Psychologica Belgica
1997, 37-1/2, 51-68.

CAN DYNAMIC CONTROL TASK KNOWLEDGE BE COMMUNICATED?

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Numerous studies on the control of complex systems have pointed out dissociations between skilled task performance and the associated verbalizable knowledge, and have claimed them to be evidence of implicit learning. In this paper, I will first discuss some methodological difficulties in examining whether knowledge is explicit and then attempt to determine whether knowledge acquired while interacting with the simulated sugar factory system designed by Berry and Broadbent (1984) can be communicated. As far as awareness is based on an objective criterion or defined in terms of verbal reports, related studies suggest that control task knowledge is accessible to consciousness. Overall, these findings provide little evidence for the strong dissociation hypothesized earlier.

Does the human cognitive system have the capability to acquire new information without paying special overt attention to that information, or without the deliberate intention to deal with it? Can learning produce knowledge that is not accessible to conscious inspection? Undoubtedly, these attractive questions emerge from raw observations of everyday life which lead us to believe that behavior is not always accompanied by conscious cognition of what is actually being used to respond to our environment. Habits, customs, and native language are all examples of rule-governed knowledge domains that may be evoked here to illustrate this intuition. What is more, when we think about the moment at which learning takes place, it seems fairly reasonable to assume that the rules for behaving in such domains may be largely extracted in an incidental way, without ever coming into conscious awareness. It is therefore not surprising to find numerous attempts in the scientific literature to capture these phenomena. The many instances of such attempts, ranging from some of the earlier work in the field of conditioning to the massive amount of literature now available on implicit learning, all testify to the fact that the scientist who tackles these topics is less motivated by a vogue than by perhaps one of the most basic and intriguing facets of cognition. Although these considerations help us understand the current enthusiasm for what today is known as implicit learning, they nevertheless leave some questions open. Does the phenomenon really exist? Have we been successful in our attempts to isolate and study implicit learning, or at least to demonstrate its existence in the laboratory?

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Some Evidence

One of the very first studies on implicit learning is surely the well-known paper by Reber (1967). Reber showed that individuals who had to simply memorize letter strings generated by an artificial grammar more rapidly attained a memorizing criterion than did individuals exposed to random strings. In addition, participants exposed to structured stimuli were later able to decide at a rate above chance level whether new strings were compatible with the grammar. These results suggested that information about the constraints of the formal grammar was acquired by the participants. Intriguingly, no one talked about the rules that generated the stimuli, nor did anyone succeed in explaining why a specific item was classified as being grammatical. Typically, individuals seemed to know more than they could say. This finding has been repeatedly replicated since then, and some empirical convergence has been obtained in other experimental settings. For instance, in a serial reaction time experiment, Lewicki, Hill, and Bizot (1988) found that practice reduced the time taken to indicate the location of a stimulus on a screen, although the participants were not able to articulate the predictive relationships between the stimulus positions. Experiments on the control of complex systems have also provided parallel findings. Berry and Broadbent (1984) devised a control task where participants acted as managers of a small sugar production factory. They were required to reach and then maintain a specific target production level by manipulating the number of employees. The authors showed that practical experience alone increased the participants' ability to control the dynamic simulated system, but had no effect on their ability to answer a subsequent questionnaire. In an analogous way to what happens in artificial grammar experiments, the individuals were unable to express the rule that related the responses of the system to the decisions they had made. On the whole, these studies present a systematic pattern: there is an increase in a performance measure testifying that information is acquired by the cognitive system, and another measure suggesting that this information is inaccessible to conscious inspection. In the traditional view, such dissociations are interpreted as demonstrating the existence of a special learning mode, called implicit learning, that works on complex stimulus environments by breaking down the code in a passive manner, without consuming many attentional resources and without producing knowledge available to consciousness. However, this rendition of the body of data, at least in its strongest version (see for example Reber, 1989), has been contested more and more due to two main problems that have now become clear.

Does the Information Acquired Resemble the Rules as They Are Conceived of by the Experimenter?

The first major problem in implicit learning studies is related to what is currently known as the information criterion (Shanks & St. John, 1994). Once learning is demonstrated (i.e., on the basis of an increase in a performance test score), it is rather natural for the scientist to attempt to find out whether participants can report on the constraints he or she incorporated into the material. In cases where the participants failed, the experimenter would conclude that the rules were induced implicitly. But how can he or she be firmly convinced that the increase in performance really resulted from sensitivity to these constraints, and that it did not happen in some other way? In an old but highly illustrative study by Dulany (1961), participants were exposed to a verbal operant conditioning procedure in which they were reinforced (with a "umhmm") for each plural noun they output. As in Greenspoon (1955), the participants were "conditioned", i.e., they produced more and more plural nouns, although none of them later reported the correct relationship between their responses and the "umhmm" of the experimenter. However, Dulany noticed that some individuals said the reinforcement was triggered by the production of a word that belonged to the same semantic category as the previous one, and curiously, he also noticed that only those individuals exhibited significant "learning". It therefore looked as though learning was accompanied by a conscious rule. But the rule was underinterpreted as not being responsible for performance changes because it differed from the rule conceived of by the experimenter. Such misrepresentative rules were called *correlated models* by Dulany.

Follow-up studies suggested that several implicit learning investigations were biased by such an artifact. In artificial grammar learning, some investigators argued that classification performance could be accounted for by bringing in knowledge of bigrams, trigrams, legal positions, local rules (either correct or misrepresentative) or some other prevalent features (Dulany, Carlson, & Dewey, 1984; Perruchet & Pacteau, 1990; Dienes, Broadbent, & Berry, 1991). Perruchet, Gallego, and Savy (1990) provided some evidence that the decrease in response latency in Lewicki et al.'s (1988) serial reaction time experiment may have been based on knowledge about the relative frequency of simple target transitions rather than on rule acquisition. In short, when performance is examined carefully through relevant transfer tasks, it seems likely that fragmentary pieces of information or correlated models are responsible for learning.

How Can Explicit Knowledge Be Appraised?

The second major problem in implicit learning studies concerns the test devised to tap awareness. In other words, what counts as a test of consciousness? In the experiments by Reber and Lewicki et al., interviewing was the method used to determine whether participants acquired explicit knowledge. Berry and Broadbent, being perhaps somewhat suspicious of the reliability of this sole technique, preferred to rely in addition on a transfer task, i.e., a questionnaire where participants answered several questions about what they had learned during the control task. In some sense, these authors were precociously in line with the sensitivity criterion recently discussed by Shanks and St. John (1994). Indeed, verbal reporting might be blamed as being an inaccurate method for assessing whether knowledge acquired during learning is explicit, and may be so partly because verbal data are gathered after the task is carried out by the participant. Consequently, the absence of some of the retrieval cues affords the opportunity for knowledge, no matter how available to awareness it was during learning, to be inaccessible to consciousness at testing time.

Objective Awareness

According to Shanks and St. John (1994), it is therefore necessary to use an awareness test that can detect all conscious knowledge possibly utilized on the performance test. This can supposedly be achieved by the so-called *objective tests* of awareness (Stadler, 1989; Willingham, Nissen, & Bullemer, 1989). Such tests have the following properties: (a) they share some characteristics with the performance test, such as retrieval cues, task demands, and so on, and (b) individuals are explicitly encouraged to answer on the basis of their conscious knowledge. Advocates of this method suggest that it makes it possible to decide whether knowledge is explicit or implicit, depending respectively on whether success or failure is observed. This proposal is not unanimously accepted in the scientific community, however. The line of attack is based on the logical argument that the performance test and the awareness test are made so alike that whatever the nature (implicit or explicit) of the information acquired, it can be used on both tests. To take matters to extremes, only associations can be obtained with the objective test approach, and the nature of the information acquired or used cannot be deduced from such associations (see for example Catania, 1994). To illustrate this problem with formal grammar learning, remember that individuals exposed to structured stimuli performed above chance level on a subsequent grammatical test when informed about the existence of the rules. If we agree with the objective test criterion, then it follows that knowledge of artificial grammar is explicit.

However, there is always the possibility that performance on an objective test of awareness is contaminated by implicit knowledge, so that classification performance does not provide any evidence that the knowledge is explicit. This is evidently the interpretation of the partisans of implicit learning.

Subjective Awareness

To overcome the uncertainty about the information objective tests provide, some authors have advocated using *subjective tests* of awareness (Dienes, this issue; Dienes & Perner, 1994). That is, when making a decision on an objective test, the subject has to state his/her opinion about whether he/she possesses the knowledge needed to carry out the task or say how confident he/she feels about the decision made. According to the advocates of this method, knowledge can be considered implicit if individuals perform above chance level on the objective test, while stating that they do not have the necessary knowledge or that they achieve the task entirely by guessing. From recent empirical work (Dienes, Altmann, Kwan, & Goode, 1995; Shanks & Johnstone, n.d.), it looks as though performance on objective tests forces us to regard knowledge as being conscious, whereas the opposite conclusion would be drawn as soon as subjective criteria are taken into account. The relationships between these indexes are probably complex and certainly need clarification through further investigation. Note that some problems with the meta-knowledge approach have been pointed out: a lack of meta-knowledge may simply result from the subject's reluctance to admit having knowledge, especially if that knowledge is poor or the subject does not feel confident about it (Reingold & Merikle, 1990). These considerations stress the fact that from the information conveyed by objective and subjective tests, it may be somewhat difficult to determine the true nature of knowledge acquired in implicit learning situations.

A Little More About Verbal Techniques

It is generally agreed that verbal methods tap explicit knowledge, even though serious shortcomings have been reported. As evoked above, interviewing may be rejected because like any retrospective technique, it affords the opportunity for not fully eliciting all of the explicit knowledge possessed by the participants. Verbal reports also suffer from criticisms similar to those applied to subjective tests: individuals may not report knowledge in which they have little faith. Moreover, equating explicit knowledge with verbal knowledge surely constitutes an oversimplification (e.g., it may be very difficult to put into words mental images that are nevertheless available to awareness). In sum, one of the main discrediting features of verbal techniques is that there are several reasons why incompleteness can occur. In my opinion, there is another major objection that might be made against verbal techniques, or more precisely, against the way verbal data have generally been utilized in studies on implicit learning. Many of the papers using this technique have only given raw information about what participants reported. Often, the reader is only briefly told that individuals were unable to verbalize the constraints incorporated into the material. Relative to the information criterion discussed above, this does not provide any evidence that the information responsible for the performance changes was implicit. Sometimes the reader is merely provided with anecdotal examples or case studies supposed to give strong empirical support for implicit learning (Reber & Lewis, 1977; Reber & Allen, 1978). In such a case, superficial treatment of the verbal data is particularly invalidating, especially since Reber and his coworkers reported verbalization of fragmentary knowledge. The authors have concluded that the fragmentary pieces of information elicited are clearly insufficient to account for the performance level, although no analysis has been made to examine the relationship between verbal knowledge and actual performance. This obviously weakens the conclusion drawn. In sum, few attempts have been made to utilize verbal data satisfactorily. Perhaps this state of affairs results from difficulty finding a method that would enable comparisons of performance and verbal knowledge, since doing so would imply analyzing the verbal data and scoring or scaling it in some way.

Mathews and his colleagues found a good way to get around this problem. Using the artificial grammar learning paradigm, Mathews et al. (1989) asked participants to state everything they thought an unseen partner could use to classify letter strings as they did. Novices (also called *yoked subjects*) were given these reports and then took the grammaticality test without any prior exposure to grammatical stimuli. The crucial finding was that yoked subjects performed above chance. However, their classification performance remained behind that of the original learners, thereby suggesting that grammar knowledge could be only partly elicited. As far as the information criterion is concerned, this ingenious procedure offers the colossal advantage that the experimenter does not have to analyze verbal reports to determine whether explicit knowledge is available. Therefore, he cannot be induced to underestimate some of the elicited knowledge, even if it appears irrelevant in accounting for performance. Relative to the sensitivity criterion, it remains however unclear that the results prove that not all of the classification knowledge can be reported (see e.g., Dienes et al., 1991). For example, the yoked subjects may make mistakes in applying the instructions.

With the above considerations in mind, I will now discuss the accessibility of control task knowledge. Taken as a part of the evidence in favor of implicit learning (see for example Reber, 1989), studies on the control of complex systems have pointed out dissociations between skilled task performance and associated verbalizable knowledge, formerly claimed to be very strong (see for example Berry & Broadbent, 1984). However, follow-up studies compel us to partially or even totally revise this viewpoint. The sections that follow, which are partly illustrated with my own empirical contribution to this area, will address two main questions: (a) Does control task knowledge resemble the rule of the simulated system? (b) Can it be reported verbally?

Control Task Learning and Explicit Knowledge

One of the well-known control tasks is the sugar factory task devised by Berry and Broadbent (1984). Participants were asked to imagine they were in charge of a small sugar factory. While controlling the factory, they had to attain a target level of 9,000 tons of sugar by manipulating the level of employment. Possible sugar production levels ranged between 1,000 and 12,000 tons and the possible number of workers in the work force ranged between 100 and 1,200. The relationship between sugar production and the work force is as follows: $P1 = 20 * W - P0 + R$, where P1 is the next sugar production level, W the number of workers currently employed, P0 the current sugar production level, and R a random term (0 or $\pm 1,000$ tons) that forced the participant to exercise continuous control on the simulated system. After two sets of 20 trials with the control task, Berry and Broadbent exposed participants to various questions that asked them to decide in certain states of the system what level of employment would be needed to attain some specified target production level or to predict the output that would result from a given work force. A crucial finding was that control task performance increased with practice but questionnaire performance did not. In addition, these two measures were not correlated and no one was able to state the rules of the system. This dissociation suggests that control task knowledge is not reportable, whether by means of objective awareness tests (as a questionnaire would be called today) or via interviews.

Does Control Task Knowledge Resemble the Rules of the Simulated System?

Suppose now that while interacting with the simulated system, participants mainly acquire knowledge about "what to do to attain the training target." Taking this reasoning to extremes, imagine that only accurate responses (i.e., cases where the training target is reached) are stored and associated with the related states of the system. Later on, stored responses are given when the same states are encountered again. This simple learning mechanism is capable of accounting entirely for the previous findings: (a) control task performance can increase with practice, (b) there is little chance that acquired knowledge will be elicited on the post-task questionnaire, and (c) the rule for the simulated system cannot be reported.

Using the sugar factory task, Marescaux, Luc, and Karnas (1989) tested the plausibility of this *look-up table* account. After two training sets of thirty trials with a target production level of 9,000 tons, participants were given some questions that closely matched the training task (i.e., questions that were presented in much the same way as in the control task). The questions varied along two dimensions: (a) the target production level required was either the same as (9,000 tons) or different from (6,000 tons) that required during training, and (b) the mini-history given to subjects in each question was taken from either a hypothetical interaction or their own training protocol. In the latter case, individuals were faced with situations they had come across while running the sugar factory and had precisely reached one of the two targets stated above. They could thus accurately answer the questions simply by giving the same level of employment as they had given while interacting with the simulated system. These questions were called *Selected questions* as opposed to *UnSelected questions* from a hypothetical interaction. Hence, the questionnaire included the following kinds of questions: Selected-9,000, UnSelected-9,000, Selected-

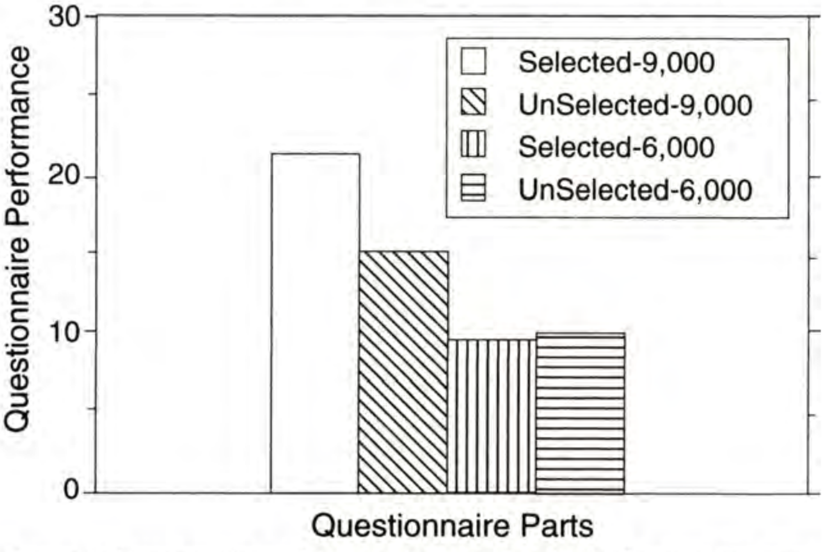

Figure 1. Questionnaire performance by type of problem. Selected questions were situations individuals had come across while interacting with the simulated sugar factory system and for which they had reached the target required in the question. The unselected questions were taken from a hypothetical interaction.

6,000, and UnSelected-6,000. According to the strong implicit learning contention, i.e., that the rule of the simulated system is acquired during training, participants could be expected to perform similarly on all questions. But this was not what happened (see Figure 1).

Performance was better when individuals answered questions involving the training target. Moreover, participants were found to be especially able to cope with situations where they had succeeded during training. Overall, the results suggest that control task learning is mediated by a look-up table where successful responses are associated with the corresponding states of the system. This finding was recently replicated and even refined by Dienes and Fahey (1995). It is therefore not so surprising that Berry and Broadbent found that none of the participants were capable of stating the rule of the system, as it seems highly probable that rule induction is not responsible for performance changes on the control task. Similarly, the knowledge base acquired during learning is probably too specific to deal with the complexity and variability of the kind of post-task questionnaire generally proposed to participants. The flaw in the claim that skilled task performance and the associated verbalizable knowledge are dissociated is that the questionnaire and verbal report methods are probably unsuitable for tapping the knowledge base supporting control task performance.

Can Control Task Knowledge Be Reported Verbally?

According to Shanks and St. John, the fragmentary knowledge revealed in the preceding two studies (Marescaux et al., 1989; Dienes & Fahey, 1995) can be considered explicit. For a number of reasons discussed above, this point of view is doubtful and I will turn now to the question of whether control task knowledge can be reported verbally. Using the teach-back technique and the sugar factory task, Stanley, Mathews, Buss, and Kotler-Cope (1989) showed that control task knowledge was not as tacit as was formerly believed: the information provided by trained participants enhanced the performance of novices. However, original learners needed about 600 training trials before their instructions became helpful, although their own performance improved significantly long before that. In addition, when helped, novices never performed as well as their trained partners. Consequently, Stanley et al. argued that control task knowledge is implicit at the first stages of learning and may only become explicit after somewhat extensive practice with the task.

However, there are several opportunities for knowledge reported by original learners to be underestimated with the indirect method employed by Stanley et al. (Dienes et al., 1991; Marescaux & Karnas, 1991; Shanks & St. John, 1994):

(a) the elicitation method in no way guarantees that all explicit knowledge is fully reported; (b) original learners might not report knowledge in which they are not very confident, especially if that knowledge is developing; (c) the original learners might produce unclear instructions that novices have trouble understanding; (d) novices may make mistakes in applying the instructions; and (e) at moderate levels of practice, original learners might state instructions that are of limited significance for yoked partners. Note that the last potential source of bias is drawn directly from the look-up table account of learning in control tasks. In Marescaux et al. (1989), participants were given a limited amount of practical experience with the sugar factory task and were found to acquire very specific knowledge. Naturally, this finding was established through a so-called objective test, i.e., a method that in no way ensured that correct decisions were not under unconscious influence.[1] But imagine now that a trained participant can report on such fragmentary pieces of knowledge. There is no guarantee that his/her instructions will enhance the performance of a yoked partner, simply because the novice would have to come across the same situations as those encountered by the original learner for his performance to be affected by the instructions.

To avoid some of these potential sources of artifact, Marescaux and Karnas (1991) conducted an experiment to analyze verbal reports and compare explicit knowledge of participants with their own performance.[2] Sixteen participants performed the sugar factory task on 6 sets of 30 trials each, after which they were interviewed. They were asked to state whatever might be useful to a subsequent unseen partner for carrying out the task. The final debriefing interview was managed in such a way that participants were encouraged to state all explicit knowledge they possessed, i.e., they were prompted to report to the best of their ability. The interviews were recorded, fully transcribed, and then analyzed.

What kind of information is reported after training? With the information criterion in mind as well as the empirical evidence that acquisition of specific knowledge might be a viable account for learning in control tasks, the reports were analyzed in such a way that anything that appeared to be potentially useful in controlling the sugar factory was noted and "scored". Each participant was then assigned to one of three qualitative levels of a crude verbal knowledge classification, as follows: some participants made no statements that appeared

[1]Note that in an unpublished study, Dienes and Fahey (1994) found no relationship between response accuracy in situations where participants had been successful while interacting with the simulated sugar factory system and the ability to recognize those situations as being previously encountered. Hence, a meta-knowledge approach does not suggest that specific knowledge like that revealed by the objective test is explicit.

[2]This experiment will be reported fully in a forthcoming paper (Marescaux, n.d.).

useful to control the sugar factory and were assigned the Low Verbal Knowledge level (e.g.,"I can only say that the production of the sugar factory is not a linear function that simply depends on the number of workers, because the production varies from cycle to cycle. So the production varies with the number of workers, but how? I cannot answer that. Perhaps in a purely random way."). Some other participants stated that it was possible to attain the target production level, but what they recommended doing was only correct under specific circumstances (e.g.,"When I am at 12,000 tons, I type 1,000 workers and the production decreases to about 9,000 tons, sometimes just reaching it, sometimes going down to 8,000 tons." or "For me, the best number is 900 workers. I often reached the target with it. So I advise using it."). Note that the specific knowledge was either fully accurate or misrepresentative. The participants who made only statements of this type were assigned to a Middle Verbal Knowledge group (Middle VK). Finally, some individuals elicited a rule of thumb that could help in many situations encountered in the sugar factory task (e.g.,"If you recruit the same number of workers twice in a row, production will return to its previous level. So if I first overshot and then undershot, I know I'll overshoot again if I recruit the same number of workers. So I have to decrease the work force. The reverse is true. If I first undershot and then overshot, I'll undershoot again if I recruit the same number of workers. So, I'll increase the work force to prevent undershooting."). Such a rule does not resemble the formal rule of the system (i.e., the previous level of employment is not part of the equation of the system) and does not allow for predicting what the number of individuals in the work force needed to reach the target sugar production level. Nevertheless, it does predict the direction in which the work force must be changed to manipulate the production level in the right way, and does so even if the current situation is not previously encountered or if a new target is required. These participants were classified as having High Verbal Knowledge (High VK), even if they also expressed specific knowledge. With this classification in mind, it was hypothesized that High VK participants would perform better than Middle VK participants, and that the latter would perform better than Low VK individuals.

Is there a relationship between verbal knowledge and actual performance? Sixteen participants were trained on 6 sets of 30 trials with a target production level of 9,000 tons. Unfortunately, two verbal protocols were lost due to an error in the use of the tape recorder. Figure 2 shows the performance means on the control task, for the three verbal knowledge levels.

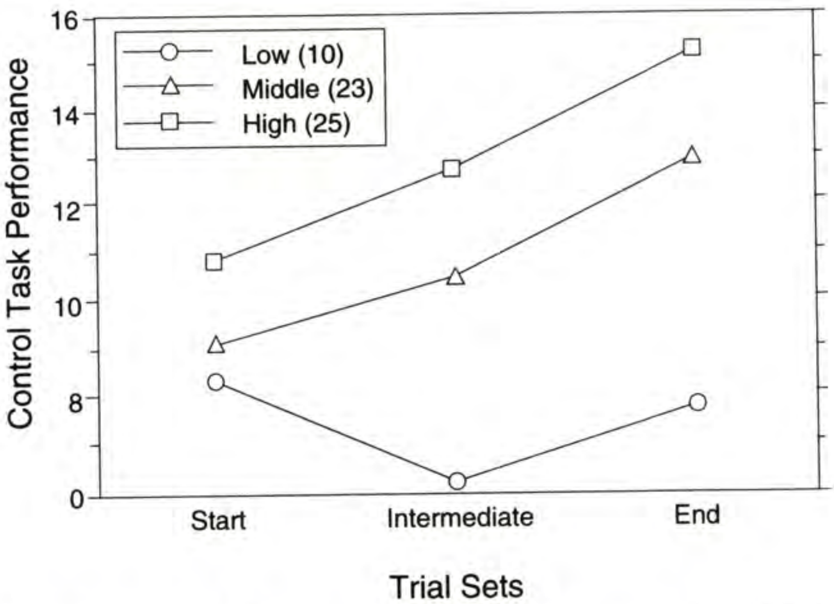

Figure 2. Control task performance on the first two (Start), next two (Intermediate), and last two (End) trial sets, according to the verbal knowledge of the participants as determined on the basis of the final debriefing interview. The number of participants in each verbal knowledge group is shown in parentheses.

As Figure 2 shows, control task performance increased as VK went from Low to High. Unlike Middle and High VK subjects, Low VK participants did not progress over time in their ability to control the sugar factory. In their verbal accounts, there was no obvious evidence that they had acquired any information that allowed them to cope with the simulated system, and this was perfectly in line with their performance pattern, which also testified in favor of no learning. Furthermore, Middle and High VK participants stated information that was relevant to control, but there were qualitative differences in the information elicited. Middle VK was assumed to be useful only under specific circumstances, whereas High VK was supposed to be helpful in many situations. Therefore, these qualitative differences were expected to produce quantitative differences in terms of the number of situations with which Middle and High VK participants were able to cope. From this point of view, their performance patterns were also in line with what they reported.

In some sense, all participants reported verbal knowledge that made their performance understandable. Overall, these results suggest an association between verbal knowledge and actual performance which may appear sooner than claimed by Stanley et al., who postulated that implicit knowledge develops before explicit knowledge. But the Marescaux and Karnas study did not provide any evidence that control task knowledge could be reported fully. To address this question, another experiment was conducted using the yoked subject technique.

Is there a relationship between verbal knowledge elicited by original learners and actual performance by original and yoked subjects? Overall, 90 participants took part in this experiment (see footnote 2). Half served as original learners and half as novices. The first day, the original learners performed four sets of thirty trials with the sugar factory task. They were required to attain a target production of 9,000 tons. In comparison to the training period used in Marescaux and Karnas (1991), the number of training trials was reduced to obtain a better breakdown of the original learners into Verbal Knowledge groups. Once trained, the original learners were interviewed with the same teach-back technique as in the previous experiment. The next day, each original learner came back and was given a full verbatim transcript of his or her verbalization and advised to give the partner he/she would meet later as much information as possible about how to control the factory. After having carefully read the transcript, the original learner had a talk with a yoked subject who was told to ask for any additional explanations desired. After the talk, the original learner 'retired' and the novice performed two sets of 30 trials with the same target production level as the one required of the original learner the previous day. The experiment was continued until there were at least 12 original learners in each Verbal Knowledge group. Figure 3 shows the control task performance means of the original learners and their yoked partners, for each level of verbal knowledge reported by the original participants.

Again, control task performance increased between Low and High VK for both the original learners and their yoked partners. Novices receiving High VK instructions were definitely helped: their performance was better than the beginning performance of their associates. Similar comparisons showed that novices receiving Middle VK advice were only marginally helped and that novices assigned to Low VK partners were not assisted at all. Moreover, all novices were found to perform as their associates did at the end of their training. Overall, these results again suggested an association between verbal knowledge and actual performance and provided no genuine evidence in favor of the residual dissociation proposed by Stanley et al.

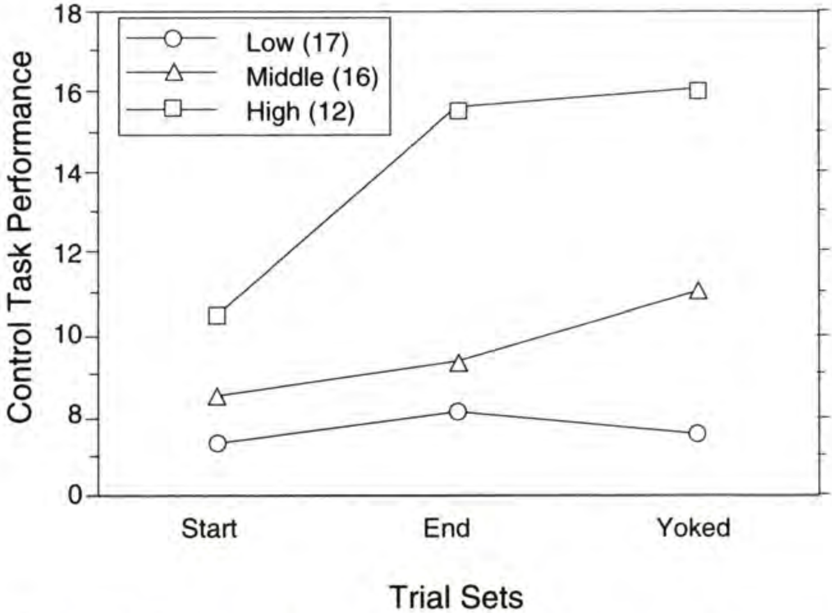

Figure 3. Control task performance (i) of the original learners on the first two (Start) and last two (End) trial sets, according to their level of verbal knowledge as determined on the basis of the final debriefing interview (the number of participants in each verbal knowledge category is shown in parentheses), and (ii) of the novices who received instructions from their trained partners (Yoked) on the two trial sets.

Discussion

Studies on the control of complex systems have revealed dissociations that were formerly claimed to be very strong. This early claim only held its own as long as unconditional adhesion was given to the assumption that rule induction is responsible for learning. Increasing evidence has suggested, however, that implicit learning could be rooted in the acquisition of fragmentary pieces of information or of correlated models (Dienes et al., 1991, Dulany et al., 1984, Perruchet & Pacteau, 1990; Perruchet et al., 1990). The particular case of learning in complex system control does not seem to escape this "general rule". After a limited amount of practical experience at controlling a simulated system, participants exposed to a suitable transfer task elicited responses suggesting that very local knowledge had been acquired (Marescaux et al., 1989; Dienes & Fahey, 1995). The acquisition of such specific knowledge might be a viable account for learning. Moreover, agreement with this assumption made the Berry and Broadbent findings understandable without recourse to any explanation in terms of a dissociation. No participants reported the constraints of the simulated system, simply because they probably did not know the rule. For a very similar reason, they were unable to answer a questionnaire that required knowledge of how the simulated system worked. The early claim that skilled task performance and the associated verbalizable knowledge can be clearly dissociated does not hold up under close analysis and is most likely biased by an infelicity with respect to the information criterion. Note that these considerations do not mean that there is no dissociation, i.e., specific knowledge as revealed by the appropriate transfer task might be not accessible to verbalization.

Despite the different ways proposed recently to examine the accessibility of knowledge (Dienes, this issue; Shanks & St. John, 1994; Shanks & Johnstone, n.d.), it is generally agreed that verbal reports tap awareness. Hence, I chose this definition of awareness and attempted to analyze verbal data to determine whether there is a relationship between reported knowledge and actual performance. In so doing, I found large interindividual differences in the nature of the information reported by trained participants. Some of them did not express anything that appeared useful for the control task, others reported specific knowledge, while still others elicited a rule of thumb that could be applied to many states of the system. These qualitative differences were assumed to result in quantitative differences in performance, and as a whole, verbal knowledge was cogently associated with actual performance. Moreover, novices performed as well as their trained associates just before the latter produced the instructions. Novices were either substantially or marginally helped by general or specific knowledge-based advice, respectively. Overall, these findings provide no genuine evidence of a dissociation between skilled task performance and associated verbalizable knowledge.

Although many of the findings presented here were in line with the conclusions drawn by Stanley et al. (1989) who suggested that two knowledge structures could develop while interacting with a simulated system (i.e., memory-based knowledge and a mental model), a remaining question is the residual dissociation. As pointed out above, there are several opportunities for explicit knowledge to be underestimated with the teach-back technique used by Stanley et al. Some of them may originate in the possibility that not all explicit knowledge is fully reported by the original learner, and others might come from the yoked partner's difficulty understanding or applying the instructions given. The elicitation methods devised in the experiments reported herein were aimed at minimizing these biases: (a) during the interview, trained participants were prompted to report as much as they could, and (b) instructions were given to novices by the original learner himself via a genuine conversation, so that novices could ask for additional information when needed or so that the original learner could detect (from verbal or nonverbal stimuli) that his/her partner was not understanding. Although I do not entertain the naive belief that all explicit knowledge can be reported or understood in this way, these elicitation methods may allow us to come closer to the sensitivity criterion.

Conclusion

On the whole, the findings presented here support another way of looking at learning in control tasks, one where the dissociation is not as strong as previously assumed. Learning, if any, was accompanied here by knowledge that was available for free report. This knowledge did not resemble the rule inherent in the material, but was either fully or partially accurate, and sometimes even misrepresentative. Whatever its form, verbal knowledge was nevertheless shown to account for performance. However, this empirical fact was demonstrated when learning was over. Under these conditions, it is not implicit learning per se that is ruled out, but rather the contention that regularities detected and used in a situation, perhaps without allocation of special attentional resources or the use of explicit strategies, may be inaccessible upon later explicit request. These considerations are what has led to the partial revision of our understanding of the nature of the products of implicit learning that we are currently witnessing in today's literature (see for example Berry & Dienes, 1993, Perruchet, 1994).

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Received April, 1997