ACTA NEUROBIOLOGIAE EXPERIMENTALIS

Acta Neurobiol Exp 2007, 67: 179–186

Evidence for differentiation of arousal and activation in normal adults

S. Mohammad VaezMousavi[1], Robert J. Barry[2], Jacqueline A. Rushby[2], and Adam R. Clarke[2]

[1]Department of Sport Sciences, Imam Hossein University, Tehran, Iran; [2]Brain & Behaviour Research Institute and School of Psychology, University of Wollongong, Wollongong, NSW 2522, Australia

Abstract. "Arousal" at a particular time has been defined as the energetic state at that moment, reflected in electrodermal activity and measured by skin conductance level. In contrast, task related "activation" has been defined as the change in arousal from a resting baseline to the task situation. The present study, replicating some aspects of a previous investigation of these ideas in children, aimed to further explore whether the separation of "arousal" and "activation" was useful in describing state effects on the phasic Orienting Response (OR) and behavioral performance. A continuous performance task (CPT) was used with normal adults. It was found that the magnitude of the mean phasic OR to targets was dependent on arousal, but not on task-related activation. A performance measure (reaction time) improved with increasing activation, but not with arousal. These findings support our previous suggestions concerning the value of conceptualizing arousal and activation as separable aspects of the energetics of physiological and behavioral function.

Correspondence should be addressed to R.J. Barry,
Email: robert_barry@uow.edu.au

Key words: arousal, activation, electrodermal activity, reaction time, continuous performance task, adults

INTRODUCTION

Skin conductance level (SCL) is a sensitive measure of the tonic modulation of sympathetic activity (Malmo 1959), and continues to be regarded as the "gold standard" in the measurement of arousal (e.g. Barry and Sokolov 1993). A recent study with children (Barry et al. 2004) showed that resting SCL was inversely related to alpha power in the simultaneous eyes-closed EEG, and directly related to alpha frequency. These data, compatible with traditional EEG arousal concepts (Cobb 1963, Sharpless and Jasper 1956), support the use of SCL as a simple measure of CNS arousal. Studies using functional imaging techniques (e.g., Critchley 2002, Critchley et al. 2001, 2002), and other animal and human experiments, demonstrate descending cortical and subcortical influences on hypothalamic and brainstem mechanisms controlling sympathetic arousal. In particular, the amygdala exerts an influence on autonomic measures including skin conductance activity (Asahina 2003, LeDoux 1996, Phelps et al. 2001, Williams et al. 2001). Lesion and electrical stimulation studies also implicate specific brain regions, including orbitofrontal, cingulate and insular cortices, in generating changes in peripheral autonomic measures (Cechetto and Saper 1990). These specific regions have been recognized as associated with emotional and motivational behaviors (Critchley 2002, Damasio 1994). Such findings indicate the close association of central and peripheral measures of arousal.

It has long been recognized that the individual's functional state moderates their response to a stimulus. A model of such responding in relation to cognitive/perceptual processing is the Orienting Reflex (OR) (Barry 1996). The OR is the primary reaction of the body to a novel stimulus, and its elicitation may be considered as one of the most fundamental properties of living organisms (Sokolov 1963a). Sokolov's theory of the OR states that incoming stimuli are compared with representations of previous stimuli in a cortical neuronal model. The output of the comparison process, which is amplified by the current arousal level, produces the OR to stimulus-model mismatch (Sokolov 1963a,b). Dual-process theory (Groves and Thompson 1970), on the other hand, sees the magnitude of a phasic reflex as the result of hypothetical processes: habituation (H) and sensitization (S). H is a decremental process that develops in the specific neural pathways involved in processing a particular stimulus, and S is an incremental or energizing state process; outcomes of these multiply to determine the reflex magnitude. That is, common theories of OR elicitation view current arousal as an amplifier of physiological response magnitude (Barry and Sokolov 1993).

Examination of the literature suggests that arousal/activation also amplifies or improves aspects of performance. For example, early work (Duffy 1962, Malmo 1959) proposed links between performance and arousal/activation level. There are several hypotheses describing the arousal/performance relationship, among them the inverted-U hypothesis of optimal state, which is commonly applied in sport psychology (e.g., Haywood 2006). But the arousal concept has not been particularly influential in psychophysiology. One reason for this is the lack of consistency reported between a range of measures often taken to apply to arousal, such as heart rate and skin conductance level (e.g., Croft et al. 2004, Lacey 1967, Lacey and Lacey 1970). Barry and coauthors (2005) considered that another reason was confusion arising from poor definition of the terms "arousal" and "activation", which have often been used interchangeably. Various terminologies that have been used to describe states of attentiveness in the CNS include arousal, alertness, vigilance, and attention. As most terms are used extensively with diverse associations, it seems that none are ideal to describe these cortical states (Oken et al. 2006).

Barry and others (2005) followed the separation proposed by Pribram and McGuiness (1975, 1992), using "arousal" to refer to the current energetic state, and "activation" to refer to task-related mobilization of arousal. This conceptualization is illustrated in Fig. 1, where arousal variation is shown as a function of time. Arousal generally increases from baseline levels when the individual is engaged in a task, and this change in arousal (from baseline to task) is identified as task-related activation. The construct of "arousal" is always specific to the time of SCL measurement, either resting ("baseline") or "activated" (during the task), while "activation" always refers to a change in SCL from baseline to task. Barry and colleagues (2005) then linked the effects of arousal to phasic physiological responses, similar to the OR usage sketched above, and related the effects of acti-

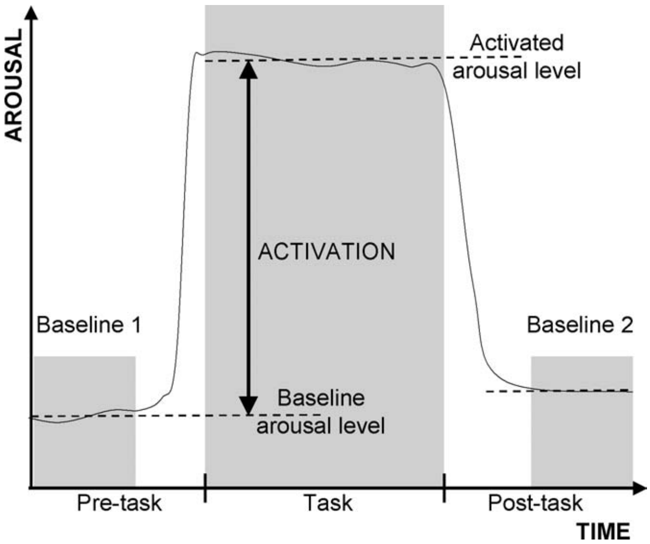

Fig. 1. The current conceptualization distinguishing between "arousal" and "activation". "Arousal" refers to the individual's energetic state at any moment, and is measured by SCL at that time. The task-related "activation" is defined as the change in arousal from resting baseline to the task. During a task, the current (activated) level of arousal affects physiological response amplitudes, while the task-related activation affects behavior/performance on the task.

vation to behavior/performance measures, such as reaction time (RT). They used this conceptual division to study children's performance in a continuous performance task (CPT).

One problem with the CPT is that stimuli have short interstimulus intervals (ISIs), commonly around 1 s. The electrodermal response has an onset latency between 1–3 s (Barry 1990), so the short ISI precludes the traditional stimulus-by-stimulus response quantification of the phasic OR. An ERP-style averaging approach was introduced by Barry and O'Gorman (1987, 1989): electrodermal data time-locked to each of the stimulus omissions in a fixed-ISI paradigm were averaged for each time point in the epoch, producing an average response to stimulus omission. That methodology generated theoretically-useful implications regarding the OR mechanism, providing an incentive for its subsequent use. For example, Barry and others (1993) used the method to provide phasic OR response profiles to examine the nature of N1 response decrement in an ERP habituation paradigm. The ERP-style response-averaging approach was used by Barry and coauthors (2005) to obtain a measure of the mean phasic OR across targets for each subject.

Barry and coauthors (2005) found that the magnitude of the mean phasic OR elicited by target stimuli was dependent on arousal, but not on task-related activation. Performance measures (mean RT and number of errors) improved with increasing activation, but not with arousal. They concluded that further investigations using arousal and activation as defined separable aspects of energetic function, and examining their effects on physiological responding and behavior, would be of value.

Therefore, the present study was designed to explore this conceptualization in adult subjects, generally replicating the Barry and colleagues (2005) child study. We hypothesized that the physiological responses are dependent on the current arousal level, and performance on the task is dependent on the task-relevant activation. Our hypotheses predict that arousal level during the CPT will determine the phasic OR to the target stimuli, but not behavioral performance. In contrast, task-related activation, defined as the change in arousal level from a resting state to the CPT, will determine behavioral performance, defined in terms of both shorter reaction times and fewer errors.

METHOD

Subjects

Twenty-two university students, 18 females and 4 males, aged from 18 to 21 years (mean age 19 years and 5 months) participated in this study. Twenty of the twenty two subjects were right handed. None of the subjects had ever suffered an epileptic seizure, serious head injuries, or periods of unconsciousness, had hearing or vision problems, or received treatment for heart/circulation/nerve or sensory problems.

Procedure

After the study was described and written informed consent was obtained, data were collected from each subject in an air-conditioned laboratory, separate from the recording equipment and experimenter. Electrodermal activity was recorded from 7.5 mm diameter Ag/AgCl electrodes on the distal phalanges of the second and third digits of the participant's non-preferred hand, at a constant voltage of 0.5 V, with an electrolyte of 0.05 M NaCl in an inert viscous ointment base.

During an initial 3 min baseline resting period, the subject was asked to sit quietly with eyes closed. The subject was then presented with a "1-9" variant of the CPT. This presented the digits 0 to 9 as 25 × 35 mm numbers on a 35 × 24 cm computer monitor, in a predetermined order. Each digit was presented for 200 ms, with an 830 ms interstimulus interval. The task consisted of two blocks containing 180 stimuli, each with 15 random presentations of the pair "1" (cue) followed by "9" (target). Subjects were required to respond only to cued targets. Responses to target stimuli which followed the cue (i.e. 9 following 1) within 1 000 ms of target onset were deemed correct. Responses to target stimuli not preceded by a warning cue, to non-targets following cues, or to other digits, were recorded as commission errors. After a practice session, the task commenced when understanding of the instructions was evident. Another 3 min baseline resting period was recorded after completion of the task. Electrodermal activity was sampled continuously at 64 Hz. This procedure was approved by the joint Illawarra Area Health Service / University of Wollongong Human Research Ethics Committee.

Data processing

Baseline arousal level was derived for each participant from the pre- and post-CPT resting periods. This was calculated as the lowest two-min mean SCL within either period. For each participant the mean SCL from the 0.5 s epochs immediately before the target stimuli during the CPT was taken as the activated arousal level. The difference between these two estimated arousal levels (activated – baseline) was taken as the task-related activation (see Fig. 1).

For each participant the mean phasic OR to the targets was obtained by averaging the SCRs at each point in the data stream over 10 s epochs time-locked to the warning cue onset. The mean OR was defined as the ERP-style response within this epoch with an onset latency between 1 and 3 s from target onset (following Barry 1990, Barry and O'Gorman 1987, 1989, Barry et al. 1993). The onset-to-peak difference was taken as the amplitude of the mean OR.

Behavioral measures of performance were taken as the mean RT for correct responses, and the total number of errors made by the subject. This was the sum of errors of omission (no response to a target within 1 s of its onset) and commission (responses made to nontarget stimuli).

Statistical analysis

An initial repeated-measures ANOVA was used to test whether there was a significant increase in arousal from the baseline to activated state. Subsequently, simultaneous multiple-regression analysis was used to investigate the relationships hypothesized in the introduction. Three measures were taken as dependent variables: OR amplitude (in μS), mean RT (in ms) and total number of errors. Each of these was regressed on the independent variables – activated arousal level (μS), and task-related activation (μS) – in separate analyses.

RESULTS

Task related activation

The overall SCL increased from 7.49 μS in the baseline resting condition to 10.20 μS in the activated task condition. This activation was statistically significant ($F_{1,21}$=6.12, P<0.05). As expected, the two within-subject measures of arousal ("baseline" and "activated") were significantly correlated across participants (r=0.58, P<0.005), sharing 33% of their variance. The measure of activation within subjects ranged from –6.60 μS to 15.62 μS, with a mean of 2.70 μS. Five of the 22 participants showed a deactivation from baseline to the CPT. They had significantly higher resting baseline levels (mean 12.77 μS) than the 17 participants who increased their arousal levels (mean 5.93 μS) ($F_{1,20}$=7.58, P<0.05).

OR amplitude

An example of an ERP-style phasic OR to targets is shown in Fig. 2. The top panel shows individual response traces time-locked to cue onset for the first 10 targets (thin lines), together with their mean (heavy line). This panel shows that the dominant electrodermal response is time-locked to the target onset, beginning approximately 1–2 s from target onset and peaking some 3 s later. The bottom panel shows the mean response for this subject over all targets. This demonstrates an onset latency of 1.55 s, with a subsequent peak 2.78 s later.

In the two panels of Fig. 3, mean OR amplitude for each participant is shown as a function of the independent variables, arousal and activation. Each set of

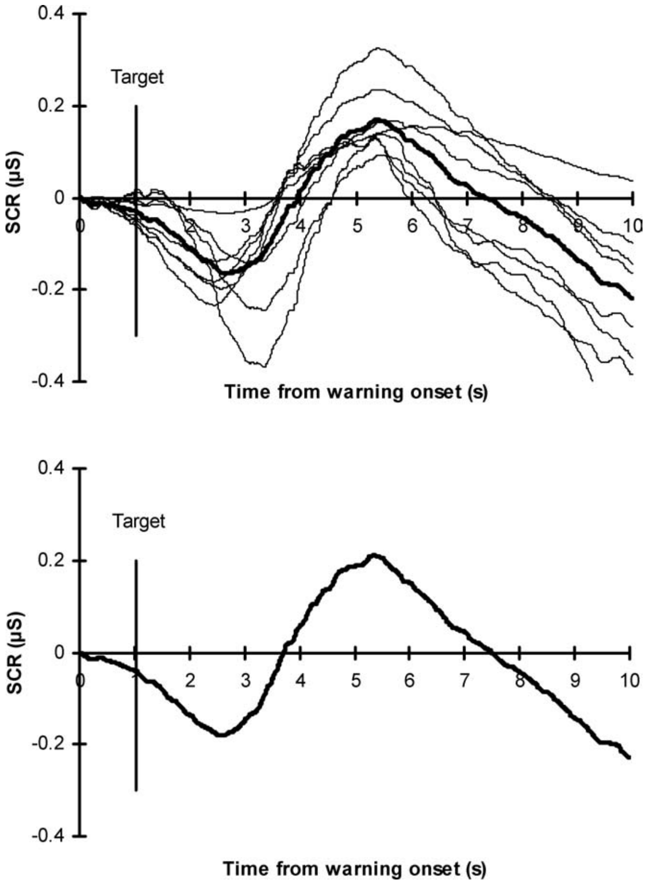

Fig. 2. An example from one participant of an ERP-style mean phasic electrodermal OR to targets. The top panel shows individual response epochs for the first 10 targets (thin lines), together with their mean (heavy line); the bottom panel shows the subject's mean response over all 30 targets.

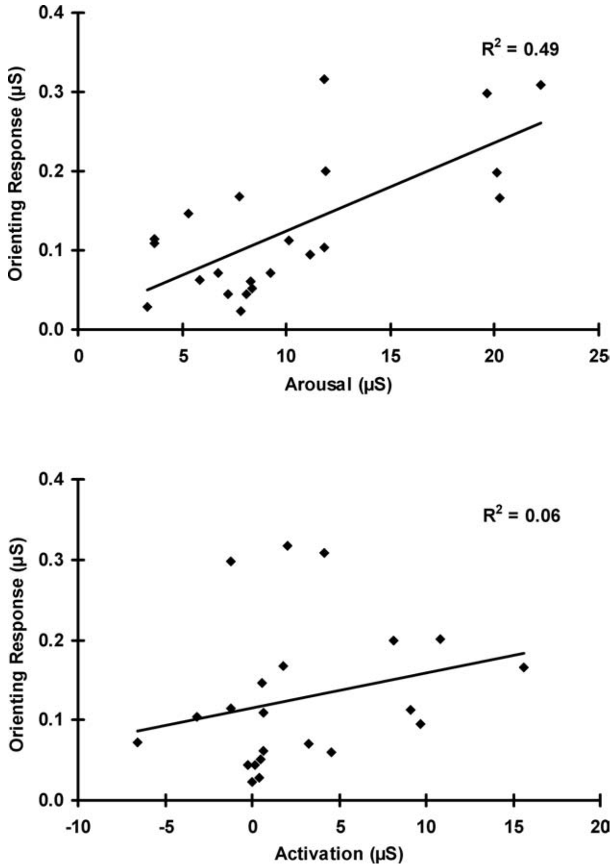

Fig. 3. Individual measures of mean OR amplitude to target stimuli, displayed as functions of arousal level (top panel), and task-related activation (bottom panel). Each set of data in this and subsequent figures is fitted with a linear regression line, and the coefficient of determination for this regression is indicated.

data has been fitted with a linear regression line to indicate the relationship with the independent variable, and the coefficient of determination is included to indicate the strength of that relation. As shown in the top panel, the phasic OR was directly dependent on arousal level, $F_{1,19}$=16.04, P<0.001, with the two variables sharing some 49% of their variance. It was not affected by task-related activation (F<1) (bottom panel).

In order to check whether baseline or activated arousal was the more important measure of arousal predicting OR amplitude, a stepwise multiple regression was carried out with both arousal measures included as independent variables. Only the current (activated) arousal level was selected as a significant predictor of the phasic OR ($F_{1,20}$=19.16, P<0.001).

Behavioral Outcomes

REACTION TIME

The mean RT for each participant is shown in relation to each of the independent variables in the separate panels of Fig. 4. There was no significant effect of arousal level (P=0.18) on this variable (top panel). As shown in the bottom panel, RT decreased significantly with greater levels of task-related activation ($F_{1,19}$=3.76, P<0.05), an effect explaining some 29% of the variance in these measures.

ERRORS

The total number of errors for each subject is displayed as a function of the independent variables in the panels of Fig. 5. The mean number of errors for all sub-

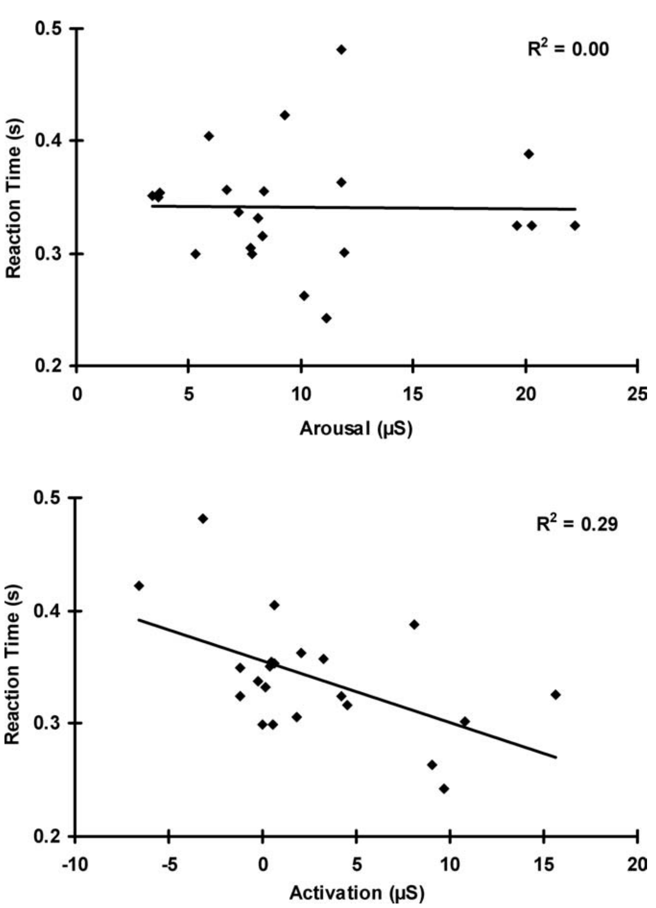

Fig. 4. Mean reaction time of each subject as a function of arousal level (top) and task related activation (bottom)

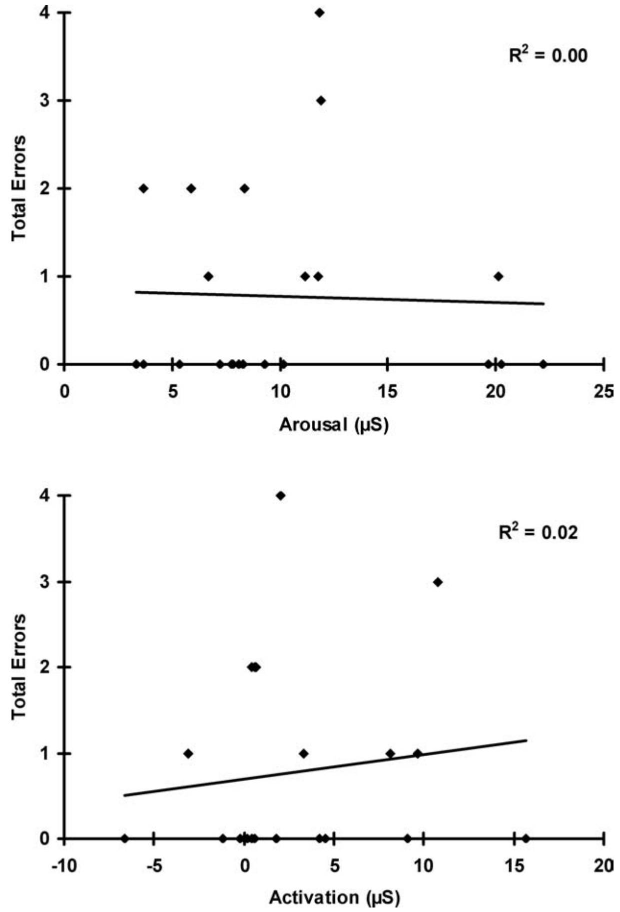

Fig. 5. Total number of errors in relation to differences in arousal level (top), and task-related activation (bottom)

jects was small (0.77) and was not significantly affected by arousal or activation (*F*s<1).

DISCUSSION

Since the overall increase in arousal level from the baseline to the CPT was significant, the concept of task related activation, and the use of the arousal change as its measure, is supported. The significant correlation between the resting and activated arousal signified that they share some 33% of the between-subject variance, and this allows a potential for between-subject differences in task involvement, in addition to baseline arousal levels, to contribute to differences in the activated arousal level.

At the individual level, 17 of 22 subjects showed this task-related activation from the baseline condition to the CPT condition, while the other 5 showed a deactivation. A similar finding was reported by Barry and coauthors (2005). They noted that the subgroup of subjects who showed a negative level of activation in the task had significantly higher baseline arousal levels, suggesting that they might perhaps have been anxious at the beginning of the laboratory session, with their arousal elevated above true resting levels. To avoid this phenomenon, they suggested that future studies should obtain baseline arousal measures from both the beginning and end of the experimental session and use the lower of these measures as the best estimate of resting arousal level. The present study followed this suggestion, and used the lower of the arousal measures from the beginning and end of the experimental session as baseline. Even so, there were 5 subjects with negative activation, again with elevated "baseline" levels. This finding suggests that the 3 minute periods used as potential baselines may not be long enough for the SCL to reach its minimum level, either at the beginning of the session, or after the CPT. Other investigators have used a longer period of resting time to allow SCL to asymptote. For example, Del-Ben and others (2001) and Moya-Albiol and others (2001) defined their baseline after 10 minutes of rest, and Andersson and Finset (1998) recorded their baseline SCL after 15 minutes of rest. Recent unpublished data from our laboratory suggests that SCL may continue dropping for a period of 20–30 min before reaching a stable level. We thus suggest that a longer period of rest for the five subjects who showed a negative activation would have ensured a lower level of baseline, which in turn would have resulted in a positive activation measure. This would also affect the activation level for other subjects in an additive fashion. Future attempts to explore the arousal/activation conceptualization should ensure a longer period of rest before estimating the baseline level.[1]

A phasic OR to the target stimuli in the CPT was apparent during the task. This was similar in latency and morphology to previous studies in this laboratory (Barry and Sokolov 1993, Barry et al. 2005). The stepwise multiple regression showed that the current arousal level, rather than the baseline arousal, or the activation, was the significant predictor of the phasic OR. This finding supports the notion that the current arousal level acts as an amplifier of the phasic OR elicited during the CPT (Barry et al. 2005). As noted in the Introduction, this is consonant with the amplifying role attributed to arousal in both Sokolovian and dual-process theories of OR evocation.

The measure of task-related activation was found to determine behavioral efficiency in terms of RT. Current arousal level did not affect RT. These results provide noteworthy support for our previous findings (Barry et al. 2005) and our hypotheses in the present study. We did not find a significant correlation between activation and number of total errors. A negative relationship was found between these variables in the previous study, where increasing activation was accompanied by error reduction (Barry et al. 2005). The paucity of errors in the present study (mean = 0.77), compared to the previous study (mean = 1.95), may explain this finding. Future attempts to explore the relationship between activation and performance in terms of number of errors could manipulate task difficulty to ensure greater error numbers to assist statistical analysis.

The overall findings of the present study indicate that arousal and activation can be conceptually separated – the former as the energetic state at a particular time, and the latter as the change from a resting baseline to the task situation. We found that current arousal level significantly affected OR magnitude, but not behavior in the CPT. In contrast, activation in the CPT affected at least one of the measures of behavior in the task, but not the OR to the target stimuli. These findings support the previous arousal/activation findings from this laboratory. The important effects in this study were of greater strength, with the significant r^2 values ranging from 0.32 to 0.48.

This study was similar to our previous study (Barry et al. 2005) in exploring the arousal/activation concepts across subjects. Each subject provided one data point in each panel of Figs 3, 4, and 5, and hence the study can be thought of as examining individual differences in state measures, and the effects of these differences on phasic OR and behavioral performance outcomes. Future studies in this area could usefully explore these relationships on a within-subject basis.

CONCLUSIONS

The overall results of the present study verify previous findings concerning differentiation of the energetics dimension into “arousal” and “activation”. Arousal affects physiological responding, such as the phasic OR magnitude, while task-related activation affects behavioral performance. The importance of this separation is that it may be useful in modifying and refining the conventional understanding of the role of the energetics dimension in physiological and behavioral performance. In turn, this may encourage further research aimed at building on this foundation and re-assessing the role of energetics in psychophysiology. Pursuing this line of investigation in terms of individual differences in skilled performance, perhaps in a re-thinking of the inverted-U hypothesis, could be fruitful.

REFERENCES

Andersson S, Finset A (1998) Heart rate and skin conductance reactivity to brief psychological stress in brain-injured patients. J Psychosom Res 44: 645–656.

Asahina M, Suzuki A, Mori M, Kanesaka T, Hattori T (2003) Emotional sweating response in a patient with bilateral amygdala damage. Int J Psychophysiol 47: 87–93.

Barry RJ (1990) Scoring criteria for response latency and habituation in electrodermal research: A study in the context of the orienting response. Psychophysiol 27: 94–100.

Barry RJ (1996) Preliminary Process Theory: Towards an integrated account of the psychophysiology of cognitive processes. Acta Neurobiol Exp (Wars) 56: 469–484.

[1] We repeated the main statistical analyses after exclusion of the five subjects who showed a deactivation due to higher level of “baseline” SCL. The phasic OR amplitude was still dependent on arousal (P<0.01). It did not show any dependence on activation (P=0.41). Reaction time still reduced with increasing activation (P<0.05). It did not show dependence on arousal (P=0.23). The number of errors showed no significant effect of either independent variable. In summary, again the phasic OR was determined by arousal, and one of the two measures of behavior was determined by activation rather than arousal.

Barry RJ, O'Gorman JG (1987) Stimulus omission and the orienting response: Latency differences suggest different mechanisms. Biol Psychol 25: 261–276.

Barry RJ, O'Gorman JG (1989) Methods and mechanisms in electrodermal studies of omission responding. Biol Psychol 28: 271–277.

Barry RJ, Sokolov EN (1993) Habituation of phasic and tonic components of the orienting reflex. Int J Psychophysiol 15: 39–42.

Barry RJ, Feldmann S, Gordon E, Cocker KI, Rennie C (1993) Elicitation and habituation of the electrodermal orienting response in a short interstimulus interval paradigm. Int J Psychophysiol 15: 247–253.

Barry RJ, Clarke AR, McCarthy R, Selikowitz M, Rushby JA, Ploskova E (2004) EEG differences in children as a function of resting-state arousal level. Clin Neurophysiol 115: 402–408.

Barry RJ, Clarke AR, McCarthy R, Selikowitz M, Rushby JA (2005) Arousal and activation in a continuous performance task: An exploration of state effects in normal children. J Psychophysiol 19: 91–99.

Cechetto DR, Saper CB (1990) Role of the cerebral cortex in autonomic function In: Central Regulation of Autonomic Functions (Loewy AD, Spyer KM, eds). Oxford Univ. Press, Oxford, UK, p. 208–223.

Cobb WA (1963) The normal adult EEG In: Electroencephalography (Hill D, Parr G, eds). Macmillan, New York, p. 232–249.

Critchley HD (2002) Electrodermal responses: What happens in the brain? The Neuroscientist 8: 132–142.

Critchley HD, Melmed RN, Featherstone E, Mathias CJ, Dolan RJ (2001) Brain activity during biofeedback relaxation. A functional neuroimaging investigation. Brain 124: 1003–1012.

Critchley HD, Melmed RN, Featherstone E, Mathias CJ, Dolan RJ (2002) Volitional control of autonomic arousal: A functional magnetic resonance study. Neuroimage 16: 909–912.

Croft RJ, Gonsalvez CJ, Gander J, Lechem L, Barry RJ (2004) Differential relations between heart rate and skin conductance, and public speaking anxiety. J Behav Therapy Exp Psychiat 35: 259–271.

Damasio AR (1994) Descartes' Error: Emotion, Reason, and the Human Brain. Grosset Putnam, New York.

Del-Ben CM, Vilela JAA, Hetem LAB, Guimaraes FS, Graeff FG, Zuardi AW (2001) Do Panic patients process unconditioned fear vs. conditioned anxiety differently than normal subjects? Psychiatry Res 104: 227–237.

Duffy E (1962) Activation and Behavior. John Wiley and Sons Ltd., New York.

Groves PM, Thompson RF (1970) Habituation: A dual–process theory. Psychol Rev 77: 419–450.

Haywood KM (2006) Psychological aspects of archery In: The Sport Psychologist's Handbook: A Guide for Sport-Specific Performance Enhancement (Dasil J, ed.). John Wiley and Sons Ltd., London, p. 549–568.

Lacey BC, Lacey JI (1970) Some autonomic-central nervous system interrelationships In: Physiological Correlates of Emotion (Black P, ed.). Academic Press, New York, p. 214–236.

Lacey JI (1967) Somatic response patterning and stress: Some revisions of activation theory In: Psychological Stress Issues in Research (Appley MH, Trumbull R, eds). Appleton-Century-Crofts, New York, p. 14–44.

LeDoux JE (1996) The Emotional Brain: The Mysterious Underpinnings of Emotional Life. Simon and Schuster, New York.

Malmo RB (1959) Activation: A neurophysiological dimension. Psychol Rev 66: 367–386.

Moya-Albiol L, Salvador A, Costa R, Martinez-Sanchis S, Gonzalez-Bono E, Ricarte M, Arnedo M (2001) Psychophysiological responses to the Stroop Task after a maximal cycle ergometry in elite sportsmen and physically active subjects. Int J Psychophysiol 40: 47–59.

Oken BS, Salinsky MC, Elsas SM (2006) Vigilance, alertness, or sustained attention: Physiological basis and measurement. Clin Neurophysiol 117: 1885–1901.

Phelps EA, O'Connor KJ, Gatenby JC, Gore JC, Grillon C, Davis M (2001) Activation of the left amygdala to a cognitive representation of fear. Nat Neurosci 4: 437–441.

Pribram KH, McGuiness D (1975) Arousal, activation, and effort in the control of attention. Psychol Rev 82: 116–149.

Pribram KH, McGuiness D (1992) Attention and para-attentional processing. Event-related brain potentials as tests of a model. Ann N Y Acad Sci 658: 65–92.

Sharpless S, Jasper H (1956) Habituation of the arousal reaction. Brain 79: 655–680.

Sokolov EN (1963a) Higher nervous functions: The OR. Ann Rev Physiology 25: 545–580.

Sokolov EN (1963b) Perception and the Conditioned Reflex. Pergamon, Oxford.

Williams LM, Phillips ML, Brammer MJ, Skerrett D, Lagopoulos J, Rennie C, Bahramali H, Olivieri G, David AS, Peduto A, Gordon E (2001) Arousal dissociates amygdala and hippocampal fear responses: Evidence from simultaneous fMRI and skin conductance recording. Neuroimage 14: 1070–1079.

Received 29 December 2006, accepted 21 March 2007