatic, and two dimensional) Standard error bars are reported

Table 1 Mean memory span scores as a function of the presence of an interference task (without, with), the interference task (patterned-motor, motor, spatial, and visual interference), and the Corsi task version (standard, automatic, and two dimensional) Standard errors are reported in italics

	Standard version		Automatic version		Two-dimensional version	
	Without	With	Without	With	Without	With
Patterned-motor interference	6.25	4.42	5.92	5.25	5.67	5.00
	0.20	*0.28*	*0.25*	*0.25*	*0.31*	*0.29*
Motor interference	6.42	4.92	6.25	5.75	6.00	5.75
	0.20	*0.28*	*0.25*	*0.25*	*0.31*	*0.29*
Spatial interference	5.91	5.18	6.18	4.36	5.64	5.09
	0.21	*0.29*	*0.26*	*0.26*	*0.32*	*0.31*
Visual interference	6.00	5.50	6.00	5.30	5.40	3.90
	0.22	*0.30*	*0.27*	*0.28*	*0.34*	*0.32*

more important with respect to the goal of investigating the processes underlying the performance at the CBT. Results of the Newman-Keuls test showed that in the single-task condition, there was no significant difference among the performances of the participants at the three versions of the CBT ($p > 0.05$ in all cases). This finding ensures that the administration procedure did not affect the difficulty of the task. However, the effects of the three kinds of interference upon the three versions of the CBT were very specific. Indeed, the motor interference task and the spatial tapping task affected negatively the standard version of the test ($p < 0.001$ in both cases), but not the automatic and the two-dimensional versions ($p > 0.5$ in both cases). The spatial interference task affected negatively the participants' performance at the automatic version of the test ($p < 0.001$), but not the standard and the two–dimensional versions ($p > 0.05$ in both cases). The visual interference task affected negatively the participant's performance at the two-dimensional version of the test ($p < 0.001$), but not at the standard and automatic versions ($p > 0.05$ in both cases). Importantly, such finding cannot be ascribed to the four interfering tasks being not equivalent with respect to each other, because of the triple dissociation procedure we employed.

General discussion and conclusions

Results of the present experiment suggest that a component of working memory that deals with motor information has the major role in the standard version of the CBT. Indeed, the effects of both the finger snapping and the spatial tapping tasks were notably larger than those of the spatial and visual interference tasks. The general pattern of our results supports this interpretation. Indeed, in the "automatic" version of the CBT, the spatial interference task was more effective than both the motor interference tasks and the visual interference task, whereas in the two-dimensional version of the CBT, only the visual interference task was effective. Such result does not depend on confounding due to the three versions of the CBT being not equated in terms of difficulty, because in the single-task condition, the performance of the participants was the same in the three versions of the test. Also, it does not depend on the spatial interference task involving a verbal coding of the spatial locations where the tones came from, as the phonological loop has been shown to be not involved in the CBT (e.g, Vandierendonck et al. 2004). Also, the results suggest that the two-dimensional version of the CBT depends on the visual component more than on the spatial component of the visuospatial sketchpad. Likely, this was due to the two-dimensional version of the CBT being presented on the frontal plane (i.e., the computer monitor, all the blocks were at the same distance from the participant) instead of being extended in the third dimension.

The finding that performance on the standard version of the CBT largely depends on individuals coding the movements of the examiner is in fair agreement with the hypothesis that a component of working memory that deals with motor information actually exists and is independent of the component of working memory that deals with spatial information (e.g, Smyth and Pendleton 1990; Woodin and Heil 1996). It is also in fair agreement with the growing body of neurophysiological and psychological studies that suggest a close link between observing and performing an action (e.g, Stephan et al. 1995; Deiber et al. 1996; Rizzolatti et al. 1996; Paccalin and Jeannerod 2000). Interestingly, van Asselen and coworkers (van Asselen et al. 2006) have interpreted results of a study on stroke patients as suggesting that the right dorsolateral prefrontal cortex (DLPFC) and the right posterior parietal cortex (PPC) are involved in keeping spatial information in memory over a short time period, as was assessed with the CBT. While the involvement of both the DLPFC and the PPC in spatial memory tasks is not new (e.g., Wilson et al. 1993; Owen et al. 1998; Walter et al. 2003), it is worth noting that this is not at variance with the hypothesis that a specific component of working memory for positional movements is involved in the CBT. For instance, lesion and physiological studies have shown that the DLPFC has a crucial role in visuospatial control of actions and visuomotor transformations (e.g, Curtis and D'Esposito 2004; Hoshi and Tanji 2004). Indeed, Hoshi (2006) suggested that the dorsal part of the DLPFC is involved in representing processed motor information, such as arm use or target location, and in integrating multiple classes of information for planning action. Similarly, the PPC is involved in visuomotor transformation and is thought to serve as a sensory-motor interface for visually guided eye and limb movements (see Buneo and Andersen 2006, for a review). Though, more research is needed in order to specify the relationship between the complex functional architecture of the DLPFC–PPC system and the specific features of the working memory components, including those measured by the CBT.

Finally, it is worth noting that the motor and spatial interference tasks affected only marginally the performance on the two-dimensional version of the CBT. Such a result might suggest that the two-dimensional and the standard versions of the CBT measure at least partially different components of the working memory. This finding is especially relevant because in recent years, two-dimensional, computerized versions of the CBT have been used rather frequently in clinical and experimental settings (e.g, Joyce and Robbins 1991; Lange et al. 1992; Vandierendonck et al. 2004).

In accordance with the idea that the standard and the two-dimensional version of the CBT measure different working memory components, Claessen et al. (2015) recently reported a higher span in the standard compared to the electronic version of the CBT. They suggested that

this difference might be due to a motor priming effect, present in the standard CBT and absent in its electronic version, which is caused by participants observing the examiner's motor sequence during the encoding phase. Results by Brunetti et al. (2016) seem to speak against this hypothesis, as they found that including information about the trajectory between two subsequent locations in the electronic two-dimensional version of the task significantly increased the participants' span compared to when trajectories were absent. They concluded that trajectory information is incidentally provided during the standard CBT by the experimenter's movement and hence that the participants' performance on the standard version of the task would not be caused by a direct motor resonance. However, because of the absence of a direct comparison between standard and electronic version of the CBT in the Brunetti et al. study (2016; i.e., they did not include a standard CBT in the experimental design), it is impossible to claim that the beneficial effect of the trajectory they found on the electronic version of the CBT could fully explain the results obtained by Claessen et al. (2015) on the standard CBT (as the authors also pointed out; p. 466). Furthermore, the advantage of trajectory information could also be due by the trajectory matching the constraints of biological motion and could thus be easily accounted for by evoked movement. Indeed, motor priming has been shown to be evoked even by stimuli that are weakly related to movement (e.g., Fecteau et al. 2010; as the authors also pointed out; p. 465). A theoretical framework that includes a component of working memory that specifically deals with motor information could potentially account for both findings of Claessen et al. (2015) and Brunetti et al. (2016).

In conclusion, the present study suggests that the Corsi block-tapping task is a rather complex test of visuospatial memory. Indeed, the performance on the task seems to depend largely on a component of working memory specifically dealing with motor information. This finding was not previously described in the literature and should be taken into account when interpreting the results of the task, for instance in clinical settings.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval All procedures performed in the present study were in accordance with the ethical standards of the 1964 Helsinki Declaration and its later amendments or comparable ethical standards.

Informed consent All participants were informed verbally about the procedure and potential risks of their participation and gave their consent to participate to the study.

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