Chapter 16

On the Psychophysiology of Extraversion

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1. Introduction

Initial research on individual differences in personality centered on the development of questionnaires. These were the only available tools for the description and prediction of behavior. Later, trait models were developed that attempted to move from personality description to a multilevel causal form of explanation. As noted by Gale & Eysenck (1992), psychometric methods have achieved good levels of predictive validity for psychologically and socially important human behaviors. This success in describing personality bolstered attempts to identify the biological substrate of psychometric derived indices of individual variation.

Scores on psychometric instruments are examined using a variety of procedures that record bioelectrical signals. These include procedures to monitor autonomic nervous system activity, such as electrodermal and cardiac recordings, and cortical activity, with electroencephalographic and event-related potential procedures. Investigations of elementary physiological events in normal thinking, feeling, and interacting individuals are now feasible. The techniques provide windows through which psychological processes and neurological generators of bioelectric activity can be observed unobtrusively (see, e.g. the recent Handbook of Psychophysiology by Cacioppo et al. 2000). A number of different psychophysiological responses and methods are applied to verify hypotheses and for further exploration of the biological bases of temperament and personality dimensions, notably extraversion (E), neuroticism (N) and sensation seeking (SS). The research on biological and psychophysiological determinants of temperament and personality emerged from specific hypotheses proposed by Pavlov and Eysenck in their classic experimental research on personality (Eysenck 1963, 1967; Nebylitsyn & Gray 1972; Strelau 1983).

This chapter begins with a brief outline of the main hypotheses that were explored using psychophysiological methods to study individual differences in personality, with specific emphasis on the extraversion trait. Subsequently, the most consistent psychophysiological results will be described and discussed.
2. The Physiological Bases of Personality:
Extraversion and the Inverted-U

Eysenck (1967) proposed that individual differences in E could be understood in terms of differences in optimal levels of arousal. This concept was previously elaborated by Hebb (1955) and linked to functions of the ascending reticular activating system (ARAS; Moruzzi & Magoun 1949). This system regulated the activation of the cortex. It was advanced that the set point of activation (threshold) of the ARAS of introverts was lower than for extraverts. Extraverts, on the other hand, who were characterized by higher thresholds of arousal in the ARAS, reach their optimal level of arousal at higher levels of stimulation. Although the physiological mechanisms of arousal and arousability were not explicitly defined, the hypothesis of optimal level of arousal proved to have strong heuristic value. The arousal hypothesis attracted a great number of studies on individual differences in E, N and SS using electrocortical and autonomic indices of activation of the ARAS.

Zuckerman’s interest in the role of catecholamines in personality led him to the work of Stein (1978) and Gray (1982, 1987). They attributed a central role to dopamine in approach motivation and reward mechanisms of the mesolimbic system. An analysis of the literature on the monoamines led Zuckerman to reconsider the optimal level of arousal theory. Instead of the ARAS, he focused on the activity of the brain catecholamine systems, i.e. dopaminergic and noradrenergic systems (Zuckerman 1979, 1984). Positive mood, exploratory activity and sociability (extraversion) are expressions of optimal levels of catecholamine activity. Some years later, Zuckerman (1991, 1994) formulated a model in which monoamine neurotransmitters play a leading role in personality traits. He linked dopamine to approach motivation, serotonin to behavioral inhibition and norepinephrine (and GABA) to arousal mechanisms.

In his review of the biological bases of personality, Eysenck (1990) outlined the problems encountered by the researcher in attempting to link physiological functioning, behavior, and personality. One of the most relevant problems raised by Eysenck (1990) concerns the fact that a single physiological measure cannot be considered a representative index of general cortical arousal or excitation. It is known, in fact, from psychophysiological research (Lacey 1967; Lacey & Lacey 1958) that certain events, such as emotional stimuli, may act in different ways in different physiological systems, depending on individual differences, i.e. response specificity. One individual may be prone to react to a threatening stimulus through a rapid increase in skin conductance activity; another through an increase in heart rate; and a third through a more pronounced activation of the EEG, and so forth. Therefore, no single physiological measure is sufficient to describe the complexity of the response. One possible way to resolve this issue is to take measures that are representative of a large number of systems and to score physiological changes in the activity of the most relevant systems.

Eysenck’s (1967) view of physiological arousal is multidimensional because he postulates two distinct systems: cortical and visceral arousal. Although it is clear that there are numerous dimensions of arousal (Vanderwolf & Robinson 1981), it is not clear how different psychophysiological indices are composed to evaluate the reactivity of different arousal systems. From this perspective, a failure to support Eysenck’s theory may be due to inaccuracy of the measuring method, or to a wrong choice of the physiological variable.
Moreover, the fact that each individual may be more sensitive to certain stimuli and less sensitive to others, i.e. stimulus specificity, may also contribute to experimental error. Individual variability in floor and ceiling effects and the difficulty in defining resting levels of a given physiological measure also pose some difficulty for evaluating the association between personality and neurophysiological measures (Eysenck 1990).

The well-known Yerkes-Dodson law (Yerkes & Dodson 1908) and the Pavlovian law of transmarginal inhibition (Pavlov 1928) also present a challenge in linking personality, behavior and physiological response. Both laws describe a nonlinear relation between stimulus and response. With increasing intensities of stimulation, the strength of response at first increases and then declines, producing an inverted-U. This inverted-U relation appears to hold for the interactive effects of $E$ and arousal manipulations on performance and neurophysiological functioning. Arousing or stressful conditions tend to improve (or have lesser effect on) the performance of extraverts, but impair that of introverts (Revelle et al. 1987). To explain findings of this kind, it is generally assumed that introverts are optimally aroused, but extraverts are normally under-aroused. Increasing the intensity of stimulation increases the arousal of extraverts to the optimal level, but leads to over-arousal for introverts. However, to make a precise prediction is difficult. It can be predicted that the high-arousal of introverts, as compared to the low-arousal of extraverts, will lead to a reversal of the stimulus-response relation at a lower point of stimulus intensity than would happen for extraverts, but it is difficult to know the precise switching point. Nevertheless, both the Yerkes-Dodson law and transmarginal inhibition effects have been demonstrated for a multiplicity of behavioral responses (Eysenck & Eysenck 1985). Direct physiological evidence in support of the relation between arousal measures and performance is limited. It was observed, however, that with direct stimulation of the medial reticular formation in chimpanzees the performance is optimal for specific ranges of excitation (Fuster & Uyeda 1962).

3. Extraversion and Skin Conductance Level

The base level of electrodermal activity, or skin conductance level (SCL), is an index of tonic arousal either in the baseline resting condition or in a brief period preceding stimulation during the experimental condition. Individual differences in tonic arousal between introverts and extraverts were usually assessed with SCL measurements during periods preceding stimulation or during conditions involving simple sensory stimulation. Differences in tonic levels of electrodermal activity between introverts and extraverts are seldom observed when simple sensory stimulation is used and when subjects are not challenged by task demands (see, e.g. Coles et al. 1971; Davis & Cowles 1988; Kishimoto 1977; Nielsen & Petersen 1976; Smith 1983). However, some consistent findings have emerged when subjects are challenged by task demands. In particular, Fowles et al. (1977) compared SCL for introverts and extraverts during a series of tones varying in both stimulus intensity and amount of stress preceding the tones. Results from this study indicated that SCL is higher for extraverts at higher levels of stress and SCL is higher in introverts for lower levels of stress. In the study by Smith et al. (1986), introverts had higher SCLs than extraverts while they were engaged in a task requiring sustained attention and introverts were less affected by a distraction condition than were extraverts.
Electrodermal lability, i.e. the rate of spontaneous fluctuations of skin conductance response (SCR) in the absence of specific stimulation, is also considered as an index of tonic arousal (e.g. Barland & Raskin 1973). In some studies, introverts were found to exhibit a higher rate of nonspecific SCR compared to extraverts (Coles et al. 1971; Gange et al. 1979; Mangan & O’Gorman 1969).

4. Extraversion and Skin Conductance Responses

Recording of SCRs was a common procedure for assessing the arousal hypothesis. Sokolov’s (1963) model of attention and the orienting response (OR) often provided a context for this work. In terms of the OR model, Eysenck (1967) predicted that introverts would exhibit stronger OR, i.e. larger SCR amplitude, and slower habituation or more persistent SCRs, compared to extraverts. These predictions were widely tested and a number of reviews of this literature are available (Eysenck 1990; Eysenck & Eysenck 1985; Graham 1979; O’Gorman 1977; Smith 1983; Stelmack 1981, 1990; Stelmack & Geen 1992). In their review of the literature, Stelmack & Geen (1992) concluded that introverts consistently exhibit greater SCR amplitudes than extraverts to simple visual stimuli and auditory stimuli of moderate intensity (75–90 dB). This effect was mainly observed in the greater initial SCR amplitude, slower habituation rate, or greater SCR amplitude to habituated stimuli following a stimulus change (Crider & Lunn 1971; Fowles et al. 1977; Gange et al. 1979; Mangan & O’Gorman 1969; Nielsen & Petersen 1976; Smith et al. 1981; Stelmack et al. 1979, 1983; Wigglesworth & Smith 1976; Zahn et al. 1994). Studies using auditory stimulation of low-intensity (60 dB or lower intensity) fail to differentiate introverts and extraverts (Bartol & Martin 1974; Coles et al. 1971; Hastrup 1979; Koriat et al. 1973; Krupski et al. 1971; Mangan 1974; Mangan & O’Gorman 1969; Sadler et al. 1971; Siddle & Heron 1976).

Studies using high-intensity sounds (greater than 90 dB) found a reversed relation between E and SCR, i.e. SCR amplitude was smaller for introverts, compared to extraverts (Smith et al. 1981, 1983, 1984; Wigglesworth & Smith 1976). The reverse relation for moderate and high-intensity tones was clearly demonstrated by Wigglesworth & Smith (1976) using 80 and 100 dB tones. The effect was attributed to transmarginal inhibition, a mechanism thought to protect the individual from harmful effects of high-intensity stimulation. It was proposed that this inhibition is initiated at lower levels of stimulation for introverts (Eysenck 1981).

Similarly, Geen (1984) reported that introverts prefer stimuli of lower intensity compared to extraverts. When introverts received bursts of noise stimuli at the stimulus intensity preferred by extraverts, introverts exhibited a greater number of evoked SCRs indicating a higher level of activation for these subjects. Extraverts that received noise bursts at the intensity preferred by the introverts displayed the smallest number of SCRs. No differences between E groups were obtained when noise bursts were delivered at the intensity level preferred by each group. These results are in line with the generally accepted view that stimulation of moderate intensity evokes a positive affective response (positive hedonic tone) whereas high-intensity stimuli are regarded as sources of discomfort (negative hedonic tone).
On the Psychophysiology of Extraversion

Smith and colleagues implemented an interesting approach to understand the relation between E and arousal in examining the differential effects of systematic arousal manipulation on extraverts and introverts (Smith et al. 1981, 1983). Arousal level was manipulated by varying the amount of caffeine that was ingested. Introverts exhibited larger SCRs under placebo and low stimulant dosages, whereas extraverts were more responsive with higher dosages. This study was followed by another project where arousal level was varied by caffeine dosage, stimulus intensity, and the presence or absence of a preparatory stimulus (Smith et al. 1984). The preparatory signal reduces the response to the stimulus that follows it. Subjects were assigned low, medium or high doses of caffeine or a placebo that were previously placed in a randomly numbered vial. Subjects heard two sets of tones of 1500 Hz with one tone at each of six intensities, 60, 70, 80, 90, 100, and 110 dB. In one set of tones, a 4.5 sec preparatory light signal onset before each tone. The light signals reduced SCR amplitudes only at the highest level of stimulus intensity.

Introverts had higher overall SCL and SCR magnitudes compared to extraverts. As is shown in Figure 1, introverts had larger SCRs at the lowest three stimulus intensities, whereas with increasing stimulus intensity the group differences were diminished. In fact, introverts produced slightly smaller responses than extraverts at the highest intensity.

Another interesting effect observed in this SCR study is illustrated in Figure 2. In the non-signal condition, response amplitudes decreased for introverts with increasing dosage level of caffeine, whereas the extraverts displayed an increase in response amplitude with increasing dosage. With the presentation of the preparatory signal, introverts showed a larger initial decrease in responsiveness from the placebo to the lowest caffeine level, followed by an increase in responsiveness for the condition in which the preparatory signal was delivered. For extraverts, in contrast, the presence of the signal did not

Figure 1: Skin conductance response (SCR) of introverts and extraverts as a function of stimulus intensity. Source: From “electrodermal activity and extraversion: Caffeine, preparatory signal and stimulus intensity effects,” by B. D. Smith et al. (1984), Personality and Individual Differences, 5, Figure 1, p. 62. Copyright by Elsevier Science Ltd. Reprinted by permission.
Figure 2: Interaction between personality groups (introverts vs. extraverts) and preparatory stimulus on skin conductance responses. Source: From “Electrodermal activity and extraversion: Caffeine, preparatory signal and stimulus intensity effects,” by B. D. Smith et al. (1984), Personality and Individual Differences, 5, Figure 3, p. 63. Copyright by Elsevier Science Ltd. Reprinted by permission.

appreciably change the response pattern as a function of caffeine dosage level. In terms of the tonic measure of SCL, an increase in SCL was observed with increasing levels of caffeine dosage and higher SCLs in introverts than in extraverts. Smith et al. (1984) discussed their findings in terms of the greater focus of attention induced by higher levels of arousal.

In a later study, Smith et al. (1986) controlled attention demands by randomly assigning half of extraverts and introverts to an attention condition and the other half to a distraction condition. Subjects received two blocks of 19 habituation trials each. One block included a test stimulus and the other included a dishabituation stimulus, i.e. a previously habituated stimulus that followed the novel test stimulus. In one of the two trial blocks an auditory, preparatory signal preceded each stimulus. Overall, introverts showed larger SCRs, and greater SCR to the dishabituation stimuli than extraverts. As expected, the preparatory signal reduced responding significantly more for introverts compared to extraverts. The distraction condition affected responses of extraverts more than it did for introverts.

The notion that introverts are morning types, i.e. have higher arousal levels and better performance in the morning than extraverts, was advanced by a number of authors (e.g. Revelle et al. 1987). Wilson (1990) assessed this hypothesis with a psychophysiological method by employing a self-monitoring electrodermal recording system that enabled participants to record their SCL throughout the day. Sixty-one men and 50 women measured their own SCL hourly throughout one working day, and recorded their activities and drug intake. Although it appeared that introverts were more highly aroused than extraverts in the morning, these effects were not statistically significant.
5. Extraversion, Heart Rate, and Cardiovascular Measures

A number of cardiovascular measures have been used to explore arousal differences between introverts and extraverts. In the majority of cases no differences between extraverts and introverts on baseline or tonic heart rate (HR) were reported (e.g. Myrtek 1984; Pearson & Freeman 1991). However, HR changes in response to stimuli or environmental changes yielded some more consistent findings. For example, Gange et al. (1979), in an experiment on vigilance, found no HR differences between introverts and extraverts during a baseline period. They did observe higher HR for introverts than for extraverts in all vigilance conditions, including a condition in which no task was performed.

Graham & Clifton (1966) suggested that phasic HR deceleration is the cardiac component of the orienting response and that phasic acceleration is the cardiac component of the defensive response. If we assume that, with increasing intensities of stimulation, introverts are more reactive than extraverts, it follows that introverts are more likely to display more pronounced HR accelerations to these stimuli than extraverts. Moreover, extraverts should display more pronounced HR decelerations to stimuli of low and moderate intensities. Results obtained in the study by Orlebeke & Feij (1979) indicate that introverts had a greater rate of HR acceleration to a tone of 60-dB intensity over the first five trials than did extraverts. However, this finding remains difficult to evaluate because only tones of a single level of intensity were used.

In a subsequent study, Hirschman & Favaro (1980) recorded HR activity during the presentation of highly aversive pictures known to elicit defensive reactions (e.g. photographs depicting mutilation). The average HR over the five beats preceding each stimulus onset and over 15 beats that followed it was analyzed for groups of introverts and extraverts. Extraverts did not show HR changes over the first eight post-stimulus beats and continuous deceleration thereafter. On the other hand, introverts initially showed a HR acceleration, but this response pattern was followed by a HR deceleration. These HR reactions to aversive stimuli can be considered in agreement with the hypotheses of Orlebeke & Feij (1979).

Geen (1984) measured pulse rates (PR) of introverts and extraverts during two paired associate learning experiments in which they either chose the level of intensity of noise to be heard or were assigned to one of four levels of noise stimulation, low, intermediate-low, intermediate-high, and high intensities. In both experiments, extraverts preferred higher intensity levels than introverts. There were no differences between groups when they were stimulated by the noise level that was preferred either by themselves or assigned to yoked members of the same personality classification. It was observed that preferred levels of stimulation in introverts and extraverts are related to arousal levels in the form of an inverted U, with introverts exhibiting higher PR than extraverts at intermediate levels of stimulation.

Pearson & Freeman (1991) engaged introverts and extraverts on an arithmetic task with various levels of difficulty. Although baseline levels were identical for the two groups, introverts showed larger HR reactivity to the task than extraverts. This difference was due to the fact that extraverts had no HR changes during the task, whereas introverts showed significantly higher HR during task performance. The easy condition produced the least difference while during moderate and difficult conditions there were equally large differences between groups.
In another study by Richards & Eves (1991), personality and temperament measures were compared between subjects who showed HR accelerative defensive responding (accelerators) and subjects whose HR remained relatively unchanged during the interval following high-intensity auditory stimulation. Introverts and subjects with low N scores, compared to extraverts and stable subjects, showed higher levels of HR throughout the experiment.

Kaiser et al. (1997) examined HR changes for individuals with high and low levels of N, E, and psychoticism (P). They were instructed to listen to the presentation of 10 auditory tones (60 dB, 1 kHz), i.e. an irrelevant condition, and then they were required to count the tones (relevant condition). High P subjects had smaller heart rate changes to the irrelevant stimuli and smaller differences between the relevant and irrelevant conditions than did low P subjects. High N subjects, compared to low N subjects, showed enhanced cardiac responding to relevant stimuli, but there were no effects of differences in E. The absence of differences between introverts and extraverts may be attributed to the easy task demands and low-intensity stimulation that were employed. As previously noted, differences between extraverts and introverts are consistently observed with stimulation of moderate intensity.

In Gray’s (1970, 1973) modification of Eysenck’s (1967) model of personality, anxiety, i.e. high N, low E, is characterized by sensitivity to signals of punishment. This disposition is mediated by a behavioral inhibition system (BIS). On the other hand, impulsiveness, i.e. low N, high E, is characterized by sensitivity to reward. This disposition is mediated by a behavioral activation system (BAS). Fowles (1980) argued that HR activity is a good index of the BAS. This, of course, leads to the prediction that higher levels of impulsivity are associated with higher levels of cardiovascular activity in response to reward stimuli. This hypothesis is somewhat at odds with the lower cardiac responses to physical stimulation of extraverts noted in this literature review.

This issue was examined by De Pascalis et al. (1996) who reported that high and low N subjects, as well as introverts and extraverts, were differentiated with the HR deceleration response. Extraverts were more sensitive to signals of reward, i.e. more pronounced HR deceleration to signals indicating the winning of a fixed amount of money, whereas introverts were more sensitive to signals of punishment, i.e. more pronounced HR decelerations for signals indicating a loss of a fixed amount of money. High N exhibited more pronounced anticipatory HR slowing than low N to signals of both reward and punishment. These results appear consistent with Gray’s theory. However, as Matthews & Gilliland (1999) pointed out in their comparative review of the personality theories of Eysenck and Gray, it is curious that introverts, but not high N, should be especially sensitive to punishment signals.

6. Extraversion and the Electroencephalograph

Psychophysiological recording is a direct source of data for monitoring the ongoing electrical activity of the brain during perceptual and cognitive processes. High levels of arousal are indexed by low amplitude, high-frequency activity in the alpha range (8–13 Hz). The EEG, however, does have limitations as an indicator of the ongoing brain activity. First, because the EEG is recorded using electrodes placed on the scalp, activity of the cortex is not assessed directly. Second, because of volume conductivity of the electrical field in the brain,
the EEG is composed of a mixture of electrical activities generated from different parts of the
cortex. This may produce erroneous impressions of the source of activity from any specific
area of the cortex. In spite of these limitations, EEG measures not only provided reliable
indices of brain damage, but they proved to be a good way to study physiological processes
underlying arousal, attention, memory, vigilance, emotion, and cognitive activities. This
was apparent from the first EEG recording of alpha rhythm by Berger (1929). From this
initial demonstration, there were great expectations that this technique could be employed
to study the basic brain functions that mediate mental activity. Some years after Berger’s
discovery, Lemere (1936) suggested that the electrical activity of the brain is related in
some way to personality style. The optimism for this new method was encouraged by the
discovery of the function of ascending reticular-activating system (ARAS) as an arousal
system of the brain (Magoun 1963; Moruzzi & Magoun 1949). Later, numerous studies
investigated the relation between personality and the properties of the bioelectrical activity
of the brain. A prominent area has been the association of EEG-alpha activity, recorded from
the posterior regions of the skull, and individual differences in arousal between introverts
and extraverts. The desynchronization of the EEG, i.e. the transition from high-amplitude,
low-frequency (alpha activity) to low amplitude, high-frequency (beta activity), was linked
to the increased activity of the ARAS when attention is directed to incoming stimulation or
to response generation (Table 1).

After the discovery of the ARAS, some valuable insights were gained concerning the
neurological generators of EEG activity (Cooper et al. 1965). In 1967, H. J. Eysenck
incorporated those advances in understanding of the arousal system in a reformulation
of his theory of personality. Eysenck proposed that individual differences in E and N are
determined by differences in cortical arousal that can be indexed by EEG measures (Eysenck

Table 1: Mean spectral peak amplitudes of alpha (8–13 Hz) activity for introverts and
extraverts over the left frontal region (FP1, F3, and F7), over the right frontal region (FP2, F4,
and F8), and the central regions (Fz, Cz) where extraverts were found to have significantly
higher levels of alpha activity.

<table>
<thead>
<tr>
<th></th>
<th>Mean (μV)</th>
<th>S.D.</th>
<th>Minimum (μV)</th>
<th>Maximum (μV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Introversion</td>
<td>4.5</td>
<td>1.57</td>
<td>2.0</td>
<td>8.2</td>
</tr>
<tr>
<td>Extraversion</td>
<td>6.8</td>
<td>3.17</td>
<td>0.7</td>
<td>15.8</td>
</tr>
<tr>
<td>Low anxiety</td>
<td>5.6</td>
<td>2.98</td>
<td>2.0</td>
<td>15.8</td>
</tr>
<tr>
<td>High anxiety</td>
<td>5.9</td>
<td>2.64</td>
<td>0.7</td>
<td>11.6</td>
</tr>
<tr>
<td>Tender minded</td>
<td>5.4</td>
<td>3.15</td>
<td>0.7</td>
<td>15.8</td>
</tr>
<tr>
<td>Tough poise</td>
<td>6.1</td>
<td>2.44</td>
<td>2.0</td>
<td>11.6</td>
</tr>
<tr>
<td>Subduedness</td>
<td>6.2</td>
<td>3.26</td>
<td>2.3</td>
<td>15.8</td>
</tr>
<tr>
<td>Independent</td>
<td>5.4</td>
<td>2.41</td>
<td>0.7</td>
<td>11.6</td>
</tr>
</tbody>
</table>

(* p < 0.05; ** p < 0.01). From “Extraversion-introversion and 8–13 Hz waves in frontal
cortical regions,” by Y. Tran et al. (2001), Personality and Individual Differences, 30, Table 2, p. 210. Copyright
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There was considerable research interest in this arousal hypothesis. However, the enthusiasm for exploring individual differences in arousal and psychological processes with EEG measures diminished considerably because of difficulties in obtaining response-specific measures. Moreover, the evidence for linking EEG measures and personality differences has been judged inconsistent. Investigation of the relation between individual differences in personality and EEG measures of arousal has not yielded any reliable findings (Gale 1983; Stelmack 1990; Stelmack & Geen 1992).

The extensive literature that examined the relation between EEG and personality was reviewed first by Gale (1981, 1983). During the past three decades, some studies have found a positive relation between EEG alpha activity and extraversion, i.e. greater EEG alpha activity for extraverts (Gale et al. 1969; Marton & Urban 1966; O’Gorman & Mallise 1984; Savage 1964; Zuckerman 1991). Others reported a negative relation between EEG alpha activity and E, i.e. greater EEG alpha activity in introverts, an effect that contradicts the arousal hypothesis (Broadhurst & Glass 1969; Young et al. 1971) or no differences between introverts and extraverts (Fenton & Scotton 1967; Gale et al. 1971). Gale (1981) suggested that these inconsistent results reflect a pervasive weakness in the research methods and designs that characterize this work.

According to Gale (1981, 1983), one potential confounding factor is the arousal level elicited in the studies reviewed. Gale rated experimental conditions that require solving problems or time-controlled tasks as high-arousal experiments. Conditions in which participants are asked to do nothing, but to keep their eyes closed and not fall asleep are rated as low-arousal experiments. Gale (1981, 1983) concluded that high- and low-arousal conditions were not appropriate for studying relations between personality and EEG since differences between the two introverts and extraverts are masked at the extreme poles of arousal conditions. Conditions of very low-arousal would produce strong feelings of boredom in extraverts and thus they are likely to attempt to increase their arousal levels. In contrast, with high levels of stimulation introverts produce the paradoxical reaction of reduced indices of arousal as postulated by the Pavlovian law of transmarginal inhibition. For the evaluation of the relation between E and EEG, Gale (1983) suggests conditions that elicit intermediate levels of arousal. This is where subjects are allowed some mild interaction with the experimenter, such as receiving instructions to open and close their eyes.

Cortical levels of activation or arousal have been associated to amplitude and frequency of the alpha rhythm (Gale 1983; Golan & Neufield 1996). High-amplitudes and low-frequency of the alpha rhythm are associated with a low level of arousal, while low amplitudes and a high-frequency are associated with a high level of arousal. In the cases in which subjects are instructed to open and close their eyes, which require alertness without concentration, it is hypothesized that extraverts will display higher amplitudes and faster alpha waves than introverts. Gale’s hypothesis was tested in three experiments using testing with eyes open and eyes closed as the two conditions. O’Gorman & Mallise (1984) carried out the first experiment in which subjects were engaged in a number of arousal conditions. E was measured using the EPQ and a measure of amplitude EEG-alpha activity was obtained. Contrary to Gale’s hypothesis, extraverts were found to have more pre-stimulus alpha activity than introverts under all conditions except opening and closing eyes on instruction where the reverse was observed.
In a subsequent study in which subjects were required to open and close their eyes on instructions, O’Gorman & Lloyd (1987) reported that subjects with high scores on narrow impulsiveness showed less alpha spectral power than subjects with low scores. This study also failed to confirm Gale’s hypothesis, since no differences in alpha activity were found between extraverts and introverts. In the third more recent study by Tran et al. (2001), four factors were controlled as possible sources of equivocal results in previous research in this field. These factors were: (1) the cortical site where the alpha wave is measured; (2) the method used for EEG analysis; (3) the questionnaire used; and (4) the age of the subjects engaged. Fast Fourier Transform was used in this study to analyze the EEG and spectral peak amplitude in the alpha band (8–13 Hz) was measured. EEG was recorded from frontal, central, and posterior scalp sites while subjects opened and closed their eyes on instructions. To reduce possible bias, a diverse sample of participants with a broad age range (22–60 yrs) was tested. Subjects completed Cattell’s 16 Personality Factor questionnaire and from those results E and other dimensions were derived as second-order personality traits. Frontal EEG alpha activity was found to be associated with E, with extraverts showing larger spectral peak amplitudes in the alpha band than introverts but only at frontal recording sites. In contrast, at posterior sites of the scalp, no significant associations were found.

The findings by Tran et al. (2001) do support Gale’s hypothesis and Eysenck’s (1967) theory of E. Furthermore, they indicate the importance of the frontal regions of the brain in the development of personality. This also supports Gray’s (1970) suggestion that the physiological basis of arousal levels in extraverts and introverts should involve the frontal lobes as a component of a negative feedback loop including the orbital frontal cortex, the medial septal area and the hippocampus.

Venturini et al. (1981) measured spectral characteristics of spontaneous EEG and characteristics of the alpha attenuation responses (AAR) to acoustic stimulation (90 dB) for introverts and extraverts. The AAR characteristics consisted of AAR latency from stimulus onset, duration of the AAR, AAR instability, and duration of transitory resynchronization. Although no significant differences were found in basic alpha rhythm, significant differences between extraverts and introverts were found in the AAR characteristics. Extraverts habituated to the auditory stimulus while introverts were more responsive to auditory stimulation. It is advantageous to include these measures of AAR in future studies on individual differences because they provide specific indices of the physical characteristics of the alpha generating system.

7. Extraversion and Event-Related Potentials

Event-related potentials (ERPs), formerly termed evoked potentials, are event-related voltage changes in the ongoing EEG activity that are time-locked to sensory, motor, and cognitive events. ERPs can be used to identify and classify perceptual, memory and linguistic operations. These potentials arise from the synchronous activities of neuronal populations engaged in information processing. The ERPs are usually obtained by signal averaging, i.e. by summation of the time-locked electrocortical responses that occur on each repetition of the event. The averaging procedure assumes that the ERP and the background EEG summate
independently. As averaging proceeds, the ERP waveform summates, while the random background EEG (noise) decreases in amplitude as the sum proceeds. This method extracts the event-related activity that is often difficult to distinguish in the ongoing EEG activity.

One of the useful applications of ERP measurements is to demarcate the timing and classification of specific stages of information processing. Under specific conditions, ERPs can be recorded for each sensory modality. A characteristic waveform corresponds to each modality. The components (or peaks) of the ERP waveform are usually labeled positive or negative according to their latency and polarity. The latency of a component is usually given in milliseconds. The earlier a peak or component emerges, the more likely that the peak is determined by physical characteristics of the stimulus (exogenous component).

Time periods as short as 10 ms are associated with the auditory brainstem response. The majority of ERP studies investigated responses that occur in the first 100–500 ms following a stimulus. Early components (N100, P200) relate to sensory properties of stimuli and to selective attention. Later ERP waves are used to index endogenous cognitive activity.

The positive going ERP component at 300 ms (P300) is related to processes that involve classifying or updating memory representations of stimuli. The amplitude of the P300 increases as the demand for cognitive resources increases and as the significance of the event and its relevance to the subject increases. The latency of the P300 measure appears to be independent of the time needed for response-related processes. It is a good index of the time needed to categorize and evaluate the stimulus. The endogenous generated components of P300 or later components, e.g. N400 or P650, are sensitive indices of selective attention and decision-making activity (Hillyard & Picton 1987; Rugg & Coles 1995). A number of ERP paradigms were used to evaluate differences in cortical arousal between introverts and extraverts.

8. Extraversion and Event-Related Potentials to Auditory Stimulation

Stelmack et al. (1977) reported the first ERP results consistent with the arousal hypothesis by showing that introverts are more sensitive to auditory stimulation than extraverts. They recorded ERPs to low- (0.5 Hz) and high- (8.0 Hz) frequency tones at three levels of intensity (40, 55, and 80 dB) in two experiments with a total of 60 subjects differing in degree of E. Subjects were required to count a series of alternating high- and low-frequency tones to increase the level of attention. Introverts exhibited greater amplitude of the N1-P2 peak than extraverts with the low-frequency tones of 55 and 80 dB. No differences between extraversion groups were observed with high-frequency tones. The authors suggested that employing low-frequency auditory stimulation facilitated the observation of differences between introverts and extraverts because the individual variability of ERPs to low-frequency tones is greater than for high-frequency tones (Rothman 1970). The larger amplitude of ERP response (N1-P2) of introverts to low-frequency moderate intensity tones is illustrated in Figure 3. A subsequent study by Bruneau et al. (1984) reported that when tones are presented by alternating high and low frequencies or by varying the intensity of the tones in a series, differences between introverts and extraverts are more likely than when tones are presented in a repetitive fashion.
Figure 3: N1-P2 peak amplitude of the auditory evoked response to high (8.0 kHz) and low (0.5 kHz) frequency tones delivered at 80 dB for introverts, middle and extraverts. Source: From “Extraversion and individual differences in auditory evoked response,” by R. M. Stelmack et al. (1977), Psychophysiology, 14, Figure 2, p. 371. Copyright by Blackwell Publishing Ltd. Reprinted by permission.

Stelmack & Michaud-Achorn (1985) demonstrated that in a repetitive series of stimuli with short inter-stimulus intervals, the enhanced N1-P2 peak amplitude for introverts, notably at the central recording site Cz, is only observed for the first stimulus in the series. This is because response amplitude is greatly reduced after the first stimulus, an effect suggesting that the recovery cycle of the response is not completed.

De Pascalis & Montirosso (1988) used a tone-probe paradigm to elicit ERPs while participants identified target words in meaningful and meaningless speech passages. For extraverts, N2 peak amplitude was larger in the meaningful than in the meaningless condition, whereas the reverse was observed for introverts. For extraverts, this finding was paralleled by higher ratings of subjective engagement in the meaningful than in the meaningless condition, whereas the reverse trend was observed for introverts. The authors interpreted these findings as indicative of differences in sensory discrimination between introverts and extraverts. Moreover, extraverts displayed smaller P2 amplitude in the left hemisphere than introverts. No differences between groups were found in the...
right hemisphere. This finding is consistent with the larger N1-P2 amplitude for introverts reported by Stelmack et al. (1977).

This review of auditory ERP studies indicated that the larger N1 and P2 amplitudes for introverts than extraverts is consistent with the arousal hypothesis, i.e. greater arousability for introverts than extraverts. It is also clear, however, that N1 and P2 components are influenced by exogenous, physical properties of the stimuli and thus, reflect differences in sensory reactivity between groups. When the task is complex and late components of the ERPs are involved, i.e. N2 or P3, the differences in E would be understood in terms of processing capacity.

9. Extraversion, Attention, Cognition, and Event-Related Potentials

There were numerous attempts to link attention and cognitive components of the ERPs to E. Reviews of ERP and E indicate similar problems as those reported in the EEG studies (Eysenck 1990, 1994; Stelmack & Geen 1992; Zuckerman 1991) with a considerable degree of variation in testing conditions, stimulus characteristics, and subject selection. The P300 ERP component appears to be a promising measure to differentiate introverts from extraverts. It is known that the P300 component reflects cognitive and attention processes. As Eysenck (1994) pointed out, habituation, orienting responses, and stimulus classification are processes that are associated with both P300 and the concept of cortical arousal and that P300 could be used with advantage in testing the E-arousal hypothesis.

Daruna et al. (1985) were the first to report a significant link between the P300 amplitude and extraversion. They compared introverts and extraverts using a selective attention paradigm. Subjects were instructed to predict the occurrence of high- or low-frequency tones. Introverts displayed larger P300 amplitude over frontal, central and parietal sites than extraverts (see Figure 4). Task performance failed to discriminate the groups. The authors interpreted this finding as indicating that introverts allocated more attention resources to the task than extraverts (Kramer et al. 1987; Polich 1987). O’Connor (1983) also reported larger P300 amplitude for introverts than for extraverts using a varied reaction time (RT) paradigm.

Subsequently, Pritchard (1989) examined the relation between P300 amplitude and E using an auditory oddball paradigm in which P300 as elicited by infrequently occurring target tones in a series of standard tone. He failed to find an inverse relation between P300 amplitude and E. Differences in the selection of subjects and in the stimulus conditions used make it difficult to compare the results among these studies. Moreover, the larger P300 amplitude seen in introverts may not be evident in initial trials or in sessions using a small number of trials. This is because it has been shown that this difference may be due to the greater habituation in extraverts and thus more likely to occur only after subjects had spent sufficient time on the task to produce habituation. Ditraglia & Polich (1991) observed this habituation effect. They elicited ERPs using a simple two-tone auditory discrimination task with a two-trial block replication procedure. P300 amplitude to the target stimuli declined significantly between the two blocks for extraverts, but did not change across trial blocks for the introverted group (see Figure 5). These results were consistent with Eysenck’s suggestion that habituation is faster in extraverts. This finding is also in agreement with the greater
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Figure 4: Grand average of the auditory evoked response for introverts \( (n = 12) \) and extraverts \( (n = 12) \). Evoked responses are shown as a function of rare (\( R_0 \)) low-frequency tones (0.6 kHz; 6.5 dB), frequent (\( F_0 \)) high frequency tones (2.4 kHz, 65 dB) occurring immediately before a rare tone. Source: From “Introversion, attention and the late positive component of event-related potentials,” by J. H. Daruna et al. (1985), Biological Psychology, 20, Figure 1, p. 254. Copyright by Elsevier Science Ltd. Reprinted by permission.

Vigilance usually exhibited by introverts (Eysenck & Eysenck 1985) and with EEG-alpha attenuation response findings previously obtained in our laboratory (Venturini et al. 1981). In this case, extraverts habituated to auditory clicks, while introverts did not. Subsequently, Cahill & Polich (1992) manipulated the target stimulus probability while setting time-on-task to a minimum to avoid habituation effects. Under these conditions, extraverts produced larger P300 peaks than introverts. Extraverts also displayed a significant stimulus probability effect by producing a steeper increase of peak amplitude with diminishing target stimulus probability.

In a later study by Polich & Martin (1992), male and female subjects were engaged in three target tone detection tasks that varied the probability of target stimulus occurrence. The P300 elicited by target tones provided some results that supported previous findings. In male subjects, introverts showed greater P300 amplitude than extraverts, while female subjects did not show such trends. These results appear in the same direction as the P300 findings from previous studies (Daruna et al. 1985; Ditraglia & Polich 1991), but not from others (Cahill & Polich 1992; Pritchard 1989). The reason for this discrepancy is not clear. It is possible that Polich and Martin have used a more complex task than simple target tone detection or it may be related to the influence of the habituation rate of the P3 for different personality types (Ditraglia & Polich 1991; O’Gorman 1977).
Figure 5: Event-related potentials and electro-ocular activity (EOG) for introverts ($n = 16$) and extraverts ($n = 16$) recorded over central regions (Fz, Cz, Pz) across trial blocks 1 and 2, each composed by 20 target trials. Source: From “P300 and introverted/extraverted personality types,” by G. M. Ditraglia & J. Polich (1991), Psychophysiology, 28, Figure 1, p. 180. Copyright by Blackwell Publishing Ltd. Reprinted by permission.

Similar to other electrocortical measures, the relation between the P300 component and the E dimension is not simple. However, this does not imply that the P300 is not a valuable tool for testing personality theory. Ortiz & Maojo (1993) recorded ERPs from extreme scorers on E while introverts and extraverts were engaged in an auditory oddball task. Latency and amplitude of P300 component were measured. Introverts had greater P300 amplitude than extraverts over Fz, Cz, and Pz. There were no significant differences between groups for P300 latency. The P300 amplitude for introverts was more than three times that of
extraverts. These findings are contrary to findings reported by Pritchard (1989), but confirm earlier work of O’Connor (1983) and Daruna et al. (1985).

Stenberg’s (1994) review of these effects suggests that P300 is larger in extraverts when the task is cognitively demanding. Brocke et al. (1996) reported two studies, one using an auditory vigilance task and the other using a visual vigilance task with a high level of task difficulty. They maintained that differences between introverts and extraverts might be better evidenced by situations requiring an effortful response. In both studies, larger P300 amplitude, mainly across frontal electrode sites was observed for introverts than extraverts under vigilance conditions with a high level of task difficulty. No group differences were observed when task difficulty was very low.

Subsequently, Brocke et al. (1997) engaged introverts and extraverts in a 32-minute visual vigilance task under three different experimental conditions: (1) without acoustic stimulation; (2) with 40 dB SPL; and (3) with 60 dB SPL white noise. Introverts showed larger P300 amplitudes in the baseline and 40 dB white noise conditions, whereas extraverts had a larger P300 amplitude in the 60 dB condition. These results were explained by authors in terms of the control theory of arousal. That is, in monotonous situations extraverts increase their effort as reflected in a steady decrease in the P300 amplitude. For these subjects the constant decline in stress due to additional stimulation (60 dB white noise) was reflected in a steady increase in the P300 amplitude. In contrast, situations with low degree of stimulation are more suitable for introverts and demand a low degree of compensatory effort (increase in P300 amplitude). An alternative explanation of these results is that, in general, introverts are more sensitive to stimulation than extraverts and that the higher intensity stimulation competes for attention resources with the visual stimuli during the vigilance task.

A significant relation between E and ERP responses across low- and high-effort demanding tasks was also observed in a study of our own (De Pascalis 1993). Subjects were engaged in two visual and auditory stimulus-recognition tasks of low and high difficulty. A significant positive relation between E and ERP responses to targets was found for difficult recognition tasks across both visual and auditory stimuli. Easy recognition tasks failed to evidence a significant relation between E and ERP responses.

During a difficult stimulus recognition task, a positive relation was observed between E, frontal 40-Hz ERP response, an index of focused arousal. This effect was observed in the left hemisphere for both visual and auditory modalities. A similar positive relation between E and frontal N2 peak amplitudes was obtained for auditory stimuli. These effects contrast with results of a later study (De Pascalis 1994) using a visual stimulus recognition task under stress and no-stress conditions. A significant negative relation was obtained between E and frontal P2 and N2 peak amplitudes both for the no stress and stress conditions. These results also suggested that the frontal cortex plays a leading role in differentiating extraverts from introverts with ERP components that index attention and discrimination during the stimulus recognition process (i.e. the P2 and N2 ERP components).

In a recent study on E by Gurrera et al. (2001), the P300 wave was elicited by novel auditory stimuli during an auditory discrimination paradigm. Three types of stimuli were used: frequent (70%) nontarget tones, infrequent (15%) target tones, and infrequent (15%) non-target novel sounds. Frequent tones (1 kHz) and target tones (1.5 kHz) were 97 dB short duration (50 msec) tone pips. Novel sounds were 50–150 msec in duration and had a more complex spectrum than the sinusoidal tone pips, but were of comparable average
intensity. A positive relation between E and frontal P300 amplitude was observed to these high-intensity novel tones.

With respect to P300 latency, there is little experimental evidence for any consistent differences between introverts and extraverts.

10. Extraversion and Auditory Brainstem Responses

Auditory brainstem responses (ABRs) are short-latency evoked potentials that emanate from the auditory pathways and nuclei of the brain stem. ABRs develop within the first 10 ms of stimulation. The neural generators are better understood than the later ERP components that develop between 100 and 800 ms. The ABR waves I-VII are thought to emanate from the synchronous action potentials of successively higher levels of the ascending auditory pathway. ABR waves labeled I and II reflect activity of the distal and proximal portions of the auditory nerve, respectively, and waves III, IV and V reflect in the cochlear superior olives, and lateral lemniscuses, and inferior colliculi, respectively. The generator of waves VI and VII are at present less defined (see Hughes et al. 1988; Möller 1994), but wave VII seems to relate to initial cortical projection activity. The ABR is reliably sensitive to stimulus intensity (Hecox & Galambos 1974). The amplitudes of the ABR waves increase exponentially with increasing stimulus intensity (Wilson & Stelmack 1982). Latency increases as stimulus intensity is reduced, an effect that is observed in all sensory modalities, and is attributed to a diminished rate of neural firing (Picton et al. 1977).

Compared to other ERPs, the ABR is notably resistant to fatigue or habituation. The ABR does not change in amplitude or latency after 20 minutes of continuous stimulation (Salamy 1984) or during different stages of sleep and arousal, including metabolic coma. The seven waves of the ABR are indexed by absolute latency from stimulus presentation and by their inter-peak latencies (i.e. the conduction times from one peak to another peak). Faster peak latencies or conduction times are thought to reflect higher levels of neural activity. ABR peak amplitude measures are less reliable than ABR latency (see Chiappa 1997; Hall 1992). In a recent article, the reliability for peak latency was greater than for peak-to-trough amplitude and much greater than for baseline-to-peak amplitude measures (Stelmack et al. 2003). The ABR is manifestly insensitive to sleep, attention or arousal conditions, i.e. there is little or no effect of these conditions on ABR latency and amplitude.

There is a general consensus that the stability of ABRs across arousal states either assessed through subjective measures or environmental manipulations means that the ABR indexes peripheral rather than central nervous system (Chiappa 1997; Stelmack 1990). There is, however, some evidence that the ABR may be sensitive to changes in attention (e.g. Lukas 1980) and to drug-induced modulations of central nervous system arousal centers (e.g. Church & Shucard 1987). This suggests that the ABR may also reflect the influence of ARAS levels. The ABR, however, is less sensitive to arousal states than other measures of central nervous system activity.

A number of ABR reports indicate that introverts exhibit faster wave V latency and faster wave I-V conduction times than extraverts. Stelmack & Wilson (1982) compared the ABR of introverts and extraverts that were elicited by brief clicks varying in intensity from 55–90 dB. They found positive correlations between E and latency the ABR for wave I and...
wave V at 75, 80 and 85 dB. This finding led the authors to state that differences between introverts and extraverts are evident in peripheral nervous system processes and the effects could not be predicted from the activity of the ARAS. It is known that the inhibitory influence of the olivo-cochlear bundle on the auditory nerve (wave I), the cochlear nucleus (wave II) and the inferior colliculus (wave V) is reduced or absent for intensities above 75 dB and, in any event, the inhibitory effects are independent of the ARAS (Desmedt 1975). And again, the ABR is manifestly insensitive to sleep, attention or arousal conditions.

The faster ABR latency for introverts than extraverts was also reported in several other studies (e.g. Andress & Church 1981; Bullock & Gilliland 1993; Cox et al. 2001; Swickert & Gilliland 1998). On the other hand, Gilliland and colleagues (Bullock & Gilliland 1993; Matthews & Gilliland 1999; Swickert & Gilliland 1998) argue that faster brainstem transmission in introverts is a result of increased arousal of the brainstem reticular formation because the auditory pathway (as many other brainstem pathways) receives collaterals from and projects collaterals to the reticular formation (Guyton 1981; Klepper & Herbert 1991; Scheibel 1980). This view is compatible with Eysenck’s (1967) arousal theory in that individual differences in the ABR reflect the influence of differential arousal of the ARAS.

In a recent study, Bar-Haim (2002) assessed the response characteristics of the acoustic reflex arc of introverts and extraverts. Because of the anatomical overlap between the neural pathway of the acoustic reflex arc and the generators of the earlier ABR waves (waves I, II and III), it was assumed that increased abnormalities in ABR functioning among introverts would confirm that initial peripheral action of the auditory system is responsible for individual differences between introverts and extraverts as indicated by ABR measures. Introverts displayed a greater incidence of abnormal middle ear acoustic reflexes and lower acoustic reflex amplitudes than extraverts. Unexpectedly, these differences were more pronounced for stimuli presented at a frequency of 2 kHz compared to lower-frequency stimuli presented at 0.5 and 1 kHz. Stelmack & Wilson (1982) also reported a similar interaction of stimulus frequency and extraversion for ABR wave V latency, i.e. introverts showed shorter wave V latencies than extraverts for 2 kHz tones, but not for 0.5 kHz stimuli. The reason why 2 kHz is more effective than 0.5 kHz may lay in the fact that ABRs are reliably elicited by the onset of abrupt click stimuli that excite mainly high-frequency nerve fibres. Low-frequency tones that are characterized by relatively slow rise times are less effective in eliciting discernible ABRs (see Stelmack & Wilson 1982). Results from this study support the position that faster ABR latencies in introverts, compared to extraverts, are the product of differential sensitivity and functioning of peripheral nervous system mechanisms rather than central arousal processes.

11. Extraversion and Contingent Negative Variation

In a reaction time task where a warning signal is presented prior to an imperative signal to respond, a negative brain potential, termed the contingent negative variation (CNV), is generated prior to the imperative stimulus (Walter et al. 1964). This ERP wave is considered as an index of preparation for a motor response. This response is localized primarily over the fronto-central region of the brain. In typical CNV paradigms, the interval between the warning stimulus and the imperative stimulus that requires a motor response varies...
between 1 and 4 sec. The CNV wave is composed of early and late components (Rohrbaugh & Gaillard 1983). The early component is considered to be a general response to salient or novel stimuli. The late component is related to the readiness potential, i.e. the slow negative brain potential shift preceding a motor response (Kornhuber & Deecke 1965). It is generally accepted that larger late CNVs are associated with shorter reaction times.

Significant differences between introverts and extraverts were reported in a number of CNV studies. In several reports, the CNV was larger for extraverts than for introverts in neutral or control conditions (Lolas & de Andracà 1977; Plooij-van Gorsel & Janssen 1978; Werre et al. 1973). Werre (1983) reported that distraction smoothed the differences in CNV response between extraverts and introverts. Later, Dincheva et al. (1984) observed that extraverts displayed larger CNV amplitude than introverts during a control condition. They also observed that extraverts were more susceptible to distraction than introverts as evidenced by a greater reduction in CNV amplitude when novel tones were presented unexpectedly. Subsequently, Piperova-Dalbokova et al. (1984) confirmed the larger CNV amplitude of extraverts than introverts.

In a CNV study by Werre (1986), a significant correlation between CNV amplitude and extraversion was found. The most salient effect was evident when motivated young adult students performed a novel reaction time. A significant positive correlation between CNV amplitude and E was found. In contrast, there were no significant effects when they repeated a standard task or performed a dual task, i.e. a second task in addition to the standard task. In a more recent study, Werre et al. (2001) observed that caffeine increased early CNV amplitude (between 600 and 1600 ms after S1) for extraverts and decreased CNV amplitude for introverts. Chlordiazepoxide, regarded as an inhibitory drug, had the opposite effect. Early CNV was not correlated with reaction time and decreased in amplitude across consecutive sessions. In contrast, there were no significant drug effects on late CNV or on RT, either with or without an interaction with extraversion. Late CNV showed also a strong negative correlation with reaction time, but early CNV had a positive effect on this relation. E was negatively correlated with reaction time.

12. Extraversion and Motor Control

There is a general consensus that E is characterized by individual differences in the expression of motor behavior (Brebnr & Cooper 1974; Eysenck 1957; O’Connor 1989; Stelmack 1985). Extraverts have been found to be more active and restless in restricted environments (Gale 1969) and to be more active and involved in athletic activities than introverts (Eysenck et al. 1982). Extraverts tend to speak more often in interview situations (Campbell & Rushton 1978) and to have a greater preference for physical activity (Furnham 1981). However, in the pursuit-rotor tracking task, which requires refined motor control, introverts tend to perform more effectively than extraverts (Frith 1971; Horn 1975). Introverts also tend to emit less frequent responses than extraverts (Brebnr & Cooper 1974) and they exhibit fewer false positive errors in a reaction time task that favored response sets (Brebnr & Flavell 1978).

With respect to reaction time tasks, faster reaction times for extraverts than introverts were observed in several studies (Barratt 1967; Buckalew 1973; Keuss & Orlebeke 1977;
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Figure 6: Percent motoneural reflex recovery functions for introverts \((n = 23)\) and extraverts \((n = 36)\) at increasing inter-stimulus intervals. Source: From “Personality and individual differences in spinal motoneuronal excitability,” by R. T. Pivik et al. (1988), Psychophysiology, 25, Figure 3, p. 20. Copyright by Blackwell Publishing Ltd. Reprinted by permission.

Robinson & Zahn (1988). However, null effects were reported in several other studies (Casal et al. 1990; Gupta & Nicholson 1985; Hummel & Lester 1977).

While it is generally accepted that there are individual differences in the expression of motor behavior between extraverts and introverts, the physiological bases of these differences remain largely unexplored. Pivik et al. (1988) examined individual differences in motoneuronal excitability by recording the spinal monosynaptic H-reflex for subjects who varied in E. It was recorded as the action potential of the evoked reflex from the calf muscle of the leg. Pairs of electrical pulses were presented at varying interstimulus intervals (50 msec–2 sec). Reflex recovery was calculated as a ratio of the reflex amplitude of the second stimulus \((H2)\) in the pair to the first stimulus in the pair \((H1)\). With increasing interpulse intervals, the reflex response amplitude of the second pulse increases, or recovers, relative to the first pulse. Using this method, the authors observed that extraverts displayed reduced motoneural excitability as determined by analysis of recovery functions. These differences are shown in Figure 6.

Extraverts did not differ from introverts in the intensity of the stimulation required to elicit muscle action potentials or the conduction velocity of the nerve of those potentials. The authors concluded that the observed effects were not attributable to differences in initial levels of excitability, but rather to the reduced motor excitability in the central nervous system.

Britt & Blumenthal (1991) examined differences in motoneuronal sensitivity between introverts and extraverts by recording startle reflexes. Brief bursts of white noise stimuli were presented at 85 and 60 dB intensity with and without a prepulse tone. For introverts, the latency of the startle response was shorter at 85 dB intensity than at 60 dB, whereas for extraverts, there was no difference in response latency for the two intensity levels of stimuli. The authors argued that extraverts might have a less sensitive motoneuronal system. The corollary of this interpretation is that this is an intensity effect reflecting the greater sensitivity of introverts to sensory stimulation.
Moderate exercise also appears to have differential effects on mood or perceived arousal. Extraverts report that they are more energetic after a brisk 10-min walk, whereas introverts describe themselves as less tense (Thayer et al. 1987). Stelmack & Pivik (1996) also observed this effect. They reported that a brisk 10-min exercise increased General Activation scores, as measured by Activation-Deactivation Adjective Check List (Thayer 1978). Extraverts reported greater increases in energetic arousal than introverts. In this study, the effect of exercise on motoneuronal excitability, as measured by H-reflex recovery functions, was also investigated. Significant personality group differences in H-reflex recovery function were limited to the longer inter-pulse intervals. Introverts displayed greater motoneuronal recovery than extraverts during the pre-exercise period, an effect that replicated previous findings (Pivik et al. 1988). Exercise reduced these individual differences by increasing excitability for extraverts.

It has been reported that levels of dopamine-beta-hydroxylase (DBH) are increased following exercise, an effect that may be indicative of reduced dopaminergic activity (Bove et al. 1984; Calhoon 1988). Furthermore, levels of DBH are negatively correlated with extraversion (Calhoon 1988). The consistency of these effects is influenced by the strenuousness of the exercise and the level of fitness of participants (Calhoon 1991). Stelmack & Pivik (1996) speculate that moderate exercise may have the effect of reducing dopaminergic activity and that this may have increased spinal motoneuronal excitability (as measured by H-reflex recovery functions) especially for extraverts.

Another line of research examined individual differences in E by means of independent measures of decision time (DT) and movement time (MT). In this research, response time measures are obtained by means of a response panel to make use of a home button. The DT is scored as the time from stimulus onset to the release of the home button, and the MT as the time from this release to the subsequent press of a target button. Thus, the DT reflects central processes such as speed of stimulus recognition, stimulus evaluation and response organization (Sanders 1998; Sternberg 1985). MT is largely independent of cognitive requirements in the task and is a good measure of speed of response execution (Doucet & Stelmack 1997, 2000; Jensen & Munro 1979; Theios 1975).

There are some studies on extraversion that measured both DT and MT (Doucet & Stelmack 1997, 2000; Muniz-Fernandez & Paz-Caballero 1984; Rammsayer 1995, 1998; Rammsayer et al. 1993; Stelmack et al. 1993). No DT differences between extraverts and introverts are reported in all of these studies, whereas there is some evidence that extraverts have faster MTs than introverts (Doucet & Stelmack 1997; Rammsayer 1995; Stelmack et al. 1993). This finding also endorses the view that individual differences in extraversion are related to peripheral levels of the central nervous system (Stelmack & Pivik 1996).

To account for individual differences in speed of responding and motor control between extraverts and introverts, Brebner & Cooper (1974) advanced the idea that central mechanisms of stimulus analysis or response organization can be in one of two states, excitation or inhibition. In tasks demanding stimulus analysis, introverts are characterized by greater stimulus excitation and lower stimulus inhibition, whereas extraverts are characterized by the opposite pattern. In tasks demanding response organization, introverts are characterized by greater response inhibition and lower response excitation, whereas extraverts are characterized by the opposite pattern. According to Brebner’s model (Brebner 1985, 1990), introverts are more disposed to analysis of sensory information than extraverts,
whereas extraverts are disposed to faster motor response preparation. Rammsayer & Stahl (2002) used recordings of lateralized readiness potentials (LRPs) to test Brebner’s hypothesis that the latency of central response organization is shorter for extraverts than for introverts.

The LRP has emerged as an important tool in mental-chronometry approach since it provides a discrete index that traces the time course of stimulus processing from stimulus onset to response execution (e.g. Gratton et al. 1988; Kutas & Donchin 1980; Smid et al. 1987). The LRP is derived from the readiness potential (Kornhuber & Deecke 1965) that appears several hundred milliseconds prior to voluntary hand movements and reflects the asymmetrical cortical activation ipsi- and contra-lateral to the responding hand (Gratton et al. 1988; Rugg & Coles 1995). Processing time associated with stimulus analysis is indexed by stimulus-locked LRP latency, i.e. the time interval between stimulus onset and LRP onset. Response-locked LRP latency, i.e. the time interval between the onset of the LRP and completion of the motor response, indexes speed of response organization. Thus, using a LRP recording method may help in highlighting differences between introverts and extraverts in both stimulus analysis and response organization.

Rammsayer & Stahl (2002) engaged two groups of extraverted and introverted women in a two-choice go/no-go reaction-time task while LRP recordings were obtained from left- and right-central scalp sites overlying the primary motor cortex. Reaction times were significantly longer for introverts than for extraverts. This behavioral difference in performance was partially paralleled by the LRP data. There were no significant differences in stimulus-locked LRP latencies. However, response-locked LRP latencies were substantially shorter for extraverts compared to introverts. The authors concluded that the observed differences in response-locked LRP latencies between introverts and extraverts indicate that individual differences in E are referred to differences in fundamental motor processes (Doucet & Stelmack 1997, 2000; Stelmack & Pivik 1996). This study is one of the first to provide electrophysiological evidence of faster central response organization in extraverts compared to introverts, a result supporting Brebner’s (1983, 1985) model of extraversion.

Concurrent with the study of Rammsayer & Stahl (2002), Houlihan et al. (2002) also conducted an LRP experiment. Subjects were engaged in an easy two-stimulus task in which the predictability about the imperative stimulus was varied. ERPs were derived to examine P300 amplitude and latency to the imperative stimulus as well as LRP from electrodes over the motor cortex. LRP onset was earlier in extraverts than introverts in all conditions, while no significant differences were obtained for P300 component. Again, these findings provide evidence for faster central motor processes in extraverts and suggest that LRP is a valid and sensitive approach to study individual differences in extraversion in terms of both sensory and motor components of information processing.

13. Conclusions

There is a substantial body of evidence, at different levels of brain processes, linking extraversion to individual differences in stimulus processing and motor behavior. Introverts, compared to extraverts, are characterized by greater electrodermal and electrophysiological
reactivity to sensory stimulation. There is little evidence that introverts and extraverts differ in tonic or basal levels of electrocortical and autonomic activity. This conclusion is derived from the fact that there are no E-related differences in skin conductance levels for conditions inducing low levels of arousal and in skin conductance levels preceding stimulation. Similarly, E-related differences are rarely observed with EEG measures obtained during low-arousal conditions or sleepiness. When physiological arousal is manipulated by administering central nervous system stimulants (e.g. caffeine, nicotine) or depressants (e.g. Chlordiazepoxide), systematic effects that are consistent with arousal theory predictions (Eysenck 1967) are observed with electrodermal response and event-related potential measures. These effects support the view that introverts are more arousable than extraverts, i.e. they are characterized by enhanced reactivity to stimulation. They do not support the notion that individual differences in extraversion are characterized by individual differences in tonic arousal. However, it is not clear whether the enhanced sensitivity to stimulation of introverts reflects differences in central or peripheral nervous system processes or both.

The E-related effects on ABRs indicated that the greater sensitivity of introverts may be referred to differences in axonal or synaptic transmission at the level of auditory nerve. The experimental evidence supports the view that the arousal construct itself cannot be generalized. A main reason lays in the fact that extraversion-related differences are linked to arousability rather than to base levels of tonic arousal. Furthermore, ERP differences in E are not evident across the full continuum of intensity levels, but mainly for stimulation of moderate intensity. Another limiting aspect of the arousal hypothesis lies in the fact that psychophysiological response measures of arousal are not similarly effective in detecting individual differences in E. Significant effects also depend on specific task requirements. The arousal hypothesis has received considerable support using SCR and ERP to auditory stimulation and to a lesser extent ERPs to visual stimulation. HR measures, on the other hand, yielded mixed results.

The experimental evidence of individual differences in motoneuronal excitability introduced a new line of research on the biological concomitants of extraversion. On a variety of tasks requiring a motor response, there is good evidence that extraverts differ from introverts in their expression of motor behavior. Recent research has demonstrated that this difference is in both peripheral response execution processes and on central stimulus analysis and response selection processes. Recent research has demonstrated faster movement times and earlier onset of LRPs in extraverts than introverts.

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