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Reactivity effects of concurrent verbalisation during a graph comprehension task

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Abstract

We report an experiment investigating how concurrent verbalisation during a task can affect performance (a so-called “reactivity” effect). Participants studied three-variable line graphs while (a) concurrently thinking aloud or (b) silently studied the graphs and provided an interpretation once they felt they had understood it. Results showed that verbalisation hindered performance significantly compared to the silent condition. To support the claim that the act of verbalising was hindering performance, competing explanations were also tested, which confirmed thinking aloud as the most likely cause. This contradicts claims by Ericsson and Simon (1993) that thinking aloud reflects but does not affect performance and provides further evidence that verbalising thought processes can hinder performance.

Introduction

Arguably one of the most important advances to have occurred during the cognitive revolution has been the attempt to develop theoretical justifications and rigorous methods for obtaining information about cognitive processes through the analysis of verbal reports produced during their execution.

Although the use of personal reports to infer mental processes has a long history, the approach has always remained controversial, with critics arguing that data obtained from them may be unreliable or that the methods themselves distort or react with the cognitive processes under investigation. The employment of verbal reports was given a cognitive basis and justification by Ericsson and Simon (1993) and their theory of protocol generation.

As a result of their analysis of the different types of verbalisation, the use of verbal protocol methods is now considered a legitimate approach for tracing thought processes and being a valid source of data about the steps involved in problem solving and decision making (Wilson, 1994). Since the original proposal, the think aloud method has been widely adopted, resulting in a large body of research into the processes underlying decision making, problem solving, text comprehension, diagrammatic reasoning, writing, and various other tasks (Crutcher, 1994).

The method considered by Ericsson and Simon (1993) as being the most valuable and rigorous is the *concurrent think aloud* method in which experiment participants are asked to simply verbalise their thoughts while carrying out a task. Ericsson and Simon (1993) claim that if appropriate instructions are given and followed carefully, the reports participants provide are an accurate reflection of the thought sequence that would have been followed if participants performed the task silently.

Questions remain however concerning the possible reactivity effects of thinking aloud while performing a task and a number of recent studies have revealed that verbalising while performing a task can hinder performance, challenging Ericsson and Simon’s (1993) claim that verbal reports are non-reactive.

This area of research has primarily focused on tasks such as face recognition and insight problem solving where the processes involved in reaching a solution are not accessible to the individual to report (Chin & Schooler, 2008). Schooler and Engstler-Schooler (1990) investigated whether describing a previously seen face would later hinder participants’ ability to correctly recognise the face later. They found that compared to a control group who did not describe the face, those who did performed significantly worse in the recognition test. Schooler and Engstler-Schooler (1990) called this effect “verbal overshadowing”, proposing that verbal overshadowing occurs when attention is directed to information that can easily be verbalised and so eclipses information that cannot easily be put into words.

Ericsson and Simon (1993) have challenged findings such as these arguing that the method employed did not adhere to guidelines of how protocols should be elicited. They distinguish between different techniques employed to elicit verbalisations—when participants are asked only to report their thoughts (Type 1 verbalisations) and when participants are asked to explain them (Type 3 verbalisations). Numerous studies (e.g., Wilson and Hodges (1992); Wilson, Hodges, and LaFleur (1995)) have reported reactivity effects but have required participants to provide a reason for their decision (e.g., “why do you prefer this painting over the other one?”) which would elicit Type 3 verbalisations, a technique Ericsson and Simon accept is prone to reactivity effects. This is because when researchers ask “why?” questions, participants are required to process information which they would normally not need to, thus altering their thought processes and making the method susceptible to reactivity effects (Ericsson & Simon, 1993). Therefore, there are only a handful of studies reporting reactivity effects when employing this method which adhere to the criteria outlined for eliciting valid protocols.

Despite this, there is a growing consensus that under certain circumstances, employing the verbal protocol method may result in reactivity effects (e.g., Schooler, Ohlsson, and Brooks (1993); Wilson (1994)). However, studies conducted to investigate this research question have focused on tasks

where verbal overshadowing of information is likely to occur (e.g., insight problems). Although this research is useful for identifying particular instances in which the think-aloud method may be susceptible to reactivity effects, the question remains whether these results generalise to tasks where information is more readily available for verbalisation. There is a need therefore for a greater range of tasks to be tested to determine whether reactivity effects are limited to tasks where information may be difficult to verbalise, especially considering the growth in areas this method has been applied to (Wilson, 1994).

In addition, it has been assumed that it is the act of thinking aloud itself which results in reactivity effects. There is the possibility of an alternative explanation however. When employing the think aloud method, the experimenter must be present with the participant, which may affect performance—the widely investigated “social facilitation/inhibition effect” (Zajonc, 1965; Rosenthal, 1976; Huguet, Galvaing, Monteil, & Dumas, 1999).

One study which potentially indicates this could be the case was conducted by de Vet and de Dreu (2007), who studied the effects of concurrent verbalisation on creativity in a group setting. They found that thinking aloud impaired performance, particularly in individuals who were sensitive to other people’s opinions of them. Although the authors concluded that the presence of others played a role in the performance impairments, it is difficult to generalise these results because the large groups used in the study are not typical of the scenarios used in the majority of verbal protocol studies.

Current experiment

The aim of this study is twofold. Firstly, we seek to determine whether reactivity effects found in the literature are due to the demands of thinking aloud or whether potential competing explanations (e.g., experimenter presence) could account for this effect. Secondly, we also wish to investigate whether reactivity effects are limited to the types of tasks investigated in previous verbal overshadowing experiments by requiring people to think aloud while performing a task in which information is readily available for verbalisation.

To do this we employed a graph comprehension task for a number of reasons. First, in such tasks the information being processed is readily available at all times, thereby reducing the burden on working memory and freeing up resources for the interpretive task (Pinker, 1990). Second, previous research into graph comprehension employing verbal protocols (e.g., Ratwani, Trafton, & Boehm-Davis, 2008) has demonstrated that such methods are able to provide a reliable trace of the problem solving processes undertaken by users.

Finally, the graphs we employed, although widely used in statistics to depict relationships between more than two variables, are relatively simple and constrain the interpretative processes available to users. Evidence for this assertion is provided by Halford, Baker, McCredden, and Bain (2005) who manipulated the number of graphically displayed statis-

tical interactions participants were required to process. They found performance for 2×2 problems (the type employed in our task) was near perfect but a steep drop in performance emerged when the graphical representation depicted 3 or 4 way interactions; consistent with processing capacity constraints.

Based on these criteria, one might expect no effect of concurrent verbalisation to be found in this task. However, in a previous study in which we compared graph comprehension assessed by written and verbal reports, we found the written interpretation to be superior in terms of accuracy and detail (Ali & Peebles, 2011). These findings did not reveal whether the differences were a result of a facilitation produced by the act of writing or a detriment from verbalising. The previous study laid open the possibility that this task may be susceptible to reactivity effects. Therefore this study will attempt to determine whether this is the case.

Assessing potential reactivity effects in a comprehension task

To measure reactivity effects, the output from thinking aloud is compared to that of a “silent” condition using dependent measures such as number of correct responses and this is the method adopted in this study. In problem solving tasks the output of the silent condition may be simply a solution to the problem, e.g., $29 \times 4 = 116$. In a graph comprehension task however, the output is a series of statements expressing the participants interpretation of the data depicted.

In the think-aloud condition this will result in participants verbalising their interpretation of the graphs until they complete the task. If reactivity effects are not an issue then performance will not differ between the think-aloud and silent condition, i.e., the demands of verbalisation will have no effect on the ability of participants to successfully apply the processes involved in graph comprehension. If however performance is superior in the silent condition to the think aloud condition then the act of verbalising is interfering in the processes involved in graph comprehension.

However, the silent and think-aloud condition is not comparable with these types of tasks because the silent condition involves two stages: an initial silent stage in which the participant constructs the interpretation and a second stage where this interpretation is reported to the experimenter. As this task is split into two stages it could be argued that improvement in performance could occur for a number of reasons other than remaining silent. For example, being explicitly required to communicate understanding to someone else could perhaps result in an improvement.

However, this effect can be balanced by including a further control condition where the second stage of the silent condition is incorporated into the think aloud condition. Therefore, in order to test whether communicating understanding affects performance, a third “summary” condition was included. If it is the act of communicating understanding (and not performing the task silently) which alters performance this condition

will be on par with the silent condition. If however the findings are similar to the think aloud condition then the silent and think aloud condition are comparable. This condition acted as a further control condition allowing for comparisons between the silent and think aloud condition.

Finally, the fourth condition tests any potential influence of experimenter presence on performance by including a “solitary” condition. These manipulations result in three conditions where participants are required to think aloud throughout the task and one condition where participants remain silent. If it is the demands posed by verbalisation resulting in reactivity effects performance should be superior in the silent condition than the other three conditions tested.

Method

Participants

Sixty undergraduate psychology students (41 female, 19 male) from the University of Huddersfield were paid £5 (approximately \$8) in grocery store vouchers to take part in the experiment. The age of participants ranged from 18.1 to 29.7 years with a mean of 22.2 years ($SD = 2.1$). The participants were in their first year of a three year psychology degree and were randomly allocated to the experiment conditions.

Design

The experiment was an independent groups design with four between-subject variables: whether participants were in the think aloud, silent, solitary or summary condition. 15 participants were allocated to each of the graph conditions.

Materials

The stimuli used were six three-variable line graphs depicting a wide range of (fictional) content. The graphs were generated using the PASW Statistics software package (produced by SPSS Inc.). Stimuli were printed in colour (with the levels of legend variable in blue and green) on white A4-sized paper. Examples of the stimuli used are depicted in Figure 1. The variables in the graphs were chosen so that no prior knowledge of the domain or relationships would influence interpretation.

Procedure

In the first think-aloud control condition participants were informed that they were to be presented with a sequence of six three-variable line graphs and that their task was to try to understand each one as fully as possible while thinking aloud. The nature of the task was further clarified by telling participants that they were being asked to try to understand the relationships between the variables (rather than simply describing the variables in the graph), to try to comprehend as many relationships as possible, and to verbalise their thoughts and ideas as they did so. During the experiment, if participants went quiet, the experimenter encouraged them to keep talking. If participants stated that they could not understand the graph, it was suggested that they attempt to interpret the parts

of the graph they could understand. If they still could not do this, they were allowed to move on to the next trial.

In the second silent condition participants were informed there were two stages to the task. In the first “quiet” stage they could take as long as they wanted to understand the graph they were viewing as much as possible. In the second “talking” stage they were required to tell the experimenter what they had understood about the graph.

In the summary condition participants were instructed that the experiment consisted of two stages—in the first “think aloud” stage they were to think aloud whilst interpreting the graph. In the second “talking” stage they were to tell the experimenter what they had understood about the graph.

In the solitary condition instructions were identical to the think-aloud condition except participants were told they would be left alone throughout the experiment but it was important they remember to think aloud throughout the task.

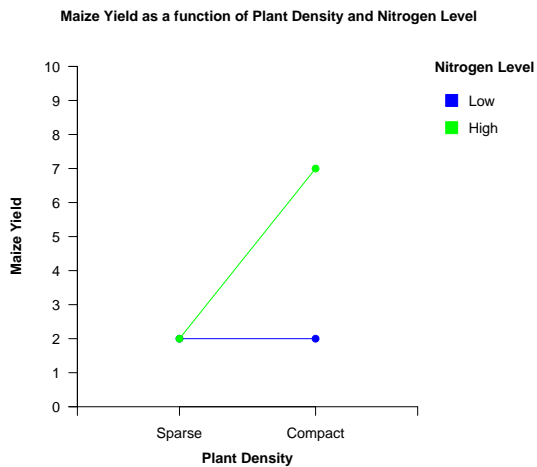
The instructions were designed to be consistent with Type 1 verbalisations, where participants are required to think - aloud throughout the task, but not explain or justify the statements they made. According to Ericsson and Simon (1993) eliciting protocols in this manner should result in no reactivity effects.

Stimuli were presented in random order and all participants were informed that there was no time limit to the task. Verbal protocols were recorded using a portable digital audio recorder.

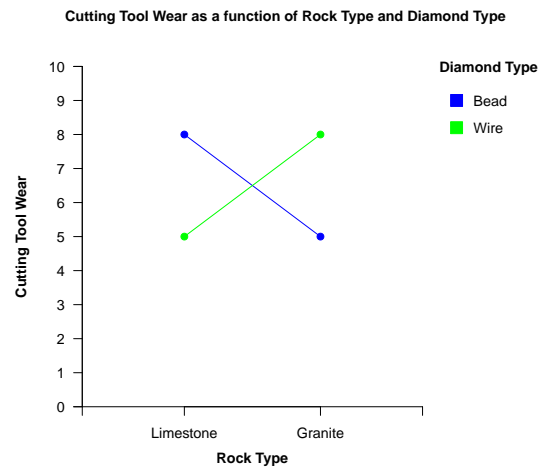
Data analysis

The verbal protocols participants produced while interpreting the graph were transcribed and their content analysed. Only statements in which a sufficient number of concepts could be identified were included for analysis. For example, the statement “low nitrogen levels have no effect on maize yield whether plant density is sparse or compact” was included whereas “low nitrogen affects. . . um. . . I’m not sure” was not. Data analysis was conducted according to the procedure and criteria employed in our original study (Peebles & Ali, 2009; Ali & Peebles, 2013). For each trial, the participant’s statements were analysed against the state of affairs represented by the graph. If a participant made a series of incorrect statements that were not subsequently corrected, then the trial was classified as an incorrect interpretation. If the participant’s statements were all true of the graph or if an incorrect interpretation was followed by a correct one, however, then the trial was classified as a correct interpretation. An example of a correct interpretation for the line graph in Figure 1a is “Whether nitrogen level is low or high when plant density is sparse, maize yield is two. When plant density is compact for low nitrogen level, maize yield is still at two but this increases to seven when nitrogen level is high”.

In addition to this trial-level performance analysis, we also analysed the nature of the errors made in incorrectly interpreted trials. When participants made an erroneous interpretation that was not subsequently corrected, in addition to classifying the trial as an incorrect interpretation, we coded



(a) Graph 4



(b) Graph 6

Figure 1: Two of the six line graphs used in the experiment.

the type of error against the trial. As these graphs depict a relationship between three variables, if participants failed to incorporate all three variables into their interpretation the trial was coded as an error. The nature of the fault was categorised according to which of the variables had been ignored or misrepresented or whatever other error had occurred. Errors followed a similar pattern to the original experiment. An example of an incorrect interpretation for the line graph in Figure 1a is “When plant density is sparse, nitrogen levels remain low. When plant density is compact, nitrogen levels increase”. In this instance the graph viewer is ignoring the dependent variable, maize yield. Verbal protocol evidence revealed participants were unable to provide an interpretation incorporating all three variables. One participant providing this interpretation stated “I don’t understand how maize yield fits into it. I can understand the graph if I focus on plant density and nitrogen level” and then proceeded to ignore the dependent variable. The occurrences and explanations for why these errors occur are explained in greater depth in Ali and Peebles (2013).

In this way, each participant’s trials were coded as being either correctly or incorrectly interpreted. The verbal protocol for each trial was initially scored as being either a correct or an incorrect interpretation by the first author and a sample (approximately 20%) of trials were independently coded by the second author. The level of agreement between the two coders was approximately 90%. When disagreements were found, the raters came to a consensus as to the correct code.

Results

Figure 2 displays the number of correct trials in each verbal protocol condition. The silent condition resulted in a higher

number of correct trials compared to the other three conditions. A comparison of the number of correct trials between the think aloud, solitary, silent and summary conditions revealed that the silent condition resulted in a significant increase (Kruskal-Wallis $H = 7.93$, $df = 3$, $p < .05$) in the number of correctly interpreted trials (mean rank = 40.83) compared to the think aloud (mean rank = 24.60), solitary (mean rank = 27.0) and summary (mean rank = 29.57) conditions.

Three post-hoc Mann Whitney U tests (with alpha levels Bonferroni adjusted to .017) revealed the significant difference to be between the silent condition and the think-aloud condition ($p = .005$), but not the solitary condition ($p = .713$) nor the summary condition ($p = .595$).

Discussion

The results of this experiment reveal that participants who attempted to verbalise their interpretation of graphs were significantly less likely to provide a correct interpretation than subjects who interpreted the graphs silently before verbalising their interpretation. Additional control conditions revealed that it was not experimenter presence (the solitary condition) or the act of communicating understanding to someone else (the summary condition) which resulted in the performance differences between the think aloud and silent condition. These results definitively demonstrate that verbalisation results in reactivity effects; in this case a detriment in observed performance.

Although previous research has found that requiring participants to think aloud can result in reactivity effects, these findings have been challenged based on how the method was employed. For example, Cook (2006) required participants

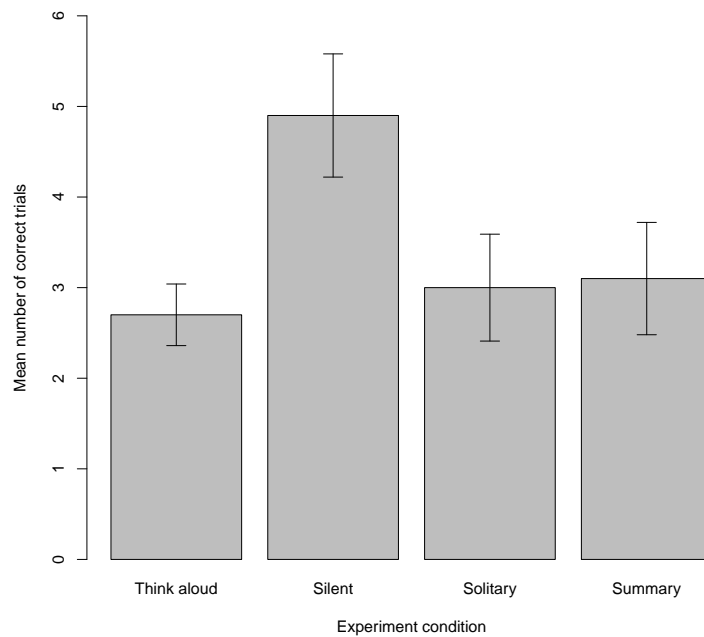


Figure 2: Mean number of correct trials for the experiment conditions. Error bars indicate standard error.

to solve a series of algebra tasks with problems presented by computer in the silent condition but with cards in the verbalisation condition. This introduced a potential confound of verbalisation condition and stimulus format.

In a recent meta-review, Fox, Ericsson, and Best (2011) identified 95 studies employing verbal protocols. Studies were excluded from the meta-analysis if they did not include a comparison to a control condition, if findings were considered suspect because of potential confounding variables, or if effect sizes were not reported. Based on this analysis, the authors concluded that “Studies with confounds are common because few studies with verbal report and silent conditions are designed explicitly to test directly for reactivity” (p. 323).

The experiment reported here directly addresses these issues. We carefully followed Ericsson and Simon’s guidelines for eliciting protocols and explicitly tested the think-aloud condition by comparing output to a silent condition as well as ruling out potential competing explanations for the difference observed between the think-aloud and silent condition.

These findings provide a strong demonstration that reactivity effects can emerge even when participants are asked only to report their thoughts (Type 1 verbalisations) and are not asked to explain them (Type 3 verbalisations). In addition, the task used in this experiment does not fall into a category where information is difficult to verbalise, demonstrating that reactivity effects are not limited to such tasks.

Although this task did not reveal any effect of experimenter presence, this issue deserves further investigation as tasks in the social psychology literature which can generate self-

presentation concerns may reveal findings which corroborate those of de Vet and de Dreu (2007). The increasing use of the verbal protocol method in the social psychology literature indicates further research is required to establish this method is appropriate for these types of research questions (Wilson, 1994).

Our knowledge of why reactivity effects emerge when employing the verbal protocol method is limited primarily because of the lack of studies explicitly testing for such effects. Based on previous findings, it appears that this effect is most likely due to a number of interacting factors and so such findings will not emerge consistently. Our findings demonstrate reactivity effects occur due to the demands of verbalisation and this effect is not restricted to tasks where information is difficult to verbalise.

One potential explanation which could account for the effect observed in our experiment is a competition for processing resources explanation. Russo, Johnson, and Stephens (1989) argued that the additional demands for processing resources (which occurs when individuals are required to verbalise whilst performing a task) can explain deterioration in performance. In order to deal with additional demands of verbalisation, participants can draw upon any unused resources which are not being employed. When the demands of the task exceed processing resources however, reactivity effects can occur, resulting in a detriment in performance due to the resources being divided between completing the task and verbalising throughout (Russo et al., 1989).

However, it is difficult to predict a priori whether or not

performance will be distorted by the generation of a concurrent protocol. Even when a task adheres to established guidelines for when the think aloud method is appropriate to use reactivity effects can emerge (Russo et al., 1989). Control conditions as standard practice when employing this method would help establish the conditions under which reactivity effects emerge; a necessary precursor for a theory of protocol generation which can account for reactivity effects. This practice would also allow more confidence in findings employing this method.

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