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SOCIABILITY/IMPULSIVITY AND CAFFEINE-INDUCED AROUSAL: CRITICAL FLICKER/FUSION FREQUENCY AND PROCEDURAL LEARNING

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Summary—The influence of sociability/impulsivity in caffeine-induced arousal effects was investigated in two separate experiments: Experiment 1 examined critical flicker/fusion frequency change scores (ΔCFFT) in 60 subjects; and Experiment 2 investigated procedural learning in 30 subjects. In the two experiments, subjects received either caffeine citrate (500 mg) or placebo. The pattern of results was consistent across both studies: (1) a strong interactive effect of sociability (as measured by the EPQ extraversion scale) by caffeine/placebo which showed that (a) subjects low in sociability showed the greatest increase in ΔCFFT and learned most under placebo, while the reverse was true under caffeine; (b) subjects high in sociability, showed no increase in ΔCFFT and learned least under placebo, while the reverse was true under caffeine; and (2) in neither experiment did impulsivity (as measured by the EPS impulsiveness scale) significantly interact with caffeine/placebo. The results are consistent with Eysenck's (*The Biological Basis of Personality*, 1967) theory of personality in suggesting that subjects low in sociability are highly arousable under low-arousal (placebo) but over-aroused under high-arousal (caffeine), with the reverse pattern of effects holding for subjects high in sociability. The implications of these data for the respective roles of sociability and impulsivity components of extraversion in arousal-mediated performance are discussed.

GENERAL INTRODUCTION

The concept of general arousal continues to play an important role in unifying disparate constructs (e.g. cortical arousal, task difficulty and extraversion) in personality psychology, although doubts have been expressed concerning the value of the unitary arousal system hypothesis (e.g. Neiss, 1988). Since the discovery of the ascending reticulocortical activating system [ARAS (Morruzi & Magoun, 1949)], both theoretical developments (e.g. Eysenck, 1967; Humphreys & Revelle, 1984) and empirical evidence (e.g. Anderson, 1994) attest to the utility of general arousal theory.

Eysenck's (1967) well-known model assumes that introverts and extraverts differ with respect to the sensitivity of their arousal system and the thresholds of ARAS responsivity to sensory stimulation. Introverts are said to have lower response thresholds and in consequence higher cortical arousal. In general, introverts are more cortically aroused and more arousable when faced with incoming sensory stimulation. However, the relationship between arousal-induction and actual arousal is subject to the moderating influence of protective transmarginal inhibition (TMI; a protective mechanism that breaks the link between increases in arousal and increases in response strength at high levels of stimulation): under low stimulation (e.g. quiet or placebo) introverts should be more aroused/arousable than extraverts, but under high stimulation (e.g. noise or caffeine) introverts may experience over-arousal, which with the evocation of TMI may lead to lower increments in arousal as compared with extraverts; conversely, extraverts under low stimulation should show low arousal/arousability, but under high stimulation they should show relatively higher increments in arousal.

Eysenck's (1967) theory does not make a theoretical distinction between the power of sociability and impulsivity components of extraversion to influence performance. Although these two traits are correlated (≈ 0.50), some authors (e.g. Carrigan, 1960) have suggested that they represent independent factors, combined together by a 'shot gun wedding' (Guilford, 1975) of concepts. Indeed, changes in the factorial nature of Eysenck's model, removing the majority of impulsivity items from the Eysenck Personality Questionnaire [EPQ (Eysenck & Eysenck, 1975)] extraversion scale, where

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previously they formed part of the Eysenck Personality Inventory [EPI (Eysenck & Eysenck, 1964)] extraversion scale (Rocklin & Revelle, 1981), indicates that such a distinction may be warranted.

The contribution of sociability and impulsivity components of extraversion to arousal-mediated performance remains an important but unresolved issue in personality psychology (Gray, 1981). For as noted by Eysenck and Eysenck (1985), the impulsivity component of extraversion is often found to be more predictive of arousal effects than the sociability component. There is evidence to show that impulsivity, and not sociability, often influences putatively arousal-mediated performance. This literature encompasses classical conditioning (e.g. Barratt, 1971; Eysenck & Levey, 1972), electrodermal responses (e.g. Smith, Rypma & Wilson, 1981), and academic-type cognitive performance (Humphreys & Revelle, 1984; Revelle, Humphreys, Simon & Gilliland, 1980). There is also impressive evidence that the interaction of arousal and impulsivity conforms to the Yerkes–Dodson Law (Yerkes & Dodson, 1908; e.g. Anderson, 1994), providing further theoretical support for the importance of impulsivity over sociability.

However, there is another body of equally compelling evidence to show that sociability, and not impulsivity, interacts with arousal or arousal-related phenomena. For example, Wilson (1990) found that sociability was related to diurnal variation in arousal, as measured by skin conductance (a relatively direct measure of arousal); and Gupta (1990) found sociability and not impulsivity affected verbal operant conditioning under positive reinforcement. Sociability and not impulsivity also has been found to interact with self-reported energetic arousal and time of day effects on sustained information processing tasks (e.g. Matthews, Davies & Holley, 1990a; Matthews, Davies & Lees, 1990b). These latter findings may be contrasted to the findings of Revelle and colleagues, which show complex but consistent interactions between impulsivity, caffeine-induced arousal and time of day. However, apart from Revelle and colleagues, few attempts have been made to manipulate arousal with caffeine in studying the respective effects of sociability and impulsivity components of extraversion. Therefore, the different results reported in these studies might simply reflect different conceptualizations and manipulations of arousal.

As Eysenck's theory (e.g. Eysenck & Eysenck, 1985) continues to associate arousal/arousability with (EPQ) extraversion (i.e. sociability), despite evidence for the unique role of impulsivity (also reviewed by Eysenck & Eysenck, 1985), it seems clear that the respective roles of sociability and impulsivity in arousal-mediated learning and performance need clarification. The aim of this paper is to make a contribution to the resolution of this problem.

Now, although there is empirical support for both sociability and impulsivity in mediating the effects of arousal, one major problem with the existing literature, in respect of drawing conclusions across studies, has been: (1) the different methods used to induce arousal, and (2) the different types of performance variables employed to measure the effects of arousal. It would be desirable to have unambiguous agents and indices of arousal. Bullock and Gilliland (1993) noted that to study the role of personality and arousal it is necessary to use a converging measures approach in which theoretically significant personality measures are taken, central nervous system arousal is experimentally manipulated, and psychophysiological, behavioural and self-report arousal measures are employed as response outcomes.

In order to explore the relationship between sociability/impulsivity components of extraversion in mediating the effects of arousal on theoretically-relevant measures of performance, two experiments were conducted. In Experiment 1, the effects of extraversion and arousal in critical flicker/fusion frequency (CFF) change scores were investigated; and in Experiment 2, a relatively automatic process of knowledge acquisition (also known as procedural learning) was employed. If comparable effects of extraversion and arousal could be found across these very different performance domains then these effects would lend considerable support to general arousal theory and help to discriminate between the respective roles of sociability and impulsivity in arousal-mediated effects.

Caffeine was chosen to provide an unambiguous agent of arousal, as it is known to affect all parameters of general arousal [e.g. skin resistance, muscle tension, and cardiovascular measures (Duffy, 1962)]. Caffeine is also known to have powerful effects on the central nervous system (Lader & Bruce, 1989), cognitive processes [e.g. vigilance; see Lieberman (1992) for a review] and self-reported mood (Thayer, 1989). The general arousal effects of caffeine are thought to result from the blocking of the neuromodulator, adenosine (Snyder, 1984), which itself has potent inhibitory effects on electrophysiological, biochemical and behavioural measures (Hirsh, 1984). Revelle has made extensive use of caffeine in testing the interactive effects of arousal, impulsivity and time of day on performance (e.g. Revelle *et al.*, 1980).

The CFF and procedural learning experiments were aimed at addressing one important point, that of determining the respective roles of sociability and impulsivity in arousal-mediated performance. Given that the most recent formulations of Eysenck's theory of extraversion are heavily weighted towards sociability, then the Eysenckian position might be that sociability will be the key component of extraversion in mediating caffeine-induced arousal effects. In contrast to Eysenck's position, the Humphreys and Revelle (1984) theory argues that impulsivity should be more important than sociability in mediating the effects of arousal, especially when caffeine is used as the agent of arousal-induction. Holding the means of arousal induction constant across both experiments, the use of CFF and procedural learning should provide a powerful test of the converging validity of the roles of sociability and impulsivity in affecting arousal-mediated performance.

EXPERIMENT 1

Introduction

CFF is one of the best means by which to measure cortical arousal (Curran, 1990); it has been used to support Eysenck's extraversion-arousal hypothesis (e.g. Frith, 1967); Gortelmeyer and Wieman (1982) and Grunberger, Saletu, Berner and Stohr (1982) reported that CFF thresholds are highly correlated with electroencephalographic (EEG) measures of arousal; and CFF thresholds have also been related to self-reported measures of subjective alertness (e.g. Grandjean, Baschera, Martin & Weber, 1977; Grundstrom, Holmberg, Lederman & Livstedt, 1977). Despite the fact that caffeine is effective in inducing arousal, and that CFF is sensitive to changes in arousal, the literature is equivocal as to the precise relationship between these two factors (Lader & Bruce, 1989). Doses of caffeine up to 500 mg seem not reliably to affect CFF frequency (Bruce, Scott, Lader & Marks, 1986; File, Bond & Lister, 1982; Nuotto, Mattila, Seppala & Konno, 1982; Swift & Tiplady, 1988).

The failure to find consistent relations between caffeine-induced arousal and CFF thresholds may be in large part attributed to the failure of most reports to consider the influence of individual differences in arousal/arousability. A crossover interaction between, for example, introversion–extraversion and caffeine-induced arousal would be reported as a failure to observe a main effect of drug. Eysenck (e.g. 1967) has long argued for personality to be included in drug studies, if for no other reason than to reduce the error term; however, most drug studies with human volunteers have ignored personality factors.

The nature of the hypothesized interactive effect of introversion–extraversion and caffeine/placebo in CFF thresholds is also not without its problems. Although in general Eysenck's (1967) theory states that introverts have higher levels of arousal than extraverts, there is evidence that TMI can lead to lower levels of actual arousal in the introvert, as compared with the extravert, under highly arousing conditions (Eysenck & Eysenck, 1985), especially in the case of psychophysiological parameters. Wigglesworth and Smith (1976) found that introverts showed a greater skin conductance response (SCR) to an 80 dB tone, but extraverts showed greater SCR to a 100 dB tone, suggesting TMI in introverts and a higher absolute level of arousal in extraverts. A similar finding was reported by Fowles, Roberts and Nagel (1977), who concluded that introverts showed "greater responsiveness at low stimulus intensities and the decline in responsiveness at high stimulus intensities as a result of transmarginal inhibition" (p. 142). Smith *et al.* (1981), using caffeine (vs placebo) to induce arousal, found large basal and phasic arousal (as measured by electrodermal responses) in introverts under placebo, but this finding was reversed under caffeine where extraverts exhibited the greatest responsiveness supporting the hypothesis of transmarginal inhibition of response. Eysenck and Eysenck (1967) found that introverts salivated more to lemon juice applied to the tongue, but when required to swallow the juice extraverts salivated more than introverts, suggesting that the putative increase in stimulus intensity led to response inhibition in the introvert. Therefore, it would seem that over-arousal can lead to actual decrements in the response of psychophysiological parameters (Smith, 1983; Smith, Wilson & Jones, 1983).

The purpose of Experiment 1 was essentially twofold: (1) to determine whether CFF thresholds are sensitive to personality $\times$ caffeine-induced arousal effects, and (2) to examine the relationship between sociability and impulsivity components of extraversion in mediating these effects. The study did not aim to investigate possible time of day effects (these were held constant by statistical means).

The prediction based on Eysenck's (1967) theory is that introverts should show the greatest, and extraverts the least, arousability (as shown by a pre- to post-task increase in CFF thresholds) under placebo; under caffeine, the de-arousal of the extravert should be overcome and the greater arousability of the introvert may be eroded due to over-arousal and the disruptive effects of TMI.

Method

Subjects

Sixty *S*s, 28 males (mean age = 26.54 yr, ± SD = 7.81) and 32 females (25.94 ± 7.08) were recruited through a local newspaper advertisement. *S*s received a payment of £5.00 for taking part in the study.

Personality questionnaires

The extraversion scale from the Eysenck Personality Questionnaire [EPQ (Eysenck & Eysenck, 1975)] was used to provide a measure of sociability (Soc); and the impulsiveness scale from the Impulsiveness (IVE) Questionnaire, part of the Eysenck Personality Scales [EPS (Eysenck & Eysenck, 1991)], provided a measure of impulsivity (Imp). The entire questionnaires were administered, but only the Soc and Imp scales are analysed here.

Critical flicker/fusion frequency

The CFF apparatus consisted of a control unit which allowed the experimenter to alter the flicker/fusion frequency, and a display unit for the presentation of the stimuli to the *S*. The flicker/fusion display unit comprised a metal tube 2.5 cm dia and 16 cm long with a soft eye-piece at one end for the *S* to place against the eye; the *S* viewed the stimuli with one eye and held a hand over the other eye. Inside the tube were two lenses, and a red light emitting diode (LED), so arranged that the *S* saw a uniformly illuminated red field when the LED was on. The LED was switched rapidly on/off by means of varying the voltage produced by the control unit. The frequency was displayed to the experimenter by means of a digital frequency meter which was part of the control unit.

A method of limits procedure was adopted in which the *S* viewed the flicker ascending from 25 Hz or descending from 50 Hz. This method yields two parameters: (1) the frequency at which the two intermittent lights fuse into a single percept (fusion threshold) and (2) the frequency at which the single percept separates to form two flickering lights (flicker threshold). The mean of fusion and flicker thresholds represents the CFF threshold (CFFT). The *S* was instructed to say 'Now' as soon as the flicking lights had fused (ascending threshold) and as soon as the fused lights started to flicker (descending threshold). Three ascending and descending readings were taken in alternating order.

The means of ascending and descending trials were computed; readings which were greater than 45 were excluded in order to reduce the error of measurement. Readings were rarely lower than 30 Hz and rarely higher than 40 Hz.

Design

The design consisted of two levels of arousal (caffeine citrate 500 mg and placebo). Allocation of 30 *S*s to each drug condition was (quasi-) random with the requirement of an approximately equal distribution of males and females in the placebo (M/F: 14/16) and caffeine citrate (M/F: 14/16) conditions. Median splits were performed on (EPQ) Soc (median = 14) and (EPS) Imp (median = 9), forming two groups of high and low scorers; those falling at the median were excluded from the analyses (see Table 1 for cell sizes).

Time of testing was not experimentally manipulated as a factor but rather recorded for use as a covariate in the analyses. Time was coded to form three levels corresponding to three periods: (1) 9–11 a.m. ($n = 17$), (2) 11 a.m.–1 p.m. ($n = 24$) and (3) 1–3 p.m. ($n = 19$). Two-way analyses of variance (ANOVAs) were conducted on these time periods for Soc and Imp by caffeine/placebo conditions;

Table 1. Sample sizes of personality × caffeine/placebo cells after discarding *Ss* at the median

	Caffeine citrate (500 mg)	Placebo
EPQ: Soc		
Low	15	13
High	12	15
EPS: Imp		
Low	13	15
High	15	13

no significant ($Ps > 0.20$) main or interaction effects were found, showing that the main factors of interest were not confounded by time of testing. *Ss* were blind to caffeine/placebo administration and the experimenter was blind to low/high Soc and Imp groups (questionnaires were scored after the experiment).

Procedure

Ss were told that they would be required to take a drink which might contain caffeine and that they would be asked to perform a simple computer task. A consent form describing the effects of caffeine was administered; *Ss* reporting a family history of heart disease were excluded from the study. Either caffeine citrate (500 mg) or placebo was then administered by oral vehicle (dissolved in a sugar-free water-diluted blackcurrent drink). *Ss* were not required to abstain from caffeine consumption prior to the experiment. Immediately following caffeine/placebo administration (i.e. within 3–5 min; so there could be no significant pharmacological effect of caffeine), CFF thresholds, and then Soc and Imp measures, were taken. After 25 min (during which *Ss* completed several questionnaires not relevant to this paper) *Ss* were introduced to a vigilance task. The vigilance task contained no feedback or reinforcement (data to be reported elsewhere) and lasted 25 min. Upon completion of the task (i.e. 50 min after caffeine/placebo administration), the CFF test was re-administered.

Testing took place in a sound attenuated experimental cubicle. The experimental procedures were approved by the Ethics Committee of the Institute of Psychiatry.

Results

Table 2 shows the means and standard deviations for (EPQ) Soc, (EPS) Imp, and pre- and post-task CFF thresholds, and the correlations between these measures.

The difference between ascending and descending CFFs at the beginning of the experiment was significant [$t = 2.13$, d.f. $= 59$, $P < 0.05$], but by the end of the experiment this difference had disappeared [$t = 0.17$, d.f. $= 59$, ns]. The mean difference between ascending and descending CFF change scores was significant [$t = 1.99$, d.f. $= 59$, $P = 0.05$], the mean increase for ascending (1.36, $\pm$ SD $= 3.84$) being greater than that for descending (0.46, ± 2.74) CFF scores. The mean ascending/descending CFF increased from the beginning (37.30, ± 2.26) to the end (38.21, ± 2.89) of the experiment [$t = 2.47$, d.f. $= 59$, $P < 0.05$], suggesting that arousal increased over the course of the experiment.

Table 2. Means (standard deviations, SD) and Pearson product–moment correlations for (EPQ) sociability (Soc), (EPS) impulsiveness (Imp) and critical flicker/fusion frequency (CFF) thresholds

	Mean (SD)	2	3	4	5	6
1. EPQ: Soc	13.98 (4.61)	0.48**	0.14	0.01	0.06	−0.05
2. EPS: Imp	9.52 (4.90)	—	−0.17	−0.12	−0.11	−0.20
3. CFF: ASC1	36.82 (3.97)	—	—	0.55**	0.47**	0.35**
4. CFF: DES1	37.78 (3.35)	—	—	—	0.31*	0.65**
5. CFF: ASC2	38.17 (3.46)	—	—	—	—	0.53**
6. CFF: DES2	38.25 (3.14)	—	—	—	—	—

* $P < 0.05$, ** $P < 0.01$.

ASC1/DES1, Ascending/descending thresholds taken before task; ASC2/DES2, ascending/descending thresholds taken after task.

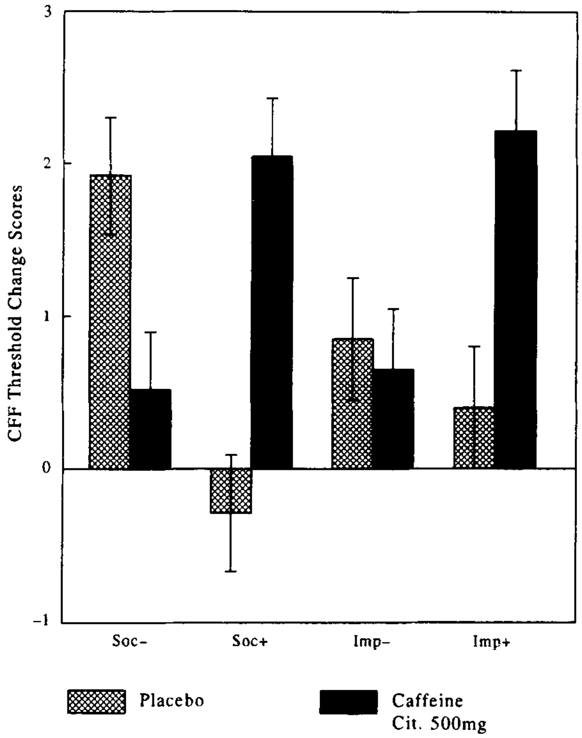

Fig. 1. Mean (± 1 SEM) CFF threshold change scores (ΔCFFT) for (EPQ) low (Soc −) and high (Soc +) sociables and (EPS) low (Imp −) and high (Imp +) impulsives under placebo and caffeine citrate (500 mg) conditions. Only the Soc −/Soc + × caffeine/placebo interaction reached formal statistical significance; however high impulsives under caffeine also showed a large and significant increase in ΔCFFT, as compared with the mean of the other three groups (note: a positive ΔCFFT value represents an increase in CFF thresholds across the task).

The CFF measure used for analysis of personality factors represented the difference between mean ascending/descending thresholds (CFFT) taken pre- and post-task (ΔCFFT; an increase in ΔCFFT was represented by a positive value, a decrease by a negative value). Age of *S*s were not correlated with ΔCFFT [$r = -0.05$, $P > 0.05$].

CFFT at the start of the experiment did not differ with respect to caffeine/placebo conditions and there was no interaction between caffeine/placebo and either of the personality variables (*P*s > 0.05). This indicated that any effect of these treatments on ΔCFFT would not be confounded by initial CFFT values.

In order to determine whether the effects of Soc/Imp in mediating caffeine-induced arousal on ΔCFFT may have been confounded by sex, by virtue of weight differences and thus a possible difference in the efficacy of caffeine to induce arousal, the distribution of Soc/Imp scores in sex × caffeine/placebo cells was examined by two-way ANOVAs. The results revealed no significant effects (*P*s > 0.05). In addition, the distribution of weight in low/high Soc and Imp × caffeine/placebo cells was examined to exclude the possibility that the effects of personality might have been weight related. Again no significant effects were found (*P*s > 0.05). The correlations between *S*s' weight and Soc [$r = -0.061$] and Imp [$r = 0.006$] were not significant.

Separate two-way Analyses of Covariance (ANCOVAs) for Soc/Imp by caffeine/placebo for ΔCFFT, using time of day as a covariate, revealed a significant interactive effect of Soc by caffeine/placebo [$F = 5.55$, d.f. = 1,50, $P < 0.05$; Fig. 1]; no main effects of Soc [$F = 0.02$, d.f. = 1,50, $P > 0.05$] or caffeine/placebo [$F = 0.82$, d.f. = 1,50, $P > 0.05$]; and a strong covariate effect of time of day [$F = 4.69$, d.f. = 1,50, $P < 0.05$; $\beta = -0.293$]. For the ANCOVA containing Imp, there was no main effects of Imp [$F = 0.34$, d.f. = 1,51, $P > 0.05$] or caffeine/placebo [$F = 0.49$, d.f. = 1,51, $P > 0.05$], and no significant interaction between these factors [$F = 2.08$, d.f. = 1,51, $P > 0.05$]; time of day was again significant [$F = 4.23$, d.f. = 1,51, $P < 0.05$; $\beta = -0.277$ (note the difference in error d.f. giving rise to a slightly differing covariate effect)].

The above Imp × caffeine/placebo effect, though statistically nonsignificant, did suggest that there might have been a weak effect of Imp in mediating caffeine-induced arousal. Inspection of Fig. 1 also seemed to show higher ΔCFFT for high impulsives under caffeine, an effect that parallels that observed for high Soc under caffeine. Comparison of the mean for high impulsives under caffeine with the combined mean of the other three groups (all comparable in mean scores) did reveal a significant difference [$t = 2.36$, d.f. = 54, $P < 0.05$], pointing to an effect of caffeine in highly impulsive *S*s.

In order to determine the unique contributions of Soc and Imp in mediating caffeine-induced arousal on ΔCFFT, two further ANCOVAs were run. These ANCOVAs were identical to those reported above, but with the addition of two (standardized) cross-product terms (Soc × caffeine/placebo and Imp × caffeine/placebo) separately entered as covariates before the main factors were considered (the error d.f. was 46). Entering the Soc × caffeine/placebo interaction as a covariate led to a reduction in the *F*-ratio for the Imp × caffeine/placebo interaction from 2.08 ($P = 0.156$) to 1.08 ($P = 0.30$); while entering the Imp × caffeine/placebo interaction as a covariate led to a reduction in the *F*-ratio for the Soc × caffeine/placebo interaction from 5.55 ($P = 0.02$) to 3.37 ($P = 0.07$). These data suggest variance overlap between Soc and Imp in their interaction with caffeine/placebo, by virtue of their positive correlation [$r = 0.48$; Table 2].

To discount finally the possibility that Soc and Imp might make unique contributions to caffeine-induced arousal effects on ΔCFFT, the sum of which adding to their separate effects, a composite measure (representing the simple summation of Soc and Imp) was formed (median split at score of 24) and a regression model was run which contained main effects of caffeine/placebo, Soc and Imp, and two interaction terms: Soc × caffeine/placebo and Soc + Imp × caffeine/placebo (computed from standardized cross-products of Soc/Imp and caffeine/placebo). The main effects were forcibly entered into the model and the interaction terms were allowed to enter by stepwise regression. The final model contained only one term: Soc × caffeine/placebo [$F = 5.98$, d.f. = 1,48, $P < 0.05$]; this showed that Imp did not add predictive variance to that contained in Soc alone.

Discussion

The results showed that both sociability and impulsivity seemed to be associated with caffeine-induced arousal, as measured by changes in CFF thresholds (ΔCFFT) over the experiment, but that the effects of impulsivity were secondary to those of sociability. There was no main effect of caffeine/placebo on ΔCFFT. The importance of sociability in mediating the effects of caffeine in the present study suggests that previous failures to find a robust effect of caffeine on CFF thresholds may be attributed to the fact that most psychopharmacological studies did not consider the possible influence of personality.

Low sociables under placebo showed large ΔCFFT, whereas under caffeine they showed smaller ΔCFFT (suggesting over-arousal and transmarginal inhibition). High sociables showed an actual reduction in ΔCFFT under placebo, and a marked increase in ΔCFFT under caffeine (Fig. 1). Assuming that the experimental situation was mildly arousing (supported by the general increase in CFFT across the task), then these results are strongly supportive of Eysenck's (1967) hypothesis that introverts are more arousable than extraverts and subject to a protective mechanism (transmarginal inhibition) that serves to inhibit further increments in arousal beyond a critical point of high arousal (cf. Eysenck & Eysenck, 1967; Fowles *et al.*, 1977; Smith, 1983; Smith *et al.*, 1981, 1983; Wigglesworth & Smith, 1976). These data add support to general arousal theory (Anderson, 1994) and highlight the importance of major personality factors in general arousal.

The finding that low sociables showed lower ΔCFFT under caffeine, compared with placebo, is comparable with the finding that high trait anxiety *S*s and anxious patients (individuals in a high state of arousal) have relatively low CFF thresholds (e.g. Clyde, 1981; Krugman, 1947). The large ΔCFFT selectively among high sociables/impulsives under caffeine is also reminiscent of Frith's (1967) finding that high (EPI) extraverts show increased arousal under noise (i.e. arousal induction). However, as EPI extraversion is composed of sociability and impulsivity, it is not clear from Frith's data to which component the effect of noise was attributable. The present results suggest that sociability might have been the more important of the two components.

Basal CFFT were taken after caffeine citrate had been administered. For this reason, the evaluation of basal level of CFFT was not attempted because of the possibility that the belief of having taken a drug may have affected performance. This aspect of the design may be seen to have worked to the advantage of the evaluation of personality × caffeine/placebo effects on ΔCFFT because belief following drug administration was comparable at the beginning and the end of the experiment: therefore only the pharmacological effect of caffeine citrate could have affected ΔCFFT (save the possibility that belief of drug action and actual drug action may have interacted in some peculiar way). Another aspect of the design which rendered analysis of basal CFFT of limited value was the fact that *S*s were not asked to refrain from caffeine consumption prior to the study (see General Discussion).

Although preliminary analyses revealed no interaction between either of the experimental factors and time of day, this finding most probably reflects small cell sizes and should not be interpreted as showing that time of day does not interact with Soc/Imp × caffeine/placebo in determining ΔCFFT. Given that the present study confirmed that ΔCFFT is an effective index of caffeine-induced arousal and that the effects of personality are consistent with Eysenck's (1967) theoretical model, the detailed analysis of the role of time of day might form the focus for future studies. The strong relationship between time of day and ΔCFFT does suggest that a triple interaction between personality × arousal × time of day (cf. Revelle *et al.*, 1980) might be found using ΔCFFT. In any event, time of day did not seem to affect the sociability × caffeine/placebo interaction effect reported in this study. Although silent on the question of time of day effects, the present results do not lend support to Revelle *et al.*'s (1980) finding, and the Humphreys and Revelle (1984) theory, that impulsivity has a greater role to play than sociability in mediating the arousal effect of caffeine.

Of the two components of extraversion, sociability and not impulsivity was related to arousability as measured by ΔCFFT. These results would seem to show the value of using ΔCFFT as a measure of personality-related arousal effects, as well as highlighting the importance of personality in explaining the effects of caffeine upon ΔCFFT. The results provide support for Eysenck's position that stresses the primary role for sociability in the effects of extraversion upon arousal-related performance.

EXPERIMENT 2

Introduction

The relationship between sociability/impulsivity and arousal-mediated performance is not directly addressed by psychophysiological studies, which focus on parameters of unknown importance to actual behaviour. Therefore, to add theoretical weight to the findings relating to CFF thresholds reported in Experiment 1, a very different form of putatively arousal-mediated performance was chosen: a type of automatic knowledge acquisition process, also referred to as procedural learning or cognitive skills learning (e.g. Hartmann, Knopman & Nissen, 1989; Lewicki, Czyzewska & Hoffman, 1987).

The procedural learning task employed in this study was modelled after Lewicki, Hill and Bizot (1988), who required *S*s to press buttons corresponding to the spatial position of a target stimulus on a computer monitor. The target stimulus moved between four locations on the monitor, and these movements were either predictable (i.e. followed a specific rule) or random (i.e. no rules determined the movement of the target stimulus). Lewicki *et al.* found that reaction times (RTs) to the predictable target movements were significantly faster than those to the random target movements, indicating that *S*s acquired 'working knowledge' of the underlying structure of the task. *S*s could not express and did not notice the structure of the task, suggesting unconscious processing. The basic effect reported by Lewicki *et al.* is very robust. Corr (1994), using a large sample of 150 *S*s (Lewicki *et al.* used only nine psychologists), had no problem in replicating these results.

Although Lewick *et al.* (1987) claimed that in procedural learning "... the subject acquires some form of intuitive knowledge about patterns of stimuli and how to process them ...", Perruchet, Gallego and Savy (1990) showed that what *S*s probably learn in the Lewicki *et al.* (1988) task is frequency information concerning the probable movement of so-called predictable and random target movements. In the Lewicki *et al.* task, predictable/random trials are confounded by frequency of type of target movement (which comprises the procedural learning rule): predictable trials, compared with random trials, have a higher probability of occurrence. This finding does not invalidate the task; rather, Perruchet *et al.*'s (1990) work shows that learning about frequency information is fundamental to many forms of learning (e.g. classical and operant conditioning; probability of stimulus–stimulus, or response–stimulus co-occurrence), and can be easily measured in a highly sensitive RT paradigm.

Procedural learning has several advantages when applied to the test of sociability/impulsivity and caffeine-induced arousal. Firstly, it is assumed to be a fundamental process which any viable theory of personality must address. Secondly, it usually involves stimulus/motor repetition and is therefore likely to be conducive to the build-up of reaction inhibition (cf. Eysenck, 1957) and de-arousal (cf. Eysenck, 1967). Thirdly, the learning process is thought to be relatively automatic, involving few conscious processing resources, so therefore ruling out secondary effects of personality. Fourthly, procedural learning has not been investigated in the context of Eysenck's theory, therefore its study allows precise theoretical predictions to be made in the absence of previous research findings, thus avoiding the problem of post-diction. Lastly, the use of procedural learning opens up new research avenues in personality psychology which may strengthen links between known personality concepts (e.g. extraversion, arousal, and the Yerkes–Dodson law) with a ubiquitous form of learning (Lewicki, 1986) assumed to be involved in language acquisition, socialization processes, social skills learning, etc.

Assuming that procedural learning is influenced by level of arousal, experimental predictions may be derived from Eysenck's (1967) theory: introverts should learn most, and extraverts should learn least, under placebo (because of introverts' higher, and extraverts' lower, level of arousal); whereas under caffeine, the de-arousal of the extravert should be overcome and the superior performance of the introvert may be eroded due to over-arousal and the disruptive effects of TMI. Assuming that procedural learning is also affected by caffeine-induced arousal, and that the effect of arousal is mediated by extraversion, it may be predicted that a comparable pattern of effects to that reported in Experiment 1 should be found for procedural learning in Experiment 2.

Method

Subjects

Thirty *S*s were tested in all, 15 males and 15 females aged between 18 and 30 yr of age. Data for one *S* in the placebo condition were lost owing to computer disk error. Thus, the sample used for analysis comprised 29 *S*s, 15 males (mean age = 25.77 yr, ± SD = 2.99) and 14 females (24.00, ± 3.88). *S*s were recruited through a local newspaper advertisement and received £5.00 payment. None of these *S*s had served in the first experiment.

Design

The design consisted of two levels of arousal (caffeine citrate 500 mg and placebo). Allocation of 15 *S*s to each drug condition was (quasi-) random with the requirement of an approximately equal distribution of males and females in the placebo (M/F: 6/8) and caffeine citrate (M/F: 8/7) conditions. *S*s were blind to caffeine/placebo administration and the experimenter was blind to low/high extraversion and impulsivity groups (questionnaire data were scored after the experiment). The experiment was run between 9 a.m. and 1 p.m. Sociability and impulsivity were measured in an identical manner to Experiment 1.

Procedural learning task

The task was nearly identical to that reported by Lewicki *et al.* (1988; where a complete description may be found). The version in the present experiment included: (1) wand and touch screen (instead of a keyboard with which to make the response), and (2) a reduction in the total number of segments from 17 to 15.

The task was composed of 15 separate 'segments' (or blocks). Each segment contained 48 sub-blocks, and each sub-block consisted of five target movements. The five target movements of each sub-block were designated as either (1) random or (2) predictable (see Introduction). In fact, the first two target movements were always random, and the last two target movements were always predictable [the 3rd target movement of each five-trial sequence was excluded from the analyses because it was not of higher frequency than the random trials (Perruchet *et al.*, 1990)]. Thus, each segment contained 240 target movements, grouped into 48 sub-blocks of five target movements. The five target movements within each sub-block were referred to as 'trials 1–5'. The only exception to the above rules was segment 14: all target movements were random, consisting of 'catch trials'.

Predictable trials (4–5) procedural rules. (1) If the preceding target movement had been horizontal, then the next target movement would be vertical; (2) if the preceding target movement had been vertical, then the next target movement would be diagonal; and (3) 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).

Random trials (1–2) procedural rules. These trials violated the rules for the predictable trials and were quasi-random.

All 48 sub-blocks were randomly presented (randomized for each *S*) with the restriction that: (1) the first trial was not predicted from the preceding trial (i.e. the 5th target movement of the immediately preceding five-trial sequence); and (2) the target never remained at the same location on two trials in succession.

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

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 not explained to *S*s.

Data reduction and scoring

For each segment the mean RT for each of the five trials was recorded. These summary data permitted the calculation of facilitated RTs on predictable trials [this was calculated by subtracting the mean RT of predictable trials 4 and 5 from the mean RT of random trials 1 and 2 (trial 3 was ignored in the analysis; see Perruchet *et al.*, 1990)]; this represented procedural learning. Mean scores across segments 13 and 15 were used to compute the asymptotic measure of performance. RTs which exceeded 1 sec were excluded from the calculation of mean performance; inspection of the raw data revealed that RTs rarely exceeded 0.5 sec; longer RTs were error responses (e.g. due to the accidental dropping of the wand).

Procedure

The administration of caffeine/placebo was identical to Experiment 1. Following caffeine/placebo administration, the personality measures were taken. After 30 min, *S*s were introduced to the computerized learning task. They were presented with the computer screen with the target (i.e. an asterisk, *) already present in one of the quadrants; then they were instructed in the correct use of the wand and the touch screen; written instructions were then issued:

> "As you can see, the screen is divided into quadrants. A target (*) will move between these quadrants and your task is to touch each target as fast as possible with the wand in the manner already described to you. A practice period follows to familiarise you with the task. *Remember that your response should be fast and accurate.* Please touch 'GO' to start."

A short practice session then commenced, and once this was complete and *S*s 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. *S*s initiated the task by touching a 'GO' box located in the centre of the screen

Table 3. Means (and standard deviations, SD) and Pearson product–moment correlations for (EPQ) extraversion and (EPS) impulsiveness

	Mean (SD)	2
1. EPQ: E	14.57 (4.81)	0.46*
2. EPS: Imp	10.93 (5.09)	—

* $P < 0.05$, $N = 28$.
EPQ: E, Eysenck Personality Questionnaire [EPQ (Eysenck & Eysenck, 1975)] extraversion scale; EPS: Imp, Eysenck Personality Scales [EPS (Eysenck & Eysenck, 1991)] impulsiveness scale.

with the wand. Each segment was demarcated by a 30 sec rest period, and the next segment was initiated by the *S*, prompted by a message appearing on the screen to 'press GO to continue'.

Equipment

The task was controlled by an ATARI ST 1040 microcomputer which recorded all responses. The stimuli were presented on an ATARI SC1224 monitor and a 'Microtec' touch screen was used to register responses. The 'wand' used by *S*s comprised a 12-in. 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 infra-red beams of light which crossed the touch 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 *S*s and the reduction of fatique due to repetitive arm and hand movements.

Statistical analysis

The interaction of caffeine/placebo × personality was computed treating personality as a continuous variable. Therefore the Analysis of Variance (ANOVA) *F*-ratio for the interaction terms reflects the homogeneity of the regression slopes for procedural learning and personality in each of the drug conditions. This approach is comparable to moderated multiple regression (Bissonnette, Ickes, Berstein & Knowles, 1990; Saunders, 1956) and is preferable to taking median splits on the personality scales because of the preservation of statistical power (Cohen, 1968), especially when statistical power is at a premium due to relatively small sample sizes (as was the case in the present experiment). These continuous × class interactions were performed by the MANOVA routine in SPSS[x].

Results

Table 3 provides the means and standard deviations, and Pearson product–moment correlations, for the personality measures. There were no mean differences in sociability/impulsivity between caffeine and placebo conditions (*P*s > 0.10). For reasons detailed below, the caffeine sample size was reduced from 14 to 13; all subsequent analyses are based on this number.

Task analysis

Figure 2 shows the RT (msec) to predictable (trials 4 and 5) and random (trials 1 and 2) targets. Ignoring segment 14 (the 'catch segment'), there were large reductions in RT latencies for random trials [$F = 7.03$, d.f. = 13,351, $P < 0.001$] and predictable trials [$F = 12.72$, d.f. = 13,351, $P < 0.001$]; and the difference between the overall means of random and predictable trials was significant [$F = 40.82$, d.f. = 1,27, $P < 0.001$].

Figure 3 shows the RT difference between predictable and random trials over the 15 segments of the task; these RT differences comprised the measure of procedural learning (note that segment 14 was random so procedural learning was not evident). A two-way (segments by caffeine/placebo) ANOVA on procedural learning scores (ignoring segment 14) revealed a main effect of segments [$F = 5.57$, d.f. = 13,338, $P < 0.01$] but no main effect of caffeine/placebo [$F = 0.32$, d.f. = 1,26, $P > 0.05$] and no interaction between these factors [$F = 1.20$, d.f. = 13,338, $P > 0.05$]; there was a

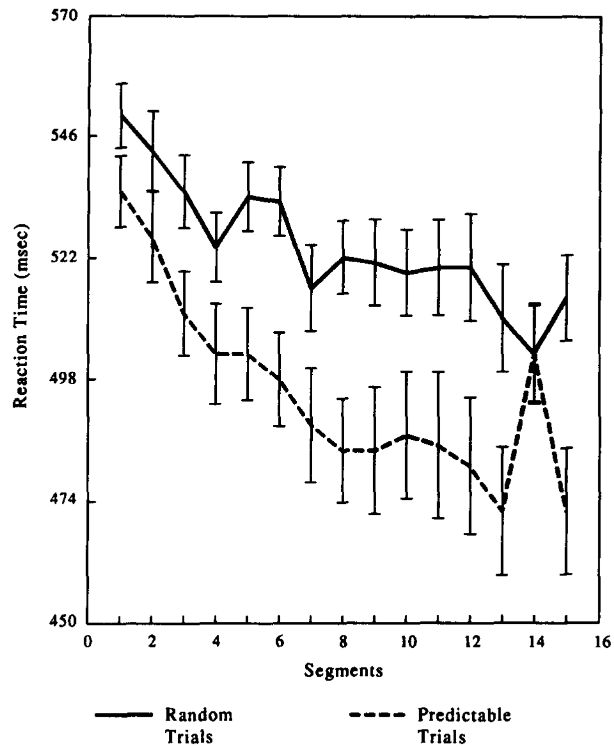

Fig. 2. RTs (msec, ± 1 SEM) to predictable (trials 1 and 2) and random (trials 4 and 5) targets over the 15 segments of the task. Segment 14 was a 'catch trial' in which all targets were random. RTs to predictable trials showed the greatest decline indicating that learning was taking place. The difference between predictable and random RTs represented procedural learning.

strong linear component [$t = 4.83$, $P < 0.0001$ and a weak quadratic component [$t = 2.60$, $P < 0.05$] for procedural learning.

Before analysing the personality data, the distribution of procedural learning scores was inspected to reveal the presence of outliers in the data [normative data were based on a sample of 150 *S*s tested in our own laboratory (Corr, 1994)]. It was found that 1 *S* in the placebo condition showed a very high rate of learning (170 msec). This compared with a maximum procedural learning score of 200 msec in the normative sample [only 2 *S*s (1.5%) exceeded 170 msec]. All other *S*s in the present experiment fell below 120 msec, which, compared with the normative data, represented the 96th percentile. It was therefore decided to exclude this *S* from the analyses. Therefore, the sample size for the placebo group was reduced from 14 to 13 and all subsequent analyses are based on this sample size (note: all analyses were rerun with the inclusion of this case, but the results did not substantially change, save for a reduction in significance levels).

Procedural learning at asymptote was investigated (mean of segments 13 and 15). A two-way ANOVA (caffeine/placebo × sex) was conducted to examine the influence of sex on learning. This revealed no effect of sex [$F = 1.27$, d.f. = 1,24, $P > 0.05$] and no interaction of sex × caffeine/placebo [$F = 2.35$, d.f. = 1,24, $P > 0.05$].

Validition checks

Several preliminary analyses were conducted in order to discount possible confounding effects in the caffeine/placebo × personality relations reported below.

ANOVA for caffeine/placebo × sex on the distribution of Soc/Imp revealed that Soc was not evenly distributed across males and females [$F = 5.07$, d.f. = 1,24, $P < 0.05$ (male mean = 15.50, ± SD = 2.90; female = 12.64 ± 5.62)], and the same was true for Imp [$F = 3.45$, d.f. = 1,24, $P < 0.10$ (male: 12.61, ± 4.94; female: 9.36, ± 4.88)]. An ANOVA for caffeine/placebo × sex on *S*s' weight

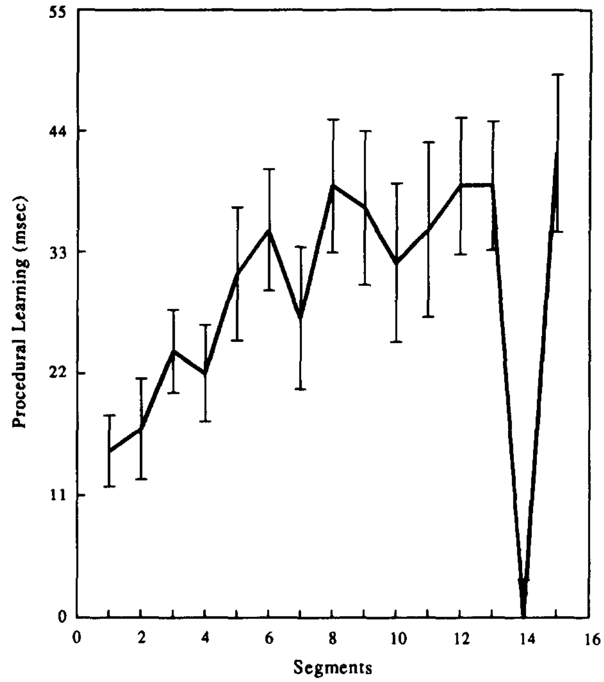

Fig. 3. Procedural learning (msec, ± 1 SEM) over the 15 segments of the task. During segment 14 all trials were random so the prior acquisition of knowledge concerning the structure of the predictable target movements did not facilitate performance.

revealed a significant effect of sex [$F = 5.81$, d.f. = 1,24, $P < 0.05$ (male mean = 70.00 kg, ± SD = 8.79; female = 62.23, ± 7.91)], as would be expected.

In order to eliminate the possibility that the effects of personality and caffeine/placebo on procedural learning might be related to *S*s' weight, by virtue of a confounding relationship between Soc/Imp and the weight-related efficacy of caffeine to induce arousal, two-way ANOVAs (drug condition × Soc/Imp) on *S*s' weight were conducted: no effects were significant. There were no significant correlations between *S*s' weight and Soc [$r = 0.23$, ns] and Imp [$r = 0.05$, ns].

Taken together with the fact that sex was (approx.) evenly distributed over the caffeine (M: 8/F: 7) and placebo (M: 6/F: 7) conditions, the above results suggested that sex could be ignored in subsequent analyses; however, sex was entered as a third factor in all subsequent analyses to confirm this expectation (no significant effects of sex were found).

Personality and procedural learning

Two-way ANOVAs were computed for Soc and Imp and caffeine/placebo conditions. For Imp, there were no main effects of caffeine/placebo [$F = 0.05$, d.f. = 1,24, $P > 0.05$] or Imp [$F = 1.33$, d.f. = 1,24, $P > 0.05$], and no interaction between these two factors [$F = 0.33$, d.f. = 1,24, $P < 0.01$]. For Soc, there was a main effect of caffeine/placebo [$F = 7.32$, d.f. = 1,24, $P < 0.05$], a marginal effect of Soc [$F = 3.77$, d.f. = 1,24, $P = 0.06$], and a highly significant interactive effect of caffeine/placebo × Soc [$F = 9.57$, d.f. = 1,24, $P < 0.01$]. The reduction in the error term afforded by the Soc × caffeine/placebo interaction resulted in the significant drug effect, with procedural learning under caffeine ($M = 46$ msec, ± SD = 34) greater than that under placebo (34, ± 28). However, given the dependence of this drug effect upon the interaction with extraversion, this result should be treated with caution. The interaction of extraversion and caffeine/placebo is shown in Fig. 4.

To explore the respective contributions of sociability and impulsivity variance in caffeine-mediated effects in procedural learning several further analyses were performed.

A series of regression models was run separately for Soc and Imp in placebo and caffeine conditions. The results show that, (1) in placebo, the simple regression of learning on Soc and Imp were weak (βs − 0.267, and − 0.393, ns, respectively), and when considered simultaneously, the β-weight for

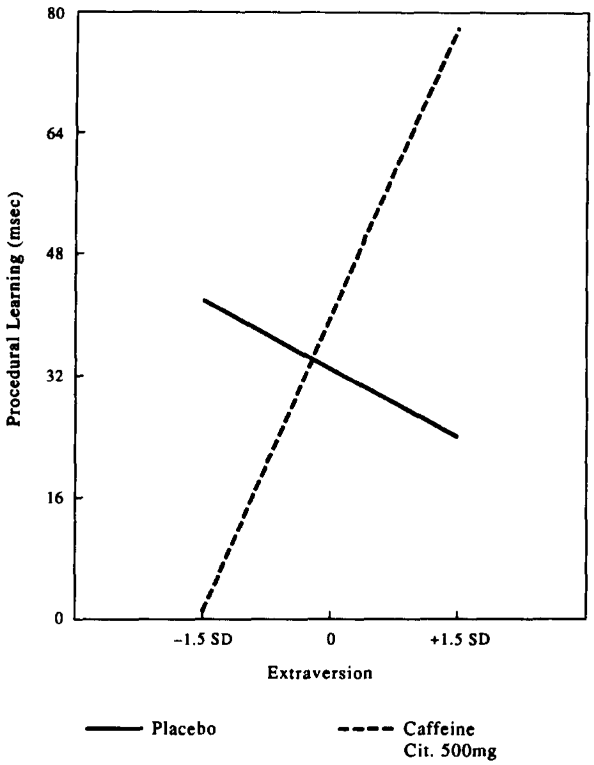

Fig. 4. Regression slopes showing the relationship between (EPQ) introversion–extraversion and procedural learning under placebo and caffeine citrate (500 mg). The higher asymptote level of procedural learning the greater the difference between RTs to predictable and random trials. Introverts learned most under placebo and least under caffeine, while extraverts learned most under caffeine and least under placebo.

Imp increased (to -0.48, ns) while it decreased for Soc (to 0.11, ns); but (2) in caffeine, the simple regression of learning was strong for Soc ($\beta = 0.67$, $P < 0.01$) and weak and negative in sign for Imp ($\beta = -0.11$, ns), and when considered simultaneously, the β-weight for Soc increased (to 0.73, $P < 0.01$) while for Imp the β-weight increased in the opposite direction to Soc (to -0.27). These data indicate that once Imp is removed from Soc, the strength of relationship between Soc and caffeine-induced arousal increases.

To discount the possibility that Soc and Imp might make unique contributions to caffeine-induced arousal effects, the sum of which adding to their separate effects, a composite measure (representing the simple summation of Soc and Imp) was formed and a regression model was run which contained main effects of caffeine/placebo, Soc and Imp, and two interaction terms: Soc × caffeine/placebo and Soc + Imp × caffeine/placebo. The main effects were forcibly entered into the model and the interaction terms were allowed to enter by stepwise regression. The final model [$F = 5.69$, d.f. = 2,25, $P < 0.01$] contained only two terms (1): main effect of Soc [$t = 2.13$, $P < 0.05$; $\beta = 0.37$] and (2) an interaction of Soc by caffeine/placebo [$t = 3.09$, $P < 0.01$; $\beta = 0.54$]. This result showed that Imp did not add to the predictive variance of Soc.

Discussion

Reaction times (RTs) were much faster to predictable targets than to random targets (Fig. 2). The pattern of RT data confirms the basic effect originally reported by Lewicki *et al.* (1988). Procedural learning, representing the RT difference between predictable and random trials, showed a gradual linear increase over the course of the experiment (Fig. 3). Eliminating the difference in target types (segment 14; Figs 2 and 3) abolished the RT facilitation effect observed in the other segments, confirming that procedural learning consisted in the different information afforded by predictable and random targets.

Following Perruchet *et al.* (1990), it appeared that procedural learning reflected acquisition of frequency information concerning the probability of target movements. Given that much learning, both in lower animals and human beings, represents the calculation of running averages of the probability of stimulus–stimulus and response–stimulus relations (Gray, 1975), the present results might perhaps be applicable to other areas of learning.

The results showed that low sociables acquired more procedural information than high sociables under low stimulation (placebo), but that under high stimulation (caffeine) low sociables suffered a performance decrement whereas high sociables enjoyed a performance enhancement (Fig. 4). These results indicate that Eysenck's theory may be important in forms of learning that contain a large component of automatic learning (e.g. motor skills, language development, social skills), and suggest that Eysenck's extraversion-arousal postulate may be applicable to more declarative forms of learning which becomes proceduralised through repetition (cf. Anderson, 1982; Fitts & Posner, 1967).

As with the interactive effect of sociability and caffeine-induced arousal in CFF change scores (Experiment 1), the present findings are consistent with an interpretation in terms of the Yerkes–Dodson law and the evocation of transmarginal inhibition in low sociability *S*s who were over-aroused by caffeine; in placebo, low sociables showed much better learning suggesting that they were closer to an optimal level of arousal for the procedural learning task. Conversely, high sociables in placebo seemed to be in a state of de-arousal due to the monotonous nature of the task; but in caffeine they seemed to be more optimally aroused. Eysenck's (1967) arousal-based theory of extraversion provides a cogent explanation of these effects. The hypothesis that the impulsivity component of extraversion (Revelle *et al.*, 1980; Humphreys & Revelle, 1984) would carry the causal burden of extraversion in mediating the effects of caffeine on a procedural learning task was not supported.

GENERAL DISCUSSION

The overall aim of the two experiments was to examine the relationship between sociability and impulsivity components of extraversion in mediating the effects of general arousal, as manipulated by caffeine, in two very different performance domains. The results from both experiments yielded a very similar pattern of findings. In both studies, (EPQ) introversion–extraversion mediated caffeine-induced arousal in a manner consistent with the hypothesis that, under placebo, introverts are more arousable than extraverts, while under caffeine, introverts are over-aroused, due to transmarginal inhibition of response, and extraverts are at, or near to, an optimal level of arousal. Given that (EPQ) extraversion is largely, but not exclusively, composed of sociability items (see Introduction), these data add support to the claim that sociability and not impulsivity mediates the effects of caffeine-induced arousal, at least in the performance domains reported in this paper. The support for sociability over impulsivity was further strengthened by the failure of the composite measures of Soc + Imp to add to the predictive variance of Soc alone.

The experiments confirm that CFF and procedural learning are suitable for testing theories in personality psychology. In particular the results show that experimental support for Eysenck's theory can be found in a novel behavioural paradigm, namely procedural learning. The novelty of procedural learning for testing Eysenck's theory suggests that the postulates of Eysenck's theory are applicable to a range of tasks which have not been previously used in personality research.

The degree to which extraversion × arousal relations determine performance may depend upon the sensitivity of performance measures to arousal; the degree to which different types of performance are arousal-mediated remains unclear and is clearly in need of more research attention. The Humphreys and Revelle (1984) model of arousal and information processing provides a useful taxonomic and causal framework for addressing these questions, although the results of the two experiments suggest that the emphasis placed on impulsivity over sociability in the model may be misplaced. The present set of findings is consistent with those studies (e.g. Matthews *et al.*, 1990a, b) which have found a stronger effect for sociability than for impulsivity in arousal-mediated performance. Matthews *et al.*'s studies have used self-report dimensions of arousal to operationalize low and high arousal groups, leaving open the possibility that psychometric descriptions of arousal, as distinct from caffeine-induced arousal, are related to sociability. The present set of data suggest that caffeine-induced arousal and sociability are indeed related.

The present results do not provide a strong test of the Humphreys and Revelle (1984) theory concerning the importance of time of day in moderating the interaction of personality and arousal. It is important for future work to focus on time of day effects in arousal-mediated performance, perhaps using CFF or procedural learning. In further work examining the postulates of Humphreys and Revelle's (1984) model, attention should be paid to possible differences in the relationship between different measures of impulsivity and performance. The consistent finding of (usually EPI) impulsivity in arousal-mediated performance (e.g. Eysenck & Levey, 1972; Revelle *et al.*, 1980) cannot be simply ignored. Perhaps (EPI) impulsivity and caffeine-induced arousal are related in certain forms of behaviour; or, perhaps, impulsivity is important in tasks which require some degree of response inhibition to achieve optimal performance. The use of CFF thresholds and procedural learning may have biased the results away from finding an effect of impulsivity because of the passive nature of the tasks.

Despite the consistent pattern of effects reported in the two studies, there are several aspects of the designs of the experiments that demand scrutiny. *S*s were not required to abstain from caffeine consumption prior to the study. Now, assuming that *S*s modulate their level of arousal in order to reach an (hedonically-defined) optimal level of arousal, then this aspect of the design may have militated against finding effects of basal arousal upon performance; and, indeed, the Soc × caffeine/placebo interaction in the procedural learning experiment did seem to rely upon strong reactions in the caffeine condition. Although this aspect of the design might appear problematic, there are several reasons for arguing that the alternative strategy of enforcing caffeine abstinence may have been even more problematic for the interpretation of data.

Firstly, there is the problem of *S* compliance as well as possible withdrawal effects (both possibly varying as an unknown function of personality). Secondly, there is the fundamental theoretical matter of the relationship between naturally-occurring basal arousal levels and the development of socio-psychiatric states (e.g. conditioning of the neuroses and socialization). If experimental data for Eysenckian relations between arousal and important socio-psychiatric states are found only when *S*s are prevented from modulating basal arousal, then how can such evidence be used to explain the development and maintenance of socio-psychiatric states when *S*s are at liberty to modulate arousal levels? To the degree that *S*s were free to modulate basal arousal prior to coming to the experiment, the systematic interaction between Soc/Imp and caffeine-induced arousal would be expected to be compromised. Perhaps, caffeine abstinence (usual in Revelle's studies) vs non-abstinence (present study) is an important factor in determining whether sociability or impulsivity influences arousal-mediated performance.

Nevertheless, Eysenck's arousal-extraversion theory seems well vindicated by the present data which show that even where there might not be large differences in basal level of arousal between introverts and extraverts because of arousal modulation there still remains large differences in arousability which affect theoretically-important forms of behaviour.

In conclusion, extraversion (i.e. sociability) mediated the effects of caffeine-induced arousal in CFF and procedural learning in a manner supportive of Eysenck's (1967) ARAS-based theory of personality: introverts seemed optimally aroused in placebo and over-aroused in caffeine, with the reverse being true of extraverts. The present experiments highlight the validity of CFF and procedural learning for testing Eysenck's theory of personality, and attest to the validity of Eysenck's theory for a wide range of performance paradigms which are arousal-mediated.

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