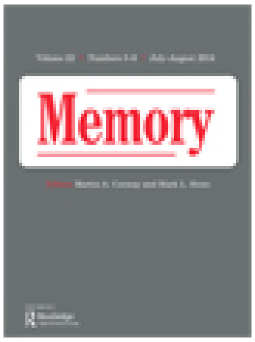

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Cross-modal and intra-modal binding between identity and location in spatial working memory: The identity of objects does not help recalling their locations

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In this study we tested incidental feature-to-location binding in a spatial task, both in unimodal and cross-modal conditions. In Experiment 1 we administered a computerised version of the Corsi Block-Tapping Task (CBTT) in three different conditions: the first one analogous to the original CBTT test; the second one in which locations were associated with unfamiliar images; the third one in which locations were associated with non-verbal sounds. Results showed no effect on performance by the addition of identity information. In Experiment 2, locations on the screen were associated with pitched sounds in two different conditions: one in which different pitches were randomly associated with locations and the other in which pitches were assigned to match the vertical position of the CBTT squares congruently with their frequencies. In Experiment 2 we found marginal evidence of a pitch facilitation effect in the spatial memory task. We ran a third experiment to test the same conditions of Experiment 2 with a within-subject design. Results of Experiment 3 did not confirm the pitch–location facilitation effect. We concluded that the identity of objects does not affect recalling their locations. We discuss our results within the framework of the debate about the mechanisms of "what" and "where" feature binding in working memory.

Keywords: Visuospatial working memory; Corsi Block-Tapping Task; Incidental feature binding.

Our perception of objects and events requires the simultaneous processing of separable features, such as shape, colour and location. Although the processing of these features is independent, we typically experience complex stimuli as unitary objects or events rather than segregated sets of features. This is possible because different features can be integrated in unified representations in memory through "binding" mechanisms (Jiang, Olson, & Chun, 2000; Maybery et al., 2009; Prabhakaran, Narayanan, Zhao, & Gabrieli, 2000). "Binding" refers to the linkage of features within or across information streams (Treisman, 1999). Binding processes are claimed to be fundamental to a broad range of psychological phenomena, including object-based perception, episodic memory, and the creation of coherent action sequences (Mesulam, 1998).

The question whether attention is required for feature binding has been matter of debate. Wheeler and Treisman (2002) argued that attention is needed to create and maintain binding

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between features. In the same direction the findings of Fougnie and Marois (2009) also showed that a concurrent tracking task disrupted memory for colour–shape conjunctions. By contrast, several studies indicated that binding in working memory (WM) is a rather automatic process (Allen, Baddeley, & Hitch, 2006; Allen, Hitch, Mate & Baddeley, 2012; Prabhakaran et al., 2000). For example, the difference in accuracy between recognition memory tasks for bound features and constituent individual features has been found to be small, suggesting a relatively automatic process (Karlsen, Allen, Baddeley, & Hitch, 2010; Vogel, Woodman, & Luck, 2001). The two hypotheses are not mutually exclusive as there is evidence of a possible coexistence of attentional and automatic processes in feature binding. Morey (2011) found that even if incidental binding is possible, explicit binding instructions drastically enhance performance in both spatial and verbal memory tasks.

An interesting approach to investigate the role of attention in feature binding is to analyse the incidental encoding of task-irrelevant features. Several studies (Campo et al., 2010; Jiang et al., 2000; Olson & Marshuetz, 2005) found that the processing of visual features involves the involuntary processing of their location. Such involuntary spatial encoding is interpreted as evidence of automatic binding. Zimmer, Speiser, and Seidler (2003) suggest that the location of objects is encoded together with the object's identity during visual processing. According to these studies, feature binding seems to be mainly an automatic process. However, under some circumstances, binding seems to require attention. In a cross-modal study, Caprio, Godoy, and Galera (2010) found no incidental binding of verbal (spoken) and visual information and a reduction in performance when both modalities needed to be encoded (e.g., divided attention). Another relevant example of the non-automaticity of binding, specifically in a spatial task, is given in a study by Bannerman, Temminck, and Sahraie (2012). The authors aimed to verify if spatial memory span is affected by adding emotionally relevant information (e.g., angry faces) to the locations used in the task. Although emotional stimuli captured spatial attention, spatial span was not affected by the emotional identity information (see also Bannermann, Milders, & Sahraie, 2010a, 2010b; Koster, Crombez, Van Damme, Verschuere, & De Houwer, 2004). Such evidence supports the idea that visual STM and spatial memory are distinct mechanisms (Della Sala, Gray, Baddeley, Allamano & Wilson, 1999; Della Sala & Logie, 2002) and that only the "where" information is important in forming accurate representations in spatial WM (Bannerman et al., 2012).

The association between features is not always symmetric: in some situations, the encoding of a feature triggers the encoding of a second one, while the encoding of the second one does not imply the encoding of the first one (Delogu, Gravina, Nijboer, & Postma, 2014; Delogu, Nijboer, & Postma, 2012; Köhler, Moscovitch, & Melo, 2001; Maybery et al., 2009; Olson & Marshuetz, 2005). In a study by Campo et al. (2010), participants who were required to remember the identity of a set of consonants presented in different locations on a screen were also able to remember their locations. It seems that the direction of what–where influences depends on the sensory modality of the stimuli. In fact, in visual WM, a change in the location of memoranda impairs their recall even when it is task irrelevant, while a change in the identity of objects does not affect visual object localisation (Köhler et al., 2001). This is often interpreted as evidence of the fact that when encoding the identity of visual objects, we also automatically process their location (Campo et al., 2010; Jiang et al., 2000; Olson & Marshuetz, 2005), while when encoding the location of visual objects, we can ignore their identity. By contrast, in auditory WM, a change in verbal identity impairs the recall of sound locations even when identity is task irrelevant while location encoding does not affect the recall of the objects' identities (Maybery et al., 2009). Such contrasting results between vision and audition support the idea that input modality can modulate mechanisms of feature location binding. According to some interpretations, these what–where asymmetric effects in vision and hearing are due to location-over-identity pre-eminence in vision and to identity-over-location pre-eminence in hearing (Delogu et al., 2014; see also Kubovy & Van Valkenburg, 2001 for an interesting theoretical framework). However, whether the direction of the asymmetry is actually determined by the modality of the stimuli is still controversial. In fact, there is evidence for an asymmetric influence of identity on location also in the visual domain (Darling, Allen, Havelka, Campbell, & Rattray, 2012; Guérard, Morey, Legace, & Tremblay, 2013). For example, Darling and collaborators (2012), in a digit span task, found a beneficial effect of presenting numbers on locations of a typical display (like a telephone keypad) over non-typical display conditions and a single-location display condition. They concluded that LTM spatial representations learned with repeated experience of a certain spatial configuration could help processing the sequential identity task. Likewise, Morey and Mall (2012), in a multimodal study with visuospatial and auditory verbal serial recognition tasks, also demonstrated asymmetric influences of identity on location. A plausible explanation of these apparently contradictory findings is that the direction of the asymmetric binding is not determined by the sensory modality of the input, but by the synchronous versus sequential method of stimuli presentation (Guérard et al., 2013).

Due to such contrasting results in literature, the role of sensory modalities in what–where binding is still unclear. In this study, we focus on what-on-where influences in visuospatial WM by associating location and identity of the stimuli intra-modally and cross-modally in a visuospatial WM task. There are only a few studies, with contrasting results, directly comparing cross-modal and intra-modal binding in a visuospatial WM task (Bannerman et al., 2012; Caprio et al., 2010).

Binding effects in feature binding research vary according to the experimental design. Sometimes feature association causes detrimental effects, sometimes additive effects and sometimes it has no effects on the quality of recall of single, multiple and bond features. The diversity of results is most likely due to different methodological approaches. Consequently, there is some confusion when referring to the qualities of binding, with the use of adjectives like automatic, incidental and effortless on the one side and controlled, voluntary and resource demanding on the other. It is particularly important to note that incidental encoding is not synonymous with effortless encoding. In fact, we cannot exclude that incidental encoding of task-irrelevant features requires cognitive resources. In this study we will use the term *incidental* to define the quality of the binding between a task-irrelevant feature, identity in our case, and a task-relevant one, location in our case.

This study has two main goals. The first is to verify if the identity is implicitly associated to spatial information in a spatial WM task. The second goal is to verify whether such association is affected by the sensory modality in which the identity information is encoded. Operatively, we tested whether and how visuospatial WM is affected by the incidental encoding of stimulus identities presented either visually or auditorily. We predicted four possible scenarios. A first possibility is to find a facilitation effect (Jiang et al., 2000; Maybery et al., 2009; Prabhakaran et al., 2000). In such a scenario, in order to recall positions, participants could rely not only on the order of spatial tapping but also on which specific object is associated with a specific position. A second option is that identity information is incidentally encoded, but being task irrelevant, it increases WM load and consequently impairs spatial performance. In a third case, since it has been demonstrated that the acoustic "what" has got a primacy on the "where" (Maybery et al., 2009) more than the visual "what" (Köhler et al., 2001), we could expect a better performance in a cross-modal (visual-acoustic) condition than in the intra-modal (only visual) condition. Finally, a fourth possibility is that there is no implicit binding. In this case, we could expect that identity information is ignored and we do not have any consequences from the addition of information about identity (as suggested by Logie, 1995).

EXPERIMENT 1

Methods

Participants. Forty-five students (8 male) with an age range from 18 to 24 (M = 19.68, standard deviation [SD] = 1.45) participated in the experiment in three different groups (n = 15 for the standard condition, n = 15 for the acoustic condition and n = 15 for the visual condition). All participants reported being right-handed and to have normal or corrected-to-normal hearing and vision.

Materials. We used a modified computerised version of the Corsi Block-Tapping Task (CBTT), consisting of nine squares displayed on the screen. Squares start flashing in a sequence and the participant has to repeat subsequently in the correct sequential order by clicking them with the mouse.

Identity stimuli were either visual or auditory. They were added to each of the squares of the standard condition of the CBTT. The presentation of the stimuli lasted for 500 ms in all conditions. Visual stimuli consisted of nine ideograms adapted from Kang (2010). Auditory stimuli consisted of nine percussive sounds selected from freely distributed sound samples. In order to avoid the influence of verbalisation, the sounds were selected when not being easily associable with any specific, easy to name musical instrument. All materials were tested in a pilot study for discriminability: in this study, participants were presented with a study sequence of five stimuli (sounds or ideograms, each lasting 500 ms), and then, after 1 s, they were presented with a probe stimulus. Participants were required to judge whether the probe was included in the study sequence. The accuracy of the memory for sounds and ideograms was analysed with two separate one-sample t-tests. Results indicated that participants recognised both the sounds, $t(9) = 9.03$, $p = .001$, and the ideograms, $t(9) = 4.42$, $p = .002$, with levels of accuracy far above chance, thus demonstrating that the subjects were able to recognise them without confusion (Table 1). Moreover, no stimulus showed facilitation effects. Images do not stand out in memory performance compared to other images; sounds do not stand out in memory compared to other sounds. Hence, all these stimuli, despite unfamiliar, were distinguishable and virtually equally identifiable for the subjects.

During the experiment, the identity features were only presented during the encoding phase (see Procedure section).

Apparatus. The study was carried out using a laptop computer (MacBook Pro). The digital version of CBTT was visualised on the computer (screen 33.1 × 21 cm; resolution 1440 × 900). The size of the squares was 2.2 × 2.2 cm (visual angle: 2.53°) and all the squares were within a bigger square of 20 × 20 cm (visual angle: 22.6°). Participants were at 50 cm from the screen. The computer was running a custom-made script in Max 6.1 (Cycling '74). Auditory stimuli were presented binaurally with headphones AKG (K171 MKII) at a comfortable volume level.

Procedure. In each trial, participants were presented with a sequence (encoding phase) of spatial locations, and they were then required to reproduce the sequence (retrieval phase) by clicking on the squares in the correct order (Figure 1). The experiment started with a training including 25 sequences of five items each, to make participants familiar with the task and with the specific locations of images or sounds in the different conditions: the identity of spatial positions. Participants performed only one of the experimental conditions and they were only trained in the condition they were going to perform.

After the training, the experiment was divided in two sections, always administered in the same order. In the first section, "Span," participants performed three trials for each sequence length, starting from a length of two elements. Sequence length progressively increased until participants failed to reproduce at least two sequences out of three for a specific length. When they failed twice to reproduce a sequence of length n, the first part of the experiment ended and the span was fixed at $n - 1$. In the second part, called "Supraspan," an additional 24 sequences of n items (span + 1) were presented and errors were counted. Both in the Span and the Supraspan sections, a phase and the next sequence were presented. Concerning the Supraspan task, a performance improvement may emerge, due to sequence repetitions. Literature (Gagnon, Foster, Turcotte, & Jongenelis, 2004; Hebb, 1961) shows that the repetition of a sequence of visuospatial items presented for immediate serial recall leads to the long-term

TABLE 1
Mean and *SD* of recognition accuracy for sounds and ideograms in the pilot study

				Sounds (n = 10) M (SD)				
1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*
0.83 (0.19)	0.6 (0.31)	0.75(0.18)	0.72 (0.19)	0.78 (0.21)	0.69 (0.25)	0.81(0.15)	0.85 (0.14)	0.76 (0.16)
				Ideograms (n = 10) M (SD)				
1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*
0.75 (0.16)	0.56 (0.22)	0.67 (0.17)	0.66 (0.2)	0.7 (0.14)	0.62 (0.27)	0.57 (0.3)	0.72 (0.22)	0.50 (0.33)

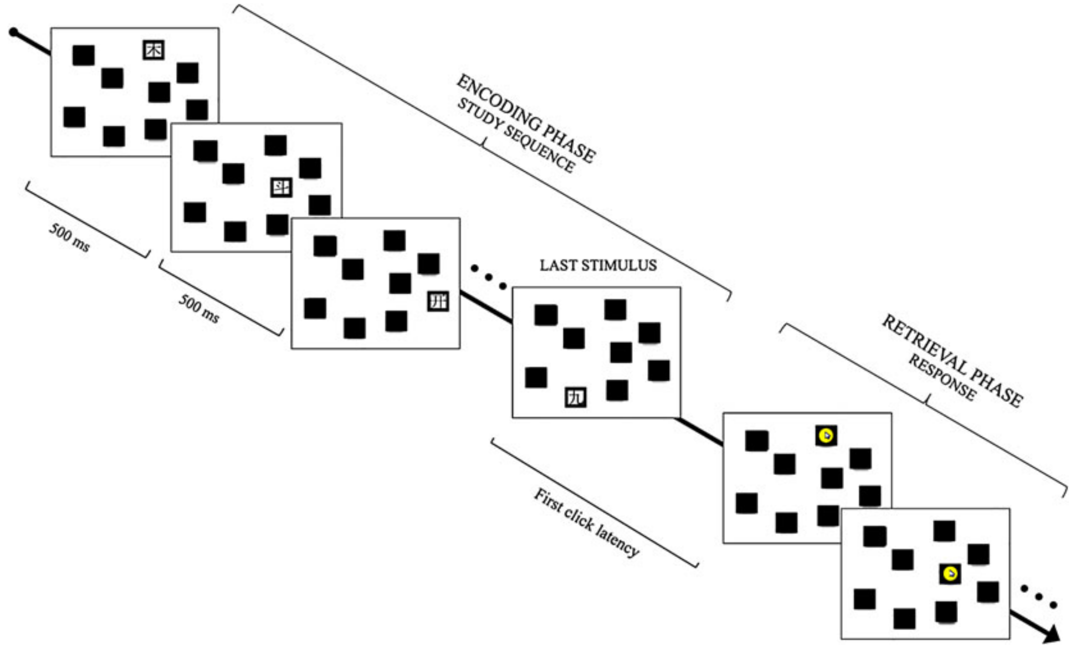

Figure 1. An example of the task in our modified computerised version of the CBTT (featuring visual identities). In the encoding phase, participants were presented with a sequence of spatial locations. They were then required to reproduce the spatial sequence in the retrieval phase by clicking on the squares using a mouse.

learning of that sequence (Couture & Tremblay, 2006). This is the so-called "Hebb repetition effect" in which participants perform a serial recall task and one particular series of digits is repeated every third trial: recall performance increased for the repeated sequence (within the 24 trials), in comparison with the non-repeated sequences (each one different from the others). So we can assume, since our sequences are all different from each other that the Hebb effect is absent in our Supraspan task and hence it cannot interact with the mapping effect.

Design and analysis. We tested three groups of participants in only one of the three conditions each. We ran a one-factor between-subjects analysis of variance (ANOVA) analysis to test if the CBTT encoding condition (i.e., standard CBTT, auditory identity added, visual identity added) influences the following four dependent variables: memory span, Supraspan score, Serial order errors and first tapping latency.

Results

Results in the three CBTT conditions are summarised in Table 2. The ANOVA analyses indicate that there is no significant difference between the three conditions, on memory Span, $F(2,42) = .97$, $p = .38$, partial $\eta^2 = .044$; Supraspan errors, $F(2,42) = .75$, $p = .48$, partial $\eta^2 = .035$; First-click latency in Supraspan sequences (the time between the onset of the last element of the sequence in the encoding phase and the first square clicked in the retrieval phase), $F(2,42) = .42$, $p = .66$, partial $\eta^2 = .033$; and Serial order errors, $F(2,42) = .66$, $p = .52$, partial $\eta^2 = .030$.

Discussion

In the first experiment, participants were tested with CBTT in three different conditions: the traditional spatial-only condition, an auditory identity condition in which percussive sounds were presented simultaneously with each block flashing and a visual condition, in which Chinese ideograms were superimposed to the CBTT squares. We found that the three conditions do not lead to different memory performances. Our results indicate that the inclusion of unfamiliar identity information to spatial information of a digital version of a CBBT task does not lead to effects on a visuospatial memory performance either in terms of span or in terms of response time. We argue that when identity information is neither relevant for the task nor associable with

TABLE 2
Mean and *SD* of Supraspan errors, Span measure, First-click latency and mean of the Serial order errors for the three different conditions of the CBTT

		Span		*Supraspan errors*		*Serial order errors*	*First-click latency*	
	n	*M*	*SD*	*M*	*SD*	*M*	*M*	*SD*
Standard	15	4.8	0.75	16.13	4.41	3.23	1341.05	290.02
Sound	15	5.13	0.62	15.66	3.75	3.1	1293.35	302.1
Image	15	5	0.52	14.27	4.37	2.95	1294.76	201.13

the spatial information, it has no effect on spatial performance and is filtered out with no costs or benefit for the spatial performance. This interpretation is consistent with the findings of Logie (1995), who stated that if identity information is not relevant for the task, it is filtered out. However, it is important to underline that the identity stimuli in Experiment 1 (percussive sounds and ideograms) were unfamiliar and unrelated to the spatial organisation of the Corsi squares. It is plausible that the lack of effect of identity information on visuospatial memory performance is due to the fact that the association between identities and locations was arbitrary and/or because the stimuli were unfamiliar. In a second experiment, we tested the influence of non-arbitrary identities and the influence of familiarity independently. A class of stimuli that were particularly suitable for our theoretical goals were piano sounds. In fact, piano sounds are inherently organised in a system of pitches (the scale) that exhibit important analogies with a vertical spatial map (no horizontal order is present). As an evidence of this, Spence (2011) reports a perceptual experiment, demonstrating that lower pitches are easier to associate to lower spatial positions while higher pitches are easily coupled with higher spatial locations. Such spatial associations make therefore possible a topological mapping between pitch and position. Moreover, a set of piano sounds can consist of a familiar sequence (selected from a tonal progression) or of an unfamiliar sequence (selected from an atonal progression).

The main goals of the second experiment are (1) to test whether task-irrelevant identity information can affect the CBTT in the case that the pattern of pitches of piano sounds matches the spatial configuration of the Corsi squares and (2) to test the influence of familiarity.

EXPERIMENT 2

In our second experiment, to operationalise familiarity, we employed two sets of piano scales. In the familiar condition, we associated a tonal scale to the Corsi squares and in the unfamiliar condition we associated an atonal scale to the squares. It has been shown that melodies that deviate from the so-called “tonal system” are perceived as incorrect, because tonal melodies or scales are more familiar in our Western culture and they are perceived as more pleasant over atonal one (Cross, Howell, & West, 1983; Peretz, 1993; Smith & Melara, 1990). To operationalise spatial consistency, the scales were associated to the spatial position of squares in two different conditions either in an “ordered” or in a “random” way. In the “ordered” condition, sounds matched the spatial vertical position of the squares. Specifically, the lower the pitch of the piano sound, the lower the position of the square to which the sound was associated to, and the higher the pitch, the higher the position of the square in the screen (see Figure 2 for an example with the tonal scale). In the “random” condition, pitches were randomly assigned to the squares, while remaining consistent throughout the experiment.

Method

Participants. A total of 54 students (11 male) aged 19–29 ($M = 20.20$, $SD = 1.66$) participated in the experiment. The sample was divided in four groups, which were tested with the following four different conditions: ordered-tonal ($N = 15$), random-tonal ($N = 14$), ordered-atonal ($N = 13$) and random-atonal ($N = 13$). All participants were right-handed and reported normal hearing and normal or corrected-to-normal vision.

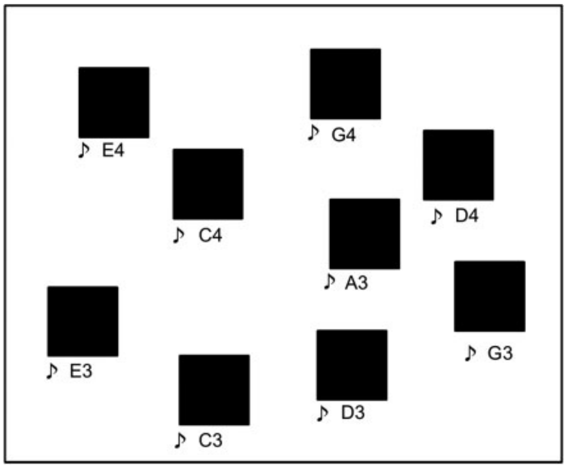

Figure 2. CBTT identity features in the *Tonal/Ordered* condition.

Materials. The audio-visual stimuli consisted of nine flashing squares arranged as in a traditional Corsi board (Figure 2). The nine squares were associated with two different sets of piano sounds (sampled at 22 kHz, lasting 500 ms). A first set consisted of a familiar (Tonal) scale (C3 - D3 - E3 - G3 - A3 - C4 - D4 - E4 - G4) and a second set included an unfamiliar (Atonal) scale (C3 - C#3 - E3 - F#3 - A3 - C4 - C#4 - E4 - F#4). These two sets of notes were associated with different mappings on the squares on the screen: in the "ordered" mapping high-pitched sounds were associated with squares displayed at the top of the screen, while low-pitched sound–matched squares were gradually placed in the lower part of the screen (Figure 2); the "random" mapping means that sounds were randomly assigned to the spatial positions. By crossing the levels of the two variables, we obtained the following four conditions: Tonal/Ordered, Tonal/Random, Atonal/Ordered and Atonal/Random.

Apparatus and procedure. Same as in Experiment 1.

Results

We conducted two-factor ANOVA analyses on the dependent variables Span, Supraspan errors, First-click latency and Serial order errors (Table 3) to assess the influence of the factors Familiarity (Tonal vs. Atonal) and Mapping (Ordered vs. Random). Outlier values (2 *SD*s above and below the mean of all subjects) were excluded from analysis (four participants).

Concerning the dependent variable Span, we found no effect of Mapping, $F(1,44) = 1.03$, $p = .32$, partial $\eta^2 = .023$, and no effect of Familiarity, $F(1,44) = 1.03$, $p = .32$, partial $\eta^2 = .023$. Also, interactions between factors were not significant, $F(1,44) = .49$, $p = .49$, partial $\eta^2 = .011$.

Concerning the dependent variable Supraspan errors, we found a main effect of Mapping, $F(1,44) = 5.6$, $p = .02$, partial $\eta^2 = .113$. Specifically, participants performing the "ordered" mapping condition committed a significantly lower amount of errors than the participants in the "random" mapping condition. We found no effect of Familiarity, $F(1,44) = .30$, $p = .58$, partial $\eta^2 = .007$. Moreover, the interactions were not significant, $F(1,44) = .01$, $p = .92$, partial $\eta^2 = .000$.

Concerning the dependent variable First-click latency in Supraspan sequences, we found no effect of Mapping, $F(1,44) = .47$, $p = .49$, partial $\eta^2 = .011$; no effect of Familiarity, $F(1,44) = .16$, $p = .69$, partial $\eta^2 = .004$; and also the interactions were not significant, $F(1,44) = .17$, $p = .68$, partial $\eta^2 = .004$.

Concerning the dependent variable Serial order errors in Supraspan sequences, we found no effect of Mapping, $F(1,44) = .83$, $p = .36$, partial $\eta^2 = .016$; no effect of Familiarity, $F(1,44) = 2.18$, $p = .15$, partial $\eta^2 = .041$; and also the interactions were not significant, $F(1,44) = 1.05$, $p = .37$, partial $\eta^2 = .061$.

TABLE 3
Experiment 2: Mean and *SD* of Supraspan errors, Span measure, First-click latency and mean of the Serial order errors for the groups performing the *ordered* and *random* conditions of CBTT

		Span		*Supraspan errors*		*Serial order errors*	*First-click latency*	
	n	*M*	*SD*	*M*	*SD*	*M*	*M*	*SD*
Ordered	25	5.04	0.75	12.41	5.28	3.33	1527.45	286.90
Random	25	5.32	1.01	15.68	4.77	3.1	1446.24	430.14
Total	50	5.19	0.90	13.96	5.35	3.2	1483.66	369.99

We obtained a significant result for Supraspan errors.

Discussion

In Experiment 2, we tested whether a congruent cross-modal spatial mapping between sounds and position and the familiarity of the identity stimuli associated with locations could be influential factors in a CBBT Task. We found a significant influence of Mapping. Specifically, participants made fewer errors in the Supraspan task when piano pitches matched the height of the square in the vertical axis of the screen. This result suggests that, in a WM task, identity information is not necessarily neglected when all or most of the attention is focused on spatial dimensions of the stimuli. In fact, identity selectively affects spatial performance only in the case where it is potentially useful for the spatial task. The beneficial influence of congruent mapping on CBTT occurs in the Supraspan task and not in the span condition. We see two non-mutually exclusive explanations for this result. First, as the Supraspan is a more sensitive measure than the traditional span, the behavioural effects of identity encoding could have emerged only in the Supraspan because it involves more trials, all of which are of the same length. Second, considering that it is manifest only when useful for the spatial task, it is likely that the encoding of identity information is strategic and voluntary instead of automatic and implicit.

Identity information is possibly filtered out when not relevant for the task (Logie, 1995). This result could confirm the statement that binding is not always an automatic process but it depends on how helpful it is for completing a task. Hence, binding could occur when it offers significant facilitation: in our case, the internal hierarchy of sounds (scale) matches with the spatial organisation of squares, thus making the binding effect appears. However, the evidence of an influence of identity processing on the memory for a sequence of location is limited to only one condition. Moreover, the effect seems rather small. Finally, given the high number of analyses performed on our data, we cannot exclude an augmented risk of type I errors. In order to exclude this and other potential sources of distortion, we decided to run a third experiment to test the same conditions of Experiment 2 with a within-subject design in which all participants perform all conditions and in which, consequently, the error variability is reduced.

EXPERIMENT 3

In Experiment 3, we replicated Experiment 2 with a within-subject design.

Method

Participants. A total of 33 students (7 male) aged 18–25 (M = 21, SD = 1.7) participated in the experiment. All participants were right-handed and reported normal hearing and normal or corrected-to-normal vision.

Materials. Same as in Experiment 2.

Apparatus and procedure. The apparatus was the same as the one used in Experiments 1 and 2. Each participant was administered with the four different conditions: ordered-tonal, random-tonal, ordered-atonal and random-atonal. The order of these conditions was counterbalanced across participants. Between each block, there was a 5-minute pause.

Results

We ran repeated measures ANOVAs on the dependent variables Span, Supraspan errors, First-click latency in Supraspan sequences and Serial order errors (Table 4), in order to assess the influence of the factors Familiarity (Tonal vs. Atonal) and Mapping (Ordered vs. Random). Substantially, we found no significant differences between the different conditions.

Concerning the dependent variable Span, we found no effect of Mapping, $F(1,32) = .44$, $p = .51$, partial $\eta^2 = .014$; no effect of Familiarity, $F(1,32) = .01$, $p = .93$, partial $\eta^2 = .000$; and interactions between factors were not significant, $F(1,32) = .52$, $p = .47$, partial $\eta^2 = .016$.

Concerning the dependent variable Supraspan errors, we found no effect of Mapping, $F(1,32) = .18$, $p = .67$, partial $\eta^2 = .006$; no effect of Familiarity, $F(1,32) = .273$, $p = .61$, partial $\eta^2 = .008$; and interactions were not significant, $F(1,32) = 1.56$, $p = .22$, partial $\eta^2 = .046$.

Concerning the dependent variable First-click latency in Supraspan sequences, we found no effect of Mapping, $F(1,25) = 1.15$, $p = .29$, partial $\eta^2 = .044$; no effect of Familiarity, $F(1,25) = .005$, $p = .94$, partial $\eta^2 = .000$; and Interactions were not significant, $F(1,25) = .49$, $p = .49$, partial

TABLE 4
Experiment 3: Mean and *SD* of Supraspan errors, Span measure, First-click latency and mean of the Serial order errors for the two conditions: *ordered* and *random*

		Span		*Supraspan errors*		*Serial order errors*	*First-click latency*	
	n	*M*	*SD*	*M*	*SD*	*M*	*M*	*SD*
Ordered	33	5.11	1.12	14.82	5.91	3.35	1335.05	416.92
Random	33	5.21	1.39	15.27	6.30	3.41	1393.81	380.83
Total	33	5.16	1.26	15.04	6.09	3.38	1364.43	398.75

η^2 = .019. First-click latencies analysis included only correctly recalled sequences. Since some subjects did not reproduce any of the sequences correctly in some conditions, resulting in missing data, the analysis on this variable was possible only in 26 out of the 33 original subjects. Consequently, the degrees of freedom of Fischer's *F* varied accordingly in all analyses carried out on this dependent variable.

Concerning Serial order errors in Supraspan sequences, we found no effect of Mapping, $F(1,32)$ = .25, p = .62, partial η^2 = .008. The main effect Familiarity was also not significant, $F(1,32)$ = .54, p = .47, partial η^2 = .017. The interaction between Mapping and Familiarity was significant, $F(1,32)$ = 5.28, p = .03, partial η^2 = .142. However, as none of the comparisons in the post hoc analysis (Tukey's Honestly Significant Difference) was significant, we interpret this result as a weak tendency towards a better performance in the tonal/ordered condition.

Discussion

In Experiment 3, with the goal of reducing the error variance, we replicated Experiment 2 with a within-subject design. We did not find any influence of identity on the CBBT performance. This result is in contrast with Experiment 2, in which we found a beneficial effect of identity on spatial performance in conditions where identity could be potentially useful. Such effect, even if small and limited to the Supraspan task, was significant in Experiment 2, but absent in Experiment 3. It is likely that the effect emerging in Experiment 2 is caused by intrinsic/non-controlled differences between the groups of participants performing different conditions. In Experiment 3, in which each participant performed different conditions, results did not confirm the small beneficial effects of identity over localisation, indicating a lack, or at least the fragility of *what-to-where* incidental binding in visuospatial WM (Figure 3).

GENERAL DISCUSSION

Previous studies provided evidence for automatic binding between location and identity in both the visual (Karlsen et al., 2010) and the auditory domain (Lehnert & Zimmer, 2006). Moreover, it has been shown that spatial memory performance is increased when locations are associated with verbal features and represent an "object" (Prabhakaran et al., 2000). In addition, locations are automatically bound when the task requires to process visual stimuli in space (Campo et al., 2010; Jiang et al., 2000; Olson & Marshuetz, 2005) in the auditory (Maybery et al., 2009) and the visual domain (Zimmer et al., 2003). Interestingly, binding occurs even when the task does not require it.

In this study we conducted three experiments in which participants performed a computerised version of the CBTT task where additional, task-irrelevant identity information were flashed in the to-be-recalled locations. In Experiment 1, identity information, either visual or auditory, was unrelated to the spatial layout. Results showed that identity information did not affect spatial recall. In Experiment 2, locations on the screen were associated with pitched sounds in two different conditions: one in which pitches and locations were randomly paired and one in which pitches with higher frequencies were associated with locations having a higher position on the screen. Results showed a higher spatial span in the pitch–location congruent condition, but the effect was only present in the Supraspan task. In Experiment 3, different from Experiments 1 and 2, we replicated the conditions of Experiment 2 using a within-subject design in which each participant performed all conditions. Results showed no effects of

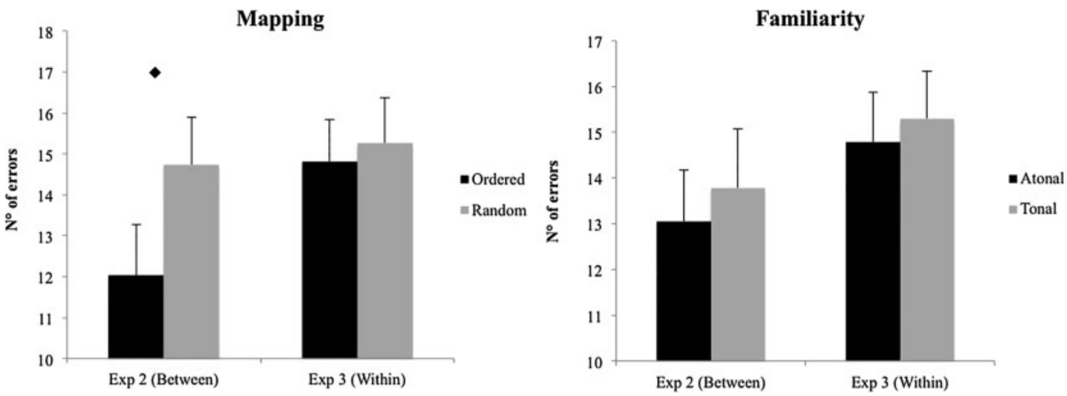

Figure 3. A comparison between Experiment 2 and Experiment 3 regarding the influence of factors Mapping and Familiarity on the Supraspan task. The diamond indicates a significant difference.

identity on the spatial memory performance in any of the conditions of the Span and Supraspan tasks.

To summarise the results of all experiments and conditions, we can say that identity information, both visual and auditory, is irrelevant at the performance level during a spatial WM task like CBTT. This result is consistent with the idea that the implicit binding of identity to locations, assuming that it takes place, does not influence spatial memory in the visual modality. It should be noted that the lack of influence does not provide evidence for a lack of binding. Actually, the results of Experiment 2 provide some evidence of the contrary, as participants could use tonal information to significantly improve their performance in the Supraspan task in the case such information was useful to the task. These results lead us to think that some kind of implicit binding happens, but that rarely has the strength to become manifest at a behavioural level. Considering that such behavioural benefit emerges only when the binding is advantageous for the task, it is highly likely that the association of task-irrelevant identity information to spatial information can be strategic and voluntary instead of automatic, or even implicit.

Alternatively, it is also possible that incidental binding takes place and it is rapidly forgotten. Previous studies demonstrated that object–location memory is fragile (see Postma [1996] for a review) and that decays rapidly as a function of the delay between encoding and recall (Pertzov, Dong, Peich, Husain, 2012). As in our experiment we test binding only in the recall phase, we cannot exclude that binding between the identity and the location is initially established during encoding, and then lost.

Similar to previous studies, our findings confirm a general lack of influence of identity over spatial processing in the visual modality. Our results are also consistent with previous evidence of non-mutual influences of spatial over identity processing in the visual modality (Köhler et al., 2001), where item location implicitly influences item identity processing even when task irrelevant (see, e.g., Campo et al., 2010; Darling et al., 2012; Jiang et al., 2000; Olson & Marshuetz, 2005) while item identity does not influence spatial performance (see, e.g., Köhler et al., 2001). Findings of spatial dominance in vision and the evidence of asymmetric influences of location over identity can be the consequence of the fact that the visual processing is intrinsically spatial in nature (Kravitz, Kriegeskorte, & Baker, 2010; Kravitz, Vinson, & Baker, 2008).

Concerning the role of sensory modalities, it seems that neither intra-modal visual identity information nor cross-modal auditory identity information has a considerable influence on visuospatial WM performance. Our findings indicate that identity information, when task irrelevant, is not influential for visuospatial memory, no matter in which modality it is encoded.

A primary interpretation for this *what-on-where* lack of influence is that location processing prevails over identity processing in vision (Kubovy & Van Valkenburg, 2001) and, consequently, identity information is subordinate to spatial processing and not able to affect it. In a multisensory perceptual context, for example, according to the modality appropriateness hypothesis (Welch and Warren, 1980), auditory stimuli cannot influence the perception of the location of a visual stimulus. More in general, our results, together with many other findings in which location processing is not easily influenced by task-irrelevant variations in non-spatial features, support the idea of a privileged role of location processing in visual WM (Pertzov & Husain, 2014). However, considering that in literature there is also evidence for an *identity-over-location* dominance in the visual modality (see, e.g., Guérard, Tremblay, & Saint-Aubin, 2009; Guérard et al., 2013; Morey & Mall, 2012), the mechanisms of integration of spatial and non-spatial features in WM are far to be fully understood.

Another reason for the lack of influence (which is not necessarily in contradiction with the previous interpretation) could be attributed to the limit of serial order recall on spatial features. It has been demonstrated that serial ordering is easier in a verbal than in a spatial context and that spatial performance increases by 25% when the request for serial order is removed (Gmeindl, Walsh, & Courtney, 2011). We can speculate that spatial span tasks like the CBTT, which have a strong serial component, are not really appropriate to measure pure spatial WM (Gmeindl et al., 2011). It is possible that by removing the serial order constraint, we could obtain different or better performances in the intra- and cross-modal conditions versus the standard one. In other words, if memory would not be strained by the serial request, it is possible that binding between identity and spatial information could emerge through better performance in spatial WM tasks.

A third interpretation for the lack of what-on-where influence could be that squares in the Corsi test are not seen like objects in space but like points linked by a visual path. If this is the case, images and sounds do not help the performance because they are unable to facilitate the creation of directional paths. In support of this interpretation, some previous studies demonstrated (Orsini, Pasquadibisceglie, Picone, & Tortora, 2001; Parmentier, Elford, & Maybery, 2005) that different paths affect serial memory and that the spatial features of a sequence are an important variable.

In this study, we conducted three experiments to verify whether task-irrelevant identity information associated to to-be-recalled locations could influence the performance in spatial sequential recall. We found none, or at least very limited influence of identity information on the spatial WM task. This result supports the idea that *what-to-where* incidental binding, if existing, does not emerge at a behavioural level. Even if the possibility of *what-to-where* binding cannot be theoretically excluded, we can conclude that the recall of visual locations is not affected by the presence of supplementary identity information in encoding. As the effect is absent with both visual and auditory stimuli, this lack of influence does not depend on the sensory modality of the identity information.

HIGHLIGHTS

- We investigated the presence of implicit location–identity binding in three experiments.
- The sensory modality of the stimuli was either visual or acoustic.
- In experiment 1, we found no effects of task-irrelevant (identity) information.
- In experiment 2, congruent mapping between identities and locations improved memory with a between-subject design.
- In experiment 3, congruent mapping between identities and locations did not improve memory with a within-subject design.
- Identity and location do not always implicitly bind.

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AUTHOR CONTRIBUTIONS

All authors developed the study concepts and contributed to the study design, from an original idea by FD. CDG and RB performed data collection and analysis. CDG drafted the manuscript while RB and FD provided critical revisions. All authors approved the final version of the manuscript for submission.

DISCLOSURE STATEMENT

No potential conflict of interest was reported by the authors.

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