Computerisation of the Corsi: Investigating the cognitive processes underlying visuospatial recall

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Abstract

The Corsi block tapping task measures visuospatial ability, but there is still some debate as to whether the task employs visual attention alone (immediate recall), short term memory, or working memory, with many assuming the forwards and backwards tasks to generally measure the same processes. The current study developed a standardised set of visuospatial sequences in order to eliminate confounding characteristics of sequence paths to ensure that all are of comparable difficulty; these were then used in both analogue and digital versions of the Corsi task to investigate whether performance was similar, with a view to validate a computerised Corsi task. It also considered and tested the potentially helpful effect of motion, which is inherent in the traditional test due to the movement of the researcher's hand between blocks and could act as a confound aiding participants.The effect of delayed recall on forward versus backward span was investigated to enable a comparison of cognitive processes used with and without a delay. Findings revealed that performance is generally greater for the forward task, the analogue conditions, without the presence of a delay, and may be aided by the motion feature. Such findings highlight characteristics of the Corsi task that may influence difficulty, act as confounding factors, or cause a change in the specific cognitive processes involved. The discussion offers our suggestion that though both the forward and backward Corsi tasks are assumed to rely on short term memory, the backward task incorporates working memory systems regardless of a delay whilst the forward task relies on simpler short term memory storage in immediate and delayed recall.

Keywords: Corsi, visuospatial, memory, forward recall, backward recall, cognitive processes

Computerisation of the Corsi: Investigating the cognitive processes underlying visuospatial recall

The Corsi block-tapping task (Corsi, 1972) of visuospatial span has been the subject of much research in the last 25 years, with international applications to a wide range of participants. Clinically, the test has been used to assess the visuospatial ability of dementia patients, children with learning disabilities, and patients with a range of neurological disorders (Berch et al, 1998). It has been indicated, for example, that decreasing sequential visuo-spatial memory span features in a range of disorders such as Parkinson’s disease (Stoffers et al, 2003), Alzheimer’s disease (Gagnon & Belleville, 2011), and paediatric traumatic brain injury (Gorman et al, 2012). Thus accurate test administration and careful measurement is crucial in diagnostics. This indicates the necessity of a standardised neuropsychological test which is sure to be a valid assessment of visuospatial span.

However, despite the body of research centred on the Corsi block tapping test, there is still lack of agreement about the specific cognitive processes measured by this task, with the discussion on its ability as a measurement of visuospatial attention span or visuospatial working memory (VSWM) still unsettled (Claessen et al, 2015). Within the Corsi task, participants are required to immediately reproduce spatial sequences in a forward condition and a backward condition. In the former, participants tap block locations on a wooden board in the same serial order in which they were presented by the examiner, whilst in the backward condition participants must tap the blocks in the reverse order to that demonstrated.

Some studies have found performance between the forward and backward tasks to be comparable (e.g. Kessels et al, 2000), which might lead one to assume that both tasks employ the same cognitive processes. However, this difference has not been consistent, with other research finding a difference in performance of forward versus backward tasks (e.g. Cornoldi

& Mammarella, 2008), raising the suggestion that the two tasks may address different processes. The backward task is assumed to measure working memory (WM) because of the active manipulation required to invert the serial order (Claessen et al., 2015) and because of the use of the central executive in this mental manipulation (Baddeley, 1986; Monaco et al, 2013). Because the forward task does not require this kind of attendance to information, it may not measure WM, or even short term memory due to the immediate response of the participants. What is certainly required of the participant in the forward task, however, is careful visuospatial attention. It is important to seek a common understanding of the processes measured by the Corsi task in order to draw valid conclusions about the abilities of patients. To achieve this, research should include a manipulation which would differentiate between the processes of attention and working memory, such as including a delay in one condition to distinguish between ongoing attention (when participants respond immediately as in the traditional Corsi task) and working memory (when participants must attend to the visual information for a short duration in their WM before responding) and studying the differences in performances of forward versus backward tasks under these conditions.

Unfortunately, the administration of the task still suffers from inter-experimenter differences, bringing the validity and reliability of assessment into question. Berch et al (1998) identify one issue with the administration of the Corsi block task to be the pointing procedure. It is explained that there is discrepancy in the manner with which different researchers point to each block; some raise the hand up away from the blocks before reaching to the next, whilst others move directly from block to block. Another issue raised is the rate of block tapping, with some examiners tapping at a rate of one block per second, and others working at a rate of one block every 1.5s or even every 3s. This could be due to the personal choice of the examiner, but slight variations can also be caused by the subjective judgement of the passing of one second, or human error. This type of small item-exposure time difference can affect accuracy (Fischer, 2001), which highlights the need for more strictly controlled presentation of items.

Another problem compromising the validity of the Corsi task is the sequences used in assessments. Although there exist sets of sequences that have been replicated across different studies (e.g. Capitani et al, 1991; Kessels et al, 2000), and sequences that have been quasi-randomly generated in an attempt to improve the items of the Corsi task (Farrell-Pagulayan et al, 2006), control of specific sequence characteristics which would ensure that sequences were of comparable difficulty was not reported. It is essential for the reliability of testing to have a standardised set of sequences of equivalent difficulties across conditions, to enable comparison between conditions. Thus the methodology of the current study will take into account factors affecting sequence difficulty when composing the items to be used.

Conversely, there could exist influencing factors within the administration of the Corsi block task that facilitate accurate performance, acting as a confound in the assessment of serial location memory. One such factor that has been largely overlooked in the existing Corsi task literature is that of the motor priming element inherent when the examiner moves his or her finger or pencil towards the next block in the sequence. Psychological assumptions of an association or overlap between observed actions and executed actions are supported by evidence of neural mirroring in the premotor and posterior parietal cortex (Iacoboni, 2009). In the context of the Corsi task, this could aid the participant since he or she observes the examiner’s pointing procedure and may have the automatic advantage of imitating this movement during his or her action execution in reproducing the sequence. However this would only be the case in the forward condition, in which participants are required to produce the sequences in the same serial order as the examiner.

Findings implicating the precuneus and dorsolateral premotor cortex of the brain in tasks dealing with movement anticipation have raised the suggestion that the precuneus might generate an internal image of an item's trajectory in order to anticipate its motion, and also that a 'prehension network' in the brain enables mental anticipation of the location of a moving object (Kockler et al, 2010). In the Corsi task, predicting the next location of the examiner's finger or pencil might equate to more exposure of blocks than is intended by a 1-block-per-second activation, supporting the notion that this movement might facilitate forward task reproduction.

As previously noted, there are a number of issues with the administration of the Corsi block task, but technological advances have long been recognised as offering promising solutions within neuropsychology. Wilson and McMillan (1992) point out the advantage of consistent presentation of stimuli across trials and the elimination of unconscious prompting by the examiner, when employing computerised methods. Furthermore, Bauer et al (2012) highlight the practical benefits of computerised neuropsychological assessment devices such as the abilities to more precisely measure reaction times on time-sensitive tasks, more accurately record and score responses, export automatically recorded data more easily, and reach a wide range of patients in different settings, which would be useful when patients are not always able to easily access neuropsychological services.

In the case of the Corsi block task, the use of a computerised version (e-Corsi) can control for the aforementioned differences in administration. Blocks can be programmed to light up in such a way that is consistent across researchers and trials. Each trial would be administered in the same way within and between participants, with reduced risk for experimenter errors, and more accurate recording of results. On top of that, e-Corsi can remove motor priming, which cannot be avoided during manual administration. Overall then, the e-Corsi would be strictly standardised and thus more accurately replicable and valid. Thus the current study aims to validate the use of a computerised Corsi task, whilst taking into account the importance of sequence difficulty comparability, and exploring the motor priming factor in the presentation of sequences, and the underlying cognitive process differences between the forward and backward tasks.

In summary, in order to validate the digital version of the Corsi block tapping task, it is hypothesized that the performance accuracy between the original and digital versions will be comparable, thus supporting the notion that the computerized version is indeed a similar assessment tool which can competently carry out the tasks of the administrator of a manual version, without influencing results.

With regards to the cognitive functions truly assessed by the forward and backward Corsi tasks, the inclusion of a delay before participants respond would be expected to induce the employment of WM in the forward task because the sequential location information must be attended to or rehearsed in order to preserve the sequence for reproduction. As it is believed that the backward task already relies on WM due to the active manipulation of information required even in immediate reproduction, a delay before responding should equate to both tasks relying on the same cognitive function (i.e. WM). If the same cognitive functions are employed, performance is expected to be similar. That is to say that, assuming the forward task ordinarily assesses visuospatial attention rather than WM, it is expected that the performances between forward versus backward tasks in the no-delay condition will be more divergent from each other than the performances between forward and backward tasks performed after a delay.

The motor priming element in the examiner’s movement in the original Corsi task will be examined in a digital context. This will be done using a tablet, on which a ball will move between the blocks of each sequence. It is hypothesized that the motor priming in this condition will aid participants and thus increase performance accuracy compared to when motor priming is removed (in the digital condition without the moving ball). This should only be the case for the forward task, because the observed and executed actions are incongruent in the backward condition, so motor priming is not considered to have an effect.

Method

Participants

For this study we recruited 54 participants in total, from Leiden University through a student recruitment programme offering course credits for participation, and from the community of Leiden through advertisements on social media, offering €5 each for participation. Participants were all adults over the age of 18. Forty-six of these participants were used in data analysis, with the initial 4 pilot participants being omitted due to technical issues discovered in the pilot trials, 2 being excluded for experiencing problems with the touchscreen and/or responding in the incorrect direction in more than 4% of their trials, and 2 for experiencing touchscreen troubles that affected their continuation of a condition, resulting in skewed data for the individuals.

Design

The study employed a 2x2x2 within-subjects design, with the independent variables being condition (two levels: traditional vs. digital), direction (forward vs. backward), and motion (present vs. absent). This design of these levels is represented in figure 1 of Appendix A. Additionally, in a second subset of the experiment, delay (present vs. absent) was introduced as an independent variable. The dependent variable was the participants' performance accuracy (Product), as measured by the product of the sequence length of the last correctly produced item (span) and the total number of correct trials (score). Span and Score were used as dependent variables in secondary analyses to investigate where participant's strengths and weaknesses lay.

Materials

Three pieces of apparatus were used to conduct the experiment across the conditions. Firstly, a traditional Corsi block board was used. This is a wooden board of 205x255mm, with 9 fixed black cubed shaped blocks (30x30mm each) placed across the board in random locations. Blocks are numbered from one to nine, so that only the researcher can see the numbers. See Appendix B (taken from Kessels et al, 2000) for the placements of blocks. Secondly, a Corsi board with the same dimensions, fitted with green LED lights inside blocks with opaque tops, was used as a hybrid combining digital presentation (i.e. no motion) with analogue interaction, to enable consideration of the effect of this interface. The third apparatus was a 16inch digital Wacom tablet displaying nine squares which light up green according to numbered sequences programmed using the software E-prime, controlled from a laboratory laptop (numbers in the sequences correspond to numbers on the blocks/squares, as with the traditional version). The squares on the tablet screen were situated as closely as possible to the same locations and relative distances as the traditional blocks, however due to technical limitations concerning programming in the E-Prime software and pixel sizes, the exact matching relative distances between squares was not possible, with the largest difference in distance between 2 squares being 14mm. The same tablet was also used to present the fourth and fifth conditions (motion and delay).

Since there were five conditions per participant, five sets of sequences were composed so as to avoid repetitive items and practice effects. Each set comprised two sequences of each sequence length from two blocks to nine blocks, for both the forward and backward conditions, with the exception of nine-block sequences in the backward condition, which consisted of a maximum of eight-block sequences.

As mentioned previously, sequences have characteristics affecting their level of complexity. Along with increasing sequence length (Fischer, 2001), these include path length (e.g. Busch et al, 2005) and path crossovers (e.g. Orsini et al, 2001). If one imagines a hypothetical line drawn out between the blocks that are presented in a serial order in a trial, this will create different paths between the blocks. These paths can be physically longer (if blocks further away from each other are involved in the sequence) or shorter (if blocks are in closer proximity). Secondly, the lines created between blocks can feature crossovers (when new lines cut across lines produced earlier in the sequence), or no crossovers. Whereas previous studies including the original Corsi block task (Corsi, 1972; Farrell-Pagulayan et al, 2006) did not incorporate these factors into the composition of sequences, the current study considered these characteristics to ensure that equivalent trials across conditions were comparable. Thus each set had equivalent items in terms of sequence length, forward or backward reproduction, path length (as measured in mm from the centre of each block) and number of path crossovers. The order of the conditions (apparatus) for each participant, and the order of the sequence sets were counterbalanced.

Participants' responses in the digital conditions were recorded automatically and digitally; in the traditional Corsi block board condition and LED condition, a paper scoring sheet was used by the examiner to record participants' answers, which could be scored according to a list of the correct responses.

Procedure

Traditional Corsi (analogue): The participant was seated across a table from the examiner, with the Corsi board between them and the block numbers facing the examiner so that the participant could not see the numbers. In the forward condition, the participants were told 'I am going to point to a series of blocks in sequence. When I am finished, please reproduce the sequence by pointing to the blocks in the *same order* as I did'. In the backward condition, participants were told ‘I am going to point to a series of blocks in sequence. When I am finished, please produce the sequence backwards by pointing to the blocks in the *reverse order* to that which I did. The examiner then pointed to the blocks in sequence before instructing the participant to start. As the participant reproduced the sequence, the researcher recorded their response on the scoring form.

LED Corsi (analogue): The sets of sequences were programmed into the E-prime software before the study commenced, so that the computer could control the order of LED block activation. As with the traditional condition, the LED board was positioned between the participant and examiner. The participants received the same instructions as in the traditional condition, edited only to explain that the blocks will light up rather than be pointed to: ‘You will now see a sequence of blocks light up. When the sequence has finished, please produce the sequence in the *same order/reverse order*, by tapping the blocks’. The examiner then selected the sequence in the E-prime software on the laboratory computer, for the condition and participant based on the counterbalanced order prepared, and ran the experiment. After being instructed to start, responses were recorded again on a paper score sheet, and the examiner indicated on the computer whether the response was correct or incorrect in order for the software to continue or discontinue the trial.

Digital Versions: Each participant completed a practice run of a simple 6 square sequence before their first digital condition, to enable them to become familiar with the touch screen thus reducing the chance of technical mistakes.

Computerised e-Corsi, no motion: The digital tablet was placed flat on the table between the participant and researcher, and the participant received the instructions ‘*you will now see a series of blocks light up in sequence. When the sequence is finished, please try to reproduce it in the same/reverse order as you saw by pressing the blocks on the screen. Try to do this as accurately and quickly as possible’*. After selecting the sequence set in E-prime and running the experiment, the squares on the tablet screen lit up green in sequential order and the participant was required to reproduce the forward and backward sequences as described in the traditional condition, by touching the squares on the touchscreen.

Computerised e-Corsi, motion: The instructions and participant procedure for this condition were the same as the previous condition. However, a ball moved between the blocks of the sequence as they lit up, visualising the path created by the sequence, to reflect this occurrence in the traditional condition. This was done through the use of videos created with Adobe Premiere Pro software. The rate remained one block per second, with the ball moving for 750ms between blocks, and landing on each block for 250ms whilst it lit up, before moving on to the next block.

Computerised e-Corsi, with delay: The requirement of the participant here was the same as in the previous conditions, however the participants were required to wait for a delay of 10 seconds before responding. This length of time is to lie within the duration of working memory at ten to 15 seconds (Goldstein, 2015). At the start of this condition, participants were reminded of the instructions and told that they would have to wait a short while before responding so were asked to try to remember the sequence. After sequence presentation, the participants saw a message on the screen for nine seconds: ‘Please try to remember the sequence in the *same order/reverse order.* Please wait.’, then a message of ‘please start’ was presented for one second to prompt the participant that they may proceed.

For all conditions, if the participant did not manage to correctly reproduce at least one item of a sequence length, the condition was discontinued and the previous sequence length completed was taken as the span. Half of the participants received the forward task before the backward task in each condition, whilst half received the backward task first.

Ethics

Ethical approval was gained from the Leiden University Psychology Research Ethics Committee on March 14th 2016 under subject number CEP16-0309/124.

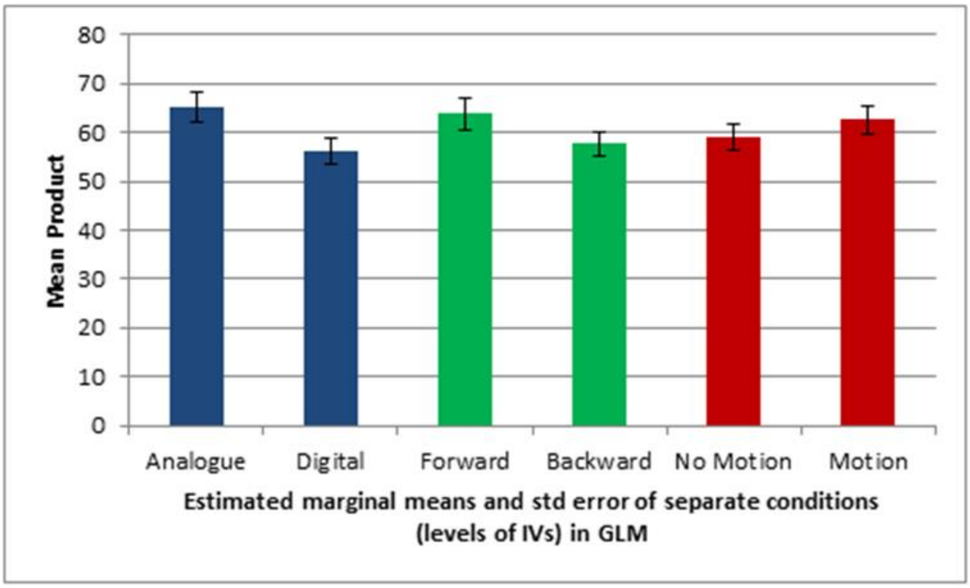
Analyses

A repeated measures general linear model (GLM) for the 2x2x2 design (condition, direction, motion) was conducted on the performance accuracy as measured by the product (span x score). This enabled comparison of performance on the analogue Corsi tasks with the digital tasks, performance across the directions forward versus backwards, and the performance when motion was present compared to no motion.

Separately, a repeated measures Analysis of Variance (ANOVA) was conducted for digital delay versus digital no-delay conditions to identify any effects of delay. For further investigation, GLM analyses were conducted on the reaction times of participants' responses to seek any information about the pattern and process of responding after a delay.

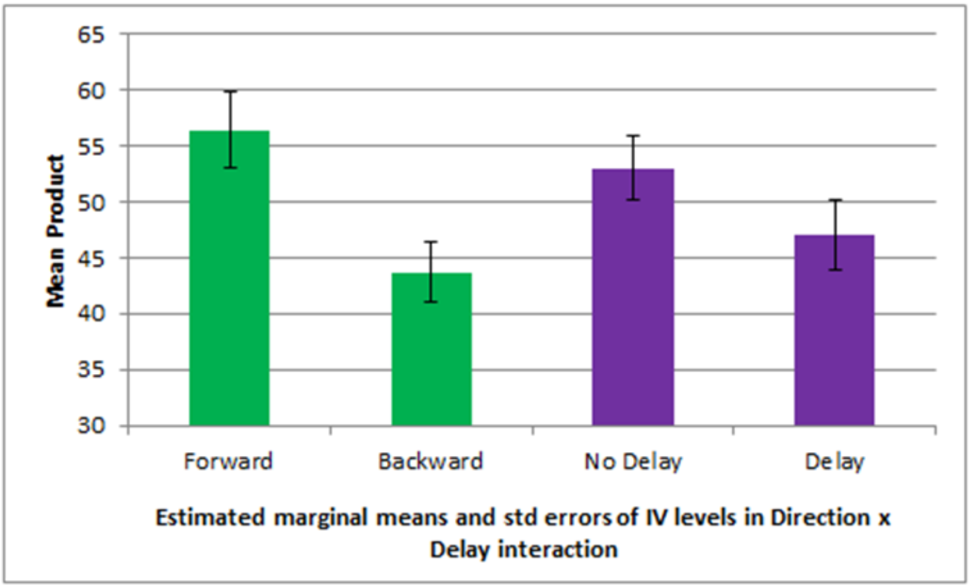
Results

The raw mean products and standard deviations for all subtests are represented in Table 1 in Appendix C. The GLM (Condition, Direction, Motion) on the products yielded findings as follows. A significant main effect was found for Condition (analogue versus digital), $F(1,45)= 27.46$, $p<.001$, $\eta_p^2= 0.379$, and for Direction (forward versus backward) $F(1,45)= 7.94$, $p<.05$, $\eta_p^2=0.150$. This indicates that performance was greater in the analogue conditions, compared to the digital ones, and greater for the forwards direction, compared to the backwards direction. For motion there was a trend level effect, $F(1,45)= 3.37$, $p<.073$, $\eta_p^2= 0.070$, indicating that performance was slightly better for conditions featuring motion, in comparison to no motion. Interactions which were significant or at trend level in this GLM analysis included; condition x motion $F(1,45) = 3.73$, $p < .10$, $\eta_p^2 = 0.077$, with follow-up simple main effects analysis revealing motion to have a significant positive effect on performance in the digital condition ($p = .009$), but not in the analogue condition ($p = .817$). A significant interaction was found between Direction x Motion; $F(1,45) = 5.51$, $p < .05$, $\eta_p^2 = 0.109$, in which motion aided performance for the backward direction only ($p = .005$) whilst not significantly affecting performance in the forward direction ($p = .836$). Further analyses were run on the span and score data separately, and these led to the same pattern of results, with the exception that the main effect of Motion was significant when using the score data, whilst it did not reach significance when using span data.



Graph 1: Data for IV levels in the GLM on Condition (analogue vs. digital), Direction (forward vs. backward), and Motion (no motion vs. motion)

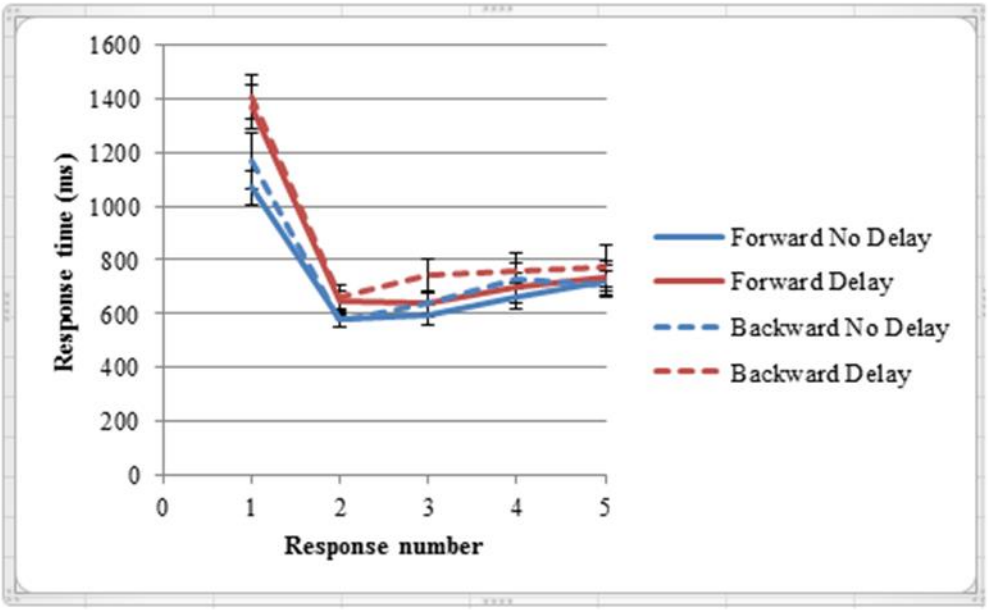
For the ANOVA investigating the effect of delay (Delay, Direction), using the data for participants' Products showed a significant main effect of Direction $F(1,45) = 21.75$, $p < .001$, $\eta_p^2 = 0.326$, with forwards performance being greater than backwards, and of Delay $F(1,45) = 7.07$, $p < .05$, $\eta_p^2 = 0.136$, with performance being greater when no delay was present compared to when a delay was present. In addition, a significant interaction was found; Delay x Direction $F(1,45) = 5.43$, $p<.05$, $\eta_p^2=0.108$, whereby the inclusion of a delay significantly lowered performance for the backward direction ($p<.005$), whilst not significantly affecting performance in the forward direction ($p=.935$). Similarly, separate analyses on the data for participants' spans and scores supported these findings.



Graph 2: Data for IV levels in the significant interaction between Direction (forward vs. backward) and Delay (no delay vs. delay)

Analyses on reaction times were conducted on 42 participants (91% of the sample) because these 42 participants reached at least a span of 5 in the digital no motion conditions without and with a delay, allowing analyses to be run on the first 5 reaction times of these conditions without missing data, to investigate how the pattern of response times might be affected by the inclusion of a delay.

Using participants' reaction time data, significant main effects were found for Delay, $F(1,41)=6.4$, $p<.05$, $\eta_p^2= 0.135$, with reaction times being longer after a delay than without a delay, for Response (i.e. the number of the touch/block in a sequence), $F(1,41)= 82.96$, $p<.001$, $\eta p^2=0.669$, with the first block touch having a longer reaction time than the subsequent block touches, and for Direction, $F(1,41)= 2.99$, $p<.10$, $\eta_p^2=0.068$, such that the reaction time was slightly longer for the backward direction than the forward direction. The interaction of Delay x Trial was significant; $F(1,41)= 3.89$, $p<.05$, $\eta_p^2=0.087$ with simple main effects analysis showing the delay to significantly increase the reaction times for Response 1 (p=.002) and Response 2 (p=.020), but not for Responses 3 to 5 (p>.05).



Graph 3: Mean response times (ms) for both forward and backward directions, with and without a delay

Qualitative Findings

Participants were asked to give any preferences or opinions on each condition of the experiment, in order to help support or further understand quantitative findings. Of the 23 participants who expressed a preference between the analogue and digital conditions (the remaining participants had mixed opinions; reporting pros and cons of both digital and analogue with no clear preference), 69.6% found the analogue versions preferable or easier. Of participants who noted a difference between the forward and backward tasks, 63.6% reported they found the forward direction easier to recall. Thirty-six participants noted a difference between the conditions featuring motion and no motion, and of these, 7 participants

(19.5%) reported either the experimenter's hand or the moving ball on the tablet to be distracting or confusing, whilst 29 participants (80.5%) reported the presence of motion made the task seem easier.

Discussion

Due to a gap in the current research base on the Corsi block tapping test of visuospatial ability, which has neglected to agree upon a standardised version of the task, it is likely that varying characteristics of different versions of the task are producing inconsistent or invalid findings. The element of motion involved in the hand movement during the presentation of the stimuli has been largely overlooked, although it is hypothesised that this would help one to recall the serial locations of blocks. This motion is generally not present in computerised versions, creating an observable difference between the two presentation styles. It is also still in dispute whether the forwards and backwards Corsi tasks measure the same underlying processes – and indeed what these processes may be. The current study aimed to answer this question by manipulating the assumed processes with the inclusion of a delay before recall and comparing the effect of this delay on both the forward and backward tasks.

Overall, it is clear from the findings of this study that manipulated differences affect performance on the Corsi block tapping task, thus demonstrating the need for a standardised test. The general pattern was that performance was greater for analogue versions of the task than for digital versions. This could however be explained to some extent by the qualitative reports from participants when asked their opinions of each task. Comments included feeling "easier to touch than the screen" in the analogue versions and that they "felt more real/ 3D/ like a game" and "more interactive because you can copy the examiner and the examiner's rhythm". Although not all participants reported a distinct preference either way, the opinions of those who did not often still reflected similar pros of the analogue conditions. If participants showed preference to analogue versions or were less confident with the digital medium compared to the analogue, this could have had some effect on their performance.

Generally, the forward direction of the task was found to yield greater performance than the backwards direction. According to Higo et al (2014), the backwards version of the Corsi task requires stronger order representation than the forwards task, which might explain the finding that the backwards direction appeared to be more difficult. Additionally, Vandierendonck et al (2004) explain that the reverse Corsi task places a higher load on cognitive processes and must employ extra cognitive systems, namely the central executive, and even at times the phonological loop as a last resort support system to aid in the backwards reproduction. Overall, it seems, the backwards task is more difficult than the forward task at a cognitive and functional level. This is in line with the qualitative finding that 63.6% of participants who recognised a difference found the forward direction to be easier to recall. This strengthens the notion that participants' perceptions of and opinions about the task reflect their performance as found in the analyses.

The effect of motion was such that rather than reaching statistical significance, it provides a potentially informative trend effect that motion may aid performance. The interaction between motion and condition also showed this potentially informative trend effect, but with simple main analysis showing motion to have a significant positive effect on performance in the digital but not in the analogue conditions. Also, considering the presence of motion significantly increased participants' scores but not their spans, it can be hypothesised that the effect of motion is not strong enough to increase one's visuospatial memory capacity, but may make it easier to and increase the chances of remembering a visual sequence that lies within their individual capacity, thus to some extent supporting individuals' ability. The large majority of participants' opinions on the presence of motion suggested that it made the task easier. Comments included "the ball was helpful as a guide", "it felt easier because my eyes followed the ball and focused my sight to where the next [block] will be", and "it feels more natural and easier, maybe because I can see the hand and follow the lines". This combined with the statistical suggestion of improved performance indicates that it is likely the presence of motion does affect the task, and this should be investigated further.

Another result supporting the usefulness of motion is that there was a significant positive effect found for motion in helping with the backwards direction – but not with the forward direction. Along with the finding that the forward direction was generally better remembered than the reverse direction, the usefulness of motion would perhaps show more prominently in the backward direction tasks, where participants generally struggled more.

The delay data showed overall performance to be greater without a delay compared to after the delay, with the interaction showing the delay to significantly hinder performance in the backward direction only. This pattern is unlike that hypothesised however it supports the notion that the forwards and backwards tasks employ different cognitive processes since the delay did not have the same effect on both direction tasks, whereas if both tasks relied on the same process, the effect of the delay on both would be assumed to be similar.

The backwards span is still assumed to measure visuospatial working memory, as the cognitive action required to complete this task certainly fits the definition of working memory generally agreed upon within psychology, including the original model of working memory (Baddeley & Hitch, 1974). Working memory, although making use of short term memory along with other processing mechanisms, is slightly discrete from short term memory in that the latter does not employ such mechanisms as the central executive for attention-related processes for managing and manipulating information (Cowan, 2008, Vandierendonck et al, 2004). This therefore leads to the conclusion that the forward Corsi task employs the more basic short term memory storage system, as the solitary difference from the backwards task is the absence of the extra manipulation of information which calls on more specific working memory systems. This would explain why the presence of a 10 second delay affected the two tasks differently, leading to the suggestion that the simple rehearsal needed in the forwards task is better handled over the course of the delay compared to the more complex processing occurring in the backward span task. Since the 10 second delay lies within the acknowledged duration range for short term memory of 0 to around 18 seconds (Peterson & Peterson, 1959, Atkinson & Shiffrin, 1971), it makes sense that performance was not significantly different after the delay compared to without the delay, further supporting the notion that forward recall relies on short term memory.

Another factor that may provide more information, which was not considered in the current study, is the point at which the serial information presented in the backwards task is inverted. There are limited existing studies which have begun to consider the timing of participants' planning of responses using reaction time data. One such study by Brunetti et al (2014) concluded that participants' responses are planned after the presentation of stimuli rather than during the presentation. The potentially informative trend effect found in the current study, whereby reaction times were suggested to be slightly longer in the backwards task than the forwards task, supports Brunetti et al's conclusion, on the consideration that planning a response in which the information must be inverted would take slightly longer to plan than a response in which the information does not need to be altered, resulting in potentially longer initial response times. Furthermore, the current study also found the inclusion of the 10 second delay to increase the reaction times, which might suggest that information be inverted just before its reproduction, as opposed to immediately after stimulus presentation, regardless of the time elapsed between the two.

Further research is recommended to investigate this phenomenon. For example, an experiment using the Corsi block task in which participants are instructed on the order of recall at different time points could shed light onto the point at which working memory systems are employed in the backwards condition to reverse the sequence. To illustrate, performance could be compared in four conditions in which participants are made aware of the order (forwards or backwards) in which they must recall the sequence, either a) before the presentation of stimuli, b) immediately after the presentation of stimuli but before the (10 second) delay, c) halfway through the delay, and d) at the end of the (10 second) delay.

Although such further research would help to understand the timing of working memory processes, the current study did show some insight into how the responses for both forward and backwards tasks are planned; the reaction times for the initial response (block touch) were longer than the subsequent block touches, both without and after a delay for both directions. This indicates that generally the response is likely planned in full before response initiation, since after the execution of the response begins there is significantly less time elapsed between subsequent block touches. Further, the trend effect showing initial reaction times for backward recall to be slightly longer than forwards fits with previous conclusions that the response is planned just before response initiation, and that the backwards task must deal with a higher cognitive load, employing the extra cognitive processes of working memory.

It is likely that the effect of motion inherent in the original Corsi task may aid at least some participants in recall, specifically in backward recall. This calls for the development of apparatus which eliminates the risk of confounding performance results in this way, such as a standard computerised Corsi (without the moving ball). Though, it is acknowledged that the cons of technological equipment, such as some participants feeling unconfident with tablet devices, should be considered. This can be overcome by allowing participants more time to familiarise themselves with equipment, perhaps in a task unlike the Corsi task so as to avoid practice effects. Future research should aim to delve deeper into the timing of the employment of working memory processes in the backward visuospatial recall to further understand how we use such complex processes to manipulate and remember information in the visuospatial domain.

In summary, this research demonstrates the need for a standardised Corsi block tapping task, which is free from confounds such as motion, and will ensure all research using the test is comparable, to strengthen the validity of findings concerning the test and visuospatial ability. We suggest that forward recall relies on simple short term memory storage as long as the recall falls within the duration of short term memory, whilst the backward recall calls on the more specific properties of working memory systems within short term memory, namely incorporating attentional processes essential for actively attending to information, which appears to make the information more vulnerable to the effect of decay during the delay, as demonstrated by significantly poorer performance after the delay.

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Appendix A

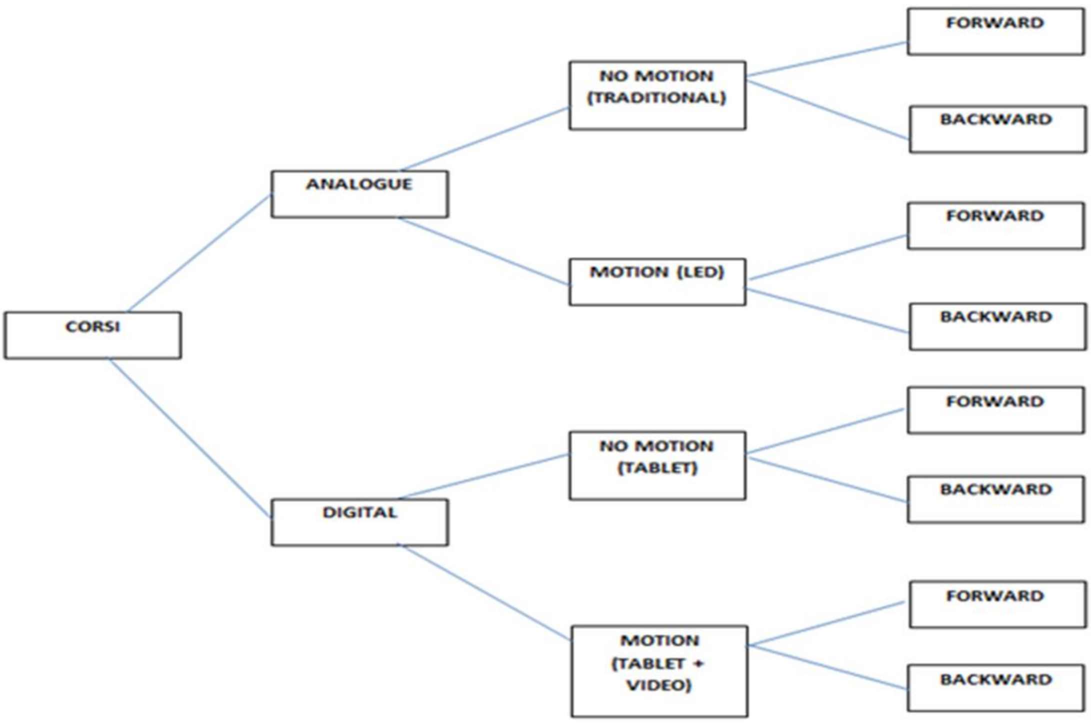
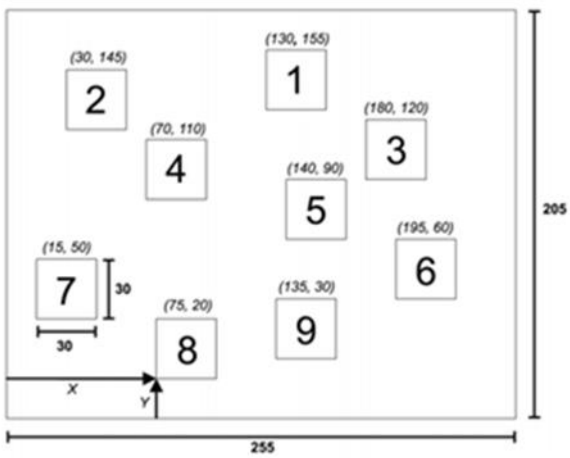


Figure 1: Diagram of main conditions/subtests, incorporating all IV levels of the 2x2x2 design.

Appendix B



The coordinates (in mm) are measured from the left-bottom corner of the board to the left-bottom corner of each cube. The digits 1 through 9 are visible to the examiner only. Taken from Kessels et al (2000).

Appendix C

Condition	Mean Product	Std. Deviation
Analogue Forward No Motion (LED)	72.02	28.242
Analogue Forward Motion (Traditional)	65.24	29.469
Analogue Backward No Motion (LED)	57.93	22.317
Analogue Backward Motion (Traditional)	65.89	23.214
Digital Forward No Motion (Tablet)	56.28	23.869
Digital Forward Motion (Tablet Video)	61.98	26.374
Digital Backward No Motion (Tablet)	49.78	23.272
Digital Backward Motion (Tablet Video)	56.93	20.79
Delay Forward (Tablet)	56.61	29.883
Delay Backward (Tablet)	37.59	18.301

Table 1: Mean Products and Standard Deviations for all (combined) conditions