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Computerization of the Standard Corsi Block-Tapping Task Affects Its Underlying Cognitive Concepts: A Pilot Study

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The tablet computer initiates an important step toward computerized administration of neuropsychological tests. Because of its lack of standardization, the Corsi Block-Tapping Task could benefit from advantages inherent to computerization. This task, which requires reproduction of a sequence of movements by tapping blocks as demonstrated by an examiner, is widely used as a representative of visuospatial attention and working memory. The aim was to validate a computerized version of the Corsi Task (e-Corsi) by comparing recall accuracy to that on the standard task. Forty university students ($M_{age} = 22.9$ years, $SD = 2.7$ years; 20 female) performed the standard Corsi Task and the e-Corsi on an iPad 3. Results showed higher accuracy in forward reproduction on the standard Corsi compared with the e-Corsi, whereas backward performance was comparable. These divergent performance patterns on the 2 versions (small-to-medium effect sizes) are explained as a result of motor priming and interference effects. This finding implies that computerization has serious consequences for the cognitive concepts that the Corsi Task is assumed to assess. Hence, whereas the e-Corsi was shown to be useful with respect to administration and registration, these findings also stress the need for reconsideration of the underlying theoretical concepts of this task.

Key words: *computerization, Corsi Block-Tapping Task, digit span, spatial span, visuospatial working memory*

INTRODUCTION

As for many scientific disciplines, technological innovations have a lot to offer to advance the field of neuropsychology. Specifically, numerous efforts have been made to develop computerized versions of standard neuropsychological tasks to facilitate administration and scoring procedures, such as for the Rey Complex Figure Test (Riordan, Lombardo, & Schulenberg, 2013) and the Wisconsin Card-Sorting Task (Heaton & PAR Staff, 2003). Not all professionals embrace the utilization of computers in neuropsychological assessment, as some of them interpreted it as a way to replace the clinician, which could lead to missing important observations (Bilder, 2011). Computerized administration might, however, contribute considerably to the standardization of standard neuropsychological tasks. Important advantages include, among many others, the ability to control stimulus presentation more strictly, to score responses automatically, and to register response times on time-sensitive tasks more accurately (Bauer et al., 2012; Bilder, 2011). However, one should

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be aware that converting a standard neuropsychological task to an equivalent computerized version results in a new and different task. The American Academy of Clinical Neuropsychology and the National Academy of Neuropsychology therefore recently published a position paper stating that computerized versions of existing tasks should be carefully evaluated in terms of their psychometric characteristics (reliability and validity) and should be accompanied with newly developed normative data as well (Bauer et al., 2012).

A specific neuropsychological task that has the potential to benefit from the practical advantages of computerized administration is the Corsi Block-Tapping Task (hereinafter, Corsi Task). In addition, computerization might also reduce the serious lack of standardization that is still inherent in this particular task (see, for a review, Berch, Krikorian, & Huha, 1998).

The Corsi Task is widely used in clinical and research contexts to assess visuospatial attention and working-memory processes in both healthy participants and patients with known or suspected brain damage (Milner, 1971; originally based on Corsi, 1972). It requires participants to reproduce a sequence of movements by tapping blocks in the same serial order as the examiner did on a board containing nine blocks at fixed, pseudorandom positions (see Figure 1 for an example). As the test procedure progresses, the number of blocks in the sequences gradually increases. Because the task also requires participants to remember the serial order of the blocks in the sequence, some researchers propose that the maintenance of sequential information is of importance as well (Mammarella & Cornoldi, 2005).

In accordance with its verbal equivalent, the Wechsler Adult Intelligence Scale-Third Edition (WAIS-III) Digit Span subtest (Wechsler, 1997a), the Corsi Task contains both a forward and a backward condition (Kessels, Van den Berg, Ruis, & Brands, 2008; Kessels, Van Zandvoort, Postma, Kappelle, & De Haan, 2000). Whereas in the forward condition participants are instructed to repeat the block sequence in the same serial order as indicated by the examiner, in the backward condition, they have to reproduce the block sequence in reverse order.

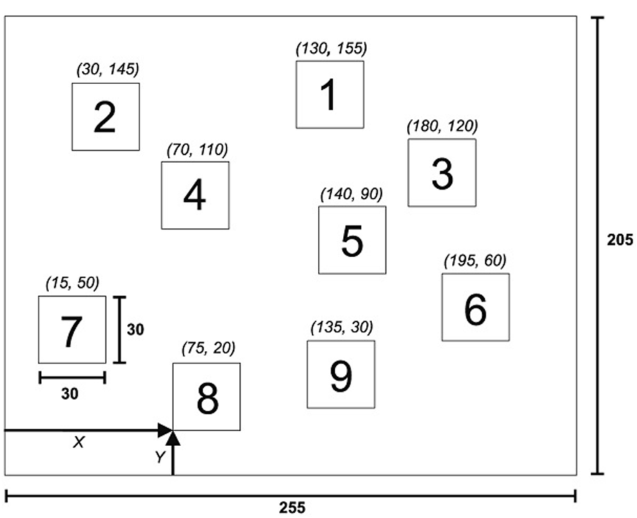

FIGURE 1 Block layout in the standard Corsi Task (adapted from Kessels et al., 2000). Coordinates are measured from the left-bottom corner of the board to the left-bottom corner of each cube in millimeters.

The lack of standardization that tends to characterize the Corsi Task follows from researchers using numerous versions of the task. For example, versions exist that are different in the physical characteristics of the test apparatus and in their administration and scoring procedures (Berch et al., 1998). The importance of standardization was clearly emphasized by Fischer (2001), showing that several task variables tend to influence performance levels. He demonstrated, for instance, that accuracy on the Corsi Task was influenced by (small) differences in item-exposure time. By developing a computerized version of this task that uses a digital interface (here, an iPad) instead of a human examiner that administers and scores the task (Bauer et al., 2012), several of these issues can be overcome. The presentation duration of the block locations can be strictly applied, whereas timing inconsistencies are likely to occur when an experimenter taps the sequences manually. As another advantage of a computerized Corsi Task, the examiner will be able to pay more attention to the behavior of the patient and the strategies that he or she applies to deal with the task, instead of being engaged with tapping the sequences with correct timing and examining the correctness of the patient's responses (Berch et al., 1998). Because some patients tend to reproduce the sequences in an extremely high tempo, using a computerized version will prevent the experimenter from making false decisions about the correctness of the responses as well.

As noted, the standard Corsi Task (Kessels et al., 2000, 2008) includes both a forward and backward condition. Participants have to reproduce the block sequence in the same serial order as indicated by the examiner in the forward condition. In contrast, in the backward condition, they are instructed to repeat the block sequence in reverse order. An additional cognitive operation might thus be required to invert the serial order of the blocks in the backward condition. Assuming that active manipulation of the input puts a higher load on working memory and is therefore more strenuous (Baddeley, 1986; Hester, Kinsella, & Ong, 2004), recall performance should be lower in the backward condition than in the forward condition. Because of this difference in cognitive operations, one could argue that the two conditions address different cognitive processes. However, there is currently no consensus on whether the conditions indeed tap into different cognitive processes based on recall performance.

Although most studies in which recall accuracy in the forward and backward conditions of the Corsi Task is compared showed comparable recall performance (e.g., Isaacs & Vargha-Khadem, 1989; Kessels et al., 2008; Mammarella & Cornoldi, 2005; Wilde & Strauss, 2002), in some other studies, recall accuracy has been found to be better in the forward condition (e.g., Cornoldi & Mammarella, 2008). The debate on the ability of the Corsi Task to assess two distinctive aspects—that is, visuospatial attentional span and visuospatial working memory—is yet undecided. Notably, the studies that have shown comparable recall accuracy in the forward and backward conditions contrast the common finding that in verbal span tasks (like the WAIS-III Digit Span subtest) the longest span backward is nearly always lower than the longest span forward (Kessels et al., 2008). Researchers accounted for these nonparallel performance patterns by pointing out that participants use different strategies across the backward conditions of verbal and visuospatial span tasks. These strategies relate to the finding that serial order information is bound more to verbal than to visuospatial working memory (Gmeindl, Walsh, & Courtney, 2011). With backward reproduction in the typical verbal span task, people tend to maintain the verbal information in its original order and then retrieve it piece by piece to reproduce it in reverse order (Thomas, Milner, & Haberlandt, 2003). In contrast, in a visuospatial span task like the Corsi Task, a block sequence might be represented as a pathway that connects the block locations rather than as a sequential series of positions (Mammarella & Cornoldi, 2005). Because all block locations remain visible during recall, only the path between the locations has to be remembered (Smyth & Scholey, 1992). Following this reasoning, the purpose of the two conditions is essentially the same in correctly remembering the pathway, but only the starting point of reproduction is different. No differences in recall performance between the forward and backward conditions will be expected accordingly.

To summarize, the lack of standardization of the standard Corsi Task might be considerably reduced by using a computerized version that presents the block sequences and collects the responses of participants automatically. Yet a computerized version of an existing task should be conceived as a new task and carefully reviewed in terms of its psychometric qualities (Bauer et al., 2012). For this reason, we aim to validate a computerized version of the Corsi Task by comparing recall accuracy to that on the standard Corsi Task.

METHOD

This study was performed in agreement with the regulations set by the local ethical review board.

Participants

Forty university-level students (20 female) with a mean age of 22.9 years ($SD = 2.7$) participated in the experiment after signing an informed consent. Whereas they were informed about the procedures to be used and the purpose of the experiment, the underlying research questions were not revealed to them. They received course credits or a small amount of money (€5 [$6.50 USD]) in exchange for participation. Only right-handed participants (self-reported) with normal or corrected-to-normal visual acuity were included. Task administration was executed by the same examiner (MC) for all 40 participants. Performance of these participants on the two versions of the Corsi Task was based on a set of new sequences that is proposed in this study (see Design and Procedure for details).

The data of an unrelated second group consisting of 80 university-level students (41 female) with a mean age of 23.2 years ($SD = 2.1$) were also taken into account. Their performance on the Corsi Task was already available from a database with data collected in a different experiment, unrelated to the experimental procedure that is described here. This group performed the standard Corsi Task based on the sequences of Kessels and colleagues (2000, 2008) as well. Although administration of the Corsi Task in this second sample was carried out by another examiner, exactly the same instructions and test protocol (Kessels et al., 2000, 2008) were used for both samples. Additional analyses were performed using these data to compare recall accuracy based on the new sequences proposed in this study with that of the sequences of Kessels and colleagues (2000, 2008).

Design and Procedure

The experiment contained three tasks: the standard Corsi Task, the computerized Corsi Task (e-Corsi), and the Digit Span subtest of the WAIS-III (Wechsler, 1997a). We added the latter task to assess whether performance in the forward and backward conditions of the verbal Digit Span relate to each other in the same way as the two conditions of the visuospatial Corsi Task. Participants were pseudorandomly assigned to one of the six test protocols (covering all possible sequences of the standard Corsi Task, e-Corsi, and Digit Span task; generated using a balanced Latin square) to make sure that they were equally distributed over the different test protocols. The participants were assigned to the six test protocols in the order they showed up to take part in the experiment.

Standard Corsi Task. Participants were seated facing the experimenter with the Corsi board in between them. The most common Corsi board was used (Kessels et al., 2000, 2008): a board (225 mm × 205 mm) containing nine wooden blocks (30 mm × 30 mm × 30 mm) placed at fixed, pseudorandom locations (see Figure 1 for the layout). Both the board and blocks were black. A digit ranging from 1 to 9 was printed on the backside of each block, which was only visible to the experimenter to facilitate the administration procedure.

In the forward condition, participants were instructed to tap the blocks in the same serial order as presented (two trials per sequence length ranging from two to nine blocks), whereas in the backward condition, they were required to reproduce the block sequence in reverse order (two trials per sequence length ranging from two to eight blocks). The examiner explained to them that the length of the block sequences would increase during the progression of the task. For each trial, the experimenter tapped a predetermined block sequence (see Appendix A) at a rate of one block per second. When the participant did not manage to correctly reproduce at least one of the two trials of a certain sequence length, the actual condition was discontinued. The two conditions were administered in counterbalanced order (pseudorandom assignment) over participants.

To be able to compare recall accuracy in the two conditions, it was essential that the level of difficulty of the block sequences was highly similar in the forward and backward conditions. Earlier studies did not take stimulus characteristics into account that are known for influencing task accuracy, such as the number of path crossings and path length (as shown by Busch, Farrell, Lisdahl-Medina, & Krikorian, 2005; Orsini, Pasquadibisceglie, Picone, & Tortora, 2001; Parmentier, Elford, & Mayberry, 2005). This study therefore provides new sequences for both conditions of the Corsi Task.

Each trial in the forward condition had an equivalent trial in the backward condition in terms of sequence length, number of path crossings, and comparable path length (Appendix B). Due to the fixed block layout, it was not possible to create two paths with exactly the same path length. For this reason, some deviation was allowed (Appendix B). Regarding path crossings, both trials with a sequence length of two and three blocks contained no path crossings, because it was not possible to create a path that crosses itself with only two or three block locations included. For the sequences containing four blocks, there was a path that did not cross itself and a second path that contained one crossing. Items with a sequence length of five and higher (up to nine in the forward condition; up to eight in the backward condition) each contained a noncrossing path and a path with two crossings.

Three accuracy measures were registered: the number of blocks of the longest correct sequence (the span), the total number of correctly reproduced sequences (the score), and the product of these two measures. Kessels and colleagues (2000) argued that the product is more reliable than the typical span capacity, as it contains both information about the maximum sequence length that participants can handle and the total number of correct trials.

e-Corsi. Participants were seated facing the experimenter with an iPad in front of them. An iPad 3 device was used for the administration of the computerized Corsi Task (e-Corsi). The experimenter controlled the e-Corsi program by way of a laptop (ASUS Notebook K72Jr Series; Intel Core i5 CPU 2.40 GHz; Windows 7 Home Premium), which allowed him to decide when to initiate trials. The iPad and laptop were connected through a wireless network. The administration procedure of the e-Corsi was equal to that of the standard Corsi Task. However, regarding the equipment, the e-Corsi board was two-dimensional because it was displayed on a tablet (iPad 3; 197 mm × 140 mm and blocks were 22 mm × 22 mm) contrary to the three dimensional standard Corsi board. Although the e-Corsi board was slightly smaller in size than the standard Corsi board, the relative block positions were the same. The flashing time of the blocks (from dark to bright yellow) was set to 500 ms, and the interblock interval was set to 1,000 ms, aiming to bring the item-presentation rate as close as possible in accordance with the tapping rate on the standard Corsi Task. The e-Corsi program registered performance in terms of the span, the score, and the product.

The same sequences were used for the e-Corsi as well as for the standard version (Appendix A). To diminish the occurrence of unwanted learning effects due to the fact that participants had to accomplish each sequence item twice, either the standard Corsi board or the e-Corsi board was presented turned around by 180° in counterbalanced order across participants. Importantly, turned-around presentation of the Corsi board did not alter the essential properties of the block sequence (the number and order of locations, the distances between locations, the path length, and the number of path crossings), whereas it did ensure the exact same level of difficulty and complexity of the stimuli. Which of the two tasks (standard Corsi board or e-Corsi board) was presented turned around was determined by pseudorandom assignment (counterbalanced order across participants). Note that turned-around presentation was inserted to avoid training effects and was not intended as an experimental manipulation.

Digit Span subtest of the WAIS-III. Participants were seated in front of a laptop (see Method section above for its technical specifications). A computerized version of the Digit Span subtest of the WAIS-III

(Wechsler, 1997a) was developed using Presentation 15.1 (software program by Neurobehavioral Systems). The forward and backward conditions were assessed in counterbalanced order (pseudorandom assignment) across participants.

Digit sequences were presented auditorily (by a male voice) by means of the internal speakers of a laptop at the rate of one digit per 1,000 ms, exactly like the item-presentation rate in the two other experiments for standardization purposes. In the forward condition (two trials per sequence length ranging from two to nine digits), participants had to reproduce the digit sequence in the same order as presented. However, in the backward condition (two trials per sequence length ranging from two to eight digits), participants were instructed to reproduce the sequence in reverse order. Directly after the presentation of the last digit, a small black "×" occurred centrally on the blank screen to signal that the participant was allowed to start the reproduction of the presented digit sequence. The experimenter manually registered the answers during the administration of the task. When the participant did not manage to correctly reproduce at least one out of the two trials of a certain sequence length, the current condition was discontinued.

Accuracy measures were the span (number of digits in the longest correct sequence), the score (number of correctly reproduced sequences), and the product (Span × Score).

Data Analysis

To validate the e-Corsi, two-way analyses of variance (ANOVAs) for repeated measures were conducted on accuracy (product) with device (e-Corsi vs. standard Corsi Task) and recall order (forward vs. backward) as factors resulting in a 2×2 design. The effect sizes of significant results are reported in terms of η_ρ^2. Significant results (alpha level was set to .05) will be followed up with Bonferroni-corrected post-hoc tests.

Accuracy (span, score, and product) on the standard Corsi Task based on the new sequences was compared to that of the second sample using sequences as described by Kessels and colleagues (2000, 2008) using independent *t* tests. Effect sizes of significant results are reported as *r* values.

Accuracy (span, score, and product) on the forward and backward conditions of the e-Corsi was compared using paired-sample *t* tests (forward vs. backward conditions). Similar analyses of accuracy (span, score, and product) were performed for the two conditions of the standard Corsi Task and the Digit Span. In case of a significant result, effect size is reported in terms of an *r* value. To correct for multiple *t* tests, an alpha level of .01 was applied. All statistical analyses were conducted with the Predictive Analytics Software.

RESULTS

Validating e-Corsi

To compare recall performance[1] on the e-Corsi with that on the standard Corsi Task (see Table 1), a 2×2 (Device × Recall Order) ANOVA for repeated measures was conducted on the product (Span × Score). The main effect of device was nonsignificant, $F(1, 39) = 2.38$, $p = .131$. In contrast, the main effect of recall order was significant and of medium effect, $F(1, 39) = 17.65$, $p < .001$, $\eta_\rho^2 = .312$, indicating that the product was higher with forward than backward reproduction. The interaction effect between device and recall order was significant as well with a small effect size, $F(1, 39) = 4.97$, $p = .032$, $\eta_\rho^2 = .113$, indicating that device type had a different effect on recall performance depending on the recall order. Bonferroni-corrected post-hoc tests were performed to break down the interaction effect. The products of the forward and backward conditions of the e-Corsi were not significantly different ($p = .091$). Regarding the standard Corsi Task, performance was significantly better in the forward condition as compared with the backward condition ($p < .001$). The comparison between performance in the backward conditions of both devices was nonsignificant ($p = .802$). In contrast, performance in the forward condition of the standard Corsi Task was significantly better compared with that of the e-Corsi ($p = .017$).

Validating the New Sequences

New sequences that were equivalent in terms of the number of path crossings and path length for the forward and backward conditions were provided to enable a solid comparison of recall performance in the two conditions. To verify whether path characteristics influence recall performance, accuracy of this study's sample using the new sequences with the standard Corsi Task was compared to that of an available second sample on the standard Corsi Task using sequences by Kessels and colleagues (2000, 2008). Participant performance based on the sequences by Kessels and colleagues (2000, 2008) is displayed in Table 2.

[1]To ensure that the scores of low-performing participants do not influence the results, the Reliable Digit Span (RDS; Schroeder, Twumasi-Ankrah, Baade, & Marshall, 2012) was calculated based on Digit Span performance for the sample consisting of 40 participants. Four participants obtained a lower RDS score than the cutoff score of ≤7. Three participants (2 male, 1 female) had an RDS of 7, and 1 female participant scored an RDS of 6. All statistical analyses were recalculated with exclusion of the scores that were obtained from these 4 participants. As this procedure did not have any consequences on the results of the statistical analyses, the scores of these 4 participants clearly do not distort the data. Therefore, the reported results are still based on the complete sample including all 40 participants.

TABLE 1
Mean Accuracy (in Terms of Span, Score, and Product) as a Function of Recall Order Separated by e-Corsi, Standard Corsi, and Digit Span

	e-Corsi	*Standard Corsi*	*Digit Span*
Span			
Forward	6.4 (1.5)	7.0 (1.2)	6.3 (1.1)
Backward	6.3 (1.2)	6.1 (1.2)	5.5 (1.2)
Score			
Forward	9.8 (2.4)	10.6 (1.9)	9.8 (2.0)
Backward	9.0 (1.9)	9.2 (1.8)	8.0 (2.3)
Product			
Forward	66.0 (29.6)	76.9 (24.8)	64.1 (23.1)
Backward	58.4 (21.9)	57.4 (22.7)	46.7 (23.4)

Note. Standard deviations are displayed in parentheses.

Independent t tests were conducted to find out whether performance based on the new sequences differed from performance with the sequences by Kessels and colleagues (2000, 2008). Performance was higher with the new sequences than with the Kessels and colleagues (2000, 2008) sequences in the forward condition for all measures: span, $t(118) = 3.94$, $p < .001$, $r = .34$; score, $t(118) = 3.23$, $p = .002$, $r = .29$; and product, $t(61.31) = 3.66$, $p = .001$, $r = .42$. In contrast, recall accuracy in the backward condition was comparable for the Kessels et al. (2000, 2008) sequences and the new sequences: span, $t(58.03) = -2.47$, $p = .017$; score, $t(118) = -2.42$, $p = .017$; and product, $t(118) = -2.38$, $p = .019$. Because equality of variances could not be guaranteed for the comparisons of the product in the forward conditions and the span in the backward conditions according to Levene's test ($p = .001$ and $p = .008$, respectively), corrections of degrees of freedom were applied to these independent t tests.

Accuracy on e-Corsi, Standard Corsi, and Digit Span

Accuracy for both the forward and backward conditions is displayed in Table 1 for the e-Corsi, standard Corsi Task, and Digit Span separately. Recall performance in the two conditions was compared using paired-sample t tests. Regarding the e-Corsi, all differences between the two conditions turned out to be nonsignificant: span, $t < 1$, score, $t(39) = 2.17$, $p = .036$, and product, $t(39) = 1.73$, $p = .091$. Hence, reproduction in reverse order did not significantly decrease the participants' recall accuracy on the e-Corsi. Participants were more accurate in the forward condition than in the backward condition of the standard Corsi Task on all three measures: span, $t(39) = 4.13$, $p < .001$, $r = .55$; score, $t(39) = 5.03$, $p < .001$, $r = .63$; and product, $t(39) = 4.87$, $p < .001$, $r = .61$. Regarding accuracy on the Digit Span, span capacity in the forward condition was significantly higher than in the backward condition, $t(39) = 4.53$, $p < .001$, $r = .59$. This difference was also significant for score, $t(39) = 5.92$, $p < .001$, $r = .69$; and product, $t(39) = 5.19$, $p < .001$, $r = .64$. These findings suggest that reversing digit sequences reduces performance to a much larger extent (large effect sizes on all three accuracy measures) than with reversing block sequences (medium effect size on the score) as compared with forward reproduction.

TABLE 2
Mean Accuracy (Span, Score, and Product) for the Forward and Backward Conditions Based on the New Sequences and the Sequences by Kessels et al. (2000, 2008)

	Standard Corsi Task (New Sequences)	*Standard Corsi Task (Kessels et al. [2000, 2008] Sequences)*
Span		
Forward	7.0 (1.2)	6.2 (0.9)
Backward	6.1 (1.2)	6.6 (0.9)
Score		
Forward	10.6 (1.9)	9.5 (1.6)
Backward	9.2 (1.8)	10.0 (1.7)
Product		
Forward	76.9 (24.8)	60.7 (18.5)
Backward	57.4 (22.7)	66.8 (19.0)

Note. Standard deviations are displayed in parentheses.

DISCUSSION

In this study, we aimed to validate a computerized version of the Corsi Task (e-Corsi) using a tablet computer (iPad 3) by comparing performance on this task to the analogous scores on the standard Corsi Task among participants. This was done because computerization of the Corsi Task leads to a more standardized administration as compared with the standard version. Practical advantages of the computerized Corsi Task include strict application of the presentation duration of the block sequences and automatic scoring. As the computer takes over both the stimulus presentation and scoring procedure that were previously carried out by the examiner, using the e-Corsi instead of the standardized version results in a shift of the neuropsychologist's role in this task: from administrator to observer. Consequently, it provides the examiner with the ability to pay closer attention to observing the patient's behavior and the strategies that he or she applies.

Assuming that both versions assess the same underlying cognitive processes, performance on the standard and computerized versions was expected to be highly comparable. The results indeed indicated that performance on the standard and computerized versions of the Corsi Task was very similar, when taking the forward and backward condition together. However, the interaction effect between administration of the task and the recall condition demonstrated that computerization clearly affected accuracy in the forward and backward conditions in a different way. Further analyses indicated that the computerization led to a decrease in forward reproduction performance down to the same level as the backward condition, diminishing the difference between these two conditions. Although the e-Corsi has shown to be highly useful because of practical advantages, these findings ask for a reconsideration of interpretation in terms of assumed underlying cognitive processes.

Given that accuracy was not better in both conditions of the standard Corsi Task, it is very unlikely that the divergent accuracy patterns originate from the different physical characteristics of the tasks (such as the size and color of the board and blocks). An important difference between the two versions, however, that may be accountable for the divergent performance patterns is that in the standard version, the experimenter taps the block sequences, whereas the block sequence in the e-Corsi is indicated by the sequential lighting up of the various blocks. Some participants reported that it was easier to remember the block locations with manual block tapping, because the experimenter "draws lines" between the blocks. If this was the case, accuracy should be higher in both conditions of the standard version. The absence of this finding in our study pleads against this explanation.

Another possible explanation for the difference between the standard and computerized version of the task is that actions people observe are automatically mapped onto their internal motor repertoire (Iacoboni et al., 1999). Several studies using motor-priming paradigms demonstrated that observing a finger movement can lead to the activation of an equivalent motor response in the observer. This would elicit facilitation in case the observed movement and executed movement are congruent (e.g., Brass, Bekkering & Prinz, 2001; Brass, Bekkering, Wohlschlager, & Prinz, 2000). The movements of both the experimenter and participant are identical with forward reproduction in the standard Corsi Task. Therefore, participants should be more accurate in this condition assuming that the occurrence of motor-priming effects leads to a (subtle) reduction of memory load. Because the movements the participant has to make with backward reproduction are different from that of the experimenter, motor-priming effects are supposed to occur only with forward reproduction. In fact, it is even possible that participants experience motor interference given that the experimenter's movements are incongruent with the pattern of movements that the participant has to execute for correct reverse reproduction. The decrease in performance in the backward condition as opposed to the forward condition might therefore be explained in terms of motor-priming facilitation in the forward condition rather than in terms of working-memory load in the backward condition. The performance on the e-Corsi is convergent with this hypothesis. Furthermore, it is known from previous studies that there is a close association between imitation and the activation of mirror neurons in the premotor and posterior parietal cortex (Iacoboni, 2009). If the Corsi Task indeed activates mirror neurons as a consequence of imitation effects, it may be that the e-Corsi does not engage mirror neurons in the same way as the standard Corsi Task does.

The outcome of the e-Corsi is not mirrored by the outcome of the Digit Span. Backward reproduction of digit sequences is clearly more difficult and puts a higher load on working memory as performance on all accuracy measures was lower in the backward condition. In fact, comparisons of accuracy between the two conditions support the view that forward and backward reproduction of digit sequences does involve different underlying cognitive processes.

More evidence for the assumption that the tapped blocks are processed as an overall pattern of a pathway instead of a sequence comes from the following: New sequences were used for both versions of the Corsi Task. Earlier studies did not take path characteristics into account, even though they have been found to influence recall accuracy on visuospatial span tasks (e.g., Parmentier et al., 2005). Therefore, each trial in the forward condition had an equivalent trial in the backward condition that contained the same number of blocks and was also highly similar in path length. Furthermore, the number of path crossings was kept constant across the two conditions. To verify the effect of the new sequences on recall performance, accuracy on the standard Corsi Task with the new sequences was compared to that of another data set of the same task using the sequences as described by Kessels and colleagues (2000, 2008). Performance turned out to be comparable in the backward conditions. With regard to the forward conditions, however, performance was better when using the new sequences as compared with the Kessels et al. (2000, 2008) sequences. This finding corroborates the notion that not only the number of blocks in the sequence determines the level of difficulty of a trial, but the path configuration (in terms of path length and the number of path crossings) is of crucial importance for this as well (Busch et al., 2005; Orsini et al., 2001; Parmentier et al., 2005). As a consequence, this finding supports the view that a block sequence is represented as a pathway that connects the block locations, rather than a sequential series of positions.

As a limitation of our study, the sample of participants consisted of a relatively small homogeneous group of university-level students, and most of them were familiar with a (tablet) computer. It might thus be that the current findings do not generalize to other groups of participants, such as clinically impaired patients and people without tablet familiarity. It should, however, be noted that affordance is very high for the e-Corsi, as participants are only required to tap a sequence of block locations on the iPad. As another consequence of the relatively small sample size, the ability to detect effects of small-to-medium size might have been limited in this study.

Furthermore, future research could assess the different performance patterns in the two versions of the Corsi Task in more detail to find out what factors cause people to perform differently depending on the device. This might be investigated by adding a condition to the computerized Corsi Task in which an image of a finger points and connects to the blocks in the sequence in contrast to the sequential lighting up of the distinct blocks. By doing this, it will be able to verify whether motor-priming and interference effects result from the examiner "drawing lines" as in the standard version. Moreover, such research might also further the insight into the exact cognitive processes that these visuospatial span tasks assess. Future research could also examine in more detail whether there are gender differences with regard to performance on the two versions of the Corsi Task, as spatial-cognitive skills tend to differ between men and women (see, for a review, Voyer, Voyer, & Bryden, 1995).

From a clinical point of view, the findings in this study clearly suggest that backward reproduction of block sequences in the Corsi Task might not be of additional value to using the forward condition alone. The application of the backward condition as representing nonverbal working-memory abilities in clinical neuropsychological practice should clearly be reconsidered, as the two conditions of the Corsi Task tend not to differ in their recruitment of nonverbal working-memory processes in addition to nonverbal attentional processes alone. Furthermore, given the high equivalency between the Corsi Task and the Spatial Span subtest of the Wechsler Memory Scale-Third Edition (WMS-III; Wechsler, 1997b), this study's results might be of importance to comparable attempts to computerize the WMS-III Spatial Span subtest as well.

To summarize, although the e-Corsi has proven to have certain practical advantages, it does appear to assess different processes than the standard version. The divergent performance patterns on the two versions are argued to result from the occurrence of motor-priming effects due to the fact that the movements of the experimenter and participant are congruent in the forward condition of the standard Corsi Task. In contrast, these effects do not occur in its backward condition, because the movements of the experimenter and participant are different and thus incongruent. Furthermore, it was also shown that performance was highly comparable for the forward and backward conditions indicating that they involve similar cognitive processes. In contrast, regarding the Digit Span, the two conditions clearly differed in difficulty. This supports the notion that reverse reproduction of digit sequences requires higher working-memory involvement than when the digit sequences are maintained in their original serial order. Following the findings of the current study, when computerizing the administration of a standard neuropsychological task, it should be carefully confirmed whether the computerized version still assesses the same cognitive processes as the standard task. Furthermore, the use of the backward condition of the Corsi Task as a representative of nonverbal working memory in neuropsychological assessment should clearly be reconsidered.

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APPENDIX A

Standard Corsi Task and e-Corsi Sequences

Sequence Length	*Forward Block Sequences*	*Backward Block Sequences*
2	1-2	5-8
	7-6	7-3
3	1-8-7	8-9-2
	9-1-6	1-8-5
4	8-4-3-9	6-1-4-9
	4-6-8-1	9-2-5-7
5	7-8-1-3-9	4-2-7-3-1
	3-9-4-7-6	6-7-4-8-5
6	7-5-2-3-6-8	9-6-3-8-1-7
	1-2-9-7-8-5	5-9-4-3-8-2
7	7-2-1-5-4-9-3	4-7-2-5-1-6-9
	3-7-9-8-1-2-4	3-6-1-7-8-2-5
8	9-6-5-8-7-3-4-2	1-4-7-3-6-5-8-9
	1-8-7-2-3-9-5-6	7-5-2-4-3-9-8-6
9	6-3-9-8-4-7-2-1-5	
	5-7-2-4-8-6-9-3-1	

Note. See Figure 1 for the corresponding block numbers and block locations.

APPENDIX B

Path Characteristics of the Sequences

Sequence Length	*Path Crossings*	*Maximum Deviation*[a]
2, 3	0 and 0	10 mm
4	0 and 1	10 mm
5, 6, 7, 8	0 and 2	20 mm
9	0 and 2	Only in forward condition

Note. Because of the block layout, it was not possible to create a path crossing in sequences containing two or three blocks or to create two path crossings in sequences containing four blocks.

[a]The maximum deviation in millimeters allowed between equivalent sequences in the forward and backward conditions.