

Learning rules unconsciously while playing Loto:

A new task and its application to assess younger and older adults' implicit learning

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Abstract

In this article, we used a new version of the "invariant paradigm", called the Loto task, to assess younger and older participants' implicit learning. Experiment 1 results showed that younger adults were sensitive to rules that they did not learn explicitly. Such implicit learning was not observed in older adults. Data also showed that sensitivity to rules correlated with explicit inductive skills. Experiment 2 results control for potential biases in these findings, such as item-specific biases or conscious strategies used by participants to look for regularities that are correlated with rules. We discuss implications of these findings for further studying and understanding abstraction of regularities in a stimulus environment.

One of the most important goals of research on implicit learning has been to determine whether people are able to unconsciously abstract the structural nature of the stimulus environment (see Cleeremans, Destrebecqz & Boyer, 1998; Reber, 1989; Redington & Chater, 1996, 2002, for reviews). In a set of stimuli governed by rules, participants are able to adjust their behaviours as if the corresponding rules have been extracted, even though participants are often unable to verbalize them. Although the implicit learning phenomenon has been investigated under well-controlled laboratory experiments, a number of previous studies have used rules that were confounded with the items instantiating the rules. The present study investigates implicit rule abstraction in a new version of the invariant paradigm (e.g. Bright & Burton, 1994; Cock, Berry, & Gaffan, 1994; McGeorge & Burton, 1990; Newell & Bright, 2002; Wright & Burton, 1995) and demonstrates the implicit learning phenomenon in a non-artificial situations.

The implicit rule abstraction phenomenon has been investigated in diverse paradigms. In the widely used artificial grammar tasks, people first study letter strings produced by an artificial grammar, which defines the order of the letters. Next, participants are told that these letter series followed rules defined by a grammar and are asked to categorize new letter strings as grammatical or ungrammatical. Participants perform this task better-than-chance; yet they are unable to state the rule used in making the grammaticality judgment (e.g., Reber, 1967, 1969). Such sensitivity to a pattern of stimuli has also been observed in other well-controlled laboratory tasks such as serial reaction time tasks (e.g., Nissen & Bullemer, 1987; Perruchet & Amorim, 1992), and in more complex interactive cognitive tasks, such as managing time intervals between successive events (e.g., Berry & Broadbent, 1984; Hayes & Broadbent, 1988) or spelling (Pacton, Perruchet, Fayol, & Cleeremans, 2001).

Very few phenomena in cognitive psychology have been debated as vividly as implicit learning phenomenon. Even though it is clear that people are sensitive to regularities in training stimuli, the nature of the knowledge that people abstract from training sets remains

unclear. For instance, implicit learning researchers wondered whether people abstract rules (Altman, Dienes, & Goode, 1995; Lewicki & Hill, 1989; Reber, 1989), store instances (e.g. Brooks, 1978) or fragment knowledge (e.g., Dulany, Carlson, & Dewey, 1984; Johnstone & Shanks, 2001; Kinder & Assman, 2000; Perruchet & Pacteau, 1990; Perruchet, 1994; Redington & Chater, 1996), or even a combination of rules and fragments (e.g., Knowlton & Squire, 1994, 1996; Meulemans & Van der Linden, 1997).

As suggested by several authors, this debate may stem from paradigms or stimuli environment that people have used to investigate implicit learning (e.g., Johnstone & Shanks, 1999; 2001; Higham, Vokey et Pritchard, 2000). In particular, one of the most important difficulties is that grammaticality and fragment composition are often confounded because rules and items generated by these rules cannot be distinguished. For example, suppose the EXQPM and EXKFM are two instances of the rule “series of letters starting by EX and ending by M”. In this case, it is impossible to create items that match the rule and does not involve the E,X, and M letters in the given positions. This makes it impossible to know whether people identify grammatical strings based on rules or rule instances. Attempts have been made to control for this problem, for example, by using transfer tasks (Brooks et Vokey, 1991; Gomez, Gerken and Schvaneveldt, 2000; Knowlton et Squire, 1996; Mathews et al, 1989), biconditional grammars (e.g., Johnstone & Shanks, 1999; 2001; Mathews, Buss, et al., 1989; Shanks, Johnstone, & Staggs, 1997), or by quantifying fragment statistics (e.g., Kinder & Assman, 2000; Knowlton & Squire, 1996; Meulemans & Van der Linden, 1997; Perruchet & Pacteau, 1990).

The present study used the "invariant paradigm" (e.g. Bright & Burton, 1994; Cock, Berry, & Gaffan, 1994; McGeorge & Burton, 1990; Newell & Bright, 2002; Wright & Burton, 1995). In the first phase of this paradigm, the subject is presented with material that contains a regularity (e.g., in numerical items, the presence of the numeral 3; McGeorge & Burton, 1990). In the second phase, they perform a recognition task in which they have to recognize

the items they just saw among new items. The experimental design is such that although all items in the second phase are new, half of them exhibit the same regularity as the items in the first phase and the other half do not. The results obtained using this task seemed promising, as participants judged familiar items that respected the rule more often than items violating the rule. However, it turned out that this finding could be explained without bringing implicit learning to bear, because the rule used covaried with other properties that subjects could utilize (e.g. Newell & Bright, 2002; Wright & Burton, 1995). Thus, for example, Wright and Burton (1995) showed that the first findings obtained with invariant paradigm (McGeorge & Burton, 1990), can be accounted for by explicit processes. McGeorge and Burton (1990) showed that participants who viewed items with the digit 3 then judged more familiar any new item with this digit 3 than new items without this digit 3. Moreover these authors showed that participants seemed unaware of the manipulated regularity. Wright and Burton (1995) showed that this may have arisen from items that did not have digit 3 containing the same digit twice more often than items containing digit 3. Thus, McGeorge and Burton's results may come from participants' consciously using regularity in the material that covaried with the rule rather than from implicit learning. The goal of the present study was to test a new version of the invariant paradigm, called the "Loto" task, while controlling for potential confounds.

The Loto task involves two phases, namely encoding and recognition phases. During the encoding phase, participants see series of numbers. During the recognition phase, participants are presented series of numbers and have to decide whether each series was presented during the encoding phase. More specifically, the encoding phase is adapted from a very popular lottery game in France (called "Loto"). In this lottery game, played by millions of French people every week, people choose six numbers among 49 (1—49) available numbers. They register these numbers in some special stores and look at the outcomes of two randoms draws on T.V. In each of these draws, six balls, on each of which a number can be read, are randomly drawn. Each ball is drawn successively with a few seconds pause in-between each

draw. At the end of the draw, the six balls are displayed on T.V. screen such that number on each ball is visible in ascending order. For each draw, gains depend on how many gambled numbers match drawn numbers: The larger the number of matches, the large the gains. The present implicit learning task was devised to simulate this lottery game.

In the loto task, participants first receive a target set of six numbers. Each of these six numbers can be any number between 1 and 49. Even if these numbers are actually selected by experimenters and are the same for all participants, the experimenter says to each participant that numbers are randomly selected by the computer. Then, people see a series of ten draws. In each draw, each number is presented as randomly drawn and is successively displayed on the computer screen. In actuality, none of the draws are random, and series of numbers respect a pre-defined rule. Participants have to successively compare numbers of each training set to numbers of the target set and calculate how many numbers in the target set match numbers in the training sets. Participants' gains are then calculated based on the number of matches, larger matches yielding larger gains. After this initial encoding phase, participants are tested with a recognition task.

In the recognition task, participants are shown 20 test sets of six numbers each. They are told that half of the series correspond to previously presented sets in the training sets, and half are new. Their task is to decide as quickly as possible for each test set whether it is a "new" or an "old" set. In actuality, none of the numbers are used in both the training and test sets. Half of the test sets violate the rule of the training sets, and the other half respect the rule. The crucial prediction in this Loto task is that implicit learning would lead participants to consider "old" target sets that respect the rules more often than targets sets that violate the rules, with no awareness of rules as shown by their inability to verbalize the rules.

Our study had two additional goals. First, an important issue concerns the nature of cognitive processes involved in implicit learning: Are these processes specific to implicit learning or are they mere inductive processes implicitly used? In line with the specificity of

implicit learning processes hypothesis, Reber, Walkenfeld, and Hernstadt (1991) showed that performance in artificial grammar task did not correlate with IQs. In order to contribute to this issue, we assessed participants' explicit induction skills with the Advanced Raven's Progressive Matrices Test.

Second, we tested younger and older adults. Mixed results have been found regarding age-related changes in implicit learning. Some studies reported no age-related differences (e.g., Frensch & Miner, 1994; Howard & Howard, 1989; 1992; Salthouse, McGuthrie, & Hambrick, 1999), whereas other studies reported age-related declines (Cherry & Stadler, 1995; Curran, 1997; Feeney, Howard & Howard, 2002; Harrington, & Haaland, 1992; Howard & Howard, 1997; 2001). Given the potential confound between rule and rule instances discussed previously and given well-documented age-related maintenance of implicit memory skills in older adults (e.g. Hultsch, Small, & Masson, 1991), it was of interest to us to determine whether an implicit learning task like the loto task would show age-related differences. This loto task was expected to show implicit learning in a natural setting (a game that all people know and that many people often play). Age-related differences in human cognition often appeared to be smaller in ecologically valid tasks (e.g., Denney & Pearce, 1989). Looking at aging effects in our loto task offered the opportunity to determine whether age-related differences do appear in ecologically valid tasks.

In Experiment 1, we tested younger and older adults in the Loto task and correlated explicit and implicit induction skills in younger and older adults. In Experiment 2, we controlled for potential confounds often mentioned in implicit learning research. That is, two types of experimental biases have often been proposed to account for experimental results that seem to demonstrate the existence of implicit learning mechanisms: (1) The results could be due to regularities that covary with the rule used, which participants detect and consciously utilize (e.g. Churchill & Gilmore, 1998; Newell & Bright, 2002; Wright & Burton, 1995). (2) The same results could be replicated without a learning phase (e.g. Dulany et al., 1984; Reber

& Perruchet, 2003; Redington & Chater, 1996). For example, with a rule involving parity status of numbers, participants may think items composed of even numbers are more familiar even though there was no learning phase. Such potential artefacts were tested (and ruled out) in Experiment 2.

Experiment 1

Method

Participants. Participants were 35 younger adults and 26 older adults. Younger adults included 29 females and 6 males and had a mean age of 21 years and 1 month (range: 19-27 years). They were undergraduates at the University of Provence in Aix-en-Provence, France, and participated in the experiment in partial fulfilment of a course requirement. Older adults included 21 females and 5 males and had a mean age of 74 years and 2 months (range: 66-84 years). They were volunteers recruited in senior citizen centers in Provence. Younger and older adults were matched on the number of years of formal education (>14 years). In addition, older adults took the Mini Mental State Examination (MMSE; Folstein, Folstein, & McHugh, 1975) to detect potential individuals at risk of Alzheimer. All individuals had normal-range, AD-free scores (i.e., higher than 27, mean=28.9). As participants with scores of 27 or higher are usually viewed as not-at-risk for AD, none were excluded from the study. Before the experiment began, younger and older participants took a French version of the Mill-Hill Vocabulary Scale (MHVS; Raven, Court, & Raven, 1986; Deltour, 1993) to ensure that older adults' verbal abilities were not lower than younger adults'. The results showed that older adults' performance was higher than that of younger adults (28.8 vs. 22.2), $F(1,50)=60.54$, $p<.05$. Finally, younger participants showed their usual superiority in the Raven's Matrix Progressive test, with mean scores of 17.2 (vs. 8.5 in older adults, $F(1,50)=55.83$, $p<.05$).

Stimuli and Material. Three pools of numbers ranging from 1 to 49 were selected. The first pool included the following six numbers: 1-14-22-33-39-49, and was used as the target set. The second pool included the following numbers: 4-5-7-8-10-13-17-18-21-25-26-28-30-31-34-42-45-46-47. The final pool included the numbers: 2-3-6-9-11-12-15-16-19-20-23-24-27-29-32-35-36-37-38-40-41-43-44-48. The 20 training sets included in the encoding phases included numbers from the first and second sets.

Ten training sets selected for the encoding phase were selected in accordance with an increasing/decreasing rule, “If the first number in a set of six numbers is larger than the second number, then the last five numbers of the set are in increasing magnitude; if the first number in a set of six numbers is smaller than the second number, then the last five numbers are in decreasing order”. Two examples are: “26-10-25-31-34-42” and “18-47-45-42-28-13”. Ten other training sets were selected for the encoding phase so as to match the so-called odd/even rule, “If the first three numbers in a set of six numbers are odd, the next three numbers are even; if the first three numbers in a set of six numbers are even, the next three numbers are odd”. Two examples of this odd/even rule are “7-17-25-26-30-42” and “4-18-28-31-39-45.”

Forty test sets were devised for the recognition phase by selecting numbers from the third pool. Twenty test sets were the matching sets, ten each matching the increasing/decreasing and the odd/even rules; and twenty were non-matching sets. Of the matching sets, ten matched the increasing/decreasing rule and ten matched the odd/even rule. Numbers in both matching and non-matching sets were selected with the constraints that both sets included the same individual numbers, and that individual numbers appeared in the same positions and in an equal number of times in both types of sets. For example, if the number 29 was seen in the first position in a matching set, it was also seen in the first position in a non-matching set.

Participants were given an answer sheet on which six boxes and ten lines were drawn. Participants were asked to use each of the six boxes to write down each of the six target

numbers and each line to successively write down each number in the training sets that matched target numbers. At the end of each of these 10 lines, participants were asked to write down the number of training numbers in each training set that matched target numbers. Finally, answer sheets included information regarding gains that depended upon the number of matching numbers. Gains of FF 15000000, 54000, 24532, and 528 were obtained when six, five, four, and three target numbers respectively matched training numbers in a given training set.

Procedure. The Experiment included three successive phases. The first two phases tested the loto task, one each for increasing/decreasing and odd/even rules followed by post-experimental debriefing. Participants were tested on psychometric tasks (i.e., MHVS, MMSE, Advanced Raven Matrix test) during the third phase.

Participants were first told that they were going to participate in an experiment that simulated the famous national lottery game, called “loto”. They were also told that they would not receive the monetary rewards related to the outcome of the game. Then they were told that six target numbers ranging from 1 to 49 had been randomly drawn by a computer. After writing down each of these six numbers, people were told that ten sets of six numbers each would be randomly drawn by a computer and that for each set they were asked to note how many numbers matched target numbers. For each of these ten training sets, numbers were displayed one after the other with one number being displayed two seconds after the preceding number. After seeing a complete set of six numbers, people were asked to calculate their gains. Of the ten training sets, only one contained three matching-winning numbers, the minimal number to make the smallest gain. After one training set, participants pressed any key on the computer keyboard to trigger the next trial.

After the ten training trials, participants were informed that one of the goals of the experiment was to see whether they would be able to recognize the 9 training sets they had just encoded among new sets (excluding the training set that contained three matching

numbers). Each of these test sets were then displayed on the computer screen. People were told that this was not a memory task (i.e., they were not required to accurately recall the series of numbers); rather, they had to make a decision based on familiarity. Once a test set was displayed on the computer screen, participants were invited to make their best “new/old” guess. Once the participants confirmed that they understood the task, each of the test set was randomly presented. The test set remained on the screen until participants responded “new” or “old” by pressing the appropriate key on the keyboard.

After this “new/old” decision task, participants were asked if they had used a special trick to determine whether an item was new or old. Then, the experimenter noticed participants how hard the recognition task was and said that one major source of difficulties was the order of the numbers. Indeed, numbers in each set were presented in random order, while they are presented in ascending order in magazines or on T.V. Then, the experimenter proposed to play the Loto game again, this time with numbers presented in ascending order. Participants were told that the computer monitoring the whole experiment randomly, drew six numbers but would display them one by one (e.g., 4-18-28-31-39-45). The same target set as for encoding phase was used, and ten other training sets (for the odd/even rule) were played again, followed by participants determining their gains for each set and the recognition test.

After this second phase, participants were asked again how they had accomplished the task. Then, after informing participants that number series were governed by rules, participants were asked if they had noticed any regularities in the training sets. Finally, the experimenter explained the odd/even rule. Participants were asked whether they had noticed this stimulus feature.

After this Loto task, participants took Raven’s (inductive reasoning) progressive matrix test, Mill-Hill Vocabulary test, and the MMSE test (older adults only). In the Advanced Raven matrix test, participants were given 20 minutes to solve as many of the 36 problems as possible.

Results and Discussion

The debriefing indicated that 9 younger (and no older) adults noticed stimulus features. Four of them claimed that many of the test sets of the odd/even rule included even numbers, and five of them claimed that they had noticed the odd/even rule once the experimenter had explained this rule to them. Although, patterns of data for these participants were similar to those of the other participants, these five participants were not included in statistical analyses. Note that including them did not change the outcomes.

Although our prediction concerns mean percent « old », we also analyzed mean response times. Response time data analyses revealed only a main effect of age on mean response times, $F(1,50)=10.0$, $p<.01$, with older adults' being slower than younger adults (5024 vs. 2901 ms).

Figure 1 displays mean percent “old” responses for each group of participants, items that violated/respected rules, and for each rule separately.

- Insert Figure 1 -

An ANOVA was conducted with mean percent “old” responses as the dependent variable, Age (younger, older adults) as a between-subject factor, Item (respected, violated rules) and Rule (Rule 1, Rule 2) as a within-subject factor. The only significant effect was a Age (younger, older adults) x Item (respected, violated rules) interaction, $F(1,50)=4.78$, $p<.05$. This showed that younger adults tended to say “old” to sets that respected rules more often than to sets that violated rules (29.0% vs. 23.8%, $F(1,25)=7.38$, $p<.05$), whereas older adults responded “old” equally often to both types of sets (26.2% vs. 27.7%, $F<1$). Note that order of rules was not counterbalanced, because the increasing/decreasing rule had to be tested first. However, as seen from Figure 1, no effect of rule or interaction involving the rule factor was observed.

Next, correlation between inductive reasoning and implicit learning was calculated. Mean number of correctly solved problems in the Raven's matrix test was correlated with mean number of "old" responses to sets that respected the rule minus mean number of "old" responses to sets that violated the rule. In older adults, correlations between performance on the Raven and performance on rules 1 and 2 were $-.24$ and $-.04$, respectively (corresponding r_s were $.30$ and $.28$ in young adults). These correlations were $r_s = .46$ ($p < .05$) and $.18$ in young and older adults, respectively, when both rules were collapsed¹.

In sum, the present results showed an implicit learning effect in young but not in older adults and a significant correlation between explicit inductive scores and implicit learning in younger adults.

Experiment 2

The purpose of this experiment was to perform two experimental controls on the results of Experiment 1. First, Experiment 1 showed that young participants who process rule-governed series of numbers during encoding phase judge as more familiar items that respect this rule than items that violate this rule during recognition phase. In Experiment 2, we wanted to rule out the possibility that participants consider more familiar items that respect the rule even without a preliminary learning phase (e.g. Dulany et al, 1984; Reber & Perruchet, 2003; Redington & Chater, 1996). This was done by having one group of participants, so-called the "subliminal-priming" group, undergo a false priming procedure. During the first phase, these participants had to read ten words displayed one at a time on the screen after a string of X's presented for 50 ms. After this phase, they were informed that before each word they had just read, six numbers had been displayed very rapidly between two series of Xs, subliminally.

¹ Correlations between Ioto task and Mill-Hill Vocabulary test were calculated. They were $r_s = .18$ and $-.34$ for young and older adults, respectively.

Then they were asked to judge the familiarity of the twenty items presented in Experiment 1. If Experiment 1 findings in young adults were due to a preference (or bias) for items that respect the rule irrespective of any type of learning, then tendency to say “old” for these items should be replicated in Experiment 2 for participants in the subliminal group.

The second aim of this experiment was to provide further support for the implicit nature of the learning observed here. In the past, it has been shown that results of implicit learning tasks, particularly ones using the invariant paradigm, could be explained by the subjects' sensitivity to certain regularities that covaried with the rule being manipulated (e.g. Churchill & Gilmore, 1998; Newell & Bright, 2002; Wright & Burton, 1995). Indeed, these experiments test only if participants are aware of the manipulated rule. Therefore, results may be explained by participants' use of explicit property of material the degree of awareness of which being untested. In this experiment, a second group of subjects, called the "regularity-judgment" group, saw exactly the same material as in Experiment 1, but with different instructions. After encoding phase, participants in this group were informed of the existence of regularities in the numbers just seen. Their task in the second phase was no longer to judge the familiarity of items but to say whether the items abided by the rules used in the first phase. It was predicted that, if participants had consciously noticed certain regularities in Phase 1, they should use those regularities in Phase 2. That is, if they noticed a regularity that covary with the rule that was used, they should use this regularity systematically to judge test items. Thus, if the observed effect in Experiment 1 comes from a property of the material that covaries with the rule, then the effect should be larger than for participants who had to say “new/old”. Participants who have make new/old judgments are highly likely to say “new” because if one number in the test series looks new to them, they will judge the series as a new one.

The other difference between Experiments 1 and 2 was that only one rule (the "odd/even" rule) was tested in Experiment 2. Indeed, there were no differences between rules

in Experiment 1, and it was impossible to ask "regularity-judgment group" to do the same task twice in Experiment 2 without running the risk that participants consciously look for rule the second time. In addition to the two control groups, a third group was tested in Experiment 2. In order to replicate Experiment 1 findings in young adults, this third group was tested exactly like in Experiment 1 with only one rule. We refer to this group as the "loto group".

Method

Participants. Participants were 104 young adults (92 females and 12 males, mean age of 19 years and 7 months). They were undergraduates at the University of Provence in Aix-en-Provence, France, and participated in the experiment in partial fulfillment of a course requirement.

Stimuli and Material. For the regularity-judgment and the lotto groups the material in both phases was the same as in Experiment 1; the rule for this material was the odd/even rule. For the subliminal-priming group, material for Phase 1 consisted of ten common words (rabbit, seat...); and material for Phase 2 was the same as in the other two groups.

Procedure.

Lotto Group

Procedure used to test participants in this group was exactly the same as that used in Experiment 1 for the odd/even rule.

Regularity-Judgment Group

The subjects in this group underwent the encoding phase exactly as participants tested in the lotto group. After playing lotto for 10 series and tallied their gains, participants were told by the experimenter : "Contrary to what I told you before, these series of numbers were not

random ; they respected some rules. You are now going to see some new series of six numbers, half of which follow the same rules and half of which violate these rules. Your task will be to decide whether each series of numbers displayed on the screen probably follows the rules or probably violates them."

Subliminal-Priming Group

During the encoding phase, the subjects in this group had to read aloud ten common words displayed one at a time on the screen. Each word was preceded by an asterisk and then a string of X's displayed for 50 ms. After this phase, the experimenter told the subject, *"As you may have noticed, each word you just read was preceded by six numbers presented very briefly (subliminally). You are now going to see the series of numbers you just saw subliminally for a longer time, but mixed in with as many new series of numbers. Your task will be to try to identify the items you already saw. Naturally, you'll find this task difficult because the numbers you saw were displayed for such short a time that you were not conscious of their presentation. So, you should let your intuitions guide you and answer according to any feeling of familiarity you might have for certain items."*

Finally, the experimenter asked each participant the same questions as in Experiment 1 to assess how aware of rules they were.

Results and Discussion

Debriefing suggested that 14 subjects noticed stimulus features. Therefore, these participants were not included in statistical analyses, leaving 30 participants in each group, although including these 14 participants did not change the outcomes.

Figure 2 displays mean item acceptance for each group of participants and for items that violated/respected rules.

- Insert Figure 2 -

An ANOVA was conducted with item acceptance rate as the dependent variable, group (loto, subliminal-priming, and regularity-judgment) as a between-subject factor, and Item (respected, violated rules) as a within-subject factor. There was a group effect ($F(2, 87) = 6.47, p < .01$), no effect of Item (respected, violated rules) ($F(1, 87) < 1$), and a marginal interaction between the two ($F(2, 87) = 2.83, p = .06$). Planned comparisons showed a significant effect of Item (respected, violated rules) in the loto group (35.7% vs. 28.0%, $F(1, 29) = 6.97, p < .05$). This item effect was not significant in either the subliminal priming group (42.7% vs. 42.0%) or the regularity judgment group (27.6% vs. 32.0%), $F_s < 1$.

General Discussion

Two experiments were ran to test implicit learning in a new version of the invariant paradigm. Three interesting findings came out in Experiment 1. First, our Loto task showed implicit learning. Second, only younger adults were sensitive to rules that governed a series of numbers encoded during the Loto task. And third, there was a significant correlation between implicit learning and explicit induction performance in younger adults. Experiment 2 showed that potential biases such as deliberate strategies or baseline preferences for some items do not account for these findings.

An important feature of the Loto task is that rule and rule instances are unconfounded. With this control, implicit learning was observed in younger adults: Participants said “old” to the series of numbers that matched rules more often than to non-matching series; yet they were unable to verbalize these rules (except for the very few participants who verbalised these regularities and who were dropped from analyses). The present approach contrasts with previous attempts at controlling such a rule and rule instances confound (e.g. Johnstone & Shanks, 2001) that resulted in no implicit learning. The difference in findings from the two studies may come from task demands, as the Loto task does not require participants to make grammatical judgments at test. It is possible that grammaticality judgments puts subjects in a

problem-solving situation that is hardly compatible with the activation of implicit knowledge: Without having realized that the material was based on rules, they are asked to perform a task using those rules. This complex and paradoxical task (having to apply unknown rules) may lead subjects to actively search for criteria to carry out the task, and then to respond solely in accordance with the criteria adopted. In the version of the task used here, subjects were simply asked to base their decision about whether the items were new or old on how familiar they seemed. This much simpler and more "fluid" task for the subject can be regarded as more conducive to the expression of unconscious processes. An additional difference may be noted. The literature contains the following paradox: in all research using the invariant paradigm, implicit learning is assessed as a familiarity feeling for items respecting the rule larger than that for items violating the rule. In contrast, in other works on implicit learning, implicit learning is assessed from participants' recognition inability (e.g., Chun & Jiang, 1998; Chun, 2000, for a review).

Another distinctive feature of this experiment concerns the nature of rules. These rules rest more on people's knowledge of numbers (e.g., parity) than on knowledge involved in other implicit learning tasks (e.g., artificial grammar rules).

Note that our effect of our manipulated rule is hard to unambiguously interpret as the fact that participants learned it implicitly and that it was the unique cause of participants' judgments. Research in the domain of categorization, for example, has reported many evidence that the same findings could be accounted for both by exemplar models and by rule models (e.g., Shin & Nosofsky, 1992). Our results showed categorical effects (parity, increasing/decreasing) and our controls enable us to say that, in contrast with some previous research, these effects do not stem from recognition of exemplars. Nevertheless, categorical effects (like those reported here) may be explained from both exemplar- and rule-based models.

The second finding –lack of implicit learning in older adults— of the present study is interesting when thinking about both aging effects in implicit learning and mechanisms

involved in implicit learning. The basic mechanism involved in implicit learning tasks in general, and in our loto task in particular, is a covariation detection mechanism that requires that information is simultaneously activated in working memory. This mechanism may be disrupted in difficult implicit learning tasks in general and in our loto task in particular. In our task, during encoding phase participants had two tasks to accomplish –encoding series of numbers and looking for matching numbers between randomly drawn numbers and target numbers. Such dual-task may have drawn processing resources away from covariation detection or implicit learning during encoding. With fewer processing resources, older adults who are known to be more disrupted than young adults in dual-task situations may have had less information (i.e., fewer numbers) simultaneously activated in working memory. This may have led their covariation detection mechanism to operate less efficiently during encoding. The present effects are consistent with those reported by Howard and collaborators (e.g., Feeney, Howard & Howard, 2002; Howard & Howard, 1997; 2001; Howard, Howard, et al., 2004) who also found age-related differences in most difficult implicit learning tasks. Consistent with Howard et al.’s analyses, decreases in working-memory resources and in processing speed with age make implicit learning less likely to occur in older adults when tested with most difficult tasks. The present research extends this conclusion to cases of ecologically valid tasks when these tasks are resource demanding. Additional data comparing implicit learning under single- vs. dual-task conditions in young adults may disrupt implicit learning in young adults like it did here in older adults.

The third finding of interest in this study is the correlation between implicit learning and induction. Reber (1989; Reber, Walkenfeld, & Hernstadt, 1991) argued that “*The unconscious processes, which have become known in the literature as implicit learning (Reber, 1989a) and implicit memory (Schacter, 1987), are the functional instantiations of a phylogenetically primitive system that developed before the emergence of conscious functioning. The assumption that these structures and the functions they subsume have phyletic primacy has a*

number of implications concerning the manner in which implicit and explicit functions are dissociable” (Reber et al., 1991, p. 888). In line with this, Reber et al (1991) found that performance in artificial grammar tasks do not correlate with IQs. Our findings do not enable to definitely rule out IQ-implicit learning independence in general. However, in our research at least, implicit learning effects were not independent of other processes, as involved in the Raven’s matrix task. Note that there were no significant correlations between the loto task and vocabulary performance. This makes it possible that a very global IQ measure does not correlate with implicit learning, an outcome that remains to be tested.

All in all, this study suggests that the Loto task may be fruitfully used in future research to further test people’s sensitivity to regularities of a set of stimuli and understand cognitive mechanisms underlying such sensitivity.

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Figure 1. Mean percentages of “old” answers in each age group (younger, older adults) and for each item type (violated vs. respected rules), separately for the ascending/descending (Rule 1) and odd/even (Rule 2) rules. Error bars are standard errors.

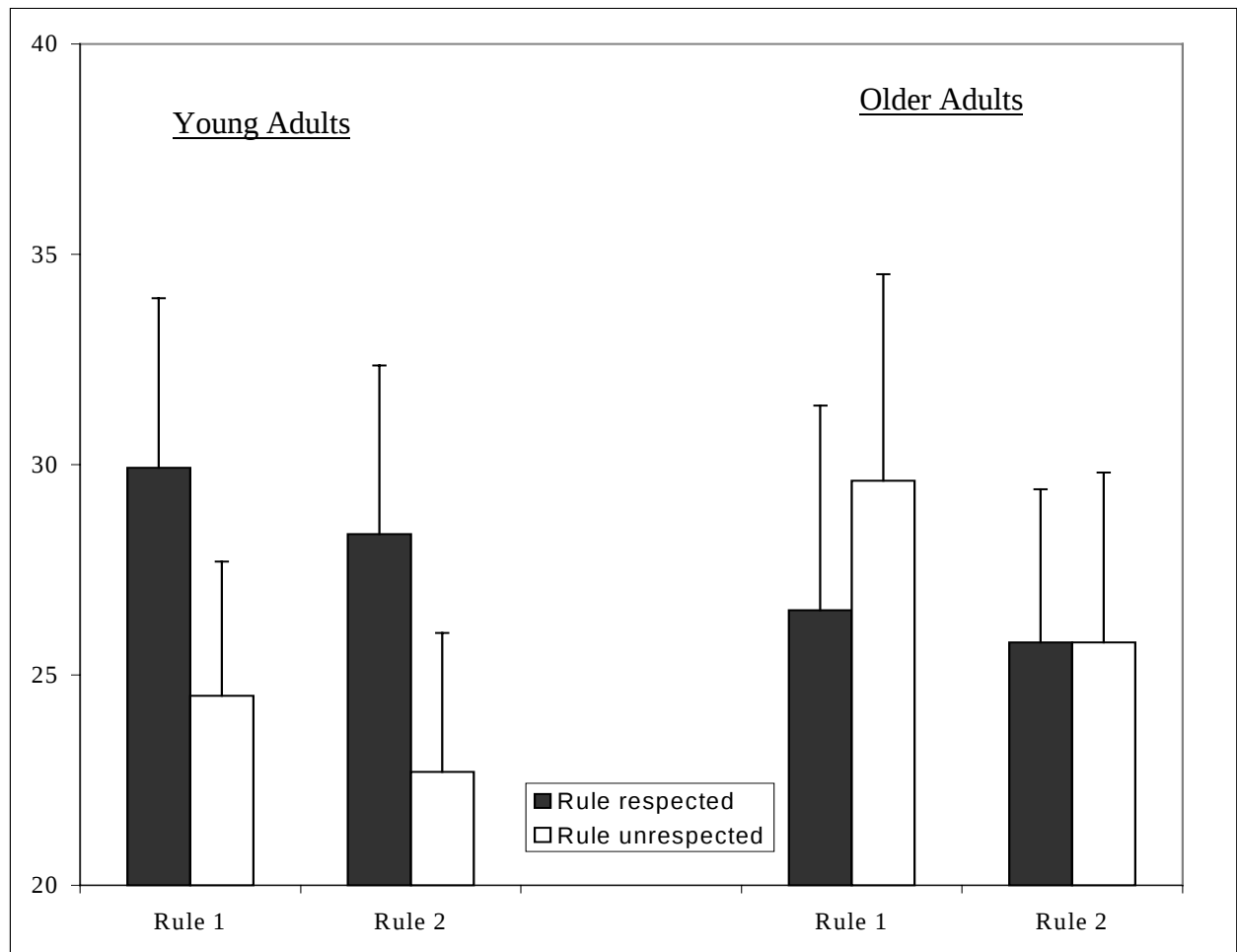
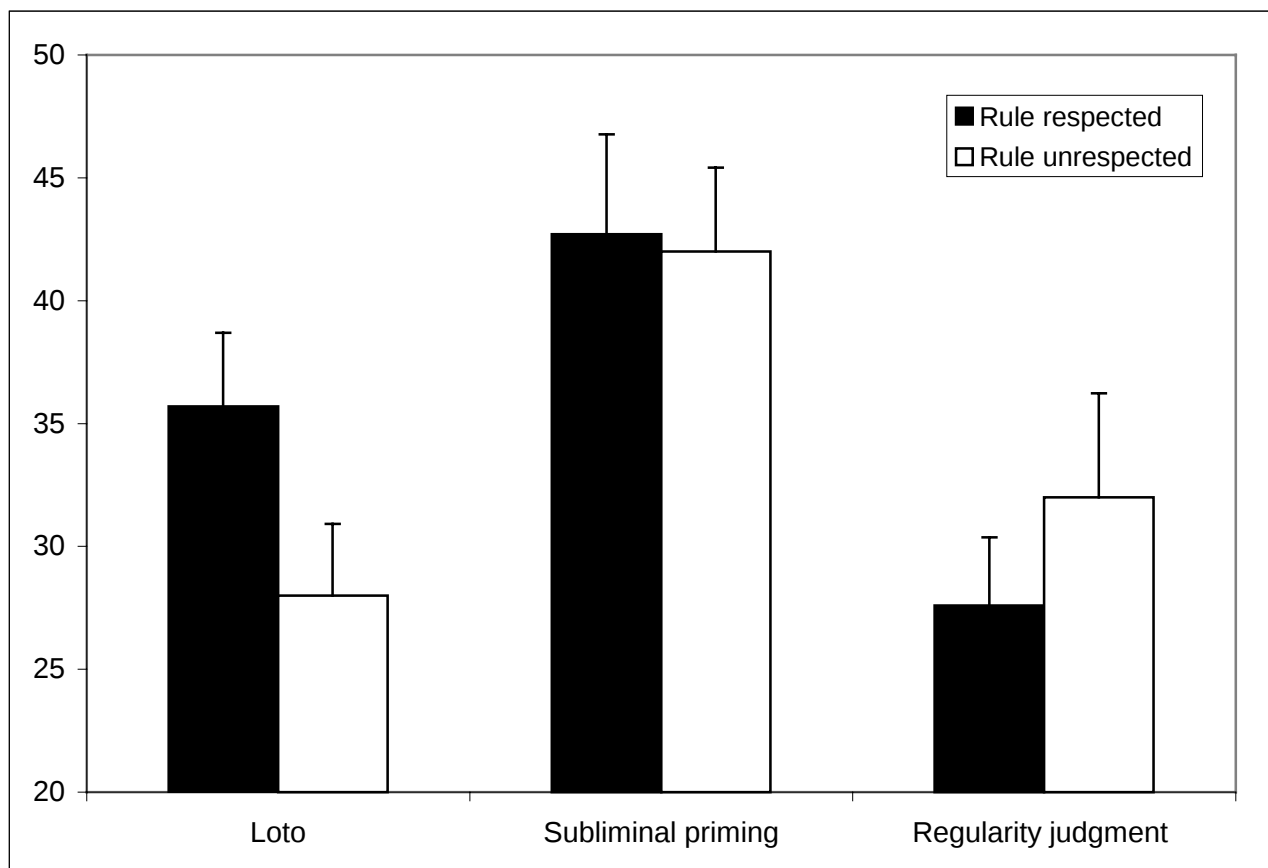


Figure 2. Mean item acceptance for each group of participant (loto group, subliminal priming group, and regularity judgement group) and for each item type (violated vs. respected rules). Error bars are standard errors.



Appendix 1: Material for Experiment 1

Training Material

Rule 1	Rule 2
4 31 26 21 10 1	5 13 17 30 34 46
8 5 7 13 14 21	10 22 26 39 47 49
26 10 25 31 34 42	4 18 28 31 39 45
30 46 42 26 21 18	7 21 25 34 42 46
49 7 8 10 33 39	8 14 22 33 39 47
31 21 30 45 46 47	7 17 25 26 30 42
25 28 14 7 5 4	5 17 21 26 30 42
18 47 45 42 28 13	1 5 13 14 26 34
47 13 31 34 42 46	4 8 10 21 31 47
17 34 13 8 7 5	5 17 21 26 34 42

Test Material

	Rule 1	Rule 2
Rule-following items	29 43 41 23 15 2	2 6 24 29 37 45
	2 36 19 16 12 11	2 12 20 27 35 41
	15 36 29 12 9 6	6 12 16 23 27 41
	6 48 41 35 24 23	12 16 32 35 41 43
	32 37 35 11 9 2	16 20 36 37 41 43
	36 22 24 32 40 48	3 9 15 20 24 44
	27 3 6 40 43 44	3 23 27 36 38 40
	22 6 9 27 29 41	9 11 19 32 36 48
	19 15 24 27 29 37	11 19 29 38 40 44
	44 20 23 32 38 48	15 27 35 36 40 48
Rule-violating items	36 43 9 27 15 41	2 9 24 29 36 45
	22 36 29 32 9 48	2 19 20 27 40 41
	6 36 35 40 12 48	6 11 16 23 24 43
	19 20 6 32 29 44	12 23 32 35 38 41
	2 48 24 35 9 11	16 27 36 37 40 43
	44 37 41 27 43 2	3 6 15 20 27 40
	15 6 24 12 29 2	3 12 27 36 41 44
	32 3 23 11 38 37	9 12 19 32 35 48
	29 22 41 23 40 6	11 20 35 36 37 44
	27 15 19 16 24 23	15 16 29 38 41 48