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GAZE MODULATES NON-PROPOSITIONAL REASONING: FURTHER EVIDENCE FOR SPATIAL REPRESENTATION OF REASONING PREMISES

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Abstract—Human and animals are able to decide that A>C after having learnt that A>B and B>C. This basic property of logical thinking has been studied by transitive inference (TI) tasks. It has been hypothesized that subjects displace the premises of the inference on a mental line to solve the task. An evidence in favor of this interpretation is the observation of the symbolic distance effect, that is the improvement of the performance as the distance between items increases. This effect has been interpreted as support to the hypothesis that ability to perform TI tasks follows the same rules and is mediated by the same brain circuits involved in the performance of spatial tasks. We tested ten subjects performing a TI on an ordered list of Japanese characters while they were fixating either leftwards or rightwards, to evaluate whether the eye position modulated the performance in making TI as it does in spatial tasks. Our results show a significant linear decrease of the reaction time with the increase of the symbolic distance and a shift of this trend towards lower reaction times when subjects were fixating to the left. We interpret this eye position effect as a further evidence that spatial and reasoning tasks share the same underlying mechanisms and neural substrates. The eye position effect also points to a parietal cortex involvement in the neural circuit involved in transitive reasoning. © 2011 IBRO. Published by Elsevier Ltd. All rights reserved.

Key words: transitive inference, gaze, symbolic distance, parietal cortex.

A basic property of logical thinking is the ability to make flexible inferences on the basis of newly learned information. One of these abilities is known as transitive inference (TI), that is the capacity to conclude that A<C by knowing that A<B and B<C (Halford, 1984; McGonigle and Chalmers, 1977). Many TI tasks have been developed to explore the mechanisms underlying flexible reasoning in humans and animals (see Vasconcelos, 2008; Goel, 2007; for review).

Some versions of the TI task require to the participants to learn the difference in magnitude of adjacent items or facts belonging to an ordered series and, after that, they are able to infer the relationship between not adjacent facts in the series (Acuna et al., 2002a; Potts, 1974; Bryant and Trabasso, 1971; McGonigle and Chalmers, 1977). It has been proposed that subjects solve this kinds of inference task by integrating the items in a coherent and unified mental representation that they can manipulate to infer relationships between them (Acuna et al., 2002a; Leth-Steensen and Marley, 2000; Johnson-Laird, 1983).

The observation of the distance effect, that is, that the further apart two items are in the series the easier is to compare them (Potts, 1974; Acuna et al., 2002a; Hinton et al., 2010), led to the proposal of the existence of a "mental line" along which subjects make comparisons between the locations corresponding to the different items. This "mental line" is analogous to the described "mental number line" whereby smaller numbers occupy relatively leftward locations compared with larger numbers (Dehaene et al., 1993). The Spatial-Numerical Association of Response Codes (SNARC) effect, initially reported as a systematic association between numbers and lateralized response (Dehaene et al., 1993), is also evident when subjects are required to judge the position of items in non-numerical ordinal sequences (Gevers et al., 2003, 2004; Previtali et al., 2010). Therefore, the facts of TI appear to share with numbers an organization along a spatial left to right mental vector.

One further evidence of the spatial nature of the "mental line" representation or, more generally, of magnitudes comes from neuropsychological studies on patients suffering of neglect caused by lesions at the level of the right posterior parietal cortex. These patients display similar right biases in the bisection of mental lines, for numerical and non-numerical ordered sequences, and in the bisection of visually perceived lines (Zorzi et al., 2002, 2006; Doricchi et al., 2005; Rossetti et al., 2004; Umiltà et al., 2009, for review).

The parietal cortex mediates the construction of an egocentric representation of sensory space that is used to organize motor interactions with the physical environment (Henriques et al., 2002; Cohen and Andersen, 2002; Ferraina et al., 2009a). Several observations on human subjects and animals showed that the parietal regions involved in space representation for action are also activated by number comparison and serial order tasks (Hinton et al., 2010; Tudusciuc and Nieder, 2009; Hubbard et al., 2005; Acuna et al., 2002b), feeding the hypothesis that reasoning based on relative quantities and spatial competences for actions share the same mechanisms and neural substrates (see Hubbard et al., 2005 for review).

There are evidences that the "mental number line" is coded according to a body-based egocentric space (Loetscher et al., 2008; Conson et al., 2009), where the left and the right are defined with respect to the body midsagittal plane. Moreover, in the "mental number line," large

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Abbreviations: RT, reaction time; TI, transitive inference.

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numbers are represented closer to each other than small numbers, that is, the mental continuum does not appear to be linear. To such regard, the magnitude effect (Terrace, 2005; Dehaene et al., 1993; Gallistel and Gelman, 1992) describes how the reaction time (RT) of subjects increases when comparing a pair of large numbers as opposed to a pair of small numbers, although both pairs of numbers are equally spaced in the series. Given the spatial organization of non-numerical quantities on a "mental line" (Fias et al., 2007; Ischebeck et al., 2008; Bächtold et al., 2000), here we tested whether a spatial variable as the eye position interacts with the use of the line.

Our data show that, when solving a TI task, subjects tend to arrange the different items in a spatially organized order. We also show that a gaze directed to the left, facilitates the use of the "mental line" to solve a TI task. These results support the role of the parietal lobe, and in particular of the right parietal lobe, in solving TI.

EXPERIMENTAL PROCEDURES

Participants

Ten right-handed subjects (two males and eight females; 79±13 Edinburg Handedness Inventory) aged between 21 and 31 years volunteered to participate to the experimental testing. All subjects were naive about the purpose of the experiments and the hypotheses being tested.

Apparatus and procedures

Behavioral testing was conducted in dimly lit room. Participants sat 30 cm away from a 19'' computer monitor that displayed the visual stimuli. Stimuli were formed by pairs of Japanese ideograms (hiragana characters) displaced either above or below a fixation point. The whole visual stimulus was 5° high and 2.5° wide (Fig. 1A). None of the subjects was familiar with Japanese language and with the used characters. This allowed to minimize the use of a verbal strategy to perform the task. In each trial the pairs of stimuli were randomly selected from a rank ordered set of stimuli (Fig. 1A, bottom). Participants were required to choose the higher in rank of each pair by moving, with their right hand, a joystick bar (Gravis Analog Pro) towards the stimulus. The joystick was kept aligned to subjects' body midline while a chin rest kept their head aligned to the center of the screen. The stimuli presentation and the response detection were controlled by Matlab (www.mathworks.com) based routines created using the Psychophysical toolbox (Brainard, 1997).

All experimental procedures were approved by the local ethics board and were performed in accordance with the ethical standards laid down in the 1964 Declaration of Helsinki.

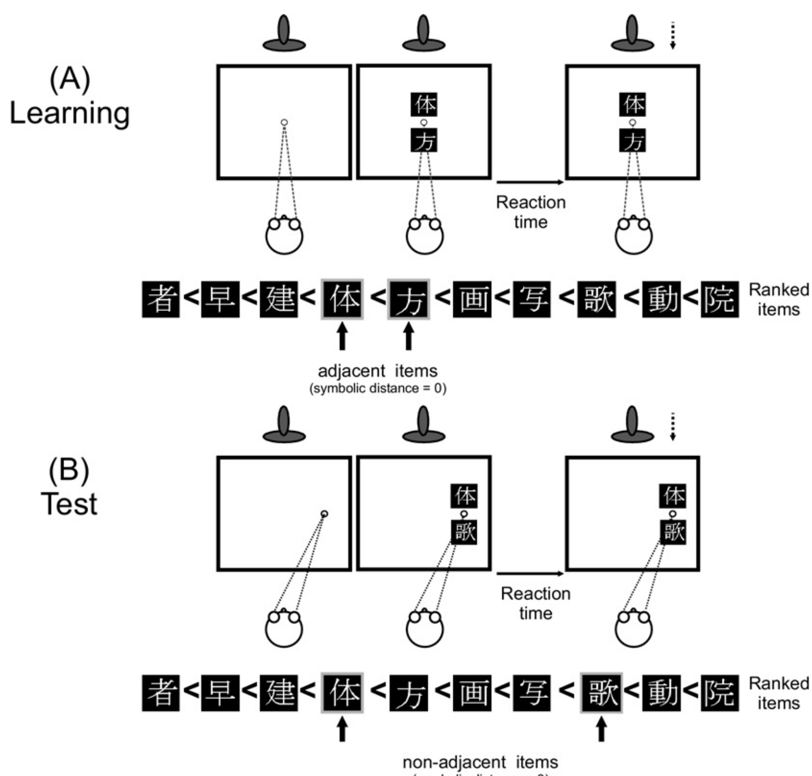

Fig. 1. Schematic of the sequence of events occurring in the Learning (A) and the Test (B) phase of the experimental sessions. Each trial started with the onset of a fixation dot followed by the appearance of a pair of items. Subjects had to maintain the fixation on the dot and move a joystick towards the item judged higher in rank, guessing the arbitrary order decided by the experimenters (rows of white symbols on black background). In each trial of the learning phase (A) the paired visual stimuli were always presented at the center of the display. The paired items presented during learning phase were always adjacent in the series therefore their symbolic distances were equal to zero. In the Tests phase (B), the paired items were randomly presented either 20 visual degrees to the right (as shown in this example trial) or to the left (not shown) of the midline and included also not adjacent items in the series with symbolic distances greater than zero. For each trial the reaction time was calculated, as the time between the appearance of the items pair and the onset of the motor response.