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BRIEF COMMUNICATION

Graphesthesia: A test of graphemic movement representations or tactile imagery?

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Abstract

Patients with corticobasal degeneration (CBG) often demonstrate agraphesthesia in the same hand they demonstrate apraxia. To recognize letters written in their hand subjects can develop a spatial representation and access graphemic representations. Alternatively, people can use movement working memory and match movement patterns to stored letter movement representations. To learn the method normally used without vision, normal subjects (12) had letters written on their palm either in the normal manner or in a reverse direction. If letters written on the hand are recognized by their spatial features (as when visually reading) direction should not influence letter recognition, but if letters written on the hand are recognized by movement patterns, then in the reverse condition recognition should be impaired. When letters were written normally there were no differences in error between the tactile and visual modality. When letters were written in reverse, however, normal subjects made more errors in the tactile than visual condition. Normally, people identify letters written on their hand by covertly copying (mirroring) the examiner and then access letter movement representations. This might explain why patients with CBG often have agraphesthesia associated with apraxia. (*JINS,* 2010, *16,* 190–193.)

Keywords: Agraphesthesia, Corticobasal degeneration, Spatial representation, Working memory, Mirror movements, Apraxia

INTRODUCTION

Graphesthesia is the ability to recognize, by the sensation of touch, symbols, designs, and alphanumerics that are written with a tipped stylus on the skin. The term graphesthesia derives from Greek grapha ("writing") and aisthesis ("perception"). Graphesthesia requires that sensory receptors on touched portions of the skin become activated and that the peripheral nervous system transmit this information to the central nervous system. The central nervous system must then integrate this input and activate the appropriate graphemic representations.

Corticobasal degeneration is a neurodegenerative disease that often presents with asymmetrical agraphesthesia, an inability to recognize numbers or letters written on the palm of one hand, as well as an asymmetrical ideomotor apraxia and apraxic agraphia (Riley et al., 1990; Riley & Lang, 2000; Lang, Riley, Bergeron, 1994; Heilman, Coenen, & Kluger, 2008). In the presence of intact elemental tactile sensation, visuospatial abilities, and the ability to visually read written numbers and letters, it is unclear why some patients with corticobasal degeneration are not able to correctly detect letters or numbers written on their hands. There are, however, at least two possible means by which people might be able to recognize letters written on their skin with their eyes closed. One possible mechanism is for the person who is being examined to use this tactile input to develop a spatial representation and then have this spatial representation access the object recognition units where the visuospatial features or configurations of letters are stored. Alternatively, the subject might use movement working memory (covertly copied or mirrored movements) in a manner similar to that used to imitate the movements made by another person and then

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match these movement patterns to stored movement representations of letters.

A letter written in pen on a piece of paper would look the same regardless if it were written in the normal pattern or in a reverse pattern. Thus, if a letter such as a capital N is written starting from right up corner and moving in a vertical downward direction, then diagonally from the right lower to the left upper corner and finally vertically downward, it would have the same spatial configuration as being written in the normal fashion (from the left lower corner, etc). If the main system that we use to detect a letter written in our palm is a visuospatial or a tactospatial system, it would not matter if the examiner started to trace the letter on the palm from the right or from the left. But if, in order to recognize the letter, the subject uses the movement pattern, this reverse pattern might interfere with recognition.

To test these alternative hypotheses, we had normal subjects identify letters written on their hands in the usual direction or in a reverse direction. If detection of the correct letters only relies on developing spatial representations and then reading this formed spatial image, there should be no difference between these two (normal and reverse) methods of presentation. In contrast, if the actual directions of movements are important, because recognition is aided by covertly copying the tactile movement, then normal subjects should find the recognition of letters and numbers written in a reverse direction more difficult than when they are written the normal direction. The purpose of this study was to learn which of these two mechanisms might account for the means by which normal subjects, who have their eyes closed, recognize letters written on their hand.

METHODS

This study was approved by the Institutional Review Board and all subjects provided written informed consent to participate. The sample included 12 subjects (5 men; 7 women). The subjects were all right-handed, with an average age of 29.25 years (SD = 14.62) and an average education of 15 years (SD = 3.16). The subjects had no history of significant head injury or neurological impairment.

The experiment assessed subjects' ability to read letters in two modalities, tactile (graphesthesia) and visual. During the graphesthesia testing session, we asked the subjects to close their eyes and told them that the examiner would write a letter (upper or lower case, script or print) on the palm of their right hand using a stylus. If they recognized the letter, they were to tell the examiner the letter written on their hand. The subjects were informed that the letters would be written in either the usual manner or in a reverse direction. The subjects had no time restrictions. A total of 12 letters were written, with each letter being written once in the usual direction and once in a reversed direction. The order in which these were drawn on the hand was randomized. Errors were counted and reaction time was recorded using a stopwatch.

During the visual reading condition, the experimenter made the movements of writing the same letters on paper using a pen without ink. Thus, the subjects were able to see the movements used to write the letters but had no visual feedback of the letter on the paper. As with the graphesthesia condition, the letters were "written" on the paper in the usual and in the reverse (mirror) direction. After the letters were written on the paper, the subjects were asked to identify the letter written. Errors and reaction time were also recorded. Consistent with the graphesthesia condition, the same 12 letters were written, with each letter being written once in the usual direction and once in the reverse direction. The order of usual and reversed writing of the letters was randomized. Hence, there were a total of 24 trials in the graphesthesia condition and 24 trials in the visual reading condition. The tactile-graphesthesia and visual reading conditions were counterbalanced across subjects.

RESULTS

The means and standard deviation of the four experimental conditions are listed in Table 1. We conducted two separate analyses, one for reaction times and another for the number of correct responses. Regarding the analyses for reaction time, we conducted a 2 (Modality: Visual and Tactile) × 2 (Direction: Forward and Reverse) repeated measures analysis of variance (ANOVA). The results indicated a significant main effect for Modality, $F(1, 10) = 31.96$, $p < .0001$, indicating that the subjects read the seen letters more rapidly than the felt letters. However, there was no main effect for Direction, and the interaction between Modality and Direction was also not significant.

Regarding the analyses for the number of correct recognition responses, we performed another 2 (Modality: Visual and Tactile) × 2 (Direction: Forward and Reverse) repeated measures ANOVA. The results indicated a significant main effect for Modality, $F(1, 10) = 13.76$, $p = .004$, indicating a greater number of correct responses when the numbers were seen as opposed to when the letters were felt. The main effect for Direction was not significant. The Modality by Direction interaction was significant, $F(1, 10) = 5.90$, $p = .035$. Multiple comparisons, using a Bonferroni correction for experiment-wise error rate ($p < .0125$), indicated a greater

Table 1. Means and standard deviations (SD) for the four experimental conditions

	Forward	Reverse
Tactile Condition		
Means corrected responses	8.90	7.72
SD corrected responses	2.95	3.37
Means reaction times (sec)	1.66	1.95
SD reaction times	0.95	1.11
Visual Condition		
Means corrected responses	10.90	11
SD corrected responses	1.7	1.90
Means reaction times (sec)	0.75	0.88
SD reaction times	0.47	0.46

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number of correct responses when the letters were seen in reverse (M = 11.00, SD = 1.90), as opposed to when the letters were felt in reverse (M = 7.72, SD = 3.37).

All other comparisons were not significant, including differences in errors between the tactile and visual modality when the letters were written in the normal (forward) direction.

DISCUSSION

In this study, when the examiner was writing in the visual and tactile conditions, there was no permanent trace of the letter that was written. Thus, to perceive the written letter, the subject either saw the examiner move a stylus when writing a letter, or felt the examiner move the stylus on the palm, both of which require working memory. In the former visual condition, the working memory was formed from a visual percept, and in the latter condition, a tactile percept. One reason why these subjects made fewer errors in the visual than tactile condition might be related to the superiority of visual versus tactile movement-spatial working memory. Perhaps, in this task, the visual modality is superior to the tactile, because, before recognition can take place, the tactile input must first be converted to a visual percept.

One problem with this modality-specific, movement-spatial working memory hypothesis is that when the subjects viewed normal (forward) movements making letters versus feeling movements making letters, there were no significant differences in errors between these modalities. If the only explanation for the significant error differences we found in the reverse condition were related to working memory, we would have expected to see a similar difference in the normal direction condition, but we did not. In addition, if movement-spatial working memory was the critical factor in the error rate difference between the normal and reverse tactile conditions, we would have expected differences in reaction times between the forward and reversed tactile conditions, but we did not find this difference. The finding that, in the reverse condition, when written letters were presented in the tactile modality, the subjects made more errors than when the written letters were presented visually, suggests that another mechanism might account for this difference.

Our a priori hypothesis was that, at least in part, when letters are written on the hand, but cannot be seen, a person identifies these letter by covertly copying (mirroring) the movements of the examiner and activating the movement representations that are normally used to write these letters. When the letters are written in reverse, people have difficulty using this strategy, because the brains of most individuals do not contain the movement representation of letters written in reverse, and not being able to use these movement representations causes subjects to make more errors. Although these results suggest that recognizing letters written on the hand is dependent on conceptually mirroring the examiner's movements and activating movement representations, these results do not preclude the possibility that some normal people, based on tactilely perceived movements, also form visual-spatial percepts and then access the stores of visual-spatial letter representations.

These conclusions, though, may need to be considered in light of the observed ceiling effect for the visual condition. Certainly, identifying a letter written on paper, even without ink, is a much easier task than identifying a letter written on the palm of the hand. Although we found an interaction between Modality and Direction, the means were not completely crossed over because of the ceiling effect of the visual condition. Different results may be found if a more difficult visual condition is utilized, such as by using letters written in different fonts and/or using both upper and lower case letters. Combinations of letters may also be used to increase task difficulty. Future research will need to be conducted to explore these possibilities.

Recently, it has been reported that patients with corticobasal degeneration can develop an asymmetrical apraxic agraphia (Heilman et al. 2008), such that while they can visually read letters, and correctly spell words aloud, they have problems writing letters, because they cannot make the series of correct movements needed to correctly form letters. Patients with this disorder often also have agraphesthesia in the same hand as they have apraxic agraphia (Heilman et al., 2008). Since these patients can read letters, they have intact visual-spatial letter representations. Thus, if these patients could form accurate visuospatial representations from tactile stimulation, they should not demonstrate agraphesthesia. It is possible, therefore, that in the absence of vision, when letters are being written on the hand, some of the patients with corticobasal degeneration, because of the presence of apraxia, cannot either conceptually mirror the examiners movements or normally activate the movement representations of the written letters, and this disability impairs letter recognition. It is possible, however, that with this tactile input, some people with corticobasal degeneration might directly develop visuospatial representations, and still others might use both mechanisms for letter recognition. Future studies, of additional patients with corticobasal degeneration who have apraxic agraphia, might help us learn if there are people who directly use visuospatial representations. The finding of patients who have apraxic agraphia, but who do not have agraphesthesia, would support the postulate that there are two mechanisms for detecting letters written on the hands, one using movement representation and the other using spatial-object representations.

There is, however, another possible reason why patients with corticobasal degeneration might have agraphesthesia. As mention earlier, the recognition of letters written on the hand with eyes closed, versus recognizing a letter written on paper with the eyes open, might also require different forms of spatial movement working memory. It is also possible that patients with corticobasal degeneration have an impaired tactile movement working memory, and tactile working memory might heavily depend on intact movement representations. Future behavioral and imaging studies will be needed to test these alternative hypotheses.

Finally, it should be mentioned, that, whereas our study included a sample of healthy, neurologically intact individuals, the sample size was rather modest. Although threats to internal validity were well-controlled through experimental procedures and the use of a completely within-subjects design, there may exist threats to external validity given the sample size. It would be beneficial for additional studies to attempt to replicate these findings in a systematic fashion using larger sample sizes, and it is the hope of the authors that this study will stimulate such research.

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