

Goal Based Episodic Processing in Implicit Learning

Peter A. Bibby

Abstract—Research has suggested that implicit learning tasks may rely on episodic processing to generate above chance performance on the standard classification tasks. The current research examines the invariant features task (McGeorge and Burton, 1990) and argues that such episodic processing is indeed important. The results of the experiment suggest that both rejection and similarity strategies are used by participants in this task to simultaneously reject unfamiliar items and to accept (falsely) familiar items. Primarily these decisions are based on the presence of low or high frequency goal based features of the stimuli presented in the incidental learning phase. It is proposed that a goal based analysis of the incidental learning task provides a simple step in understanding which features of the episodic processing are most important for explaining the match between incidental, implicit learning and test performance.

Keywords—Episodic processing, incidental learning, implicit learning, invariant learning.

I. INTRODUCTION

HAVING incidentally learnt something without being first directed to learning that which has been learnt remains a puzzling phenomenon. This kind of learning has often been called implicit learning. Its recent history begins with Reber's [1] demonstration that it is possible to behave as if the regularities that occur in a set of stimuli that have been generated from a set of rules have been learnt without knowing what the rules are that generated those regularities or being instructed to learn those rules. Learning what the rules are may not necessarily be the most important feature of the learning that takes place since there are ample demonstrations that what may be important in Reber's task may not be the rules at all [2]-[9] The incidental nature of the learning, on the other hand, remains an important feature of performance on this kind of task.

The study reported in this paper focuses on what it is about the incidental learning task itself that facilitates apparently implicit learning. The current studies focus on the learning of an invariant feature as first demonstrated by McGeorge and Burton [10]. This is a good candidate incidental learning task for examining how the incidental learning influences the later classification of stimuli since the structure of the task itself is

relatively straightforward. Participants are presented with a set of four digit numbers. They are asked to add the first two digits together, and then add the second two digits together and finally to compare the two sums and say whether the first is higher than the second, the second is higher than the first or that they are both equal. Next is a surprise recognition task. Two stimuli are presented and participants are asked to state which of the two stimuli has been seen before. In the initial, so-called incidental learning phase of the experiment each stimulus had an invariant feature. In the McGeorge and Burton case, it was the number 3. In the recognition part of the experiment, half the stimuli contained the digit 3 and half did not, but none of the stimuli had been seen before. On each test trial participants were asked to decide between each of these two kinds of stimuli. Participants selected the four digit strings that contained the digit 3 at a greater than chance likelihood. They were more likely to say that a novel string had been seen before if it happened to include the number 3 when compared to what would be expected. However participants did not report this regularity. This seems to constitute prima facie evidence of implicit learning.

Wright and Burton [11] noticed that it was possible to use frequency-based information to reject rule negative items, i.e., those items that did not contain the rule, in the test phase. Specifically, they noticed that the rule negative items were more likely to contain repeating digits than rule positive items. They hypothesized that the repeated digits were noticed by the participants in the experiment and formed the basis of a 'just say no' strategy. The implicit knowledge of the rule itself was not required to perform above chance since the rejection of novel features of the stimuli was sufficient. Similarly, Churchill & Gilmore [12] concluded that performance on this task could be best described as the rejection of salient negative stimuli rather than the acceptance of salient positive stimuli. It has been suggested that just this kind of detection of novelty in test items plays an important, though often underestimated, role in many implicit learning tasks [13]-[14]. Stadler, Warren and Lesch [15] demonstrated that simply removing the repeated digits in the test negative items removes the cross-format transfer that McGeorge and Burton [10] observed. It was demonstrated that if the incidental learning stimuli were written in digits but the test items were words there was still above chance selection of the test stimuli that contained the regularity.

Cock, Berry and Gaffan [16] found that participants were more likely to select a sequence of four digits as having been

Peter A. Bibby is with the School of Psychology, University of Nottingham, University Park, Nottingham, UK, NG7 2RD. (corresponding author phone: +44 115 951 5329; fax: +44 115 951 5324; e-mail: peter.bibby@nottingham.ac.uk).

seen before even when it did not contain the rule if it was similar to the incidental learning items. Thus, the similarity of stimuli between the incidental learning phase and the test phase was confounded with the presence or absence of the invariant feature. Participants may be selecting test items that contain the invariant feature not because it contains the invariant feature, but rather because it is simply more like the incidental learning items.

Thus there are two alternative strategies in this task that can result in above chance performance on the task; reject items that contain novel features and select items that are more similar. Neither of these strategies requires knowledge, implicit or otherwise, of the regularity present in the incidental learning stimuli. Both of these strategies are commensurate with an episodic processing account of implicit learning. Brooks [2] explained Reber's [1] findings by arguing that the structure of the learning stimuli is latent in the frequency distribution of instances that participants experience and the apparent rule following behavior can be explained by comparing new stimuli with the instances stored in memory. Whittlesea and colleagues [17]-[19] have argued that an episodic processing account wherein participants utilize the episodic knowledge acquired in the learning phase to respond in the test phase provides a good account of implicit learning phenomena. This is similar to the view espoused by Roediger and colleagues [20]-[22] who believe that performance in implicit memory tasks can be explained by the match between the processing that takes place during the learning phase and the task that is then performed in test phase. The greater the match is, the greater the evidence of learning.

So what features of the incidental learning stimuli can be recruited to solve the invariant features test task? Certainly there is evidence that participants notice novelty and they can utilize similarity but are these digit-based features all that drives the learning effect? Huddy and Burton [23] argue that the processing consistency argument of Whittlesea and Wright [18] does not specify precisely what knowledge may be transferred between the learning and test phases of implicit learning tasks. However, Huddy and Burton [23] asked participants what strategies they used to perform an incidental learning task not dissimilar to the McGeorge and Burton [10] task. Many participants reported using the earlier computations as a strategy for making decisions in the latter task. While this goes some way to supporting the episodic processing account it is not sufficiently specific to be able to say what features of the computation are participants using.

If the incidental learning task is described as a goal hierarchy it suggests the specific stimulus features that might be recruited by a processing system that employs earlier experience. The initial goal is to compare the sum of the first two digits with the sum of the second two digits. The subgoals related to this task are summing the first two digits and then summing the second two digits. The subgoals of these subgoals are either to retrieve from memory the relevant sums or to perform the actual calculations. This suggests that measures of similarity that take into account the sums that are

actually calculated may well show up regularities in the learning set and the test sets that can then be used to explain the behavior of participants in these experiments with respect to a processing account. This approach is commensurate with the claims made by episodic processing accounts and emphasizes the need to examine carefully the task that participants are set during the study phase. Such sum-focused measures of similarity have not so far been used in examining this task.

The experiment reported here focuses on the goals of the study task and suggests that goal-based regularities in the stimuli will be utilized as well as feature-based regularities in the classification task. In line with the previous research it is hypothesized that participants can use either a strategy based on the rejection of novel goal-based regularities or the acceptance of similar goal-based regularities. The experiment that follows changes the procedures used in previous experiments by (1) randomly selecting different learning and test stimuli for each participant, (2) making the test the judgment of a single stimuli of varying types and not a comparison between two different kinds of stimuli, (3) replacing the invariant digit with an invariant rule and (4) by increasing the number of study and test stimuli. Each of these adjustments reduces the possibility of confounding with the sum based regularities of the study phase. At the same time, if an episodic processing account is to be believed then there is still likely to be evidence of above chance performance in the test phase. This will be related to the actual calculations performed by participants and not simply to presence of a specific regularity in the stimulus or the frequency of particular digits or digit positions.

II. METHOD

A. Participants

Twenty undergraduate students from the University of Nottingham took part in this experiment (mean age 19.4 years, 12 females). They were paid a small fee for their participation.

B. Stimuli

The study stimuli were generated individually for each participant. Each of these stimuli was four digits long with no repeating digits. Furthermore, for each of the stimuli the second digit was always greater than the third digit. The digit string 3542 was a legal string but 5342 was not. A total of 120 such digit strings were generated for each participant. For half these strings the sum of the first two digits was greater than the sum of the second two digits and for the other half this relationship was reversed. No digit strings were used wherein the digit sums were the same. Eighty of these strings were used as study strings and 40 were used as test positive strings. A further 40 strings were generated wherein the second digit was smaller than the third digit. These were used as test negative strings. Again for half these strings the sum of the first two digits was greater than the sum of the second two digits and for half these strings this relationship was

reversed.

C. Design and Procedure

Participants were sat in front of computer on which the experiment was run using E-Studio experiment software. Participants were asked to read and then follow the instructions. Initially they were told that a series of four digit numbers would appear on the screen. They were asked to respond by pressing one key on the keyboard if the sum of the first two digits was greater than the sum of the second two digits and use a different key if the sum of the first two digits was less than the sum of the second two digits. Once they had made a response the screen was cleared and there was a 1 second delay before the next four digit stimulus was presented. Participants were asked to respond as accurately as possible. There was no instruction to respond quickly. After they had completed 20 trials of this task they were presented with the test instructions. Now they were told (falsely) that they would see a number of stimuli, half of which they had seen before and half of which they had not seen before. They were asked to press one key if they had seen the stimulus before and a different key if they had not seen it before. Again they were asked to respond as accurately as possible but there was no instruction to respond quickly. After a response had been made there was a 1 second delay, with a clear screen, before the next stimulus was presented. There were 20 instances of these stimuli, 10 test positive and 10 test negative. This study then test cycle was repeated four times. Participants were provided with no feedback on their performance throughout the experiment.

After the test phase of the experiment participants were given a post experiment questionnaire. The questions were selected to assess participants' conscious awareness of their behavior during the learning and test phases of the experiment. The first question that participants were asked was to rate the frequency with which particular sums occurred: "In the learning phase, how often did the following sums occur?" A likert type response method was used with 'rarely' as one anchor, scored 1, and 'frequently' as the other anchor, scored 6. The second question asked "Did you decide more often on the basis of: (a) I've definitely not seen it before or (b) I'm sure I've seen that before". Participants were then asked to answer 4 free response questions: (1) how often did you just guess? (2) Which types of numbers were you most confident responding to? (3) What types of information do you think you used in order to decide whether or not you had seen the stimuli before? (4) Did you have any strategies to aid you?

For the purposes of analysis the design is 2x2x4 within subjects. The first factor is whether the relational regularity, i.e., the second digit was greater than the third digits, was present or absent in the test stimuli. The second factor was the response participants made, i.e. that they had seen a four digit string before or not. The final variable was experimental block. There were four blocks of the learn-test cycle in this experiment.

D. Measures

A single measure of performance on the test task was used, i.e., the frequency with which particular responses were made. A number of stimulus similarity measures were also calculated. First, for each test item the sum of the frequencies with which its constituent digits had occurred in the previously seen study stimuli was calculated. For example, if the test item was 5389 and 5 had occurred 6 times, 3 had occurred 9 times, 8 had occurred 6 times and 9 had occurred 11 times the digit frequency score was $6+9+6+11=32$. The number of the test block to give a standardized measure over the four blocks then divided this. Next, for each test item the sum of the frequencies with which its constituent digits had occurred in the same position in the study stimuli was computed. For the test item 5839, if the 5 had occurred in position 1 twice, the 8 had occurred in position 2 twice, the 3 had occurred in position 3 four times and the 9 had occurred in position 4 five times the digit by position frequency score was $2+2+4+5=13$. Again, this was divided by the task block number to standardize across the experiment.

Two similarity measures were then calculated for the sums. The sum frequency score was calculated by summing the frequency with which sums had occurred in the study phase. For the stimulus, 5389, if the sum 8 (i.e., $5+3$) had occurred 4 times in the learning phase and the sum 17 (i.e., $8+9$) had occurred twice in the learning phase the test item was given a sum frequency score of 6 (i.e., $4+2$). A sum by position frequency score was also calculated. For the example test stimulus 5389 if the first sum, 8, had occurred in position one twice in the learning phase and the sum 17 had occurred once it was given a score 3 (i.e., $2+1$). Both these measures were divided by block number to standardize across the experiment.

The final two measures of similarity focus on sums that may be more or less salient in the match between the study and test stimuli. For each participant the distribution of sums was examined. The standardized deviation of these frequencies from the expected random frequencies was calculated. If this had an absolute value of 1 or more this particular sum was identified as relatively high or low frequency. This information was used to construct two measures of match between the learning and test stimuli. The number of test stimuli was counted for each stimulus type (i.e. test positive and test negative) by decision (seen before and not seen before) that included a high frequency sum or a low frequency sum. This was then divided by the total number of responses for each stimulus type by decision. The first of these proportions is a direct measure of those items that include high frequency sums that may be salient to participants in the learning phase. The second is a measure of those items that contain low frequency sums that may become salient in the test phase, because of their relatively low frequency, in the test phase.

III. RESULTS

Prior to analysis of performance of the test data the distribution of response times for the test data was examined. It was noticed that the time taken to decide whether a number had been seen before was not normally distributed. Closer examination of individual participants response times suggested that the time taken to respond was subject to outliers. For each subject items that showed response times more than three standard deviations from the mean were removed. A total of 2.68% of the responses were not subjected to further analysis.

To examine whether the pattern of responses varied in the test phase of the experiment a three-way (2x2x4) repeated measures analysis of variance was conducted on the counts of participants' decisions. The factors were rule (presence or absence in the test stimulus), decision (seen the stimulus before or not seen the stimulus before) and block (a level for each block of practice). There were a number of significant effects. First, there was a main effect of decision ($F_{1,19}=5.645$, $MSE=7.322$, $p=0.028$). On average participants said that a test item had been seen before (mean=5.225, $SE=.148$) more often than it had not been seen before (mean=4.506, $SE=.156$). Second, there was a main effect of block ($F_{3,57}=3.627$, $MSE=.215$, $p=0.018$). With practice participants made more decisions in times that were not outliers.

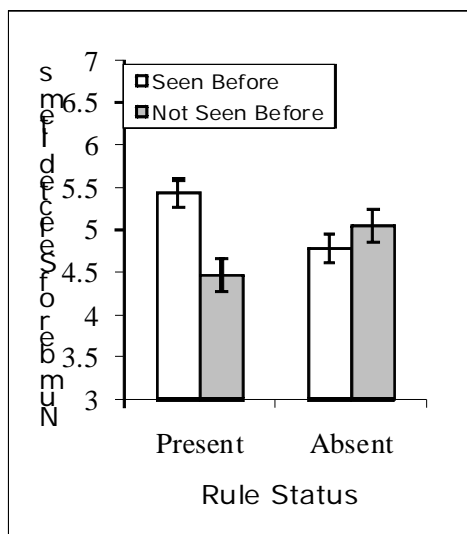


Fig. 1 Means (and standard errors) of the frequencies for the presence or absence of the stimulus rule by participant decisions

Third, there was an interaction between the rule and decision factors ($F_{1,19}=33.461$, $MSE=4.002$, $p<0.001$, see Fig. 1). When the rule was present participants were more likely to say that they had seen the stimulus before than not. This difference was not the same when the rule was absent. More specifically, the average number of times a participant said a stimulus had been seen before was greater than chance when the rule was present ($t=4.810$, $p<0.001$). Similarly, they were significantly below chance for stimulus that contained the rule with respect to deciding that they had not seen the rule before

($t=6.282$, $p<0.001$). When the rule was absent, the decision to say that at stimulus was seen before was below chance ($t=2.176$, $p=0.042$). There was no difference when the rule was absent and the decision was that a stimulus had not been seen before.

Overall, this evidence suggests participants are using a regularity in the rule-present stimuli to decide whether they have seen a stimulus before. The question arises, is it the rule that is being used or is it some other covarying property of the stimuli that is being utilized? If the observed interaction is due to stimulus feature regularities other than the rule then similar interactions should be expected for those stimulus features. To investigate this series of directed interaction contrast F-tests were conducted on the six measures of stimulus similarity. For the following analyses only eighteen participants were included since two subjects failed to provide scores because they responded 'seen before' to all the rule present stimuli in one of the blocks of the experiment.

For the digit, digit by position, sum and sum by position scores the interaction was not significant ($F_{1,17}=0.040$, $MSE=2.609$, $p=0.844$; $F_{1,17}=1.844$, $MSE=2.035$, $p=0.192$; $F_{1,17}=0.075$, $MSE=1.883$, $p=0.845$; $F_{1,17}=0.044$, $MSE=.729$, $p=0.808$; respectively). The final two regularity measures focus more strongly on the nature of the sums that have been calculated in the study phase. For the measure focusing on high frequency sums the interaction between rule and decision is significant ($F_{1,17}=6.636$, $MSE=.058$, $p=0.02$).

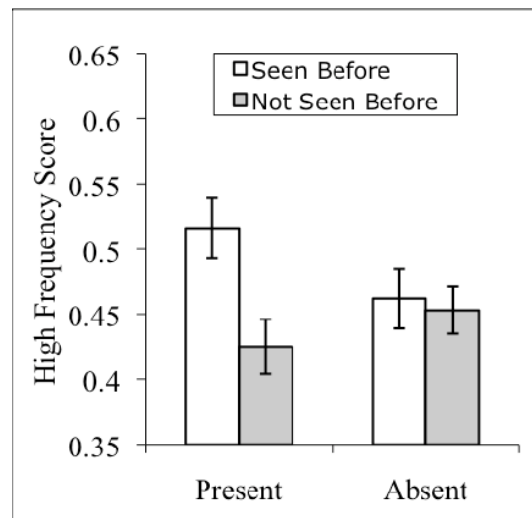


Fig. 2 Means (and standard errors) of the high frequency score for the presence or absence of the stimulus rule by participant decisions

It can be seen from Fig. 2 that when the rule is present in the stimuli at test, the proportion of items including one or two high frequency sums is higher for items that have been seen before than items that have not been seen before. This pattern is different to that observed for the test stimuli that do not include the rule. The opposite, though significant, effect is found for items that include the low frequency sums ($F_{1,17}=6.431$, $MSE=.0258$, $p=0.021$; see Fig. 3). In this case,

the proportion of items including low frequency sums when the rule is present is smaller for those that have been selected as having been seen before than those that are selected as not having been seen before. This suggests that if a sum is present in a test stimulus that occurred frequently in the study stimuli then that item is more likely to be accepted as having been seen before. At the same time, if the rule is present and a sum that occurred infrequently in the study phase is observed in a test stimulus then that item tends to be rejected as not having been seen before.

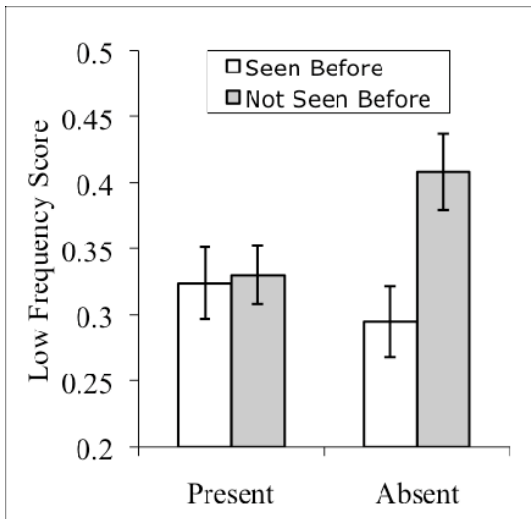


Fig. 3 Means (and standard errors) of the low frequency score for the presence or absence of the stimulus rule by participant decisions

The next issue is the extent to which participants were aware of the strategies that they were using to classify the test stimuli. The correlation between rated frequency of sums and observed frequency of sums was calculated. The mean observed correlation was $r=0.511$ with a standard deviation of 0.044. Using Fisher's r to Z transform a single sample t test determined whether this correlation was significantly above zero. The results suggest that the mean correlation was greater than zero ($t_{29}=10.570$, $p<0.0001$). This suggests that the participants' subjective ratings of sum frequency are related to the objective sum frequencies. The forced choice question, "Did you decide more often on the basis of: (a) I've definitely not seen it before or (b) I'm sure I've seen that before", 12 participants selected option (a) and 18 participants selected (b). The probability of obtaining this distribution is $p=0.081$. There is no evidence to support the conclusion that one of these two strategies was being used more than the other in this data. The responses to the second question "How often did you just guess?" were coded as frequently, sometimes, never. Of the 30 participants, 23 reported guessing frequently, 6 reported guessing sometimes and 1 reported guessing never ($\chi^2=26.6$, $df=2$, $p<0.001$). Most participants report guessing most of the time.

The open-ended questions were analyzed for evidence of

the strategies that participants were using to classify items. Eight out of nine participants who reported using sum information to classify stimuli were above chance at identifying rule present stimuli ($p=0.020$). Of the remaining 11 participants only 3 were above chance at identifying rule present stimuli. Five participants reported calculating the sums in the test phase to see if they were the same pair of sums as in the learning phase. Each of these participants was above chance in classifying the rule present stimuli. No participants could report the regularity that was present in the stimuli. Participants were unaware that the second digit in the four digit string was greater than the third digit.

IV. DISCUSSION

The primary finding is that participants selected items as having been seen before more often when those stimuli include a rule that was present during incidental learning. This indicates that participants have either learned the rule or have picked up on statistical regularities in the rule stimuli and use this information to either accept stimuli as familiar or reject stimuli as not familiar. The analyses of the other, not rule-based statistical regularities, provides evidence to support an episodic processing account. Whether a stimulus contains a sum that is high or low frequency, as experienced in the study phase, relates to whether a test stimulus containing the rule is accepted or rejected. When a stimulus is examined at test, one of the properties of that stimulus that is considered is the sums that are generated during the study phase. If a stimulus happens to contain a sum as calculated in the incidental task that is high frequency then participants are more likely to accept this stimulus as having been seen before. At the same time, if a stimulus contains a sum that is low frequency participants tend to reject the item. Participants report using this strategy.

A simple goal based analysis of the incidental learning task that participants are asked to complete during has successfully directed attention toward those components of that task that are important for performance of the test task. Participants are asked to add two digits together, the first and the second of a four digit number, and to compare them to the third and the fourth. What turns out to be important is the frequency with which particular sums occur. This is perhaps not surprising since the actual digits themselves that construct the totals are not relevant to the goal of the task. Most of the possible sums that can be computed from the stimuli are a number of combinations of digits that could produce those sums. If the sum is 11 then given the constraints on the stimuli in this experiment there are 4 ways to achieve that sum (i.e., $2+9$, $3+8$, $4+7$, $5+6$). The actual digits that are used to generate that sum are not relevant to the task during the study phase. In this case, 8 out of the 9 possible digits are used. Furthermore, neither is the order of those digits within the two digit combinations. There is very little reason to assume that the digits themselves or their order are good predictors since they are not immediately relevant to the incidental learning task.

As in previous research [11]-[12] the current results support the conclusion that participants can use a 'just say no' strategy. In this case, however, it is not repeated digits that participants are using to reject items that do not follow the rule. Rather, it is the presence of low frequency sums that is being used. The identification of novelty is not necessarily restricted to simply the digits that have been focused on. Instead, it is quite possible that any regularity that occurs at test that was not present at learning might be used to decide that a test item does not belong to the same rule based category as the learning items.

As well as a rejection strategy, there was also evidence for a similarity strategy in these results. Participants may not simply use dissimilarity upon which to base their decisions, but they may simultaneously use similarity information. Cock, Berry and Gaffan [16] found that items that did not contain the rule were still selected as having been seen before provided they were similar to the rule based stimuli. This finding is essentially replicated here. However, what distinguishes these results from others is that the measure of similarity is not what digits have been seen but rather what sums have been calculated. This measure of similarity is rather closer to the actual incidental task that participants complete than the more distal digit based measures of similarity.

With respect to the issue of conscious awareness, there is a systematic pattern of evidence which suggests that participants were indeed aware of what they were doing but not aware of the regularity in the stimuli. First, there is a strong and systematic pattern of correlation between subjective ratings of frequencies and objective measures of frequencies. Participants rated low frequency sums as rarer and high frequency sums as more frequent. Whilst this need not necessarily imply conscious awareness it does suggest that participants are sensitive to objective frequencies which is necessary to justify the high and low frequency measures of similarity used in the analyses.

Second, a majority of participants (60%) report making decisions on the basis of being sure that they had seen stimuli before but a large minority (40%) made decisions on the basis of being sure that they had not seen a stimulus before. These two strategies, which can be based on either similarity or dissimilarity, i.e. novelty, have been reported before in the literature [11]-[12]. The high and low frequency sum data supports the conclusion that both of these strategies are efficacious. Participants can choose to accept test items that include high frequency sum and simultaneously use low frequency sums to reject test items.

Third, the responses to the open ended questions suggest that those participants who referred to using sums to make their decisions tended to perform above chance on the classification task. In particular, all of the participants who stated that they used a strategy which involved calculating sums as they had in the incidental learning phase of the experiment all showed evidence of a learning effect. Whilst other strategies were reported or mentioned they were not

associated with above chance performance on the classification task. At the same time, no participants were able to report the rule based regularity in the stimuli.

V. CONCLUSION

The main aim of this paper was to examine the relationship between the incidental learning tasks used in implicit learning studies and the later tests used to assess participants implicit knowledge. It was argued that an important feature of the match between the learning and test phases in implicit learning research is the goal structure of the incidental learning task. The results clearly demonstrate that an apparent implicit learning effect can be best explained not by the presence of an invariant feature but rather by the match between the incidental learning and recognition test phases of the experiment. Specifically, the two goal based measures of high and low frequency sums covaried with performance on the recognition judgment. When participants endorsed an item that contained the invariant feature then it often included a high frequency sum. At the same time, when a digit string that followed the rule was rejected it often included a low frequency sum. The evidence suggested that participants used sum-based knowledge to either accept or reject items, which was also noted by Huddy & Burton [23]. Importantly, the influence that the match in episodic processing between the incidental learning and recognition test phases suggests that it is not necessary to invoke a specialized implicit learning process to explain the performance on this task.

REFERENCES

- [1] Reber, A. S. (1967). Implicit learning of artificial grammars. *Journal of Verbal Learning and Verbal Behavior*, 5, 855-863.
- [2] Brooks, L. R. (1978). Non-analytic concept formation and memory for instances. In E. Rosch and B. Lloyd (Eds.), *Cognition and concepts* (pp. 169-211). Hillsdale, NJ: Erlbaum.
- [3] Brooks, L.R., and Vokey, J.R. (1991). Abstract analogies and abstracted grammars: Comments on Reber (1989) and Mathews et al. (1989). *Journal of Experimental Psychology: General*, 120, 316-323. Dienes, Z., Broadbent, D., and Berry, D. (1991). Implicit and explicit knowledge bases in artificial grammar learning. *Journal of Experimental Psychology: Learning, Memory and Cognition*, 17(5), 875-887.
- [4] Gomez, R.L., and Schvaneveldt, R.W. (1994). What is learned from artificial grammars? Transfer tests of simple association. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 20, 396-410.
- [5] Knowlton, B.J., and Squire, L.R. (1994). The information acquired during artificial grammar learning. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 20, 79-91.
- [6] Mathews, R., Buss, R., Stanley, W., Blancard-Fields, F., Cho, J., and Druhan, B. (1989). The role of implicit and explicit processes in learning from examples: A synergistic effect. *Journal of Experimental Psychology: Learning, Memory and Cognition*, 15(6), 1083-1100.
- [7] Perruchet, P., and Pacteau, C. (1990). Synthetic grammar learning: Implicit rule abstraction or explicit fragmentary knowledge. *Journal of Experimental Psychology: General*, 119(3), 264-275.
- [8] Servan-Schreiber, E., and Anderson, J.R. (1990). Learning artificial grammars with competitive chunking. *Journal of Experimental Psychology: Learning, Memory and Cognition*, 16, 592-608.
- [9] Vokey, J.R., and Brooks, L.R. (1992). The salience of item knowledge in learning artificial grammars. *Journal of Experimental Psychology: Learning, Memory and Cognition*, 18, 328-344.

- [10] McGeorge, P., and Burton, M.A. (1990). Semantic processing in an incidental learning task. *Quarterly Journal of Experimental Psychology*, 42A(3), 597–610.
- [11] Wright, R. L., and Burton, M. A. (1995). Implicit learning of an invariant: Just say no. *Quarterly Journal of Experimental Psychology: Human Experimental Psychology*, 48A, 783–796.
- [12] Churchill, E.F. and Gilmore, D.J. (1998). Selection through rejection: reconsidering the invariant learning paradigm. *Quarterly Journal of Experimental Psychology*, 51A, 1–17.
- [13] Higham, P. A., and Brooks, L. R. (1997). Learning the experimenter's design: Tacit sensitivity to the structure of memory lists. *The Quarterly Journal of Experimental Psychology*, 50A, 199–215.
- [14] Vokey, J.R. and Higham, P.A. (1999) *Behavioral and Brain Sciences*, 22, 5, 787-788.
- [15] Stadler, M., Warren, J., and Lesch, S. (2000). Is there cross format transfer in implicit invariance learning? *Quarterly Journal of Experimental Psychology*, 53A(1), 235–245.
- [16] Cock, J., Berry, D., and Gaffan, E. (1994). The role of similarity processing in an incidental learning task. *Quarterly Journal of Experimental Psychology*, 47A, 1015–1034.
- [17] Whittlesea, B., and Dorken, M. (1993). Incidentally, things in general are particularly determined: An episodic processing account of implicit learning. *Journal of Experimental Psychology: Learning, Memory and Cognition*, 122(2), 227–248.
- [18] Whittlesea, B., and Wright, R. (1997). Implicit (and explicit) learning: Acting adaptively without knowing the consequences. *Journal of Experimental Psychology: Learning, Memory and Cognition*, 23(1), 181–200.
- [19] Wright, R.L., and Whittlesea, B.W.A. (1998). Implicit learning of complex structures: Active adaptation and selective processing in acquisition and application. *Memory and Cognition*, 26(2), 402–420.
- [20] Kolers, P.A., and Roediger, H.L. (1984). Procedures of mind. *Journal of Verbal Learning and Verbal Behavior*, 23, 425-449.
- [21] Roediger, H.L., III, Buckner, R., and McDermott, K.B. (1999). Components of processing. In J.K. Foster and M. Jelicic (Eds.), *Memory: Systems, process, or function?* (pp. 31-65). Oxford: Oxford University Press.
- [22] Roediger, H.L., III, Weldon, M.S., Stadler, M.L., and Riegler, G.L. (1992). Direct comparison of two implicit memory tests: word fragment and word stem completion. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 18, 1251-1269.
- [23] Huddy, V., and Burton, A.M. (2002). Generate and test: An alternative route to knowledge elicitation in an implicit learning task. *The Quarterly Journal of Experimental Psychology*, 55A, 1093-1107.