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Authors
Vallee-Tourangeau, Frederic
Webb, Susan

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Interactive Word Production in Dyslexic Children

Susan Webb and Frédéric Vallée-Tourangeau
Psychology Research Unit, Kingston University
Kingston-upon-Thames UNITED KINGDOM KT1 2EE
susan.webb@moving-minds.org; f.vallee-tourangeau@kingston.ac.uk

Abstract

In solving problems people naturally seek to modify their external environment such that the physical space in which they work is more amenable or 'congenial' to achieving a desired outcome. Attempts to determine the effectiveness of certain artifacts or spatial reorganizations in aiding reasoners solve problems must be relativised to the difficulty of the task and the cognitive abilities of the reasoners. This investigation aimed to determine the extent to which manipulating the order of letter tiles can affect participants' performance in a word production task. The sample consisted of both developmental dyslexic children and a control group of typically developing children, aged between 9 - 11 years. The word production task involved creating words from sequences of letter tiles in a 'hands' and a 'no hands' condition. Manipulating the tiles significantly enhanced word production for the dyslexic children with an easy letter set but not with a hard letter set. In turn, manipulating the tiles had a marginal impact on performance in the control children. Overall, measures of visuospatial and working memory abilities were better predictors of word production performance when children did not manipulate the tiles than when they did. Manipulating the external environment in this task enhanced performance and reduced the contribution of internal processes, including working memory.

Keywords: Psychology, distributed cognition, interactivity, individual differences, working memory.

Introduction

In attempting to solve a wide variety of tasks, people naturally seek to modify their external environment such that the physical space in which they work is more amenable to achieving a desired outcome. Scientists build (and tinker with) physical models of their object of investigation, an interactive process that provides important perceptual feedback that drives the generation and evaluation of novel hypotheses (e.g., Weisberg, 2006; Watson, 1968 – see also Clark, 1997, 2008; Giere & Moffat, 2003). Pilots use and modify external markers in their cockpit to help them gauge more easily the gap between the plane's current status and the desired speed and altitude as they engage in preparations for landing (Hutchins, 1995). On a more quotidian level, people use simple artifacts (e.g., 'Post-it' notes, Norman, 1993) or alter their physical environment to enhance their prospective memory or facilitate the execution of everyday tasks (e.g., prepare a meal, repair a bicycle, see Kirsh, 1995). In so doing, a reasoner delegates some of the information storage and/or computational costs onto her immediate surroundings, and the problem solving activity is distributed among resources internal and external to the reasoner.

Kirsh (1993) introduced the notion of 'complementary' actions, actions that support thinking, and illustrated their importance in a simple coin counting task. The error rate for a group of participants who were refrained from pointing or touching the coins in adding their total was 50%. That rate dropped to 35% when participants were allowed to point to the coins while counting, and 20% when they were allowed to touch the coins. Of course, the act of pointing or touching the coins is not an essential process required for counting. However, once the number of coins reaches a certain level then it pays off in terms of efficiency and accuracy to employ complementary actions or more direct reshaping of the environment to facilitate thinking. There are a number of important factors that can determine the amount of assistance gained by reshaping or exploiting physical environment in problem solving, among them experience, maturation, and innate abilities. When a child learns to count she may use her fingers as a visual and mental cue to guide her progress on the task. With experience, the child may no longer rely on her fingers: The task difficulty no longer outweighs the physical demands of manipulating her external environment.

Word Production

In a task where randomly presented letters (e.g., HTEGNIS) are assembled to form words, word production reflects a search process through a space of possible letter strings (Maglio, Matlock, Raphaely, Chernicky, & Kirsh, 1999; Vallée-Tourangeau and Wrightman, under review). To be sure, verbal fluency or dexterity with words is likely to be a strong predictor of performance in this task. However, an analysis of the task plausibly implicates a number of processes in the efficient and successful exploration of that space, including executive search, working memory and visualisation abilities, psychometric dimensions that vary considerably across people.

Gavurin (1967) found that a problem solver's performance on an anagram task, where no overt rearrangement of the letters was permitted, was related not only to her level of verbal ability, but also to her level of non-verbal spatial ability, as the symbolic representations

require a large degree of spatial aptitude (manipulatory visualisation). This positive relationship between spatial aptitude and anagram solving was significantly reduced once participants were allowed to physically rearrange the letters in producing their solution. This suggests that once the need for implicit spatial manipulation is factored out with the physical rearrangement of the work space, an individual's spatial ability is no longer a predictor of her performance on an anagram task.

Using a simpler word production task with random sequences of letters, participants tend to generate more words when they are allowed to manipulate the letters than when no overt physical manipulation is permitted (Maglio *et al.*, 1999; Kirsh, 1995). However, the level of task difficulty determines the effectiveness of manipulating the environment to aid task performance. In turn, the effectiveness of manipulating letter tiles in a word production task must be relativised to the individual problem solver's cognitive ability (Vallée-Tourangeau & Wrightman, under review).

It is also plausible to conjecture that individual differences in working memory capacity covary to some degree with individual differences in the ability to carry out complex internal calculations. Completementary actions may enhance the ability to carry out these complex calculations by structuring interactions with the physical space to facilitate storage and information processing. For example, Cusher and Wiley (2008) demonstrated that the ability to gesture while completing the Tower of Hanoi had a positive effect on participants' performance. The results indicated that gesturing reduced the cognitive workload, allowing even those participants with a lower working memory capacity to perform better on the task.

Thus when the demands on working memory are reduced, more cognitive effort can be focused on the solution of a task, resulting in an increase in task performance. The 'intelligent use of space' (Kirsh, 1995) and complementary actions can reduce the cognitive demands on attention control, working memory, and visual memory during problem solving. It would therefore be interesting to see the extent to which individuals with weaker working memory abilities can exploit their physical environment to improve problem-solving performance.

Developmental Dyslexia. A specific population of individuals who demonstrate impairments of working memory are developmental dyslexics (Oakhill & Kyle, 2000; Lishman, 2003). The term developmental dyslexia refers to an unexpected difficulty in reading that cannot be explained by lack of intelligence, motivation, or access to appropriate schooling (Lishman, 2003). Neuroimaging data indicate unusual pattern of functional connectivity and activation of specific regions associated with language (Benson, 2000; Simos, Breier, Fletcher, Bergman, & Papanicolaou, 2000). Snowling (1998, 2000) outlines a phonological deficit disorder theory that identifies potential processes underlying the deficit as well as the difficulties that some individuals diagnosed with developmental dyslexia demonstrate. Working memory capacity has also been implicated in the efficient processing of phonological information, as demonstrated by dyslexics' performance on a sound categorisation task involving phonological awareness (Oakhill & Kyle, 2000).

The Present Study

As Kirsh (1995, 1996) argue people naturally attempt to shape and exploit their environment to help them solve both quotidian and less prosaic problems. The development of domain specific expertise coincides with the restructuring of the physical space so that it facilitates efficient and robust problem solving. The physical space can be engineered in a way that it shoulders some of the computational costs, facilitating choice at important decision points. The present study investigated the use of the environment as a tool to facilitate cognitive processing using a sample of developmental dyslexics involved in a word production task such as the one described above (Maglio et al., 1999). Since the facilitating effect of environmental manipulations is relative to the level of task difficulty, we explicitly manipulated task difficulty. In turn, task difficulty can only be defined relative to the cognitive abilities of the reasoner. In this study, these abilities were gauged on the basis of performance on a number of working memory tasks. We predicted that participants with weaker cognitive abilities would show most improvements when invited to reshape the external environment during word production.

Dyslexic children tend to exhibit certain working memory weaknesses (Oakhill & Kyle, 2000). We conjectured that developmental dyslexic participants would perform better on a letter tile word production task if they were given the opportunity to rearrange the letters. Reshaping the problem space should facilitate the search efforts, as the changes in the external environment may reduce demands on spatial visualisation, working memory and verbal dexterity. The word production performance of the control participants, however, may not be as substantially influenced by the manipulation of the letter tiles. We also sought to gauge the overall relationship between word production performance and visuospatial/ working memory abilities. We predicted that, across both groups, working memory abilities would be positively correlated with word production performance. However, the opportunity to manipulate the letters should weaken the relationship between cognitive skills and word production performance, as weaker participants elevate their word production output, thereby shortening the left tail of the performance distribution and compressing variance. Hence, the correlation between measures of working memory abilities and word production performance should be stronger when the letter tiles are not manipulated.

Method

Norming Data

A pilot study was conducted to establish norming data for the letter sequences; these data were then used as a basis from which the letter sequences for the main study were selected.

Participants. The participants of this study were recruited at the Wiltshire School of Gymnastics (UK). Twenty participants were included in this investigation (Males = 4, Females = 16), ranging in age from 9 to 11 years ($M = 9.8$ years).

Design and Procedure. Ten different letter sequences were randomly generated without replacement until each letter sequence consisted of either 6 or 7 different letters; five 6-letter sequences and five 7-letter sequences were created. Participants were asked to produce as many words as they could from these sequences during a 2 minute time period. Participants were told that words could be of any length and that each letter could be used just once per word. The participants were then instructed to read and spell out each word as it was produced. The words were recorded on the data sheet by the experimenter to limit any confounding effects of spelling and hand writing proficiency. Each participant was presented with two of the 6-letter sequences and two of the 7-letter sequences, the order of which was predetermined on a counter balanced data sheet.

Table 1: Mean number of words produced (with standard deviation) from the six- and seven-letter sequences in a two minute period.

Six-letter sequences			Seven-letter sequences		
	M	SD		M	SD
IKGLAE	3.1	2.4	**GRSTAKP**	7.3	1.8
UATDNF	6.3	1.7	**OPARSJE**	4.5	2.4
DEIRPA	8.6	2.9	**INHEGTS**	11.6	3.4
HOADGR	6.3	2.4	**RODECUA**	5.0	1.5
CANOLT	7.6	2.6	**HETWICY**	6.9	2.1

Results The mean number of words produced from each letter sequence are reported in Table 1. The six-letter sequences did not differ much in terms of output, with the exception of a particularly hard sequence (IKGLAE) for which there was arguably a floor effect ($M = 3.1$). The seven letter sequences provided a better range of outputs, and hence we examined these sequences to identity a hard and easy set. We elected to use the sequence INHEGTS as the 'easy' letter set ($M = 11.6$) and the sequence GRSTAKP as the 'hard' letter set ($M = 7.3$); the difference was significant, $t(7) = -3.15$, $p < .05$. Finally, note that during this pilot study, participants were still producing words as the 2-minute period elapsed. Consequently a 3-minute time period was employed in the main study.

Experimental Data

Participants. Forty two participants aged between 9 and 11 years were recruited from the Dover Court Preparatory School (Singapore) for inclusion in the main study. Twenty of the participants were diagnosed with developmental dyslexia (mean age 9.9 years) and the remaining 22 participants (mean age 9.8 years) were reported to have no known learning difficulties. All participants were schooled in English and were fluent English speakers.

Design and Procedure. Participants in both groups were exposed to two different letter sequences, a hard letter sequence (GRSTAKP) and an easy letter sequence (INHEGTS). A simple word production task was conducted under two conditions: a 'hands' condition, which allowed for manipulation of the letter tiles, and a 'no hands' condition during which the letter tiles could not be rearranged. Participants were tested one at a time in a quiet room. They performed four separate tasks (spatial visualisation, word production, working memory, verbal fluency) and the testing session lasted 45 minutes.

Spatial Visualisation Task. Participants were first presented with the symbol coding task B, taken from the WISC-IV. During this task the number of digits that a participant was able to transcribe into the corresponding symbol was assessed in a 2 minute time period. This task requires executive control, visual scanning and accurate visual perception.

Word Production Task. The children were then introduced to the word production task. During this task participants were given one of the letter sequences, which was placed on the table in front of them. Each letter tile was placed one centimetre away from the next. Participants were instructed to identify, say, and spell as many words as possible using those specific letters for 3 minutes. Participants performed the task in two conditions; in the 'hands' condition participants were instructed to move the letter tiles around and reorder the letters to look for or think up words while in the 'no hands' condition participants were instructed not to touch or point to the letter tiles. The order in which the manipulation conditions and the hard and easy letter sets were presented was counterbalanced. In between each letter sequence participants were given a 3-minute distracter task, during which they were asked to complete various mazes.

Working Memory. Participants' digit span (forward and backward) was measured (the task was taken from the WISC-IV). During this task participants were orally

presented with a sequence of numbers and asked to repeat them, either in the order of presentation (forward) or in the reverse order (backward). Initially the number sequences began with just two digits, which then increased until the participant recalled a sequence inaccurately on two consecutive occasions. The backward task is more taxing as the retained information requires a degree of processing and manipulation for successful recall.

Verbal Fluency Test. The Thurstone (1938) word fluency test measured verbal fluency. Participants were instructed to say as many words as possible beginning with the letter "S" for five minutes, and then as many four-letter words beginning with "C" for four minutes. The experimenter recorded the children's words.

Results

Working Memory Profile

The mean score on the working memory tasks and verbal fluency tests of the participants in the dyslexic group were consistently lower than the mean score of the participants in the control group (see Table 2). Dyslexic children scored significantly lower than control ($M = 38.5$ v. $M = 50.0$) on the visuospatial task, $t(40) = 4.76$, $p < .001$, on the forward span ($M = 7.6$ v. $M = 9.5$), $t(40) = 2.02$, $p < .01$, on the backward span ($M = 4.0$ v. $M = 6.5$), $t(40) = 4.45$, $p < .001$ and produced significantly fewer words on the Thurstone fluency task ($M = 24.1$ v. $M = 41.5$), $t(40) = 6.34$, $p < .001$.

Table 2: Mean performance score on the working memory tasks and the Thurstone verbal fluency test for control and dyslexic participants.

	Control		Dyslexic	
	M	*SD*	*M*	*SD*
Coding	50.0	7.5	38.5	8.2
Forward Span	9.5	2.2	7.6	2.2
Backward Span	6.5	2.1	4.0	1.4
Overall Span	16.0	3.7	11.6	2.8
Thurstone	41.5	9.8	24.1	7.7

Word Production

The mean number of words produced by the participants in both groups and in both conditions are plotted in Figure 1. A clear distinction between the two groups of participants is evident. The control group produced more words than the dyslexic group over all, regardless of the manipulation condition or the level of task difficulty. The control group tended to produce more words in the hands condition ($M = 10.3$, $SEM = 1.25$) than in the no hands condition ($M = 8.7$, $SEM = 1.67$) when they were given the hard letter set; however the difference was not significant, $t(20) = 0.80$, p

$> .05$. The difference in their performance when they were given the easy letter set was indistinguishable ($M= 11.4$, $SEM = 1.50$, v. $M = 12.2$, $SEM = 0.65$), $t(20) = -0.45$, $p > .05$. A different pattern of results was observed in the dyslexic group. A much more pronounced advantage of manipulating the tiles was observed with the easy letter set than with the hard letter set. Significantly more words were produced in the hands condition ($M = 7.7$, $SEM = 0.97$) than in the no hands condition ($M= 5.1$, $SEM = 0.55$) with the easy letter set, $t(18) = 2.34$, $p < .05$, but not with the hard letter set, ($M = 4.8$, $SEM = 0.69$ v. $M = 4.4$, $SEM = 0.73$), $t(18) = .39$, $p > .05$.
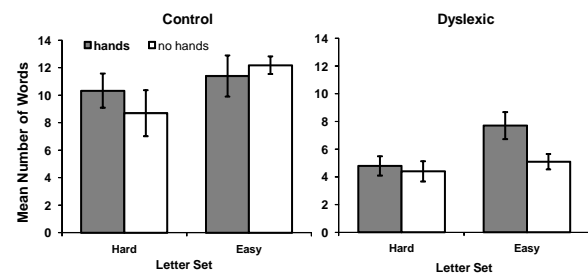

Figure 1: Mean number of words produced for the hard and easy letter sets using hands (grey bars) and no hands (open bars) in both groups of participants (with standard errors).

Predictors of Word Production

Pearson correlations were calculated to measure the strength of the relationship between working memory abilities and word production when tiles were manipulated (Hands) and when they were not (No Hands) across all participants. These correlations are reported in Table 3. Working memory abilities were strong predictors of word production performance when the letter tiles were not rearranged during the task. The spatio-visual abilities (Coding) were most strongly correlated with performance, $r(40) = .67$, $p < .001$, followed by length of the backward digit span, $r(40) = .53$, $p< .001$, which is the digit span measure that draws more heavily on working memory. When the participants could manipulate the letter tiles, however, these correlations were not as strong. While spatio-visual abilities were still strongly associated with word production performance, $r(40) = .46$, $p < .002$, the correlation between backward digit span scores and performance was only marginally significant, $r(40) = .32$, $p < .04$, and the overall digit span scores were no longer significantly related to word production performance, $r(40) = .25$, $p > .05$.

Discussion

In this experiment children were requested to generate as many words as they could during a three-minute period using sets of 7 random letters under different conditions;

participants were either permitted, or not permitted to manipulate the sequence of a letter string in order to assist word production. The focus of this study was to investigate the extent to which an individual's external environment can act as scaffolding to her internal cognitive processes in order to enhance her performance in a word production task.

Table 3: Pearson correlation coefficients ($df = 40$) for the association between working memory scores and word production performance across both groups of participants when the tiles where manipulated (Hands) and when they were not (No Hands).

		Hands	No Hands
Coding	r	.46	.67
	p	.002	.000
Forward Span	r	.12	.25
	p	.453	.106
Backward Span	r	.32	.53
	p	.037	.000
Overall Span	r	.25	.44
	p	.115	.004

We conjectured that children diagnosed with dyslexia would demonstrate significantly lower working-memory abilities than children with no known language difficulties. To test this assumption a number of working memory tasks were performed by our participants. The dyslexic group performed at a significantly lower level on all measures of working memory compared to the control group.

Generally, more words were produced when participants were permitted to manipulate and reorder the letter tiles. However this effect was only significant with dyslexic children, and this only with the easy letter set. With the hard letter sequence, the difference in words produced by the dyslexic children with and without hands was negligible. This was possibly a function of the level of difficulty of the task rather than a function of the ability to restructure the problem space. For the dyslexic participants, the hard letter set appears to have been simply too hard: only 9.1% more words were produced in the hands condition using the hard letter set, whereas 50% more words were produced by rearranging the letters with the easy letter set. In contrast, the easy letter set may have been too easy for the control group: 6.4% *fewer* words were produced by rearranging the letters using the easy letter set, while 18% more words were produced with the hard letter set. The experimental manipulation only had a marginal impact on the performance of control participants.

Correlational analyses suggested that working memory abilities were particularly strong predictor of word production performance overall when the letter tiles were not manipulated. In turn, when participants could reorder the letters, working memory abilities correlated less strongly with performance on the task. For example, the backward digit span which necessitates a more substantial coordination of working memory resources, correlated very significantly with word production performance in the No Hands condition. When participants could manipulate the tiles, however, word production performance was less strongly related to backward digit span. Thus when the environment can facilitate reasoning, internal processing abilities become less important in determining performance.

Conclusion
The dyslexic children in this study benefited the most from rearranging the letter tiles when producing words. Their less efficient working memory abilities could be compensated by reshaping the physical presentation of the letters. The control children, however, did not benefit from restructuring the environment; in fact with the easy letter set their performance was marginally poorer when they manipulated the tiles. The performance of control children was in line with the norming data obtained with the pilot study: They could just as easily produce words with or without manipulating the tiles.

People engineer cognitive niches to facilitate thinking (Clark, 2008). However, not all engineering efforts, especially those that are artificially and transiently created in the cognitive psychologist's laboratory, lead to more efficient thinking. Kirsh (1995) echoed this concern: "(…) the point of informationally structuring space is to reduce the time and memory requirements of cognition, the actual reduction in computation achieved by the various methods (…) does not, in general, lend itself to meaningful quantitative estimation." (p. 41). The data from this study suggest why it is difficult to specify a priori how and by how much the physical restructuring of the problem space can aid thinking. In essence, the effectiveness of the manipulation of the physical problem space is relative to the level of task difficulty *as well as* the cognitive abilities of the reasoner. To understand and engineer good distributed cognition design and practice, one must undertake a thorough analysis of the task, the agents that perform the task, and the nature of their interaction with the physical environment (Hollan, Hutchins, & Kirsh, 2000). There are extensive individual differences in learning styles and children's learning environments must be tailored to suit their individual needs in order for them to be able to achieve their full potential.

Acknowledgements

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