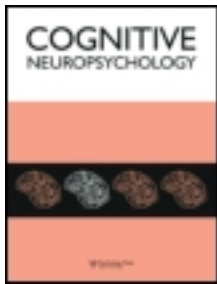


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Months in space: Synaesthesia modulates attention and action

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Months in space: Synaesthesia modulates attention and action

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Month-space synaesthetes experience months as sequences arranged in spatially defined configurations. While most works on synaesthesia have studied its perceptual implications, this study focuses on the synaesthetic influence on a synaesthete's action behaviour. S.M., a month-space synaesthete, and 5 matched controls performed a spatial Stroop-like task in a haptics and virtual reality combined environment, which was especially designed to simulate S.M.'s three-dimensional synaesthetic experience. In the experiment, a circle and a word were presented simultaneously. The word consisted of either a month name or a direction name and was located at the centre of the screen, while the circle was displayed in one of four peripheral positions—top, bottom, right, or left. When S.M. was asked to ignore the word and reach for the circle, no effects were found. In contrast, when she was asked to ignore the circle and reach for a location indicated by the word, a congruency effect was found for both months and direction words. Crucially, these effects were evident in all measurements of reaching performance (i.e., path, velocity, and trajectory of movement). Our findings revealed that for month-space synaesthetes, months trigger spatial shifts of attention in a similar manner as directions do. Moreover, these shifts of attention affected not only latent cognitive processes (i.e., reaction time) but also overt behaviour (i.e., entire hand movements).

Keywords: Month-space synaesthesia; Spatial attention; Perception and action.

Recently, spatial-sequence synaesthesia has been the object of increasing attention (e.g., Eagleman, 2009; Gertner, Cohen Kadosh, & Henik, 2009; Jarick, Dixon, Stewart, Maxwell, & Smilek, 2009; Mann, Korzenko, Carriere, & Dixon, 2009; Price & Mentozi, 2008; Sagiv, Simner, Collins,

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Butterworth, & Ward, 2006; Simner, Mayo, & Spiller, 2009; Smilek, Callejas, Dixon, & Merikle, 2007). In this type of synaesthesia, ordinal sequences such as numbers, months, days of the week, hours of the day, historical events, etc., are visualized in spatially defined configurations.

The current work focuses on the subtype of month-forms. Typically, the months are arranged in a circle or oval, although in some cases straight, horizontal, or vertical arrays can be also observed (but see Eagleman, 2009). For some synaesthetes, the representation is experienced as peripersonal (out-of-body), while for others it is mentalized in their mind's eye (Sagiv et al., 2006).

Synaesthete S.M. described her month-form as follows (see Figure 1):

The months are arranged as an ellipse and appear in my mind's eye, but can be also projected horizontally a little above waist height. The default perspective on the months is from behind October, but I can also see them from behind the current month. Historical events may be seen from an odd perspective, for instance, WWII is sometimes seen from above and behind April, but the orientation of the form doesn't change—I have to "look behind my shoulder" to see from the direction of April. Months that include many important events, such as the birthdays of family members, take up more space than do less busy months.

One of the questions typically brought up when debating sequence-space synaesthesia is whether month-space perceptions should be truly classified as synaesthesia (Cohen Kadosh & Gertner, 2011). Indeed, it was found that month-forms are relatively common (about 20%) in the general population (Cytowic & Eagleman, 2009; Mann et al., 2009; Sagiv et al., 2006). Moreover, several studies demonstrated the existence of month-space associations also among nonsynaesthete individuals (e.g., Seymour, 1980), as evidenced by the well-known SNARC (spatial-numerical

association of response code) effect (e.g., Gevers, Reynvoet, & Fias, 2003). Notwithstanding, several other studies provided evidence for the authenticity of month-space associations as a type of synaesthesia by revealing the same hallmarks—automaticity and consistency—as in other instances of the phenomenon (e.g., Jarick et al., 2009; Price, 2009; Price & Mentzoni, 2008; Smilek et al., 2007).

The account for the allegedly contrasting evidence is assumed to rely on the idea that both synaesthetes and nonsynaesthetes share the same cognitive and neural mechanisms, although they seem to differ in the level of awareness and intensity of the sequence-space perceptions. While nonsynaesthetes are unaware of their month-space associations (and therefore it is revealed only under certain experimental manipulations), month-space synaesthetes consciously and irrepressibly visualize months each time they see, hear, or think of them. Taking these points all together, a more suitable question would be whether synaesthetic experiences indicate a qualitatively different mechanism or simply reflect a normal cognitive process that applies to a more extreme point along a continuum (for further discussions see Cohen Kadosh & Gertner, 2011; Cohen Kadosh & Henik, 2007; Eagleman, 2009; Simner et al., 2009).

The realization that synaesthetes could be used for the study of normal cognitive processes, which are usually much less accessible in the nonsynaesthete population, made synaesthesia research extremely attractive. However, up to now most researchers on synaesthesia focused on the perceptual implications of this phenomenon, whether they were looking for the costs or sought to reveal its benefits (for a review, see Cohen

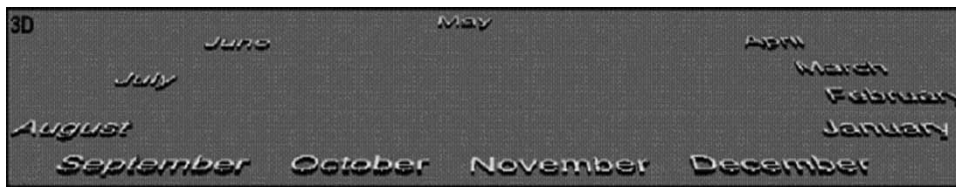


Figure 1. 3D representation of synaesthete S.M.'s default month-form.

Kadosh, Gertner, & Terhune, in press; Hochel & Milán, 2008; Simner et al., 2009; Ward & Mattingley, 2006). The novelty of the present study lies in the exploration of synaesthesia's influence on attention and action. Specifically, we were interested in revealing whether month-space associations can modulate not only covert mental processing but also overt hand movements. Achieving this aim will also provide further evidence for the validity of this peculiar phenomenon.

However, month-space manipulations are not easy to employ since space is a somewhat ubiquitous property. In order to deal with this crucial matter, we generated a three-dimensional scene that simulated the synaesthete's experience in the most realistic way. This virtual environment was built by using a combined haptics and virtual reality system, which also enabled us to collect behavioural information beyond the standard measurements of reaction time (RT) and accuracy (ACC). To date, data collecting in behavioural synaesthesia research was mainly based on measurements of reaction time (referred to as the time interval between the stimuli presentation and the participant's response onset), which was usually obtained by a solitary response in the form of a button press. This kind of reaction measurement, however, may not reflect the unfolding of conflicting internal processes as well as manually reaching for a target might. The action of reaching for a target, even rapidly, gives a broader time window during which parallel processes can unfold and influence the ongoing movement. Thus, not only trajectories but also other kinetic and temporal properties related to the reaching movement reveal competing invisible processes. Song and Nakayama (2008) concluded that the locus of attention and the time course of target selection and response competition can be revealed by observing the movement trajectory (for a review, see Song & Nakayama, 2009).

Thus, in the current study, we measured RT as the time between stimulus onset and participant's

hand movement onset and two additional measurements that are usually unfeasible in standard computerized experiments: (a) initial movement velocity (IMV), which is the initial velocity of the hand movement (measured in units of meters per second); and (b) initial path angle (IPA), which is the initial angle deviation between the straight path from the hand's rest point to the trial target and the actual path made by the participant (measured in radians).¹ Additionally, we recorded the trajectories of the participants' hand movements, hoping to extract further information regarding internal processes, which are generally less accessible with regular methods.

A month-space synaesthete (S.M.) and a group of nonsynaesthete controls were tested on a task that was based on the spatial cueing and the Stroop paradigms. The experiment was composed of two tasks—a spatial task and a semantic task. In both tasks, a word and a circle were simultaneously presented on the screen. The word consisted of either a month name (e.g., May) or a direction name (e.g., right, up) located at the centre of the screen. The circle was displayed in one of four peripheral positions—right, left, top, or bottom. We manipulated word type (month name or direction name) and word-circle congruency (congruent or incongruent) between the circle position and word meaning. As can be seen in Figure 2, in the month condition, congruent trials were defined according to the month-form of the synaesthete, while in the case of the direction condition, congruency was naturally determined according to the location specified by the directive word.

In the spatial task, participants were asked to ignore the word meaning (task irrelevant) and reach for the circle. In the semantic task, they were asked to ignore the circle (task irrelevant) and reach for the location indicated by the meaning of the word. For example, if the word "up" was presented, they had to reach an upper point on the

¹ The initial angle and initial velocity were computed at a fixed distance from the point of movement onset. The movement onset was calculated based on the moment the hand moved from the central circular hand-rest stand.

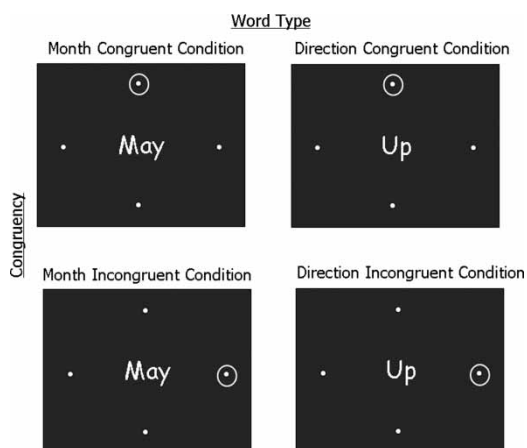


Figure 2. An illustration of the various conditions.

spatial virtual display while ignoring the peripheral circle. Alternatively, if a month name was presented, S.M. was asked to reach the spatial point indicated by this month according to her month-form. Since for nonsynaesthetes months do not consciously trigger a sense of spatial location, they were instructed to intuitively touch one of the peripheral targets on the virtual screen.

We anticipated that S.M.'s behaviour under both month and direction conditions would be similar, since for her, months are associated with specific spatial meanings similar to how direction words act for the general population. In contrast, we did not expect months to affect the controls' behaviour, since for nonsynaesthetes these words could be meaningless in the sense of explicit spatial information. In other words, for S.M. we expected a main effect of congruency, while for controls we expected a modulation of the congruency by the word type.

According to the automaticity definition of Tzelgov, Meyer, and Henik (1992), effects of the task irrelevant dimension on performance constitute an indication for the existence of an automatic process. In light of this definition, a congruency effect in the spatial block will imply that the word meaning (task irrelevant) was processed automatically, while a congruency effect in the semantic block will imply that circle location (task irrelevant) was processed automatically.

Clearly, a congruency effect in the spatial task would be considered quite astonishing since it would indicate an automatic shift of attention triggered by month names and/or directive words. However, according to the literature of the spatial Stroop effect (for a review see Lu & Proctor, 1995), the processing of the spatial location is much faster than the processing of the semantic meaning of words. Thus, it was unclear what to expect for the spatial task. Still, we hoped our extensive set of measurements could help us reveal concealed effects and thus draw more refined conclusions.

Method

Participants

S.M. is a right-hand dominant, 26-year-old bilingual English–Hebrew speaker who possesses synaesthetic associations for letters of the English and Hebrew alphabets, numbers, years of historical events, hours of the day, and months. S.M. is capable of projecting her month-form in an elliptical anticlockwise formation in front of her (see Figure 1). S.M.'s default perspective of the months is from behind October, but she can also see them from behind the current month, forcing the whole structure to rotate monthly.

The control group consisted of 5 undergraduate students who participated in the experiment in exchange for a small monetary amount or partial fulfilment of a course requirement. Every member of the control group was matched to S.M. by age, gender, language, dominant hand, and field of study. All participants gave their written informed consent to participate in the experiment and were unaware of its purpose. The experiment was approved by the local ethics committee.

Stimuli

The stimuli consisted of a word and four peripheral circles. On every trial, a randomly selected word was presented from among four directive words and four month names. The month names (February, July, May, and October) were chosen according to S.M.'s specific month-form and corresponded to the four directive words (right, left,

up, and down, respectively; see pretest mapping section).

In an attempt not to interfere with the synaesthete's representation of the months, the visible targets were chosen to be four small white spheres with 0.1 cm radius, always present in the display, marking the four peripheral positions. Nevertheless, the actual targets were transparent touchable spheres with 1.2 cm radius that enclosed each peripheral marker, making it possible to address the problem of reaching precisely for a small point in space and easing the stress of the hand movement.

Apparatus

All elements were three-dimensionally rendered by a Reaching Desktop display. A six-degrees-of-freedom PHANTOM^R (SensaAble TechnologiesTM) force-feedback device provided the appropriate haptic sensation for touch-like interaction with the graphics. The PHANTOM stylus, grasped by the participants, was used to trace their hand position, which was concealed from sight and displayed as a small purple sphere. In order to perceive the graphics, all participants observed the scene while wearing crystal eye glasses. Both stimuli presentation and data collection were conducted using this set-up, previously programmed through the Reaching Application Programming Interface (API) using Virtual Reality Modeling Language (VRML) and Python programming language.

Procedure

Each trial started with the appearance of a yellow circle in the centre of the display (initial point). The participant placed her hand on the initial position, which initiated the trial. One second later, a word and a circle were simultaneously presented. The word could be either a month name (e.g., February, July) or a direction name (e.g., right, down) and was located at the centre of the display, while the circle was placed around one of the four peripheral markers coinciding with the transparent surrounding sphere. Both the word and circle remained visible until the participant

reached the target, which indicated the end of the trial.

Congruency between word meaning and circle position was defined according to S.M.'s month-form. Thus, congruent trials were trials in which the circle position matched the spatial meaning of the word, while in the incongruent trials, these two dimensions conflicted.

The two tasks differed solely by the instructions given to the participants. In the spatial task, participants were asked to ignore the meaning of the presented word and reach for the peripheral marker surrounded by the white circle, while in the semantic task, both synaesthete and controls were asked to ignore the circle and reach for the location indicated by the word. Since months do not elicit any sense of direction for the control participants, they were instructed to intuitively reach for one peripheral location each time a month name appeared.

The participants performed the two tasks consecutively. The spatial task was always run first and the semantic task second. Each task consisted of two blocks of 192 randomized trials separated by a break. In each trial, one of the eight different words (four month and four direction names) was presented together with a circle, displayed in one of the four peripheral positions. The word and the circle were presented 12 times in a congruent configuration and 12 times in an incongruent one. Thus, each task contained 384 trials: 8 (different words) \times 2 (congruency levels) \times 12 (presentations) \times 2 (blocks). A block of 48 practice trials preceded each task.

Synaesthete S.M. performed both tasks in two different sessions approximately 2 months apart. In the first session, S.M. performed according to her default perspective of the month-form (as if she stood behind October). In the second session, S.M. reported that her month-form rotates monthly, and her perspective now was from behind the current month (i.e., July). Fortunately, the month-form rotated in such a way that the month that was previously represented on the bottom meridian (October) was now represented on the right meridian, whereas the month previously represented on the right

meridian (February) was now represented on the top meridian and so on. This anticlockwise shifting enabled us to use the same months in both sessions but in different spatial positions (i.e., May on the left, February at the top, October on the right, and July at the bottom). Thus S.M. performed the tasks in two sessions, one in which she used her default perspective and another in which she used the perspective of the current month.

Design

The manipulated variables for each task (spatial task and word task) were word type (month name vs. direction name) and word–circle congruency (congruent vs. incongruent). The dependent variables were: reaction time (RT), accuracy (ACC), initial path angle (IPA), and initial hand velocity (IHV).

Pretask mapping

In order to find the month corresponding to each one of the four positions (top, bottom, right, and left), the experiment was preceded by a month–location mapping test. In each trial, the name of

a month was presented at the fixation point, and synaesthete S.M. was required to reach for the month’s location on the virtual display as it appeared in her “mind’s eye”. The mapping test was performed at the beginning and at the end of each of the two experimental sessions, resulting in a total of four mapping measurements. As can be seen in Figure 3, the mapping of S.M.’s months in virtual space matches her self-reported month–form (Figure 2).

Results

Consistency analysis

In order to verify consistency of the synaesthetic representation over time, Pearson correlations were computed between every possible pair of the four mapping sessions. Namely, we carried out correlations between each combination of sessions across 12 months. Synaesthete S.M. showed a high consistency in locating the months in their fixed placements. Highly significant correlations were found for both x , $r(12) \geq .96$, $p < .001$, for all correlations, and y coordinates, $r(12) = .99$, $p < .001$, for all correlations.

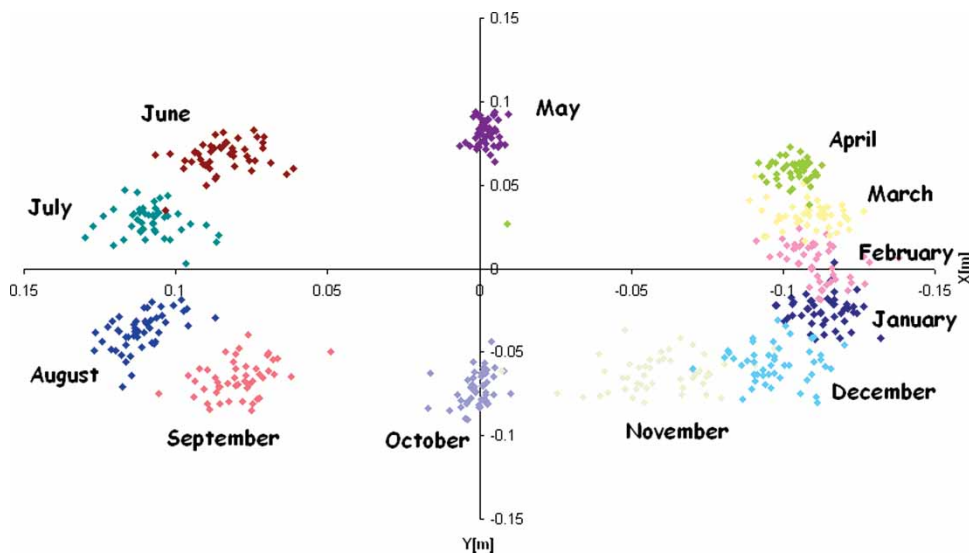


Figure 3. XY coordinates of S.M.’s mapping across repetitions. Each point represents one reaching trial. To view a colour version of this figure, please see the online issue of the Journal.

Spatial task

All participants were 100% accurate in this task. Means for reaction time (RT), initial path angle (IPA), and initial movement velocity (IMV) were calculated for both S.M. and controls. These mean values were subjected to a three-way analysis of variance (ANOVA) with group (synaesthete, controls) as a between-subject factor and word type (direction, month) and word-circle congruency (congruent, incongruent) as within-subject factors.

For both synaesthete S.M. and controls, no interaction or main effects were found to be significant for all measures (all F s < 1, *ns*).

Semantic task

The same three-way ANOVA was performed as that in the previous task. Error rates were generally low (2% for synaesthete S.M.).

For S.M., main effects of congruency were found for all three measures: $F(1, 4) = 22$, $MSE = 0.26$, $p < .005$; $F(1, 4) = 74$, $MSE = 0.003$, $p < .005$; $F(1, 4) = 212$, $MSE = 0.000$, $p < .001$, for RT, IPA, and IMV, respectively. Further analyses revealed significant congruency effects in the direction names condition for IPA and IMV measures: $F(1, 4) = 14.4$, $MSE = 0.008$, $p < .025$; $F(1, 4) = 18.5$, $MSE = 0.0001$, $p < .025$, respectively. However, these effects were only nearly significant for RT measures, $F(1, 4) = 4.7$, $MSE = 0.56$, $p = .09$. Crucially, significant congruency effects were found for all measures in the month names condition: $F(1, 4) = 8.4$, $MSE = 0.38$, $p < .05$; $F(1, 4) = 34$, $MSE = 0.003$, $p < .005$; $F(1, 4) = 440$, $MSE = 0.0001$, $p < .001$, for RT, IPA, and IMV, respectively (Figure 4, A–C).

For controls, significant interactions between word type and congruency were found for all measures: $F(1, 4) = 10.6$, $MSE = 0.7$, $p < .05$; $F(1, 4) = 8.5$, $MSE = 0.008$, $p < .05$; $F(1, 4) = 9.5$, $MSE = 0.0001$, $p < .05$, for RT, IPA, and IMV, respectively. Further analyses revealed a significant congruency effect for the direction name condition, $F(1, 4) = 27$, $MSE = 0.6$, $p < .01$; $F(1, 4) = 15.2$, $MSE = 0.009$, $p < .025$; $F(1, 4) = 8.8$, $MSE = 0.0001$, $p < .05$, for RT, IPA, and IMV, respectively, but not for the month name condition, $F(1, 4) < 1$, *ns*; $F(1, 4) < 1$, *ns*; $F(1, 4) =$

5.3, $MSE = 0.0001$, *ns*, for RT, IPA, and IMV, respectively, as was expected (Figures 4A–4C).

Moreover, we analysed S.M.'s performance in the two different sessions carried out approximately 2 months apart. Generally, the pattern of results of the first session was replicated in the second one; namely, S.M. showed a congruency effect for month names as well as for direction names in the semantic task, $F(1, 4) = 8.5$, $MSE = 0.26$, $p < .05$; $F(1, 4) = 128$, $MSE = 0.003$, $p < .001$; $F(1, 4) = 87$, $MSE = 0.000$, $p < .001$, for RT, IPA, and IMV, respectively, but not in the spatial one, $F(1, 4) < 1$, *ns*; $F(1, 4) = 1$, $MSE = 0.000$, *ns*; $F(1, 4) = 5$, $MSE = 0.000$, *ns*, for RT, IPA, and IMV, respectively.

Note that S.M. has two possible perspectives: a default perspective and a current month perspective, due to the monthly rotation of her month-form. Thus, the two sessions differed in their month-space association. Specifically, month-space associations that were congruent in Session 1 became incongruent in Session 2. For example, in Session 1, July triggered leftward movements (i.e., July + left position of the circle = congruent trial), while in Session 2, July triggered downward movements (i.e., July + left position of the circle = incongruent trial).

In order to dissociate behaviour from month-space association we performed a two-way ANOVA with perspective (default vs. rotated) and session (first vs. second) as within-subject factors, only for the month name condition. A significant interaction between these two variables was observed for all three measurements: $F(1, 3) = 78$, $MSE = 0.2$; $p < .005$; $F(1, 3) = 43$, $MSE = 0.02$, $p < .01$; $F(1, 3) = 50$, $MSE = 0.000$, $p < .01$, for RT, IPA, and IMV, respectively. Namely, RTs for congruency determined according to the default perspective were shorter in the first session than in the second one, while RTs for congruency determined according to the rotated perspective were shorter for the second session than for the first one (Figure 5).

Analysis of movement trajectories

S.M.'s hand movement trajectories were recorded during every trial of the experiment. Two

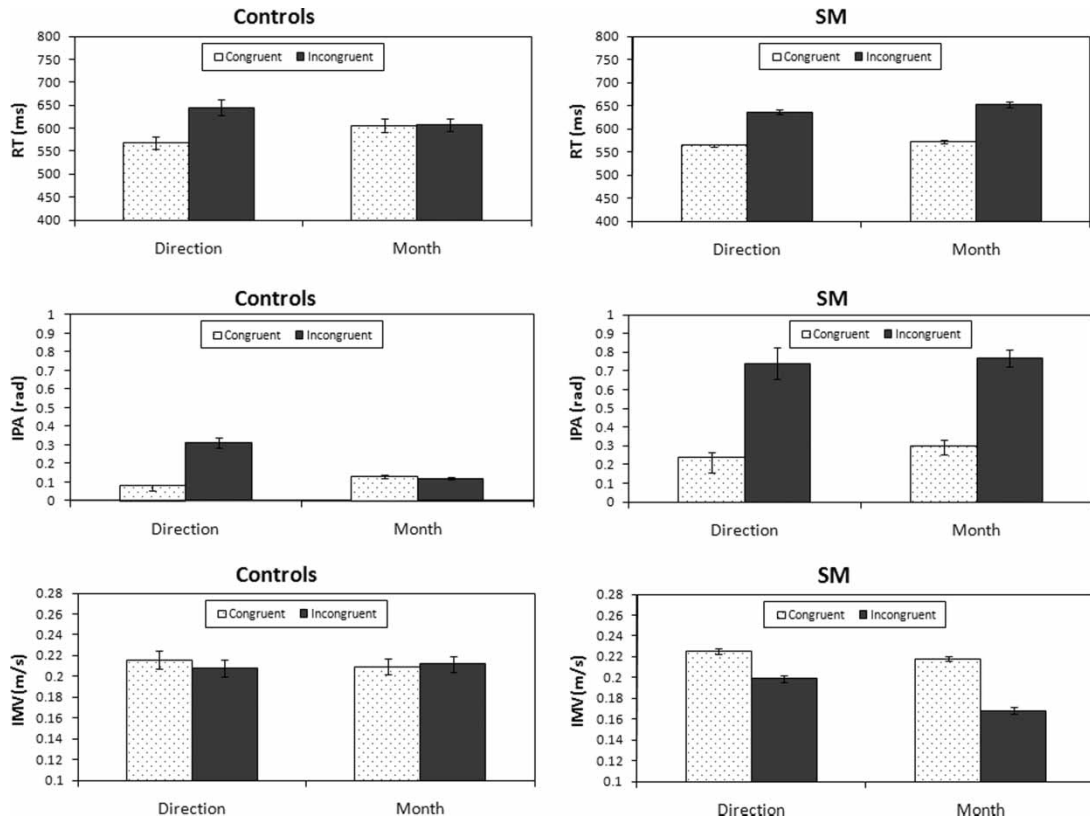


Figure 4. Mean (A) reaction time (RT), (B) initial path angle (IPA), and (C) initial movement velocity (IMV), as a function of word type, congruency, and group in the semantic task.

statistical measurements were calculated in order to analyse these hand movements: (a) the total trajectory length (in cm), and (b) the standard deviation (in cm) from the optimal (shortest) hand path to the target. These measurements were subjected to a two-way ANOVA with congruency and word type as the within-subject factors.

As can be seen in Figure 6, A and B, synaesthete S.M. showed similar hand trajectory patterns for both month and direction trials. Specifically, in the semantic task, S.M.'s mean path deviation was significantly larger for incongruent trials than for the congruent ones, both for the month, $F(1, 43) = 19$, $MSE = 0.0001$, $p < .001$, and for the direction condition, $F(1, 43) = 9.1$, $MSE = 0.0001$, $p < .005$. Similarly, the

mean trajectory length was shorter for congruent than for incongruent trials for both conditions: $F(1, 43) = 17.8$, $MSE = 0.0004$, $p < .001$; $F(1, 46) = 11.5$, $MSE = 0.0007$, $p < .0025$, for month and direction, respectively. The opposite trend was observed in the spatial task, wherein no significant effect was found for the mean deviation or for the mean path length (all F s < 1 , *ns*).

Discussion

The current study was aimed at investigating the phenomenon of month-space synaesthesia by revealing its manifestation in the domains of attention and action. Commonly, behavioural research is restricted to the study of the

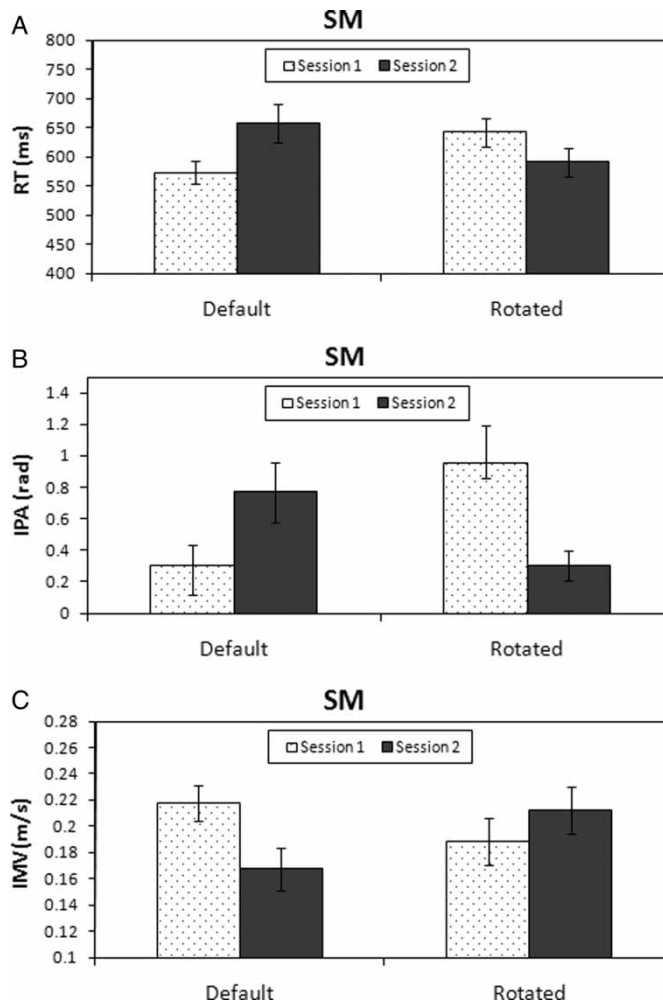


Figure 5. Mean (A) reaction time (RT), (B) initial path angle (IPA), and (C) initial movement velocity (IMV), as a function of session and perspective of S.M. in the semantic task. Error bars depict one standard error of mean.

initialization of movement (RT). However, the novel employment of a virtual reality technique in the current study allowed us to evaluate the effect of the synaesthetic experience on the actual movement.

We obtained significant results for the semantic block, in which participants were instructed to ignore the location of the circle and reach for the location directed by the word. Specifically, synaesthete S.M. displayed a congruency effect for both direction words and month names—that is, she was faster and more accurate in her

movement toward the correct location when the circle's placement matched the location referred to by the word. In contrast, the controls showed the congruency effect only for direction words, but not for month names.

It is well established by now that directional words trigger shifts of attention to the indicated locations, whether they are relevant or irrelevant to the task at hand (e.g., Hommel, Pratt, Colzato, & Godijn, 2001; Logan & Zbrodoff, 1979). Since month names do not function as social conventions for directive information, they

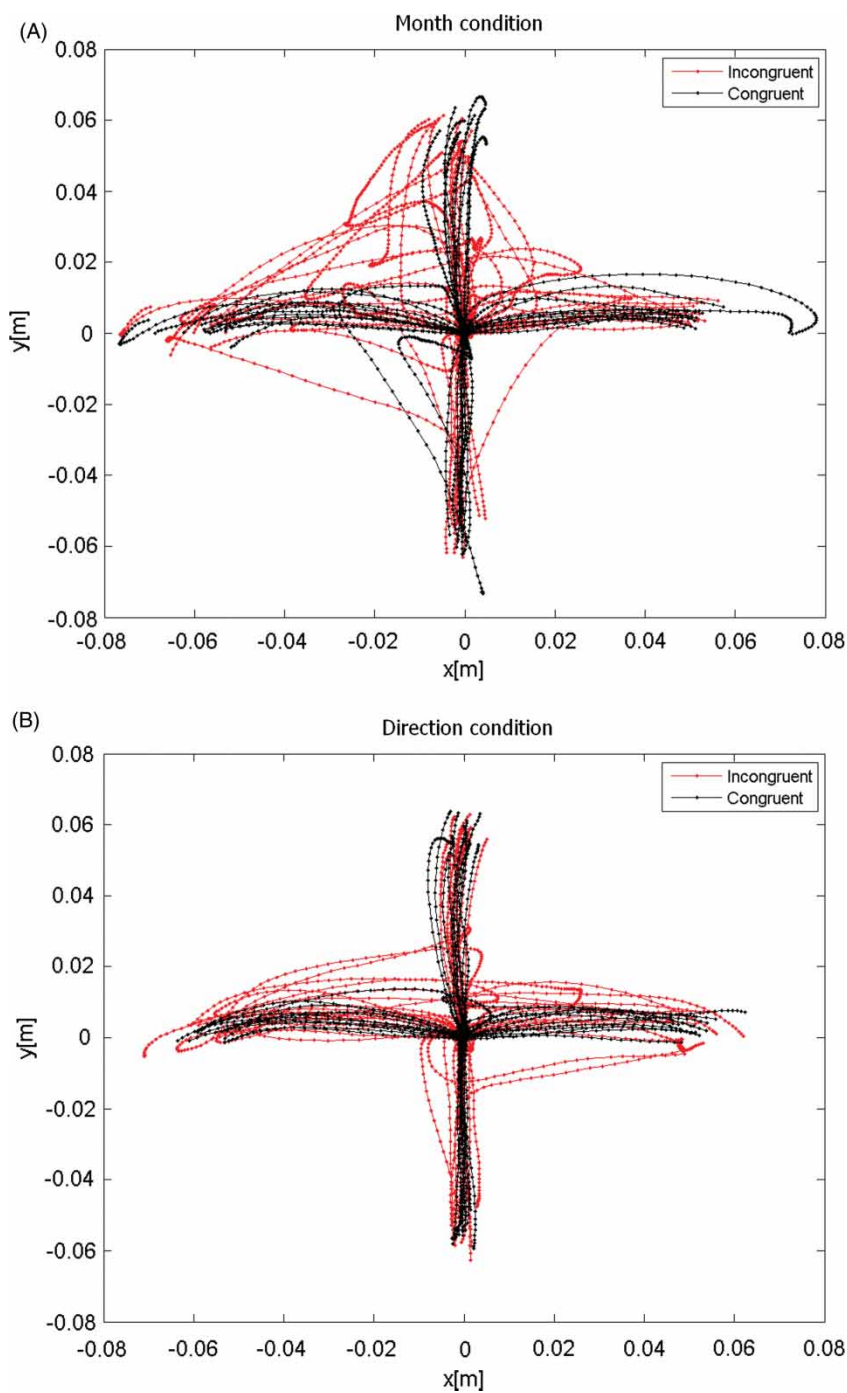


Figure 6. Synaesthete S.M.'s hand trajectories as a function of congruency for (A) month and (B) direction conditions. To view a colour version of this figure, please see the online issue of the Journal.

are not expected to operate the same way as direction words do. Nevertheless, our findings suggest that they might serve as such for month-space synaesthetes. According to our results, for synaesthetes, but not for controls, month names oriented attention to specific locations in a similar manner as directional words did. These shifts of attention were in line with the particular synaesthetic month configuration and affected performance accordingly.

Our results showed that these selective shifts of attention affected not only the initiation of movement but also the entire movement. In other words, the interaction of the spatial cueing with the synaesthetic percept of the month affected hand movements. As depicted in Figure 6A, in incongruent trials, S.M.'s hand movement involuntarily advanced in the direction of the peripheral circle and subsequently veered toward the correct spatial location. We suggest that this pattern of action accounts for the congruency effect found for the latent measurement—RT, IPA, and IMV. Namely, the additional manual reaching measurements helped us to reveal spatial manifestations of internal cognitive processes. Thus, it would be reasonable to argue that month-space synaesthesia biases visuospatial attention, which in turn affects not only latent cognitive processes but also overt actions.

Selective attention is crucial for perception in the sense that it functions as a filter for the perceptual system in order to prevent an overload by the surrounding world. In addition, studies showed that selective attention is necessary in order to control (restrain or facilitate) possible actions (e.g., Johnson & Proctor, 2004). For example, the visual attention model (VAM) postulates that selection for perception and selection for action are bounded together through a common mechanism of visual attention. Namely, intentional shifts of attention to certain stimuli also establish a motor program for action on these stimuli (Schneider, 1995). The current study strengthens this reasoning by showing that actions within the virtual space were modulated according to the allocation of attention evoked by the meaning of the word. This was evident

not only for directive words in general but also for month names, bolstering the notion that month-space synaesthesia is a genuinely authentic condition.

Our experiment was composed of both spatial-cueing and Stroop-like elements, allowing us to examine the processes of voluntary versus automatic attentional control.

We did not manage to show automaticity of word processing (month or direction) as evidenced from the null effects in all measurements of the spatial task (word irrelevant dimension). Namely, month names and directive words did not automatically evoke shifts of attention to the corresponding spatial locations, either for synaesthete or for controls. How can this asymmetry in the results be explained? The lack of congruency effect in the spatial task fits with numerous studies showing asymmetry in spatial Stroop effects (e.g., Logan & Zbrodoff, 1979; Palef & Olson, 1975; Seymour, 1973; for a review see Lu & Proctor, 1995). In these studies, ordinary participants were presented with location words (e.g., below, right) in matching or conflicting spatial positions. Participants were asked to indicate the word position and ignore its meaning (spatial task) or to attend the word meaning while ignoring the word spatial position (word task). In all these studies, Stroop-like effects were found only in the word task but not in the spatial one. Palef and Olson (1975) suggested that the occurrence of Stroop interference is due to the relative time required to process the relevant and irrelevant aspects of the stimulus. Accordingly, we believe that the lack of congruency effect in our spatial task demonstrates this exact situation; that is, the faster process (location of a word) modulates the slower one (meaning of a word) but not vice versa. Interestingly, Palef and Olson also showed (Experiment 2) that when equalling the processing speed of the two dimensions, interference occurs in both directions. This is also in line with Logan and Zbrodoff (1979), who suggested that the spatial Stroop asymmetry is ascribed to the "extent to which the information is available early enough to be attended" (p. 172).

Thus, in order to verify whether our results are indeed a matter of differences in speed of processing, we analysed the data from the spatial task using a variation of the Vincentizing analysing method (Vincent, 1912). This analysis enables forming groups of latencies (RT) distributions according to percentiles: The first quartile includes means ranging within the shortest 25% of trials of the distribution, the second and third quartiles include means ranging within the middle 50% of trials of the distribution, and the fourth quartile includes means ranging within the longest 25% of trials of the distribution. Mean RTs of correct responses were submitted to a three-way ANOVA with word type (months vs. directions), word-circle congruency (congruent vs. incongruent), and time (first, second, third and fourth quartile) as within-subject factors.

Reasonably, we were interested only in the fourth quartile, which includes means ranging within the highest 25% of the trials of the distribution. No interactions between quartile and any of the two other variables (i.e., congruency and word type) were found to be significant (Table 1). This suggests that word meaning did not modulate the effect of physical location, regardless of general RT.

Alternatively, spatial attention might be another possible platform for explaining the asymmetric results between the spatial and semantic tasks in our study. In a typical trial, an abrupt exogenous peripheral stimulus (circle) was presented simultaneously with an endogenous informative central one (word). The exogenous stimulus is assumed to automatically capture attention while the endogenous stimulus allocates

attention volitionally (Jonides, 1981; Yantis & Jonides, 1990). According to the literature, exogenous shifts of attention are thought to be autonomic and quickly initiated, while endogenous shifts of attention are considered to be slower to initiate and are under volitional control (e.g., Berger, Henik, & Rafal, 2005; Johnson & Proctor, 2003; Muller & Rabbitt, 1989). Thus, when the fast process of abrupt onset of a relevant peripheral circle competed with the slower process of a central irrelevant word, as was the case in the spatial task, no effects were observed. However, in the semantic task, when the setting was reversed, and the meaning of the word became the relevant information while the location of the circle became irrelevant, the fast automatic process interfered with the slow volitional one, and a congruency effect was observed. Unfortunately this is not to say that months oriented attention automatically; however, we would like to argue that the spatial properties of the months were processed early enough (and maybe even in line with the process of the spatial circle) to conflict with the circle's location and, in turn, to affect S.M.'s attention and action (see detailed discussion in the following section).

Do nonsynaesthetes have month-space associations?

We cannot disregard the fact that congruency was defined according to the synaesthete's experience and thus might not reflect possible month-space associations of nonsynaesthete participants. In order to verify that controls truly did not have a congruency effect for month-space associations, two manipulations were employed for the month condition of the semantic task. First, we searched

Table 1. Reaction time as a function of word type, congruency, and quartile

	Word type							
	Month				Direction			
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Congruent	343	372	392	428	339	369	386	429
Incongruent	340	364	385	424	339	367	388	419

Note: RT = reaction time (ms) from stimulus presentation until the start of participant response; Q = quartile.

for common strategies that could be used by the control participants. No systematic patterns of performance were detected within or between participants. For instance, some participants showed preference to reach a constant location regardless of the month name; others tended to reach for the circle (which was supposed to be ignored). Second, we analysed the controls' results under the assumption that a possible hidden strategy was being used. We divided the controls' data, trial by trial, according to whether their reaching location was the same as the circle position or different from it. That is, any trial where the participant's reaching location coincided with that of the circle was considered a congruent trial based on the participant's own strategy (if one was indeed employed), while trials where the reaching location did not coincide with the circle location were considered to be incongruent trials.

One participant was excluded from the analysis since she always reached for the circle, and thus no incongruent trials could be extracted from her data. Importantly, the rest of the controls did not show a congruency effect for the RT and IMV measurements: $F(1, 3) = 5.4$, $MSE = 0.1$, ns ; $F(1, 3) = 1.7$, $MSE = 0.0001$, ns ; for RT and IMV, respectively. However, the IPA analysis showed a significant congruency effect, $F(1, 3) = 18.2$, $MSE = 0.0006$, $p < .05$. How can that be? While all the other latent measurements quantify the initiation of the movement and do not take into account the final reaching location, the IPA calculates the gap between the participant's initial trajectory and the final reached target. Thus, the effect found for the IPA indicates that independent of the month name presented, the controls started their hand movement by reaching in the direction of the circle and only then veered to a different location or continued their movement toward the circle. Combined with the fact that none of the other measurements produced a congruency effect, it would be reasonable to conclude that the controls' behaviour was seemingly random, which in turn validates our claim that month names were spatially uninformative for them.

The above supplementary findings lead to two important observations. First, S.M. and controls

performed similarly in the sense that for both, attention was first captured by the peripheral circle, and they initially reached towards it. However in contrast to controls, S.M. modulated her action by veering to the "right" location, indicated by the word meaning. This is shown by the IPA measure since the initial angle is the only parameter that relates the immediate response of the participant with the final response—all other parameters report the participants' first reaction.

Second and most important, it seems that S.M.'s month-space association is activated early enough (perhaps at the same time as the peripheral circle) to affect response, even with the circle interfering with S.M.'s action. This observation comes from the fact that control participants showed a congruency effect for IPA but not for the other measures. Since the controls' first reaction was always toward the circle, all other measures did not present congruency effects; for example, average RT was the same for congruent and incongruent trials because the controls' initial reaction was always to reach for the circle, independently of the month presented. However, S.M. presented congruency effects not only for IPA, but for all other measures. Namely, although similarly to the control participants, S.M. started every movement by initially reaching for the circle, her synaesthetic association became activated at an early stage of processing and conflicted with the circle spatial location. Otherwise, we would expect to see the same pattern of effects as that of the controls—that is, a congruency effect only for IPA, but not for all the other measures.

These two observations strengthen our argument that S.M.'s month-space associations are authentic and are processed early enough to disrupt reflexive shifts of attention triggered by exogenous peripheral spatial stimuli.

Summary

This study is the first experimental work presenting attentional/perceptual effects of synaesthesia on overt behaviour (i.e., action). We found that

for synaesthetes, but not for controls, month names and spatial location interactively affected hand movements. This was indicated by a congruency effect in all measures of reaching performance (i.e., trajectory, velocity, angularity, and latency of movement). Although automaticity of word processing was not achieved, this does not mean that month names or directive words have no potential to automatically trigger spatial shifts of attention. Further research designed to test the spatial Stroop effect under conditions where the two dimensions are manipulated to have equal processing speed is required. Such a study might provide us with a broader understanding of the potential of month-space perceptions to automatically affect performance.

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