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Personality and dual-task processing: disruption of procedural learning by declarative processing

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Abstract

In two experiments, procedural learning, consisting of serial reactions to predictable/random target movements, was studied (1) under either (a) dual-task or (b) single-task conditions for blocks 1–3, and then under (2) single-task conditions for blocks 4–6. In Experiment 1, the declarative dual-task comprised mental arithmetic; in Experiment 2a, the counting of nonsense syllables. Mental arithmetic, but not the less cognitively demanding counting of nonsense syllables, significantly impaired procedural learning (a further control condition during dual-task processing, comprising all random targets, eliminated the possibility that latent learning occurred under mental arithmetic). Personality factors, viz. Psychoticism and Neuroticism (Experiment 1), and Psychoticism (Experiment 2a), modified the effects of dual-task processing, although these effects were modest in terms of effect size. High scores on Psychoticism were associated with an erratic pattern of performance during single-task processing in blocks 4–6, pointing to a perseveration of the effects of dual-task processing in blocks 1–3. A further experiment (2b) showed that there was little awareness of the procedural rule used in Experiments 1 and 2a. Results point to the general conclusion that there are considerable individual differences (related to Psychoticism and Neuroticism) in the effects of dual-task processing on procedural learning, sufficient to either obscure or confuse the effects of experimental variables. In order to illustrate the possible implications of these experimental and personality results, the behavioral phenomenon of latent inhibition is discussed. © 2002 Published by Elsevier Science Ltd.

Keywords: Psychoticism; Neuroticism; Procedural; Declarative; Learning; Latent inhibition

1. Introduction

The purpose of this article is to examine the effects of the major dimensions of personality (i.e. Extraversion, Neuroticism and Psychoticism) on a phylogenetically old form of knowledge acquisition, viz. procedural learning, under manipulations of attentional demand. Although there are known to be marked individual differences in declarative learning, related to well-established

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factors of personality, there is a paucity of studies exploring putative effects of personality on procedural learning (a form of learning that is implicated in a wide array of cognitive and behavioral processes). This research was motivated by the argument that the synthesis of individual differences and experimental-cognitive research is an essential precondition for the advancement of both personality and experimental psychology (Eysenck, 1997).

Although still subject to debate, procedural learning seems to reflect a knowledge acquisition system that does not depend upon awareness of the learning experience and/or the learned material (Hayes & Broadbent, 1988). In contrast, a controlled processing system seems to underlie conscious processing; this requires awareness of the learning context and to-be-learned material, and leads to declarative knowledge. These two types of learning/memory processes are also known as implicit and explicit, respectively (Graf & Schacter, 1985). Declarative information is measured by such tasks as recall and recognition memory, while procedural information is measured by simple performance tasks, such as mirror reading, pursuit rotor, and sequence reaction time (RT) tasks, as well as complex tasks, such as artificial grammar learning, complex stimulation tasks, and stimulus covariation (McDowell, Lustig, & Parkin, 1995).

The distinction between declarative and procedural systems is supported by their dissociations (e.g. Feldman, Kerr, & Streissguth, 1995), although associations have also been reported (e.g. Perruchet & Baveux, 1989). For example, amnesics are severely impaired on declarative but much less impaired on procedural processes (Corkin, 1968; Nissen & Bullemer, 1987; Nissen, Willingham, & Hartman, 1989; Squire, 1986); these savings are found also for perceptual tasks (e.g. Cohen & Squire, 1980), indicating that procedural learning is not limited to motor skills. Dissociations can also be experimentally produced (Jacoby & Dallas, 1981; Roediger & Blaxton, 1987).

Some theorists (e.g. Hayes & Broadbent, 1988) have argued that procedural learning is insensitive to limitations in attentional resources, particularly those involving working memory (Baddeley, 1987). Therefore, performance of procedurally learned information should be unaffected by simultaneous controlled processing. However, the experimental literature on this point is divided (for a review, see McDowell et al., 1995).

For example, Nissen and Bullemer (1987) tested participants on a serial RT task under either distraction or no distraction. Under the distraction condition, low and high frequency tones were presented just before each trial, and participants were required to count the number of low tones presented. The major result from this study (Experiment 2a) was that tone-counting abolished serial RT learning; and that the difference in performance between groups when switched to random and predictable sequences was identical (Experiment 2b), suggesting that learning was absent under the distraction task.

Other evidence suggests that procedural learning does occur during dual-task distraction. Cohen, Ivry and Keele (1990), using a similar task to Nissen and Bullemer (1997), found that dual-task processing did not abolish procedural learning, and nor did increasing the difficulty of the dual-task (tone-counting). Frensch, Buchner, and Lin (1994) also found procedural learning under dual-task processing, as did McDowall et al. (1995).

The reasons for these differences in results are as yet unclear, although it is a possibility that individual differences in performance may be partly responsible. However, few studies have addressed this issue in detail, maybe because of the widely accepted belief that procedural learning processes "...owing to their phylogenetic antiquity, will show less individual-to-individual variation than comparable explicit [learning] processes" (Reber, Walkenfeld, & Hernstadt, 1991, p. 894). But a number of studies challenge this belief.

Corr, Pickering, and Gray (1995) reported that procedural learning is influenced by a crossover interaction between extraversion and caffeine-induced arousal, in accordance with Eysenck's (1967) arousal-based model of personality: introverts showed impaired, and extraverts improved, performance under caffeine. Corr and Kumari (1997) found that the effects of haloperidol (which has sedative properties) on procedural learning is also moderated by extraversion, in a manner opposite to the effects of caffeine reported by Corr et al. (1995): introverts showed improved, extraverts impaired, learning under haloperidol. Corr, Pickering, and Gray (1997) reported a trait anxiety×punishment effect on procedural learning, in accordance with Gray's (1970, 1982) reinforcement model of personality: anxious participants learned most under punishment (least under control; in addition, the personality factor of psychoticism was found to impair procedure learning in both conditions). Such findings suggest that procedural learning may be sensitive to the same influences as more traditional forms of learning, some of which are arguably procedural in nature (e.g. classical conditioning; Levey & Martin, 1981). These findings are not a product of trivial effects (e.g. effort), as overall RT yields quite different results to the procedural learning measure which is composed of the *difference* in RTs to predictable and random targets.

1.1. Dimensions of personality

On the basis of previous research, three major dimensions of personality may be especially important in procedural learning: Extraversion, Neuroticism and Psychoticism.

1.1.1. Extraversion

Eysenck's (1967) arousal-based theory of personality postulates that introverts and extraverts differ with respect to the sensitivity of their cortical arousal system. Compared with extraverts, introverts are postulated to have generally lower (ARAS) response thresholds and thus higher cortical arousal. With regard to dual-task distraction, it is possible that extraverted individuals would be better able to tolerate these effects. This outcome could be due to two factors: (a) induced arousal resulting from dual-task conditions; or (b) the increased cognitive complexity of the procedure, which previous research indicates tend to impair the performance of introverts.

1.1.2. Neuroticism

The second dimension in Eysenck's scheme is Neuroticism, which reflects emotional drive. In general terms, it may be expected that attentional processing has slower decay functions in high Neuroticism individuals, resulting in a failure to modulate behavior in reaction to changing environmental contingencies (i.e. when switched from dual-task to single-task conditions). In the context of dual-task distraction, high Neuroticism individuals should show perseveration deficits resulting in impaired learning. These deleterious effects should be most pronounced under relatively stress-inducing conditions.

1.1.3. Psychoticism

The third dimension in Eysenck's scheme is Psychoticism (P; Eysenck & Eysenck, 1976), which relates to psychosis-proneness and antisocial behavior. There is evidence that Psychoticism and attentional processes are associated (Eysenck & Eysenck, 1991). For example, high Psychoticism individuals display impaired latent inhibition (LI; i.e. retardation of unconditional stimulus–conditional stimulus (UCS–CS) learning following prior exposure of a CS (e.g. white noise) without reinforcement; Lubow, 1989). This LI effect is interpreted as reflecting impaired processing of the pre-exposed CS due to impaired inhibitory processes in high Psychoticism individuals (i.e. a failure to learn that the CS is of no consequence; see Gray, Feldon, Rawlins, Hemsley, & Smith, 1991).

Now in human studies, for LI to be observed, pre-exposure of the CS must be made in the presence of a dual-task (i.e. masking task, e.g. counting nonsense syllables). Contrary to the conventional view of human LI, it is possible that dual-task (declarative) processing impairs high Psychoticism individuals in the performance of the primary task (i.e. procedural learning of the irrelevance of the CS); that is, the "masking task" may have an important causal role to play in human LI. The hypothesis derived from this analysis predicts that high Psychoticism individuals should show impaired procedural learning in the presence of dual-task distraction.

1.2. Procedural learning task

The procedural learning task employed in this study was identical to that used by Corr et al. (1995, 1997); this is a modified version (Corr, 1994) of the task developed by Lewicki, Hill, and Bizot (1988). The task consists of a long series of reactions to a target that moves between four locations on a computer monitor. Some of these target movements are random while others follow regular patterns and are predictable (see Method). Participants point to the target with a wand which activates a touch-sensitive screen; the target then moves to another location and participants continue to follow the target as it moves between four locations. RTs show a selective decline to predictable targets as compared with random targets, this difference reflecting procedural learning. This task is conceptually similar to Nissen and Bullemer's (1987) serial RT task which involved participants pressing one of four buttons corresponding to four lights.

1.3. Summary of experiments

In order to examine the impact of personality on the disruption of procedural learning by dual-task processing, three experiments are reported.

Experiment 1 examines the putative interaction of the major dimensions of personality (Extraversion, Neuroticism and Psychoticism) and procedural learning under (1) either (a) dual-task or (b) single-task conditions (blocks 1–3), and (2) then under single-task conditions (blocks 4–6). This experiment also examines the possible effect of latent learning during dual-task conditions (i.e. mental arithmetic) by comparing procedural learning during blocks 4–6 of those who underwent, during blocks 1–3, either (a) random and predictable trials or (b) completely random trials.

Experiment 2a replicates the basic design of Experiment 1, with a different dual-task (i.e. the counting of nonsense syllables). This dual-task condition was identical to the masking task used in the human latent inhibition studies reviewed earlier (see Gray et al., 1991).

Experiment 2b assesses awareness of the procedural rules used in Experiments 1 and 2a, and estimates the degree of association between these measures and (a) procedural learning and (b) measures of personality.

2. Experiment 1: dual-task processing and personality

Experiment 1 had the aim of exploring the relationship between general factors of personality on the disruption of procedural learning by dual-task processing. In order to address the question of the effects of dual-task processing, an additional control group was run in which participants were exposed to random sequences during the first half of the task (i.e. blocks 1–3). Compared to the performance of this additional (random) group, if participants exposed to predictable sequences during the first half of the task showed enhanced learning during the latter half of the task then this would indicate that, albeit covert, learning occurred during dual-task processing.

A number of predictions were made.

1. High Psychoticism individuals would be most disrupted by dual-task conditions during single-task performance in the latter half of the task. This prediction was derived from the latent inhibition findings, discussed earlier.
2. High Neuroticism individuals' performance would be disrupted by task-irrelevant cognitive processes (e.g. worry) which would perseverate throughout the task leading to a failure to modulate behavior appropriately in response to changed contingencies (e.g. from dual-task to single-task processing). As this experiment entailed mental arithmetic (a common manipulation of stress in psychophysiological studies), Neuroticism effects are likely to be found.
3. With regard to Extraversion, it is difficult to make a precise prediction based on established theory (too little work has been conducted on the effects of Extraversion on procedural processes). However, in general, where an effect of Extraversion is found then, as dual-task conditions are both arousing and cognitively complex, extraverts should outperform introverts (introverts' performance is often impaired by the induction of arousal, which in turn is known to disrupt complex cognitive operations; Revelle, 1987).

3. Method

3.1. Participants

Sixty volunteers were recruited via advertisements placed in local newspapers, 30 males (mean age = 26.85 years, S.D. = 4.22) and 30 females (27.45, 5.03).

3.2. Design

An independent randomized groups design was employed in which participants were (quasi) randomly allocated to two experimental conditions during blocks 1–3: (a) dual-task (procedural learning and mental arithmetic; $n = 20$), and (b) single-task (procedural learning only; $n = 20$). In the dual-task condition, participants undertook mental arithmetic (counting backwards in 3s from randomly chosen numbers—between 100 and 1000). Equal numbers of participants were allocated to each condition. The learning task was six blocks long; all participants performed without distraction during blocks 4–6.

An additional Random Control Group (RCP; $n=20$) was run to examine possible latent learning under the dual-task condition. This group received all random trials during blocks 1–3 (single-task condition), and normal random/predictable trials during blocks 4–6. Their performance was compared with the dual-task group that received random/predictable trials throughout the task.

3.3. Personality questionnaires

Broad personality dimensions (Extraversion, Neuroticism and Psychoticism) were measured by the Eysenck Personality Questionnaire (EPQ; Eysenck & Eysenck, 1975). This scale also contains a Lie (L) measure. This is a widely used and highly researched instrument, especially in biological and experimental psychology, measuring three factors that are common to many other personality models, although Psychoticism is sometimes differently termed (e.g. Emotional Detachment) or reversed in sign (e.g. Agreeableness/Conscientiousness).

3.4. Procedural learning task

The task was composed of six separate blocks, and each block contained 48 sub-blocks; each sub-block consisted of five target movements. The five target movements of each sub-block were designated as either: (a) random (trials 1 & 2) or (b) predictable (trials 4 & 5). The first two target movements of each sub-block were always random, and the last two target movements were always predictable. Therefore, each sub-block contained 240 target movements, grouped into 48 sub-blocks of five target movements.

3.4.1. Predictable trials (4–5) procedural rules

(a) If the preceding target movement had been horizontal, then the next target movement would be vertical; (b) if the preceding target movement had been vertical, then the next target movement would be diagonal; and (c) if the preceding target movement had been diagonal then the next target movement would be horizontal. These rules determined a maximum of 12 different five trial sequences. Each of these were repeated four times (total = 48).

3.4.2. Random trials (1–2) procedural rules

These trials violated the rules for the predictable trials and were therefore, strictly, non-random.

All 48 sub-blocks were randomly presented (randomized for each participant) with the restriction that: (a) the first trial was not predicted from the preceding trial (i.e. the 5th target movement of the immediately preceding 5-trial sequence); and (b) the target never remained at the same location on two successive trials.

The screen background was black, and the two intersecting lines, which separated the screen into four equally sized quadrants, was white as was the moving target (which comprised an asterisk, *). The target appeared centrally in one of the quadrants. The movement of the target was initiated by the participant "touching" the screen with a wand (see later). The target area was defined as a 2-cm radius around the target. The target moved to another quadrant only if it had been "touched" with the wand. The movement time of the target was (almost) instantaneous.

The movement of each target was accompanied by a musical note unique to each of the five trials; the sequence of notes was chosen to resemble the well-known theme tune of Steven Spielberg's film "Close encounters of the third kind". This tune helped to demarcate the sub-blocks of trials, although the significance of the sub-blocks was never explained to the participants.

3.5. Data reduction and scoring

For each block, the mean reaction time of each of the five trials was recorded. These summary data permitted the calculation of facilitated RTs on predictable trials. This was calculated by subtracting mean RTs of predictable trials 4 and 5 from mean RTs of random trials 1 and 2. The difference in these RTs represented the procedural learning score. RTs which exceeded 1 s were excluded from the calculation of mean performance; RTs rarely exceeded 0.5 s, and where they did this reflected error responses (e.g. accidental dropping of the wand).

3.6. Equipment

The task was controlled by an ATARI ST1040 microcomputer which recorded all responses. The stimuli were presented on an ATARI SC1224 monitor, and a "Microvitec touchtec 501″ touch screen was fitted over the front of the monitor to register responses. The "wand" used by participants comprised a 12 inch long thin perspex tube. The wand did not have to touch the screen for a response to be registered; rather, the wand had to break a matrix of infrared beams of light criss-crossed the touch screen and covered the monitor screen. The spatial position of the target position on the touch screen corresponded exactly with the target position on the computer monitor. An elbow rest was provided for the comfort of participants and the reduction of fatigue due to repetitive arm and hand movements.

3.7. Procedure

Participants were told that they would be required to perform a simple computerized learning task. Once informed consent had been obtained, the EPQ was administered. Following completion of the personality measures, participants were introduced to the learning task. A short practice session then commenced, and once this was complete and participants had demonstrated that they could use the wand/touch screen in the appropriate manner, they were told that the main part of the task would start.

The mental arithmetic task consisted of participants being required verbally to count backwards in threes from randomly chosen starting points from 100 to 1000. Participants were told to continue counting throughout the task at a regular rate. Each block was demarcated by a 30-s rest period. The next block of trials was initiated by the participant, prompted by a message appearing on the screen to "press GO to continue". Testing took place in a sound attenuated experimental cubicle. The experiment was run between 9 a.m. and 1 p.m. The ethical considerations were assessed by the Ethics Committee of the Institute of Psychiatry, University of London.

4. Results

Personality scores were comparable to published norms: Extraversion ($M = 16.32$, SD = 4.64, Min.–Max. = 4–22, median = 18.00); Neuroticism (9.15, 5.53, 1–21, 8.50); Psychoticism (7.77, 4.47, 2–17, 7); and Lie (4.95, 3.37, 0–14, 3.50). Table 1 presents the RTs to random and predictable trials under single-task and dual-task conditions.

4.1. Omnibus analysis of variance

First, an analysis of variance (ANOVA) was performed which comprised: (1) one between-groups experimental Condition (single-task vs dual-task processing); and (2) two repeated-measures factors, (a) Blocks (RTs across the six blocks of the task), and (b) Trial Type (RTs on predictable and random trials; their difference representing learning). (The Random Control Group was analyzed separately; see later).

For clarity, ANOVA results for RTs and procedural learning are presented separately.

4.1.1. RT analysis

There was a main effect of Condition, $F(1, 38) = 13.47$, $P < 0.001$, revealing that, overall, RTs were longer in the dual-task ($M = 554$, SEM = 11) than in the single-task ($M = 505$, SEM = 7) condition. The Blocks effect was also significant, $F(5, 190) = 38.37$, $P < 0.001$, reflecting a general decline in RTs across the task (Table 1). The significant Condition×Blocks interaction, $F(5, 190) = 9.89$, $P < 0.001$, reflected the fact that RTs in the single-task condition showed a gradual decline over the task; in the dual-task condition, RTs were longer during blocks 1–3, but showed a rapid decline during blocks 4–6, reflecting a general facilitation effect on RT from being released from the dual-task processing condition (Table 1).

4.1.2. Procedural learning analysis

A main effect of Trial Type, $F(1, 38) = 58.68$, $P < 0.001$, confirmed that RTs on predictable trials ($M = 533$, SEM = 7) were faster than those on random trials ($M = 542$, SEM = 7), showing that procedural learning occurred. A significant Trial Type×Blocks interaction, $F(5, 190) = 3.75$, $P < 0.01$, showed that learning increased over the blocks of the task (Table 1).

Table 1
Mean (SD) RTs to random (R) and predictable (P) trials over the 6 blocks of the task in each single-task and dual-task conditions in Experiment 1

Block	Single-task		Dual-task		Random control group	
	R	P	R	P	R	'P'
1	535 (41)	523 (51)	621 (85)	615 (86)	689 (93)	677 (72)
2	524 (32)	506 (36)	582 (76)	571 (65)	662 (123)	680 (114)
3	516 (34)	500 (40)	592 (71)	589 (78)	681 (97)	669 (105)
4	511 (43)	498 (49)	527 (40)	518 (44)	573 (36)	564 (38)
5	503 (33)	483 (41)	522 (44)	504 (49)	566 (39)	544 (53)
6	489 (31)	467 (37)	516 (31)	488 (54)	553 (37)	532 (50)

"P" trials are random trials that during blocks 1–3 were presented in positions 4 and 5 in the 5-trial target sequence.

Neither Condition×Trial Type, $F(1, 38)=1.13$, $P>0.05$, nor the Condition×Trial Type× Blocks effect, $F(5, 190)=0.94$, $P>0.05$, were significant. Therefore, without consideration of personality effects, the single vs. dual-task conditions did not, overall, affect learning over the blocks.

4.2. *Personality and procedural learning*

Learning at block 3 (end of dual-task processing) was compared with the last three single-task processing blocks (4–6). The ANOVA models comprised: (a) one between-groups experimental Condition (dual-task vs. single-task), and (b) one repeated measures factor, Blocks (4 levels). A priori contrasts were taken on the Blocks factor, providing three contrasts (block 3 vs. block 4; block 3 vs. block 5; block 3 vs. block 6). Three separate ANOVAs were run for (median-split) Psychoticism, Extraversion and Neuroticism.

4.2.1. *Psychoticism*

The main effect of psychoticism approached formal significant, $F(1, 33)=3.71$, $P=0.06$; Psychoticism×Blocks also approached significance, $F(3, 99)=2.45$, $P=0.07$; as did the Psychoticism×Blocks×Condition term, $F(3, 99)=2.52$, $P=0.06$. Decomposing the variance of this last effect in terms of the three a priori contrasts revealed a significant difference for block 3 vs. block 6, $t=2.54$, $P<0.05$; but not for the block 3 vs. block 4, $t=0.50$, $P>0.05$, or block 3 vs. block 5,

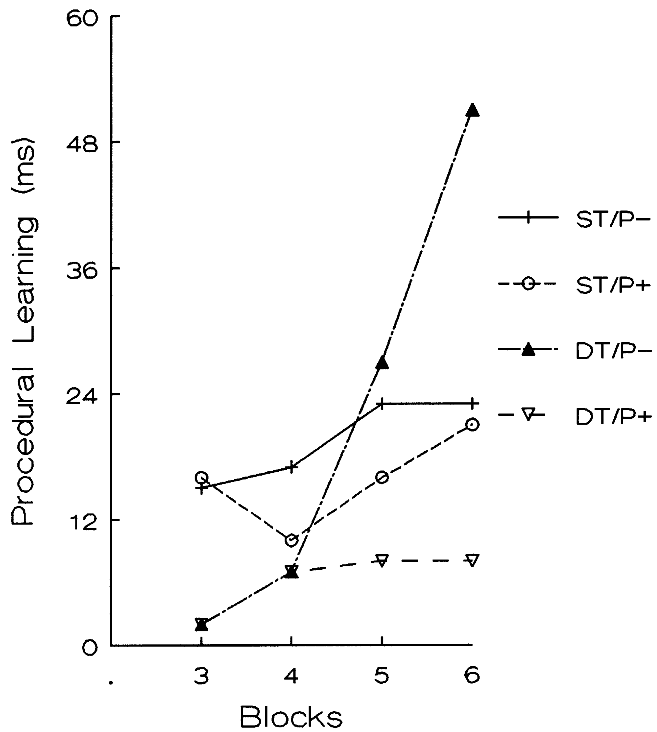

Fig. 1. Mean procedural learning scores (ms; difference RT from random and predictable trials) for low (P−) and high (P+) EPQ Psychoticism under dual-task (DT) and single-task (ST) conditions in Experiment 1.

$t = 0.88$, $P > 0.05$ (Fig. 1). No other effects involving Psychoticism approached statistical significance.

Fig. 1 shows that during block 3 there were no effects of Psychoticism, but a large difference between the dual-task and single-task conditions. The interesting differences emerged in blocks 4–6. Under single-task conditions, both low and high Psychoticism individuals made progress, with the high group showing less consistent performance, but by block 6 their learning scores were very similar and not statistically different ($t = 0.26$, ns). In contrast, under dual-task conditions, high Psychoticism individuals enjoyed only a marginal improvement in performance, whereas the low Psychoticism individuals' performance increased markedly ($t = 2.50$, $P < 0.05$). It seemed as if the low Psychoticism individuals were able to reallocate their attentional effort, exerted during initial dual-task conditions, to enhance their learning in blocks 4–6; in marked contrast, the high Psychoticism individuals continued to show impaired performance, indicative of an inability appropriately to reallocate attentional resources.

4.2.2. Neuroticism

The only significant term was Neuroticism×Blocks×Condition, $F(3, 108) = 3.97$, $P < 0.01$. Decomposing the variance of this last effect into three a priori contrasts revealed a significant difference for block 3 vs. block 6, $t = 2.70$, $P < 0.01$; a near-significant effect for block 3 vs. block 5, $t = 1.88$, $P = 0.07$; and a nonsignificant effect for block 3 vs. block 4, $t = 0.56$, $P > 0.05$. No other effects involving Neuroticism were significant.

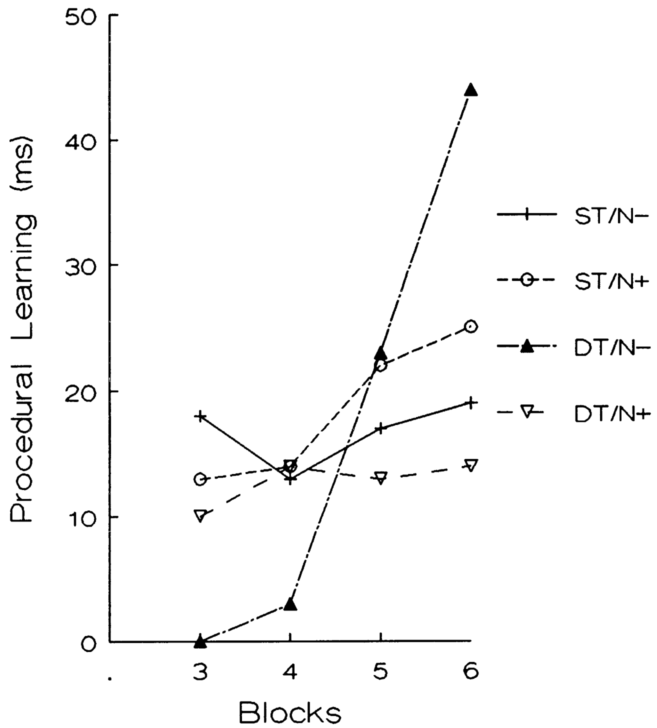

Fig. 2. Mean procedural learning scores (ms; difference RT from random and predictable trials) for low (N–) and high (N+) EPQ Neuroticism under dual-task (DT) and single-task (ST) conditions in Experiment 1.

As seen in Fig. 2, the pattern of effects for Neuroticism was not dissimilar to that observed for Psychoticism; notably, low Neuroticism individuals, upon release from dual-task processing in blocks 4–6, showed superior learning, perhaps reflecting the reallocation of attentional resources to learning; in contrast, the high Neuroticism individuals failed to show any appreciable increase in learning in blocks 4–6. These similar effects of Psychoticism and Neuroticism were observed despite the fact that these personality factors were weakly correlated in the current sample ($r=0.112$, ns).

4.2.3. Extraversion

A main effect of Extraversion, $F(1,36)=5.59$, $P<0.05$, related to superior learning in extraverts ($M=18$, SEM = 3; introverts: $M=9$, SEM 3). There were no interactions with Condition or Blocks.

4.3. Control comparisons

A number of questions were raised by the effects of dual-task processing on learning that have a direct bearing upon the interpretation of the personality effects observed earlier. First, merely being exposed to the stimuli during dual-task conditions in blocks 1–3 may exert a nonspecific effect facilitating subsequent learning under single-task conditions in blocks 4–6 (stimulus familiarity effect). Alternatively, learning may have taken place during blocks 1–3, but dual-task processing may have disrupted the performance of this learning (latent learning). These two possibilities are examined next.

4.3.1. Stimulus familiarity effect

Three *t*-tests were run for learning during dual-task blocks 4–6 and single-task blocks 1–3. If mere exposure facilitated performance then learning during blocks 4–6 in the dual-task (DT) condition should be superior to learning during blocks 1–3 in the single-task (ST) condition. Neither of the three contrasts were significant (ST1/DT4: $t=0.80$; ns; ST2/DT5: $t=0.23$, ns; ST3/DT6: $t=0.71$, ns), indicating that learning during the latter portions (blocks 4–6) of the dual task condition resembled learning during the initial portions (blocks 1–3) of the single-task condition discounting the stimulus familiarity effect hypothesis.

4.3.2. Latent learning effects

In order to examine possible effects of latent learning under dual-task processing, a comparison was made of procedural learning in the two dual-task conditions to determine whether participants who had been exposed to predictable trials during blocks 1–3 showed superior performance during blocks 4–6 to participants who had been exposed to random trials during blocks 1–3. (This analysis compared the dual-task condition, analyzed earlier, with an additional Random Control Group comprising completely random trials during blocks 1–3 followed by single-task predictable trials; see Method.)

Table 1 shows the RTs in the Random Control Group, in which there were no significant differences between random and "predictable" trials (i.e. fourth and fifth target movements of the 5-trial sequence) in blocks 1–3 (Ps >0.05), in contrast to significant differences in blocks 4–6 (Ps <0.05). These results confirm that all the trials in blocks 1–3 were random, and did not convey procedural information to participants.

A two-way (6 Blocks×2 Condition) ANOVA on learning revealed no main effect of Condition, $F(1, 38)=0.10$, $P>0.05$, or Condition×Blocks, $F(5, 190)=1.01$, $P>0.05$; but the Blocks main effect was significant, $F(5, 190)=4.780$, $P<0.05$, indicating that learning increased over the course of the task (i.e. in blocks 4–6). None of the *t*-test comparisons between the two conditions were significant. The obvious conclusion from this analysis is that, during dual-task processing, procedural learning was no different to that seen with completely random trials; thus, dual-task processing abolished procedural learning.

5. Discussion

Results replicate Nissen and Bullemer's (1987) finding that no advantage of practice is evident in performance immediately following release from distraction; however, advantage of practice was evident during the latter part of the task in participants who scored low in both Psychoticism and Neuroticism. Analysis of putative latent learning effects discounted the possibility that these participants experienced performance, rather than learning, impairment under dual-task conditions. It was evident that the manipulation of dual-task processing was effective as it significantly slowed down RTs irrespective of predictable and random trial types, indicating that mental arithmetic consumed processing resources.

Individuals high in both Psychoticism and Neuroticism failed to show normalization of procedural learning performance in blocks 4–6. There are several possible explanations for this result. First, perseveration of dual-task processing effects in the no-distraction blocks might have been responsible. This interpretation is supported by the perseveration effects being restricted to high Psychoticism and Neuroticism individuals, who are known to be easily distracted by off-task factors. Second, it is possible that low Psychoticism/Neuroticism participants may have become sensitized to the stimulus environment during blocks 1–3, developing superior perceptual-motor skills, which led to rapid learning during block 4–6. However, this possibility was not supported by the finding that neither the Psychoticism×Condition×Blocks, nor the Neuroticism× Condition×Blocks interactions were significant for RTs, indicating that these individuals did not differ in their general response speed (which might be expected to reflect the acquisition of differential perceptual-motor skills). In addition, test of the stimulus familiarity hypothesis suggested that mere exposure to the stimuli during dual-task conditions did not facilitate subsequent performance.

In an attempt to replicate the results of Experiment 1, Pickering and Chopra (1996) confirmed the pattern of effects reported here; that is, high Psychoticism individuals showed relatively poor procedural learning in blocks 4–6 following dual-task conditions. Their interpretation of this effect was that high Psychoticism individuals suffer fatigue and de-arousal as a consequence of the demanding dual-task conditions during blocks 1–3. Therefore, they may have been in a sub-optimal arousal state with a resulting impairment of performance; unlike low Psychoticism individuals, they may thus have been unable to switch attentional resources in the subsequent single-task conditions.

In support of this interpretation, Clark, Hemsley, and Nason-Clark (1987) found that high Psychoticism individuals had less overall cardiac reactivity and fewer skin resistance responses than low Psychoticism individuals, pointing to a link between Psychoticism and de-arousal. The effects of Psychoticism on procedural learning is consistent with other evidence showing that high Psychoticism individuals have a generalized impairment in learning, both in procedural learning (Corr et al., 1997) and eyeblink conditioning (Beyts, Frcka, Martin, & Levey, 1983).

6. Experiment 2a: dual-task processing and personality

This experiment replicated the basic design features of Experiment 1, with one crucial change: the dual-task comprised, not mental arithmetic, but the counting of nonsense syllables. In the dual-task condition (blocks 1–3), participants were required to pick one syllable and to count the number of times it was presented; single-task participants also heard these syllables but were told to ignore them. Thus, both the dual and single-task participants were exposed to the same stimuli, but only those in the dual-task condition were required to engage in effortful, attentional processing. (Nonsense syllables were chosen to provide an analogue of the dual-task used in typical human studies of latent inhibition, where an effect of Psychoticism is often observed.) Various aspects of mood and motivation were also measured in order to explore the possible causal dynamics behind personality effects.

The pattern of Psychoticism effects was hypothesized to be the same as that given in Experiment 1 (given the use of LI masking stimuli, this was a central prediction). Regarding Neuroticism, because the counting of nonsense syllables is less stress-inducing than mental arithmetic, it was hypothesized that the pattern of Neuroticism effects observed in Experiment 1 would be either weakened or abolished.

7. Method

7.1. Participants

Forty-six volunteers were recruited, 27 females (mean age = 23.40, SD = 6.25), 19 males (mean age = 26.00, SD = 6.32). First-year psychology students participated in exchange for course credits.

7.2. Design

The design of the study was identical to Experiment 1, with the exception of the dual-task.

7.3. Personality questionnaires and mood measures

Identical personality measures to Experiment 1 were taken. In addition, measures of Energetic Arousal (EA), Tense Arousal (TA), Hedonic Tone (HT), and Anger/Frustration (AF), as well as Motivation and Workload (Dundee Stress State Questionnaire; Matthews, Joyner, Gilliland, Campbell, Huggins, & Falconer, 1999), were taken. The 8-item Motivation Scale taps intrinsic motivation, reflecting degree of engagement and interest in a task (i.e. "How motivated were you to do the task?", "How would you feel if you performed badly on this task?"). The 9-item Workload scale measures degree of effort demanded by the task (e.g. "Please rate the physical demand of the task'', ''How much physical activity was required?'', ''Please rate your performance'', ''How successful do you think you were in accomplishing the goals of the task?'').

7.4. Dual-task processing: nonsense syllables

The nonsense syllables employed in previous latent inhibition experiments were used (e.g. Baruch, Hemsley, & Gray, 1988a, 1988b; the tape was obtained from the Psychology Department at the Institute of Psychiatry, London). The 39 different syllables were recorded on audiotape, with each appearing between 4 and 6 times in a quasi-random (fixed) order. The syllables were read out in a male voice, and presented binaurally via headphones.

7.5. Procedure

Participants in the single-task condition were asked to listen passively to the tape of nonsense syllables at the same time as performing the first 3 blocks of the computer task. Participants in the dual-task condition were instructed to count a different nonsense syllable for each of the first 3 computer blocks, and this syllable was reported to the experimenter at the end of each block. All participants performed during blocks 4 - 6 under single-task conditions with the headphones still on but the tape switched off. All other procedural details were identical to Experiment 1.

8. Results

Personality scores were comparable to published norms: Extraversion ($M=14.89$, SD = 4.37, Min.–Max. = 5–22, median = 15.50); Neuroticism (10.63, 5.41, 2–22, 9.50); Psychoticism (8.02, 4.51, 0–21, 7.00); and Lie (4.41, 3.42, 0–14, 4.00). Table 2 presents the RTs to random and predictable trials under single-task and dual-task conditions.

8.1. Omnibus analysis of variance

An identical analysis to Experiment 1 was conducted.

Table 2
Mean (SD) RTs to predictable and random trials over the six blocks of the task and in each of the experimental conditions (single-task and dual-task processing) in Experiment 2a

Block	Single-task		Dual-task	
	Random	Predictable	Random	Predictable
1	548 (49)	544 (55)	549 (50)	545 (57)
2	538 (44)	530 (49)	532 (44)	524 (56)
3	531 (44)	517 (48)	528 (52)	512 (57)
4	519 (44)	491 (45)	509 (35)	492 (43)
5	513 (40)	489 (42)	507 (38)	492 (42)
6	510 (47)	484 (48)	503 (39)	477 (48)

8.1.1. RT analysis

The main effect of Condition was nonsignificant, $F(1, 44)=0.09$, $P>0.05$, revealing that, overall, RTs were similar in dual-task conditions ($M=514$, SEM = 9) and single-task ($M=528$, SEM = 9) conditions. The Blocks effect was significant, $F(5, 220)=43.32$, $P<0.001$, reflecting a general decline in RTs across the task (Table 2). The Condition×Blocks interaction, $F(5, 220)=0.25$, $P>0.05$, was nonsignificant.

In contrast to the Condition results of Experiment 1, the manipulation of dual-task processing in this experiment, by nonsense syllable counting, did not slow down RTs, suggesting that it did not impose the same attentional load as mentally counting backwards in threes.

8.1.2. Procedural learning analysis

A significant main effect of Trial Type, $F(1, 44)=51.79$, $P<0.001$, showed that RTs on predictable trials ($M=508$, SEM = 7) were faster than those on random trials ($M=524$, SEM = 6), confirming that procedural learning occurred. A significant Trial Type×Blocks interaction, $F(5, 220)=14.53$, $P<0.001$, showed that learning increased over the blocks of the task (Table 2). The Condition×Trial Type effect was not significant, $F(1, 44)=0.62$, $P>0.05$, and neither was the Condition×Trial Type×Blocks effect, $F(5, 220)=1.64$, $P>0.05$. These effects on learning are highly similar to those obtained in Experiment 1.

8.2. Personality and procedural learning

These analyses were identical to Experiment 1.

8.2.1. Psychoticism

The main effect of Psychoticism showed a trend towards formal significance, $F(1, 38)=2.32$, $P=0.14$ (as in Experiment 1); but the Psychoticism×Blocks term was significant, $F(3, 114)=3.63$, $P<0.05$. The overall Psychoticism×Blocks×Condition term, $F(3, 114)=1.76$, $P=0.16$, though not significant overall showed, as in Experiment 1, significant contrasts when decomposed: significant effects for block 3 vs. block 6, $t=2.13$, $P<0.05$; but not for block 3 vs. block 4, $t=1.28$, $P>0.05$, or block 3 vs. block 5, $t=0.27$, $P>0.05$. These effects are shown in Fig. 3.

The precise pattern of effects shown in Fig. 3 differed somewhat from that found for Psychoticism in Experiment 1, despite the fact the same Psychoticism×Condition×Blocks effect was significant for the block 3 vs. 6 contrast. Under the single-task condition, low Psychoticism individuals showed a marked improvement in learning from blocks 3–6, in contrast to high Psychoticism individuals who showed an erratic learning progression finally reaching a level of learning in block 6 that was not much better than that achieved at block 3. Under the dual-task condition, low Psychoticism individuals showed a steady increment in learning over the blocks, but once again high Psychoticism individuals took a variable path, with learning performance collapsing in block 5, but markedly improving in block 6. As in Experiment 1, high Psychoticism was associated with inconsistent learning performance, and this seemed to be most marked under dual-task conditions.

8.2.2. Neuroticism

The Neuroticism×Blocks×Condition term, $F(3, 126)=1.90$, $P=0.13$, failed to reach an acceptable level of significance; and nor were any of the individual contrasts significant ($P\text{s}>0.10$).

8.2.3. Extraversion

There were no significant or near-significant effects.

8.2.4. Psychoticism and mood/motivation measures

Given the fact that Psychoticism was a significant factor in influencing learning in both experiments, its relations to mood and motivation measures were examined.

First, before the experiment, high Psychoticism individuals were lower on Energetic Arousal, $F(1, 40) = 9.34$, $P < 0.01$ ($M = 20.33$, SEM 1.08; low psychoticism, 24.48, 0.82), Motivation, $F(1, 40) = 5.75$, $P < 0.05$ (38.71, 1.61; low Psychoticism, 45.29, 2.22), and higher on Anger/Frustration, $F(1,40) = 4.62$, $P < 0.05$ (8.67, 0.66; low Psychoticism, 6.81, 0.56). High Psychoticism individuals were clearly in a negative affective state before they even began the procedural learning task. This finding is consistent with the characterization of the high Psychoticism individual.

Although there were no main effects of Condition on subjective measures taken after the task (controlling for pre-task scores), a number of interesting associations were found with Psychoticism. Controlling for motivation at the start of the experiment, by the end of the experiment, high Psychoticism individuals had lower motivation scores ($M = 32.57$, SEM = 1.86) than low Psychoticism individuals (42.38, 2.12), $F(1,37) = 5.15$, $P < 0.05$. This finding parallels their inconsistent level of performance throughout the experiment.

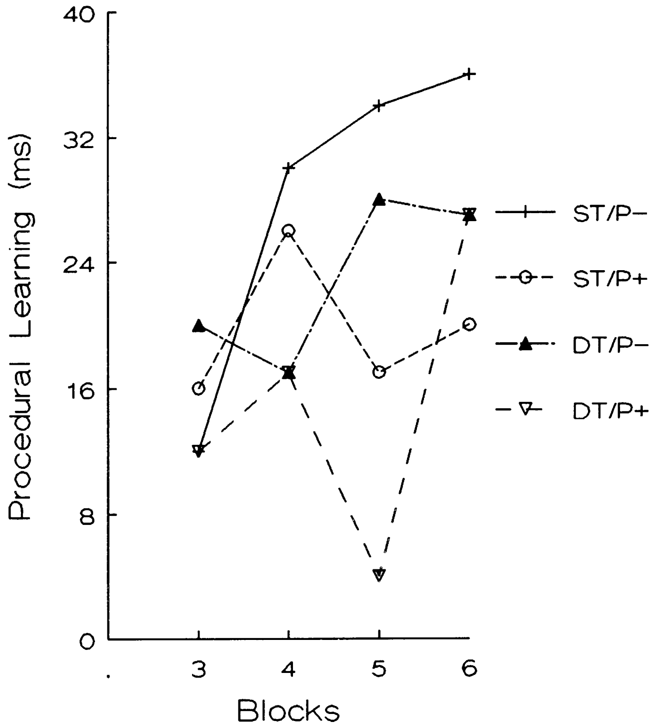

Fig. 3. Mean learning scores (ms; difference RT from random and predictable trials) for low (P−) and high (P+) EPQ Psychoticism under dual-task (DT) and single-task (ST) conditions in Experiment 2a.

9. Discussion

As in Experiment 1, Psychoticism was found to moderate the effects of dual-task processing on procedural learning. High Psychoticism participants reported being more angry and frustrated before the experiment and they were also lower in energy and motivation, factors that are unlikely to facilitate performance. However, there was no effect of Psychoticism differences on RTs, which indicates that they did attempt to perform the task, but nevertheless their procedural learning was erratic over the blocks of the task. The effects of self-report motivation at the end of the task, having controlled for pre-task scores, suggested that high Psychoticism individuals were relatively cognitively disengaged from the task, and this explanation could account for the variable levels of performance seen in blocks 4–6. There were no effects on energetic or tense arousal, which does not lend support to the arousal explanation discussed in Experiment 1. It was notable that effects of Psychoticism were evident even when a relatively cognitively undemanding dual task was employed.

Unlike Experiment 1, high Psychoticism individuals in the single-task condition also showed inconsistent performance during blocks 4–6. It is possible that high Psychoticism individuals in the single-task condition found it difficult not to be distracted by the presentation of nonsense syllables, even though they were not required to process them. This finding extends the relevance of this Psychoticism because it suggests that wherever simultaneous, however irrelevant, stimuli are presented then these may disrupt ongoing task performance.

The dual-task stimuli in this experiment (i.e. nonsense syllables) were taken from a standard version of human latent inhibition (LI; see Gray et al., 1991). It is, therefore, of theoretical interest that Psychoticism modified the effects of this type of dual-task processing. The results suggest that processing these stimuli is sufficient to disrupt performance in high Psychoticism individuals, a conclusion which suggests that the process underlying the phenomenon of LI is impaired inhibitory processing resulting from the disruptive interference of dual-task processing, and not necessarily weakened inhibitory processing per se. It is noteworthy that in human latent inhibition studies, but not animal studies, a masking task (e.g. counting of nonsense syllables) is required in order for CS pre-exposure to impair the subsequent CS-UCS association (Lubow, 1989). If dual-task processes disrupts the inhibitory (procedural) processing of the pre-exposed CS (e.g. white noise) then high Psychoticism individuals should be better able to associate the simple rule that associates the CS with the UCS: this is a typical finding in human LI studies. In addition, the results from the single-task condition suggests that merely being exposed to nonsense syllables, without the requirement to count them, may also impair LI in high Psychoticism individuals.

The most parsimonious explanation for the lack of a significant effect of Neuroticism in this experiment was the absence of a stress factor. In Experiment 1, participants had to count backwards in threes which is more stressful than simply monitoring a stream of nonsense syllables and counting one of these. The absence of the dual-task on RT supports this contention.

10. Experiment 2b: awareness of procedural rule

To what extent was the pattern of stimuli in Experiments 1 and 2a accessible to awareness? Therefore, to what extent are the effects of personality observed truly related to procedural learning? There is debate concerning the level of awareness engendered by the type of procedural learning task used here. The aim of this experiment was to address this issue.

This topic, though important, is difficult to evaluate (Shanks & St. John, 1994). In the context of procedural learning, Reber (1967) pointed to the discrepancy which exists between verbal report and the effects of practice on artificial language tasks. Brooks (1978) showed that participants could perform at above chance levels on a letter string task without being able to verbalize the rules; similar results were also reported by Broadbent and Aston (1978). However, being unable to verbalize rules does not necessarily imply that such rules are not conscious (they may be accessible by non-verbal awareness). For these reasons, it is necessary to take awareness measures that do not depend exclusively upon verbal processing, namely performance-based measures. These measures have the benefit that they may be more sensitive to the actual rules learned by participants, as opposed to the experimenter-defined rules.

Verbal report has been the most common method for assessing awareness, although previous studies have shown it to provide ambiguous and unreliable data (verbal report is formally equivalent to free-recall memory). Generate tasks are identical to the training phase of the task except for the requirement of intentional, explicit processing (generate tasks are formally equivalent to cued-recall memory). This approach has been used in previous research (e.g. Hartmann, Knopman, & Nissen, 1989). Recognition tasks also require intentional processing of the stimulus sequences, forcing the subject to decide whether the presented sequence was correct or not. If declarative (albeit covert) knowledge is used to facilitate procedural learning, then the above awareness tasks might be expected to show performance characteristics of explicit memory tasks: that is, recognition memory (i.e. recognition task) should be superior to cued-recall (i.e. generate task), which, in turn, should be superior to free-recall (i.e. verbal report).

Previous assessment of awareness with this task (Corr, 1994) showed that participants: (a) had very low confidence that they had learned the rule; (b) were unable to reproduce the rule on pencil-and-paper; (c) could not verbalize the rule; (d) could not generate on the monitor the next correct target movement at above chance level; but (e) could, at an above chance level, distinguish correct from incorrect target movements (i.e. between correct old items, and novel sequences). The aim of this experiment was to try to confirm these data in a different sample.

11. Method

11.1. Participants

Participants were the same as those in Experiment 2a, who undertook the assessment of awareness after completion of the 6 blocks of the procedural learning task.

11.2. Assessment tasks

A series of graded tasks were employed in an attempt to tease out any information available to conscious recall and performance. Tasks were presented in the following order.

11.2.1. Self-report and pencil-and-paper task

Participants were presented with an A4 sheet of paper, on which was drawn three rows of three screens. In each row, two of the screens displayed targets and the participant's task was to complete the third screen. The instructions read.

> As already stated, a set of rules governed the movement of the target you responded to during the main section of the computer task. Please spend some time thinking about what these rules might have been and give your suggestions. Where possible, use the blank sheets provided showing the screen display to illustrate your answers. Even if you are not at all confident that you know what these rules are Please list four suggestions.

11.2.2. Generate task 1

Twelve partially completed five target movements were presented on the computer monitor. The target remained in each quadrant for 0.5 s and the travel time between target positions was also 0.5 s. Participants were instructed to point the wand at the word "GO", which appeared in the middle of the quadrants, to initiate the target movements on the computer monitor. The target then moved from one position to the next, and "NEXT" appeared in the middle of the quadrants to prompt participants to guess, by pointing with the wand, the next correct target position. "GO" re-appeared after the guess and the procedure was repeated. There were a total of 12 prediction trials. The target moved a variable number of times (from 2 to 4 times) on different trials.

Instructions read:

> For this part of the task, you will see on the screen a number of target movements which will vary in length. As before, your task is to complete these sequences. When "GO" appears in the centre of the screen touch this and watch the target move; when you see "NEXT" appear you have to predict the position of the next target. Do this by touching the quadrant to which you think the target has moved. Once you have made your prediction another sequence will follow and you should touch "GO" to start this and repeat the above procedure. Please respond as fast as possible. Please touch GO to start.

11.2.3. Recognition task

Participants were then instructed:

> In the next section of the task you will see a number of completed target sequences. Some of these are "correct" and some of these are "incorrect". The "correct" target sequences are ones that are governed by the rule that you have learned during the course of the study and which you have seen, and responded to many times before. The "incorrect" target sequences do not follow any rules. Following each completed sequence the computer will request you to indicate whether the target sequence was correct. If you think the sequence was correct then touch "YES" on the screen and if you think the target sequence was incorrect then touch "NO" on the screen. Touch "GO" to begin each sequence. Please touch GO to start.

Once the target sequence had been shown on the monitor, the following message was displayed in the box in the upper half of the screen: "WAS THE SEQUENCE/CORRECT?/TOUCH YES or NO". The bottom half of the screen was separated into two sections; in one section was the word "YES" and in the other section was the word "NO". These instructions were verbally reiterated to participants. Twenty-four trials were presented: 12 correct and 12 incorrect trials; these were randomized for each participant. The target movements were accompanied by the musical note as during the learning task.

11.2.4. Generate task 2

Upon completing the recognition task, the generate task was once more presented.

11.3. Procedure

At the end of the six learning blocks, the experimenter explained that the target movements had been generated according to a specific underlying rule and that the rest of the experiment would consist of tests of awareness of these rules. The written instructions read:

> The main section of the computer task is now over. The movement of the target to which you have been responding was governed by fixed rules; this section will assess the degree to which you know what these rules are. You may feel that you have not learned anything about these rules, but this is very unlikely, although you may not find it easy to recall the information you have learned. So throughout the remaining sections of the study, please feel completely free to express your thoughts about what you think these rules might have been.

Then the assessment tasks were presented in the order shown above.

At the end of the task, all participants were offered 50 pounds if they could: (a) produce a correct 5-trial sequence; and (b) explain the rules that generated their correct sequence.

12. Results

12.1. Self-report and pencil-and-paper task

In terms of suggested procedural rules, 37% said they noticed a triangular pattern; 28% explained particular rules they remembered; 17% said they remembered their hand movements; 11% said that the musical notes guided their performance; 2% said there was a circular pattern to movements; and 4% said they were guessing. None of these verbal reports were specific enough to match the actual procedural rule; and none of the suggested rules would have been sufficient to generate the sequence of target movements shown.

Of the three attempts to predict correctly the next target movement, performance was at chance level ($M = 1.54$, SD = 0.96). Assuming that participants never returned to the previous position then they had 2 available alternatives from which to choose, given a chance figure of 1.5 correct completions.

12.2. Generate tasks 1 and 2

No significant differences were found between correct predictions in the two tasks (test 1: $M=4.78$, SD = 2.15; test 2: M = 5.09, SD = 2.27, $t(45)=0.83$, $P>0.05$). In terms of chance performance, we would expect 6 of the 12 generates to be correct, so performance was clearly not above chance.

12.3. Recognition task

Participants made a higher number of correct YES/NO decisions ($M=17.59$, SD = 4.05; out of a possible 24).

Even though £50 was on offer, none of the 50 participants were able to: (a) produce a correct 5-trial sequence; and (b) explain the rules that generated their correct sequence.

12.4. Procedural learning and awareness measures

Pearson product–moment correlations between awareness indices and procedural learning in Block 6 (Experiment 2a) showed several near-significant effects. Learning was correlated with number of correctly recognized target sequences ($r=0.265$, $P<0.05$, one-tailed); first generation of target sequences ($r=0.234$, $P=0.06$, one-tailed); and second generation of target sequences ($r=0.240$, $P=0.05$, one-tailed). These findings indicate that there was some overlap between awareness of the procedural rule and actual learning. Correlation between awareness indices and RTs to random targets did not even approach significance, confirming that the correlations with procedural learning were not due to a trivial effect of motivation or effort. However, the magnitude of these correlations were low, and taken with other information supportive of the views that the procedural rule that generated the target sequences was non-salient and only with great difficulty led to any form of conscious awareness.

12.5. Personality and awareness measures

No significant effects of personality were observed.

13. Discussion

These findings indicate that awareness of the procedural rule was poor, and there were no relationships between assessment measures and personality. Therefore, the hypothesis that awareness might have been important in the effects of personality on procedural learning may be discounted. Although assessment of awareness is problematic (Shanks & St. John, 1994), the present study took several independent sources of information, ranging from free self-report to target generation. None of the measures inspired much confidence in the awareness of the rule, although there was some indication of awareness from the recognition task. The pattern set of data closely resembles those obtained by Corr (1994) using the same set of awareness tasks.

Only recognition memory hinted at some degree of awareness. However, it is possible that participants made a categorical decision of ''incorrect'' (i.e. movements that violated predictable and random movements; and which were never seen before) and ''other'' (i.e. the predictable target movements in the present case) thus resulting in above chance levels of performance. It is also not possible to conclude that the weak association of generate performance and procedural learning was related to awareness because the participants could have completed the generate trials in a nonconscious manner. The correlation between learning and performance on generate trials was most probably a reflection of the similarity in task demands between the two performance indices (i.e. both required the same movement, which in the case of generation does not need to depend upon conscious awareness).

14. General discussion

Procedural learning represents a phylogenetically old form of knowledge acquisition, thought to underlie a range of cognitive-behavioral tasks. The results confirmed that the cognitively demanding dual-task (mental arithmetic) condition impaired the acquisition of procedural information for all individuals, and that this impairment reflected the abolition, not merely the concealment, of learning (Experiment 1); with the less cognitively demanding task (counting nonsense syllables), learning was not impaired (Experiment 2a). However, in both experiments, one major dimension of personality, viz. Psychoticism, served to moderate the effects of dual-task processing on subsequent single-task performance.

High Psychoticism individuals showed an erratic pattern of performance when released from dual-task processing; and, intriguingly, this effect was also evident when participants were merely exposed to nonsense syllables without the requirement to count them (Experiment 2a). Results from Self-Report Mood and Motivation Scales indicated that high Psychoticism was associated with impaired motivation. Neuroticism was also found to impair procedural learning, but only under the cognitively demanding dual-task conditions of Experiment 1, which would be expected to impose a greater degree of stress (mental arithmetic is commonly used in stress research). However, it needs to be acknowledged that the effect sizes of personality were modest, but they were consistent.

The precise mechanism by which declarative processing disrupts procedural learning has yet to be clarified. Although it is tempting to conclude that declarative processes use attentional resources, and therefore consume the vital attention ''fuel'' needed for procedural learning (cf. Nissen & Bullemer, 1987), other evidence points to different possibilities. First, the disruption of the *organization* of automatically learned sequences can mimic the disruptive effects of dual-task processing (Stadler, 1995). Perhaps high Psychoticism individuals experience a higher level of disorganization of procedural information in the presence of conscious processing. Second, there could be a problem in initial *stimulus analysis*. In support of this view, Badcock, Smith, and Rawlings (1988) reported that high Psychoticism individuals needed significantly longer target stimulus duration in order to identify the stimulus correctly. Third, the *performance* of well learned and organized stimulus relations may be at fault. Consistent with this possibility were the *reductions* in performance seen in the high Psychoticism individuals (it must be assumed that these reductions do not reflect the unlearning of the procedural rule). In addressing these factors, the possible moderating role of gender may also need to be examined (males, on average, score higher than females on Psychoticism).

The present studies were theoretically motivated by a reanalysis of the relationship between Psychoticism and latent inhibition. LI is usually interpreted as reflecting impaired processing of the pre-exposed CS, due to impaired inhibitory processes in high Psychoticism individuals (i.e. a failure to learn that the CS is of no consequence; see Gray et al., 1991). In human studies, for LI to be observed, pre-exposure of the CS must be made in the presence of a dual-task (i.e. masking task, e.g. counting nonsense syllables). It is, thus, possible that dual-task processing *itself* accounts for LI impairment in high Psychoticism individuals (i.e. it disrupts the procedural learning of the irrelevance of the CS).

These data may also hold implications for the experimental study of procedural learning. As discussed in the Introduction, some studies indicate that procedural learning is abolished under dual-task demands (e.g. Nissen & Bullemer, 1987), others that it is not (e.g. Cohen et al., 1990; McDowell et al., 1995). A failure to consider individual differences may lead to interpretations of experimental variables which have more to do with a number of other factors: (a) between group personality differences; (b) interactions with motivation, arousal or cognitive processes; or (c) erratic performance across blocks, leading to unstable measures of performance. Also, the cognitive demands of the dual-task may be important, as suggested by the different patterns of disruptive effects found for mental arithmetic (Experiment 1) and the counting of nonsense syllables (Experiment 2a)

The sequence of target movement was not salient, and did not, at least in any obvious way, promote the development of awareness of the procedural rule (Experiment 2b). Even the promise of a large sum of money was insufficient to reveal conscious knowledge of the procedural rule. There was also little indication that either procedural learning or the effects of psychoticism were associated with awareness.

In summary, in two separate studies, Psychoticism modified the effects of dual-task processing on a nonconscious procedural learning task. These effects were observed despite the change in the dual-task (cognitively demanding mental arithmetic vs. undemanding counting of syllables). These data are theoretically significant for a number of reasons. First, they show that well-established factors of personality are related to the effects of cognitive processing in procedural learning, and may, therefore, need to be routinely considered in experimental cognitive studies. Second, the data suggest that previously observed effects of Psychoticism on a wide range of performance measures (e.g. LI) may result from the disruptive interference in procedural learning by declarative processing.

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