Do Measures of Explicit Learning Actually Measure What is Being Learnt in the Serial Reaction Time Task? A Critique of Current Methods

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ABSTRACT: Studies of implicit learning have shown that individuals exposed to a rule-governed environment often learn to exploit 'rules' which describe the structural relationship between environmental events. While some authors have interpreted such demonstrations as evidence for functionally separate implicit learning systems, others have argued that the observed changes in performance result from explicit knowledge which has been inadequately assessed. In this paper we illustrate this issue by considering one commonly used implicit learning task, the Serial reaction time task, and outline what we see as an important problem associated with each of the commonly used methods used to assess explicit knowledge. This is that each measure requires a form of response which is dependent on the subjects having some knowledge of the serial-order of the sequence. We argue that such methods, or more specifically their analyses, seriously underestimate other sources of knowledge, which may be available to subjects during their performance of the SRT task. In support of this argument we demonstrate that subjects' serial-order knowledge can, in principle, be independent of subjects' knowledge of the statistical structure of the sequence, and we propose an alternative method for analysing performance on the Generate task which avoids this problem.

1. Introduction

1.1 Explicit learning is frequently assumed to be similar to the processes which operate during conscious problem-solving, and includes: conscious attempts to construct a representation of the task; directed search of memory for similar or analogous task relevant information; and conscious attempts to derive and test hypotheses related to the structure of the task. This type of learning has been distinguished from alternative modes of learning, termed implicit learning, in which task relevant information is acquired automatically and without conscious awareness of what is being learnt. Studies of implicit learning have shown that when individuals are exposed to a rule-governed environment, they can learn to exploit 'rules' which describe the structural relationship between environmental events. Furthermore, learning is frequently demonstrated by improvement in subjects' task performance, in circumstances where their ability to verbalise the rules is poor (Lewicki, 1986; Reber, 1987).

1.2 Findings such as these raise an number of issues. For example, while some authors have interpreted such demonstrations as evidence for a functionally separate implicit learning system, others have argued that the observed changes in performance result from explicit knowledge which has been inadequately assessed (Shanks and St John, 1994). This inadequacy may result from the relatively insensitivity of the explicit measures selected to detect conscious knowledge, or from a failure of the explicit measures to assess particular sources of knowledge which subjects can use to improve their performance. In this paper we have taken one commonly used implicit learning task in order to demonstrate the latter problem.

1.3 Numerous studies have examined implicit learning of serial-order information using the serial reaction time (SRT) task established by Nissen and Bullemer [1987] (e.g., Cohen, Ivy and Keele, 1990; Curran and Keele, 1993; Howard and Howard, 1989: Jackson and Jackson, 1992; Jackson, Jackson, Harrison, Henderson, and Kennard, 1995; Knopman and Nissen, 1989;Willingham, Nissen and Bullemer, 1989, etc.). In some, but by no means all cases, investigators have made use of one or more measures of explicit knowledge, in an attempt to validate their claim that performance on the SRT task reflects implicit learning. Where such measures have been used, they have made use of either a cued-recall 'generate' task in which subjects are presented with a stimulus and required to predict where the stimulus will move to on the next trial, or some other measure which requires subjects to make a serially-ordered response, or else recognise a serially-ordered sequence or fragments thereof.

1.4 Our primary aim in writing this paper is to outline what we see as an important problem associated with each of the above methods, i.e., that each requires some form of response which is, at least partly, dependent on the subjects having some knowledge of the serial-order of the sequence. We assert that such methods, or more specifically their analyses, seriously underestimate other sources of knowledge, which may be available to subjects during their performance of the SRT task. In support of this argument we demonstrate that subjects' serial-order knowledge, as assessed by the Generate task can, in principle, be independent of subjects' knowledge of the statistical structure of the sequence, and we propose an alternative method for analysing performance on the

Generate task which avoids this problem. Finally, in support of our proposal, we offer several re-analyses of existing data which demonstrate the existence of a small, but critically important, sub-group of subjects who are performing at chance on the Generate task when their performance is analysed using existing methods, but are performing above chance when assessed using the method we are proposing.

2. Implicit and Explicit Learning Using the SRT Task

2.1 In the SRT task introduced by Nissen and Bullemer (1987) subjects see a target stimulus, typically an asterisk, appear at one of four locations on a computer display, and are required to indicate its location by making a keypress. Two versions of this task have been developed: A between-subject version - Subjects are assigned to either a sequence condition in which the location of target stimuli follow a pattern which repeats cyclically, or to a control condition where the stimuli appear in a random order; A within-subject version - Subjects are initially trained on a repeating sequence, however, learning is assessed by presenting subjects with a block of experimental trials (e.g., a block of random trials) (Nissen and Bullemer, 1987). Both of these tasks are administered under incidental learning conditions, and learning is assessed by examing differences in response time between sequential and random conditions or between sequence and random blocks of trials (Nissen and Bullemer, 1987).

2.2 The use of this task has reliably shown: that the RTs of subjects trained on a repeating sequence decrease significantly more than those of subjects trained with a random pattern; and, that subjects trained on a repeating sequence, when transferred to a random sequence, increase their RT's significantly. Furthermore, the RT benefits afforded by the sequential condition has been observed in several different subject populations including: in young subjects with no explicit knowledge of the pattern (Willingham, Nissen and Bullemer, 1987); in memory-impaired populations (e.g., Korsakoff's amnesics [Nissen and Bullemer, 1987]; Alzheimer patients [Knopman and Nissen, 1987]; normal elderly subjects [Howard and Howard 1989; Howard and Howard, 1992]; and in groups of young subjects in which explicit memory has been temporarily impaired through the administration of drugs such as scopolamine or lorazepam [e.g., Knopman, 1991; Nissen, Knopman and Schacter, 1987]). Finally, several studies have more recently demonstrated specific deficits in SRT learning, associated with basal ganglia disease (e.g., Ferraro, Balota, and Connor, 1993; Jackson et al., 1995; Knopman and Nissen, 1991; Willingham and Koroshetz,199 3).

2.3 Recently the use of the SRT task to demonstrate implicit learning has been much debated (e.g., Jackson and Jackson, 1992; Jackson et al., 1995; Perruchet and Amorim, 1992; Reed and Johnson, 1994; Shanks and St John, 1994). The substance of much of this debate has centered around two key issues: The first of these concerns the sort of information that subjects can use to carry out the SRT task. Initially it was felt that demonstrations of improved RT performance for subjects who were presented with a sequence of stimuli, must indicate that subjects were learning about the serial-order of the sequence (i.e., knowledge of the statistical relationship between many sequence elements). However, this assumption has recently been called into question, and several authors have pointed out that subjects need not be learning serial-order information to show RT improvements when provided with a repeating sequence (Jackson and Jackson; 1992, Jackson et al., 1995; Reed and Johnson, 1994; Shanks and St John, 1994). More specifically, it has been suggested that subjects may use quite complex knowledge of the statistical structure inherent in a repeating sequence to facilitate their responses on the SRT task (e.g., Jackson and Jackson, 1992; Jackson et al., 1995). Stadler (1992) and Reed and Johnson (1994) have demonstrated that SRT performance is sensitive to the statistical relationship between trials.

2.4 The second and more substantive issue for debate has concerned the implicit nature of what is being learnt in the SRT task. This issue has more or less subsumed the question of what information is acquired, and has focused upon the adequacy of several additional tasks which have been used to assess the extent to which subjects performance on the SRT task arises as a consequence of their having explicit knowledge of the sequence (note: this assumption ignores the possibility that other, i.e., non-sequential forms of knowledge, can be utilised in performing the SRT task as suggested above). However, before considering each of these tasks in more detail, it is worth briefly mentioning one other strategy which has been used to overcome the problem of controlling for explicit knowledge (thereby demonstrating implicit learning), namely, the use of special populations of subjects, with limited abilities to develop explicit knowledge.

2.5 A number of such studies have attempted to circumvent the issue of whether the RT benefits observed on the SRT task truly reflect implicit learning, by studying clinical or special populations with impaired explicit memory. For example, Nissen and colleagues studied SRT learning in: Korsakoff's amnesics (Nissen and Bullemer, 1987]; Alzheimer patients (Knopman and Nissen, 1987); and in healthy adults in whom explicit memory was temporarily impaired through the administration of drugs (Knopman, 1991; Nissen, Knopman and Schacter, 1987). Whereas Howard and Howard (1989; 1992) have reported several studies of SRT learning in elderly subject populations. While such studies appear, almost by definition, to demonstrate SRT learning in the absence of explicit knowledge, it noteworthy that few if any, have attempted torigourously establish that their subjects do not have some form of explicit knowledge. For example, in at least one study, e.g., Ferraro et al. (1993) no attempt has been made to evaluate the extent to which subjects have explicit knowledge, whereas in several others, e.g., Knopman and Nissen (1987); Nissen and Bullemer (1987); Nissen et al. (1989); and, Nissen, Willingham, and Hartman, (1989), the investigators have simply relied on verbal report, i.e., asking subjects if they had noticed a repeating pattern. While the use of verbal report procedure might appear preferable to no procedure at all, this method is extremely unreliable. For example, in our own studies we have found that subjects trained entirely under random conditions, frequently claim to have noticed a repeating pattern, and when asked to demonstrate the pattern, can confidently tap it out (Jackson and Jackson, unpublished data).

2.6 In common with the clinical studies outlined above, many studies of SRT learning using normal subject populations (where it seems reasonable to assume that subjects might acquire explicit knowledge) have either failed to adopt any test for explicit knowledge (e.g., Stadler, 1992), or else have relied on verbal report (e.g., Curran and Keele, 1993). Many other studies however, have attempted to address more fully the issue of how explicit knowledge might influence SRT performance, by requiring subjects to carry out one or more additional tasks (e.g. Cohen, Ivry, and Keele, 1990; Perruchet and Amorim, 1992; Willingham et al., 1989). These tasks are reviewed in the next section.

3. Measures of Explicit Knowledge Free Recall Methods: Structured Questionnaires

3.1 One measure adopted by several investigators is the structured interview or questionnaire method (e.g., Jackson and Jackson, 1992; Shanks, Green, and Kolodny, 1993; Willingham et al., 1989). This measure can be viewed as a more systematic extension of the verbal report method outlined above. On completion of the SRT task, subjects are typically asked if they "noticed anything about the task". If subjects spontaneously mention the existence of a pattern they are asked to demonstrate it by pointing to the relevant locations on the computer monitor or keypad. If subjects do not mention a pattern in response to the initial probe, they are then directly asked whether they noticed any pattern or repeating sequence, and if so, to demonstrate it in the manner described above.

3.2 We wish to emphasise three important aspects of this procedure: Firstly, subjects are asked to demonstrate their knowledge of the sequence, i.e. serial-order information; Secondly, performance on this task is analysed in terms of the total number of elements correctly produced in sequence, and no account is taken of incorrect responses. The relevance of this point will be illustrated below. Finally, this measure can be seen as a free recall task in which the subject is required to generate the serial-order of the sequence without the aid of external cues.

3.3 In an extremely important study, Willingham et al., (1989) used the free recall procedure to remove from the analyses of the SRT task, any subjects who appeared to have explicit knowledge of the sequence. They demonstrated that even after removing these subjects there was a reliable learning effect on the SRT task. However, the validity of using the free recall measure for this purpose has since been questioned by several authors (e.g., Jackson and Jackson, 1992; Perruchet and Amorim, 1992; Shanks et al., 1993). For example, Jackson and Jackson (1992) demonstrated that estimates of explicit knowledge based upon different measures, i.e., free recall (structured interview) and cued recall (generate task), identify only partially overlapping sub-populations of subjects. Similarly, Shanks et al. (1993) showed that subjects classified as unaware using the free-recall task, were significantly above chance on the cued recall task. Finally, Shanks and St John (1994) have suggested that the free recall measure may be relatively insensitive, and point to the poor fit between the characteristics of the SRT task and those of the free recall procedure.

4. Cued Recall Methods: The Generate Task

4.1 The generate task was introduced by Nissen and Bullemer in their 1987 paper on SRT learning. In this task, subjects are presented with each element of the sequence and are asked to indicate by means of a keypress where the asterisk will appear on the next trial. As each element of the sequence is presented in turn, thereby providing subjects with explicit feedback on errors, the task offers good conditions for explicit learning. For this reason it is usual to present only a limited number of cycles of the sequence. Furthermore, feedback on erroneous responses is particularly apparent in the original version of this task, where subjects were required to produce the correct element before they could move on to the next element in the sequence(Howard and Howard, 1989; Knopman, 1991; Nissen and Bullemer, 1987; Willingham et al., 1989). However, other versions of the generate task have relaxed this restriction allowing subjects to move on to the next item in the sequence irrespective of the accuracy of their response (Cohen, Ivry, and Keele, 1990; Jackson and Jackson, 1992; Jackson et al., 1995). Once more we wish to emphasise that performance on this task has been analysed in essentially the same way as for the free recall task. That is, subjects are scored for the number of elements produced in the correct sequence, and no account is taken of incorrect responses. Also we would point out that when analysed in this fashion, the generate task provides a measure of subjects' knowledge of sequential order.

4.2 As Shanks and St. John (1994) point out, most authors have attempted to demonstrate implicit learning by adopting an approach based upon the so-called logic of dissociation. Thus, to demonstrate that subjects do not have explicit knowledge, it has frequently been considered sufficient, to show that subjects' performance on the SRT and generate tasks dissociate. The validity of this general approach has been discussed at length elsewhere (e.g., Dunn and Kirsner, 1988; Hintzman, 1990; Shallice, 1988; Shanks and St. John, 1994), however, it is worth considering the rationale behind this approach in just a little more detail.

4.3 A key issue raised by the distinction between implicit and explicit learning concerns the extent to which these learning mechanisms lead to fundamentally different forms of knowledge. That is, do implicit and explicit learning form dual routes to a single underlying knowledge representation ? or do they lead to qualitatively different, and independent, sources of knowledge ? Task dissociations can be of particular theoretical importance in relation to questions of this kind, and have frequently been cited as evidence for functionally separable processing systems. Thus, when some variable leads to an effect on task A but not task B, it can be interpreted as evidence that each task depends upon different processing systems. However, as has been noted by many authors (e.g., Hintzman, 1990; Shallice, 1988) single dissociations of this sort constitute relatively weak evidence for separable systems. In fact, Hintzman (1990) suggests that "If different tasks involve different processes, and different processes make dissociations possible, then dissociations . . . . . are to be expected whenever two tasks are compared (p.121)". Much stronger evidence for separable processing systems can be obtained from 'double' dissociations. i.e., where variable X leads to an effect on task A but not task B, whereas variable Y leads to an effect on task B but not task A.

4.4 In our view, reliance upon the logic of dissociation approach alone constitutes a very shaky basis for establishing that separable sources of knowledge underlie performance on the SRT and generate tasks. Firstly, dissociations between the SRT and generate tasks have invariably taken the form of a single dissociation, where subjects perform poorly on the generate task, but very much better on the SRT task. To our knowledge, there have been no demonstrations to support a 'double' dissociation between these tasks. Thus, while two recent studies have reported that Parkinson's disease sufferers show deficits on the SRT task (Ferraro et al, 1993; Jackson et al., 1995), neither demonstrated above chance performance on the generate task, or produced evidence of explicit knowledge based upon any other measure.

4.5 Secondly, as noted by Shanks and St. John (1994), this approach relies upon the assumption that the generate task is an appropriate and sufficient measure of explicit knowledge. Shanks and St. John (1994) suggest that any measure of explicit knowledge must meet two criteria. The first they term the information criterion. This states that before we can conclude that a subject does not have explicit knowledge, we must first establish that the information responsible for performance on our measure of awareness (e.g., the generate task), is in fact the information responsible for performance on the task of interest (e.g., the SRT task). The second criterion they term the sensitivity criterion. This states that before we can consider our measure as an adequate test of explicit knowledge, we must first establish that it is sensitive to all relevant conscious knowledge. Shanks and St. John (1994) propose that the prediction (generate) task fulfills the sensitivity criterion insofar as it reproduces the stimulus context of the SRT task. Furthermore, they assert that the generate task also meets the information criterion because "[it] can be performed at above-chance levels whether the subjects' knowledge is of fragments or of the complete sequence (hence meeting the information criterion)" (p.39). Later in this paper we outline several reasons for doubting the second of these assertions. Specifically, we argue that neither the generate or recognition tasks adequately meet Shanks and St. John's information criterion.

4.6 An alternative to the logic of dissociation approach is the method introduced by Willingham et al. (1989), where subjects' scores on some measure of explicit knowledge are used to remove subjects from the SRT analyses. Unfortunately, only a limited number of investigators have chosen to adopt this method - which in our view offers a more reliable method of demonstrating implicit learning. Notable exceptions are: Curran and Keele (1993) and Shanks et al. (1993), who both used the free recall method to identify subjects with explicit knowledge; and Jackson et al, 1995, who used the cued recall (generate) task to exclude subjects, and replicated Willingham et al.'s (1989) earlier finding of significant SRT learning effects after subjects with explicit knowledge were removed.

5. Recognition Methods

5.1 Perruchet and Amorim (1992) argued for the use of a recognition procedure as a more sensitive means of assessing subject's explicit knowledge. In that study, subjects completed a standard SRT learning phase using a 10-item repeating sequence, and then transferred to a test phase in which they were asked to rate whether they recognised 4-element sequences as being part of the original 10-item sequence they saw during the training phase. 50% of the 4-item sequences were taken from the training sequence and 50% were foils. The results of this study demonstrated a clear correlation (0.8) between RT and recognition performance, which Perruchet and Amorim cited as evidence that RT savings during learning phase were a consequence of explicit knowledge of sequence fragments. While interpretation of the above study has been widely debated (e.g., Cohen and Curran, 1993; Shanks and St John, 1994; Willingham, Greeley, and Bardone, 1993), for our purposes it is sufficient only to note that, in common with the free-recall and cued-recall measures outlined above, this measure is also a measure of subjects knowledge of sequential order information.

6. Do Current Methods Underestimate Subjects' Knowledge?

6.1 We have previously argued that the pattern of stimulus locations occurring in the SRT paradigm, especially the relationship between sequentially adjacent elements in the sequence (transitions), can be viewed as conforming to a grammar in which certain transitions are legal while others are not, i.e., they do not occur in the sequence (Jackson et al., 1995). In this case we define the term transition to mean the relationship between two sequentially adjacent sequence elements, and we assume that knowledge of this relationship does not require knowledge of earlier elements in the sequence. Thus, we wish to distinguish knowledge of individual transitions and their relative probabilities, from more complex representations of serial-order, which may involve knowledge of the statistical relationship between many sequence elements. Given this distinction, it follows that the speeded SRT performance demonstrated in numerous studies of SRT learning, could reflect complex representations of serial-order information. Alternatively, subjects might simply be learning a small set of the most probable transitions.

6.2 In published studies of SRT learning, 'grammatical' knowledge has not been assessed, even though it has been clearly demonstrated on more than one occasion that subject may show sensitivity to 'grammatical structure' (e.g., Reed and Johnson, 1994; Stadler, 1992). This raises three important questions. Firstly, is it possible for subjects to possess knowledge of the training sequence which is not being assessed by the free-recall, cued-recall, and recognition analyses outlined above ? Secondly, are there any data to support the notion that subjects who show little explicit knowledge of serial-order, might have a well developed knowledge of the transitional structure of a sequence ? Thirdly, is knowledge of the transitional structure of a sequence implicit or explicit ?

6.3 In order to answer the first of these questions, it is useful to consider a sequence of the sort commonly used within the SRT paradigm. Table 1 illustrates an 11-element sequence - A B D C A D B A C D C - used in one of our own studies (Jackson et al., 1995). The letters A-D in this sequence represent each of the four spatial locations at which the target stimulus can appear (also the four correct responses open to the subject). The transition table illustrated in Table 1 shows the set of legal transitions contained within the sequence, and their relative probabilities.

6.4 Implicit learning of such a sequence would invariably be assessed by comparing the reaction time savings observed following training on the sequence with reaction times to a random pattern of stimulus locations. In contrast, explicit learning would be assessed (if at all) by one or other of the following methods: recognition; free-recall; or cued-recall. Furthermore as was noted above, each of these methods would be analysed for evidence of the subjects knowledge of sequential order information. In the case of the free-recall method this would involve subjects being required to produce a sequence of responses e.g., A -> B -> D -> C -> A , whereas in the cued-recall situation, subjects would be provided with a series of cues and required to produce the next item in the sequence e.g., [A -> B], [B -> D], [D -> C], [C -> A] etc. In both cases subjects performance (knowledge) is assessed in terms of the number of items correctly produced in the correct sequential order, and no account is taken of whether or not, on erroneous trials, subjects are actually producing responses that are consistent with the transitional structure of the sequence.

Table 1
A transition table for an 11-item ambiguous sequence
A B D C A D B A C D C

		2nd element			
		A	B	C	D
	A	-	0.33	0.33	0.33
1st element	B	0.50	-	-	0.50
	C	0.66	-	-	0.33
	D	-	0.33	0.66	-

6.5 In order to demonstrate this point we carried out a simple experiment in which we completed the cued-recall task for the pattern illustrated in Table 1, but purposely made erroneous responses wherever possible. These responses were not random however, but were instead subject to the rule that all erroneous responses must be grammatically correct (i.e., conform to the transition table for the sequence). In accordance with this rule, we produced the following pattern of responses to the sequence illustrated in Table

1 (cued locations are presented in parentheses): [A] -> C; [B] -> A; [D] -> B; [C] -> D; [A] -> B; [D] -> C; [B] -> D; [A] -> D; [C] -> A; [D] -> C; [C] -> A. When analysed in the conventional manner, this pattern of responses merited an accuracy score of 18.2% correct. As an accuracy score of at least 33% could be achieved by chance, such a score would invariably be interpreted as indicating that subjects had derived no explicit knowledge of the sequence. However, if this same pattern of responses were to be correlated with the transition structure shown in Table 1, it would come as no surprise to learn that it is in fact perfectly correlated (R = 1.0). This demonstrates two points. Firstly, thatin principle at least, it is possible to have knowledge of the set of legal transitions contained in the sequence in the absence of knowledge about serial order. Secondly, that current methods of analysis do not assess the former kind of knowledge.]

Figure 1
Cued-recall (Generate) task performance analysed in terms of serial-order accuracy (% correct), and the correlation between subjects' responses and the transition structure for that sequence.

6.6 Is there any evidence to suggest that this kind of knowledge is being learnt independently of serial-order knowledge ? Another method to explore if 'grammatical' knowledge is being learnt independently of serial-order knowledge would be to demonstrate that there are subjects who score poorly on conventional analyses of accuracy on the cued-recall task, but whose responses are highly correlated with the transition structure of the sequence. We therefore set out to see if we could identify any such subjects by re-analysing cued-recall (generate task) data from several studies of SRT learning conducted in our laboratory. Figure 1 shows the cued-recall task data from subjects trained on either an 8-item, 11-item, or 12-item ambiguous pattern (data were taken from several studies: Jackson and Jackson, 1992; Jackson and Jackson 1995; Jackson et al. 1995). Note, these data represent responses to just the first two repetitions of the sequence. Accuracy in reproducing a serially-ordered set of responses (% correct) are plotted along the abscissa, while the correlation between the subjects responses and the transition table for that sequence are plotted on the ordinate axis. Inspection of Figure 1 clearly indicates that there is a positive relationship between accuracy scores and the correlation measure. Furthermore, Figure 1 also demonstrates that these measures are not completely independent. Thus there are of course no subjects who score highly on the accuracy measure, while scoring poorly on the correlation measure. However, inspection of this figure does reveal a small number of subjects whose responses, while at chance levels for the accuracy measure, are nevertheless highly correlated with the transition structure for the sequence. In this case chance performance was estimated as an accuracy score of 46% or greater or a correlation of 0.54 or less. These figures were based upon data obtained from a group of subjects (N = 44) who were trained on a number of blocks of Pseudo-random trials before being transferred to the Generate task. For these subjects, the mean percentage of correct predictions was 33% (standard deviation = 12%), while the mean correlation coefficient between subjects' responses and the transition structure of the sequence was 0.34 (standard deviation = 0.22).

6.7 While the analyses proposed above could in principle be applied to free recall measures, the relatively insensitivity of such methods renders them less desirable for the assessment of grammatical as well as serial order knowledge. Furthermore, such analyses are also unnecessary for sequences where the training sequence consists of pairwise transitions that are equiprobable. In this situation, knowledge of the transitions between elements, whether explicit or implicit, would not confer any advantage over the control condition.

6.8 We have demonstrated that knowledge of transitional probabilities can occur in the absence of explicit knowledge of serial order, however is such knowledge implicitly or explicitly represented ? Reed and Johnson (1992) have shown subjects can learn transitional probabilities, as demonstrated by their ability to substain their RT performance when a training sequence switches to a series of new sequences in which the 'grammar' is maintained but serial order disrupted. However, these authors did not assess whether subjects' 'grammatical' knowledge was explicit or implicit. While Stadler (1992) argued that probabilistic information can be acquired implicitly, he did not assess explicit knowledge. We are currently conducting several studiesin our laboratory to address this issue.

7. Conclusions

7.1 As previously noted, our primary aim in writing this paper has been to raise what we see as an important problem associated with current methods used to assess subjects performance on the SRT task. We have argued that current methods of analysis may seriously underestimate sources of knowledge, whether implicitly or explicitly represented, which may be available to subjects during their performance of the SRT task and which do not depend upon a serial-order information. In support of this argument we have demonstrated that subjects' serial-order knowledge, as assessed by the Generate task, can be independent of subjects' knowledge of the statistical structure of the sequence, and we have proposed an alternative method for analysing performance on the Generate task which avoids this problem. We have also offered several re-analyses of existing data which would appear to provide some tentative support for the existence of a sub-group of subjects who are performing at chance on the Generate task when their performance is analysed using existing methods, but whose responses are highly correlated with the grammatical structure of the test sequence. It should be stressed that these data a preliminary, and must be corroborated by further studies. However, the existence of such data would appear to confirm the possibility at least, that subjects in the SRT task may learn about the transition structure of the sequence independently of more complex serial-order information. If this is the case, then current methods for assessing subjects knowledge may need to be substantially altered to take account of this possibility.

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