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Leftward bias in number space is modulated by magical ideation

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Abstract

Background: Productive symptoms of schizophrenia and positive-symptom schizotypy have both been related to signs of right-sided hemispatial inattention ("pseudoneglect"). We here set out to explore, in healthy subjects, the relationship between mild schizotypy ("magical ideation", MI) and asymmetries in number space, i.e. a bias towards relatively small numbers, reportedly represented to the left of larger numbers.

Methods: Forty right-handed participants filled in the MI scale and performed a number line bisection (NLB) task and a randomization task (the Mental Dice Task, MDT, requiring randomization of the digits from 1 to 6).

Results: We found a pseudoneglect in number space, i.e. more errors towards small numbers in the NLB task and an overproduction of small digits in the MDT. Individual participants' MI scores were correlated to the size of pseudoneglect in both numerical tasks.

Conclusions: Explicit (NLB) and implicit (MDT) assessments of the exploration of number space may be relevant to studies of the mechanisms underlying the formation of delusional and schizotypal beliefs. We propose that, in healthy subjects, a trait-like imbalance in hemispheric cooperation may not only produce asymmetries in physical and representational space, but also predisposes to develop magical ideas. Specifically, an overproportional influence of the right hemisphere semantic system (preferentially coding oblique and remote associations) leads to the assumption of connections between randomly associated events.

Keywords: space representation; number space; pseudoneglect; schizotypy/schizophrenia; random number generation

Introduction

As early as 1936, Hungarian psychiatrist and psychologist Andras Angyal (1902-1960) described an exaggerated bias towards the left hemispace in a patient with schizophrenia (1). This patient, when asked to point to target objects placed in front of his body erred slightly (1 to 4 cm) but consistently to the left. The magnitude of this deviation was larger when the patient's psychosis was more florid. "On one occasion, which was marked by an exacerbation of his psychotic symptoms in general, the past pointing was from 15 to 18 cm" (1, p.1048).

More than half a century later, group studies have confirmed the association between acute schizophrenia and an overattention to the left side of space (e.g., 2, 3). These studies also confirmed Angyal's original observation that symptom severity was significantly correlated to the size of this left-sided bias. Thus, in one experiment (4) patients' spontaneous tendency to rotate in leftward, counterclockwise circles was related to the severity of their delusions. In another study, schizophrenic patients' tactile bisections of a rod deviated the further to the left, the more pronounced their scores on a scale rating their productive psychotic symptoms were (5). Antipsychotic medication was found to reverse hemispatial biases; while unmedicated patients with schizophrenia preferably orient towards the left, they re-orient in a more rightward direction after pharmacological treatment (6).

A relative overattention to the left side of space, notably equivalent to a "neglect" towards the right hemispace, is also observed in healthy subjects and labeled "pseudoneglect" (7, 8). It is usually explained by a dominance of the healthy right hemisphere in spatial attention, and its especially marked manifestation in schizophrenia has been taken as evidence for a right-sided hyperdopaminergia (3).

We have previously shown that, within populations of completely healthy university students (mostly men), the magnitude of left-sided deviations in spatial exploration tasks is correlated with their scores on a scale assessing schizophrenia-like experiences and beliefs, i.e. the “magical ideation” (MI) scale (9-11; but see ref. 12 for a non-replication). This was interpreted as evidence for a hemispheric imbalance in subjects with elevated MI scores. Specifically, a “right hemisphere processing bias” would not only manifest itself in a pronounced orientation towards the left hemispace, but would also bring with it an overreliance on right hemisphere language contributions. These primarily comprise a propensity to favor remote over close associations (e.g. 13, 14) and seduce to attribute undue meaning to chance coincidences in everyday life – the core symptom of magical thinking (15; ref. 16 for review).

In one experiment, we found a correlation between MI and a measure of leftward deviation exclusively for drawings *made from memory* (but not during a copying task). This lateral bias in one’s *representation of space* and its apparent link to a person’s belief systems stimulated the present investigation. In the present study, we thus set out to explore healthy individuals’ asymmetric orientation in “number space”, an entity whose spatial nature is probably more than a metaphor (17, 18). In brief, for any given numerical interval, relatively small numbers (smaller than the arithmetic mean of the sum of smallest and largest number) are implicitly and automatically associated with the left side, and relatively large numbers with the right. We assessed individual asymmetries in number space with a numerical bisection task (19) and a random digit generation task (20).

Methods

Subjects: Twenty women and 20 men volunteered in the experiment. They were recruited by flyers posted at the University of Zurich which announced a “brief behavioral experiment in number processing”. Subjects’ mean age was 26.2 years (SD=5.2 years), and all had at least a College degree (most were students or University affiliates with a University degree). A standardized interview (21) excluded subjects with a history of psychiatric or neurological illnesses and those who had first-degree relatives with such a history. Subjects with significant learning disorders or substance abuse were also not included. All subjects were right-handed (22) and gave written informed consent for the study that had approval of the local Ethics Committee.

Tasks: The first task was number-line bisection (NLB), adopted from ref. 19. It required subjects to produce the number representing the middle of an auditorily presented number interval. A sample stimulus is: “2 and 8”, correct response would be 5. There were 22 stimuli and three different interval sizes (3, 5, and 7). Each stimulus pair was once presented with the smaller digit called out before the larger and once in the opposite order. Subjects were strongly encouraged to respond as fast as possible, and no proper calculation was allowed. We calculated the number of incorrect responses that were numbers smaller than the arithmetic mean of lower and upper border (further on designated as “mid-number”) and those that were larger numbers. Note that, in spatial terms, these two error types correspond to “left-sided” and “right-sided” errors, respectively.

The second task was the Mental Dice Task (MDT), a standardized random digit generation test with a vast application history in both clinical and experimental contexts (see ref. 23 for overview). It requires subjects to mimic the falls of a die, i.e. to produce the digits from 1 to 6 in a sequence that could emerge “if they were to roll a real die over and over again”. Generation was paced at a metronomic rate of 1Hz, and a total of

66 responses were collected. For the present purpose we calculated the number of "small" digits generated by a subject (1, 2 and 3; representing the "left" side of the number space 1 to 6). This measure is a reliable indicator of healthy subjects' asymmetries in number space (20).

MI scale: This scale was originally introduced as a schizotypy inventory (24). It contains 30 true/false items of the type "I have felt there were messages for me in the way things were arranged, like in a store window" and "I have never had the feeling that certain thoughts of mine really belong to someone else" (reverse scoring). A higher score denotes thus a more distinct inclination of schizophrenia-like experiences and beliefs. Normative data can be found in ref. 25, and the English language version of the scale is printed in full in refs. 24 and 26.

Procedure: Subjects were first administered the MDT, followed by the NLB task. After about half an hour of additional testing, unrelated to the topic of the present report, they filled in the MI scale.

Results

<u>MI</u>: Scores ranged from 0 to 18, with a mean scale score of 8.35 (SD=4.29). Women (mean 8.8, SD=3.5) did not score higher than men (7.9, SD= 5.0; t=.66, p=.51). By a split at the median scale score (8.0) we created a "low MI" group (scores 0 to 8) and a "high MI" group (scores 9 to 18). Each group contained 20 subjects.

<u>NLB</u>: 23.50% (SD=3.4) of responses were correct. Analysis of the errors showed that those representing numbers smaller than the actual mid-number (M=5.0, SD=2.81)

exceeded those representing numbers larger than the mid-number (M=3.6, SD=1.92; t=2.6, p=.014).

ANOVA with MI-group as a between-subject factor and interval size as the repeated measure revealed a significant main effect of MI group (F=17.8, p<.0001) and a significant effect of interval size (F=4.31, p=.017). Subjects of the high MI group deviated more towards small numbers than subjects of the low MI group (t=3.3, p=.002). Furthermore, “leftward” deviations were largest for the intermediate interval, followed by the smallest interval, and then by the largest interval, where they were numerically, but nonsignificantly (t=.16, p=.88), larger than the actual mid-number (Fig.1). The interaction between MI group and interval size was not significant (F=.77, p=.47).

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INSERT FIGURE 1 ABOUT HERE
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Correlational analyses revealed that MI raw scores were significantly related to both the number of specifically “leftsided” errors (r=.43, p<.01; Fig. 2A) and the mean deviation from the actual mid-number (r=-.56, p<.001; Fig. 2B). “Rightsided” errors were tendentially negatively correlated to MI scores (r=-.28, p=.08). Correlations between MI raw scores and mean deviations in the 3 intervals separately (interval sizes 3, 5, and 7 digits) were all negative, with correlation coefficients of -,51, -.37, and -.30, respectively (corresponding p-values: <.001, .020, .056).

Although the direction of these correlational effects was the same for both sexes, they remained significant for the 20 men (r=.51, p=.02 for the correlation between MI and the number of errors smaller than the actual mid-number and r=-.65, p<.01 for the correlation between MI scores and mean deviation in units of 1) but not for the 20 women (r=.28, p>.23 and r=-.41, p>.05, respectively).

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INSERT FIGURE 2 ABOUT HERE
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MDT: Overall, the 40 subjects produced slightly more “small” digits (digits 1,2,3) than “large” digits (4,5,6), a difference that just reached significance by 1-tailed testing (paired t-test: t=1.7, p=.050). A clearer picture emerged when looking at the *number of subjects* producing more “small” than “large” digits. These were 20 subjects, only 10 showed the opposite relationship, and a further 10 produced exactly 33 “small” and 33 “large” digits (Wilcoxon signed rank test: Z=1.7, p<.05, two-tailed). This difference was clearly due to the subjects of the high MI group, of which 11 had more “small” than “large” digits and only 5 showed a reverse pattern (4 ties; Z=1.7, p<.05). The respective numbers for the low MI subjects were 9, 5 and 6 (Z=.72, p>.46).
Correlational analyses (Fig.3) revealed that the number of “small” digits was correlated with MI raw scores (r=.29, p=.03, one-tailed), with no notable difference in the correlation coefficients for women (r=.25) and men (r=.36).

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INSERT FIGURE 3 ABOUT HERE
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Correlations between NLB and MDT: Both number of “left-sided” errors and mean deviation in the NLB task were weakly related to the number of “small” digits in the MDT (r=.28, p=.077 and r=-29, p=.073).

Discussion

Forty right-handed subjects solved two tasks that reportedly allow a reliable quantification of asymmetries in number space and we found that the individual extent of "leftward deviations" (errors representing too small numbers) correlated with the expression of schizophrenia-like experiences and beliefs ("magical ideation"; 24).

The first task, NLB, was originally introduced in patients with right parietal damage (19), who produced too large numbers, i.e. erred towards the right side of an imaginary number line. The opposite deviation, interpreted as a pseudoneglect in number space, was demonstrated in healthy subjects (27, 28), and appears to correlate with leftward biases in the bisection of physical lines (29). Of particular importance to the topic of the present communication is an experiment that described exaggerated leftward deviations in NLB for a group of 11 patients (8 men) with schizophrenia (30). This finding was interpreted as an equivalent to previously described effects of hemispatial inattention in schizophrenic patients' exploration of real space (e.g., 2-6). We here extended these findings to a population of healthy right-handed subjects by showing that the more distinct MI as an "indicator of schizotypy" (24, p. 215), the more pronounced the bias towards the left side of number space.

This leftward bias in numerical bisection was also found in the second task, the MDT, requiring the randomization of the digits 1 to 6. Random number generation was recently introduced as a promising paradigm for assessing asymmetries in number space (20). Specifically, it was demonstrated, in more than 480 healthy subjects, that a significant overrepresentation of small numbers was prominent in the MDT. The spatial character of this pervasive number habit was rendered plausible in a series of experiments. For instance, positive correlations were found between the amount of small-number biases and the magnitude of left-visual field cueing in the perceptual judgment of chimeric faces. While previous research had established associations between MI and an overreliance on the left compared to the right half of such composite faces (31), the findings of the present study show a similar association for the left half of number space when it is explored with the MDT.

In striking accordance with an experiment that described a clear correlation between MI and leftward deviations in a tactile bisection task (9) in 20 men, but not in 20 women, the present correlation between MI and leftward deviations in NLB was likewise exclusively present in the men. This sex difference could be a consequence of more general differences between women and men in both magnitude and stability of functional hemispheric differences (32, 33). However, no sex difference was observed in the significant association between MI and the small-number bias in the MDT, emphasizing differences in explicit (NLB) and implicit (MDT) assessments of number space (34; 35).

The present results corroborate several previous findings of a correlation between MI and the magnitude of pseudoneglect, both in real space (e.g. 9, 11) and in spatial imagery (10). They highlight the usefulness of numerical bisection and randomization paradigms for quantifying the relationships between even mild schizophrenia-like thinking and asymmetries in highly abstract representations of left and right.

What could be the nature of the association between magical thinking and an orientation bias towards the left side of both physical and representational space? As noted in the Introduction, the roots of magical ideation are peculiarities of semantic processing (36). Numerous experiments have shown that those who score high on the MI scale show a preference for remote over close associations (37-39). The neuropsychological basis of such a preference is an overreliance on a right hemisphere semantic system (13, 40), and the association between magical thinking and lateral spatial attention thus originates in an imbalance in hemispheric asymmetries affecting both linguistic and spatial processing (10). We emphasize that the relationships between functional hemispheric asymmetries and the propensity to believe in causative forces that are empirically unsubstantiated are more than a scientific curiosity. Their investigation directly leads to central questions of the evolution of cerebral hemispheric asymmetries. While some authors focus on the breakdown of asymmetry in those scoring high on MI (e.g. 41), we have ourselves propagated the idea of the Janusian face of an overreliance on a coarse right hemisphere associative style (39). Specifically, we think that magical ideas are the price we have to pay for a keen sense to "see" meaningful connections between apparently independent events. Viewed from this stance, MI and related paranormal beliefs may well serve as a creative spark that balances the reduced biological fitness associated with a psychotic-like style of thinking (42, 43).

Future research will have to pinpoint those cortical networks jointly representing physical, representational and semantic space (33). Such work will not only elucidate the role of the two cerebral hemispheres for the genesis of psychotic thought (44), but also contribute to the longstanding question of the similarities between genius and madness (14, 16).

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Figure Legends

Fig. 1:

Number line bisection of three interval sizes: mean deviation from actual mid-number (in units of 1) separately for the 20 subjects of the low MI group (white columns) and the 20 subjects of the high MI group (black columns).

Error bars represent 1 standard error of the mean.

Fig. 2:

Number line bisections: Correlation between subjects' raw scores on the Magical Ideation Scale and (A) total number of errors smaller than the actual mid-number ("left-sided" on number line) and (B) mean deviation in units of 1 from actual mid-number (negative values indicate "left-ward" deviations from actual mid-number).

Fig. 3:

Correlation between subjects' raw scores on the Magical Ideation Scale and the pseudoneglect in random number generation ("Mental Dice Task", 66 random numbers from the interval 1 to 6). Black dots/lettering corresponds to data of 20 men, light grey dots/lettering to data of 20 women. Large dots represent two subjects (white for different gender). Dashed vertical line indicates chance expectation for small (and large) digits.

Fig.1:

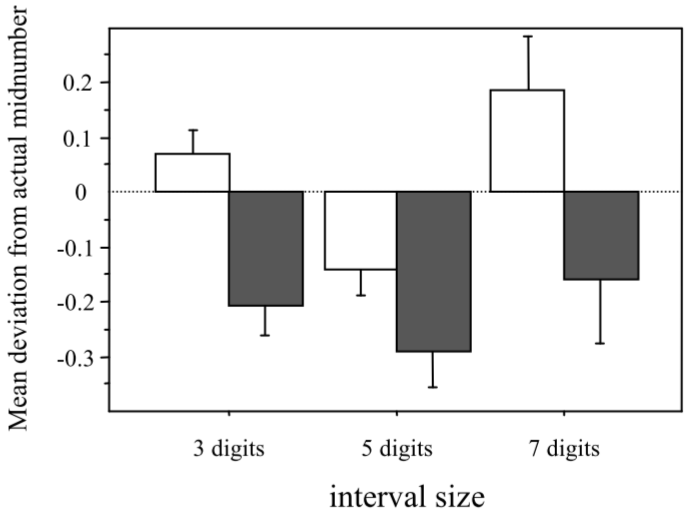

Mean deviation from actual midnumber
0.2
0.1
0
-0.1
-0.2
-0.3
3 digits
5 digits
7 digits
interval size

Fig.2:

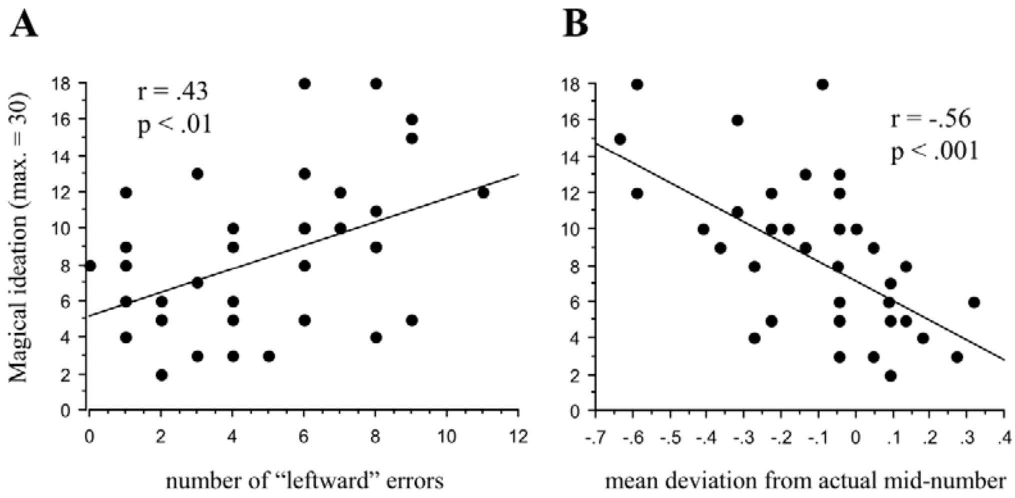
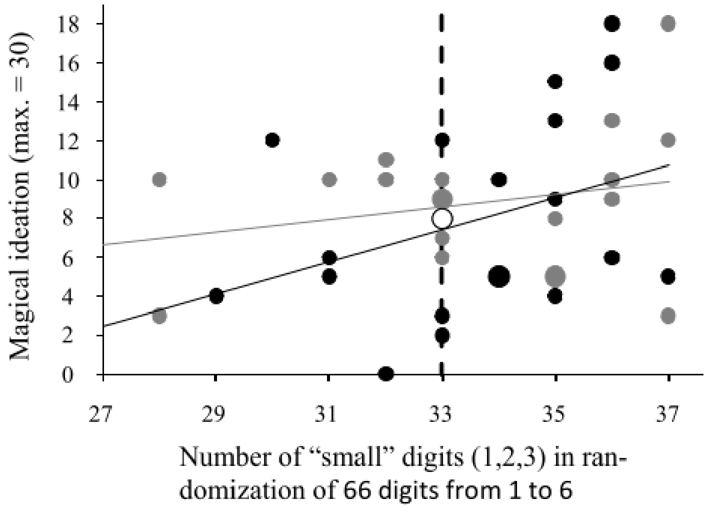

A
B
Magical ideation (max. = 30)
r = .43
p < .01
r = -.56
p < .001
number of "leftward" errors
mean deviation from actual mid-number

Fig.3:


Magical ideation (max. = 30)
0
2
4
6
8
10
12
14
16
18
27
29
31
33
35
37
Number of "small" digits (1,2,3) in randomization of 66 digits from 1 to 6