Review of Psychology,
2011, Vol. 18, No. 2, 63-70 UDC 159.9

Does the abstract thinking have a significant role in the relationship between extraversion and evoked brain potentials?

SANJA TATALOVIĆ VORKAPIĆ and MERI TADINAC

Considering the significant number of inconsistent results regarding the relationship between extraversion and evoked potentials within the Eysencks' arousal theory, a possible significant role of some other variables such as attention, task modality and difficulty, and intelligence level has been analyzed. The aim of this study was to analyze the relationship between extraversion and its electrophysiological correlates, taking into account the intellectual level of subjects. Forty-three female psychology students, within the age range 19-23 years, participated in the study. Extraversion was measured by EPQ-R and abstract thinking by ATT. The evoked brain potentials (N1, P2, N2, P3, & SW) were elicited by a standard visual oddball paradigm, in two measurement trials for each subject, using two occipital and two parietal electrodes. Correlation analyses of extraversion and evoked potentials partialized for abstract thinking have shown that the intellectual level of subjects represented a significant part of the extraversion-evoked potentials relationship, especially in the SW-latency parameter. Overall, the findings implied the great importance of analyzing individual differences in electro-cortical activity using the measures of both personality and intelligence, as both of them could play a significant and complex role in subjects' cortical arousal.

Key words: extraversion, evoked brain potentials, abstract thinking, students

Evoked potential (EP) recording procedures are among several methods used to provide measures of explanatory constructs for personality and intelligence. The constructs of interest in this study are arousal (for personality dimensions, especially extraversion), and information-processing speed and neural efficiency (for intelligence). The possible influence of introversion/extraversion on event-related potentials has been the subject of a number of studies (Lindín, Zurrón, & Díaz, 2007), as well as the often determined shorter latencies and smaller amplitudes of EPs in subjects with superior mental performance (Ladish & Polich, 1989; Polich, 1998; Polich & Herbst, 2000) in the studies of various experimental or correlation designs. The electrophysiological correlates relevant to those study aims were established by the EP-method, also used in this study. The evoked brain potentials represent voltage fluctuations that are associated in time with some physical or mental occurrence (Picton et al., 2000). A stimulus, visual or auditory, evokes a potential change in the cerebral cortex, which can be further analyzed within different time-windows according to the type of the task used. Each EP-component has its specific latency and amplitude parameters, as well as its specific psychological meaning, which are presented in Table 1 (only EP-components relevant for this study have been shown, for other details see Polich, 1993).

Table 1
Evoked potential components, their latency range and psychological meaning

EP-component	Latency range	Psychological meaning
N1	50 msec	Selective attention
P2	80-100 msec	Early information processing
N2	170-200 msec	Automatic extraction and determination of stimulus' properties target detection, reaction time
P3	250-600 msec	Allocation of attention and working memory updating
SWA	1000 msec, duration: 3-4 min	Before the stimulus presentation, while participants wait for the task

Note. Adapted from Polich, 1993.

Sanja Tatalović Vorkapić, Faculty of Teacher Education, University of Rijeka, Slavka Krautzeka bb, 51000 Rijeka, Croatia. E-mail: sanjatv@ufri.hr (the address for correspondence);

Meri Tadinac, Department of Psychology, Faculty of Humanities and Social Sciences, University of Zagreb.

Extraversion and EPs

Eysenck's (1967) arousal theory postulates that the degree of extraversion is inversely related to the cortical arousal, i.e., introverts have both a higher level and stronger reactivity of reticulo-cortical arousal than extraverts. Furthermore, because of their greater reticulo-cortical arousal, it has been hypothesized that introverts should have larger EP-amplitudes, especially amplitudes of cognitive EP-components, such as P300-wave (Eysenck, 1994; Mathews & Gilliland, 1999), and this hypothesis has been confirmed for both auditory (Bruneau, Roux, Perse, & Lelord, 1984; Stelmack, Achorn, & Michaud, 1977; Stelmack & Campbell, 1974; Stelmack & Geen, 1992; Stelmack & Michaud-Achorn, 1985) and visual event-related potentials (Soskis & Shagass, 1974; Stenberg, Rosen, & Risberg, 1988, 1990). However, other empirical findings are rather inconsistent due to the various variables of task demands and different habituation levels in extraverts and introverts (Stelmack & Michaud-Achorn, 1985; Stenberg, 1994; Stenberg, Rosen, & Risberg, 1990; Tatalović Vorkapić, 2005, 2010; Tatalović Vorkapić, Tadinac, & Rudež, 2010). Besides, the unspecific reticulo-cortical arousal proposed by Eysenck (1967) has been complemented by the effort system suggested by Beauducel, Brocke, & Leue (2006), and Brocke, Tasche, & Beauducel (1996, 1997). The authors proposed that, when the level of subject's arousal was above or below the optimal functioning level, mismatches might be produced between the current cognitive state and the required target state. Therefore, the P300-amplitude, proposed as a possible effort system index (Mulder, 1986), would decrease in the situation when energy resources were not available for processing or evaluating the stimuli because the same energy resources were dedicated to the effort system to compensate for the supra- or suboptimal levels of arousal. This new aspect of psychological-functional role of P300 is very interesting, as it brings a wider meaning that could be more useful in studies investigating complex intelligence-personality relationship in the electrophysiological context, than the earlier one: "P300-amplitude represent the index of brain activity that is required in the maintenance of working memory when the mental model of the stimulus environment is updated" (Donchin, Karis, Bashore, Coles, & Gratton, 1986, p. 256).

Intelligence and EPs

There are a lot of inconsistent results considering the relationship between EP-latencies and personality. Some studies have determined significantly shorter EP-latencies as the measure of a greater information-processing speed in extraverts (Doucet & Stelmack, 2000; Tatalović Vorkapić et al., 2010). Doucet and Stelmack (2000) explained their findings by the P3-latency sensitivity to the task demands–when the task demands were low and tended to induce monotony, the differences between extraverts and introverts changed direction and P300-latency became shorter in extraverts. Our previous findings (Tatalović Vorkapić et al., 2010) were explained by the nature of introverts as "geared to inspect" and extraverts as "geared to response" (Brebner & Cooper, 1985), resulting in significantly longer P3-latencies in introverts than extraverts. Therefore, it is clear that EP-latency, especially the P3-latency, is sensitive to the cognitive processing demands of the task. On the other hand, in the EP studies of biological substrates of intelligence, the superior intelligence performance was mainly related to faster information-processing or shorter EP-latencies (Barrett & Eysenck, 1994; Bates & Eysenck, 1993; Eysenck, 1987; Osaka & Osaka, 1980; Rhodes, Dustman, & Beck, 1969; Widaman, Carlson, Saetermoe, & Galbraith, 1993; Zurron & Diaz, 1998), higher EP-amplitudes (Eysenck, 1987; Haier, Robinson, Braden, & Williams, 1983; Josiassen, Shagass, Roemer, & Slepner, 1988; Osaka & Osaka, 1980; Rhodes et al., 1969; Shagass, Roemer, & Straumanis, 1981) and better neural efficiency, i.e., more efficient use of the cortex (Fink, Schrausser, & Neubauer, 2002).

Extraversion, intelligence, and EPs

Considering the complex relationship between personality and intelligence in context of other relevant psychological or psychophysiological variables, it has been determined that individual differences in extraversion have a moderate influence on the relationship between intelligence and cortical activation (Fink et al., 2002). The established pattern suggested that during cognitive activity extraverts were more likely to produce activation patterns in line with the neural efficiency hypothesis (i.e., less activation in more intelligent participants), whereas at rest introverts showed inverse relationship between intelligence and cortical activation. In another words, at rest the hypothesized lower cortical arousal in extraverts as compared to introverts was only found in the low IQ group, whereas during the task performance only brighter subjects matched the hypothesis (Fink et al., 2002). Generally, there was a tendency for the participants involved in a task to show shorter latencies and higher amplitudes of earlier components of evoked potentials: N1, P2 and N2. Concerning the P3-wave and other late EP-components, their relationship with personality proved to be more complex (Stelmack & Houlihan, 1995), probably due not only to the complexity of the task or to the attention level, but also to intelligence. Taken together, these findings suggest that subjects' intellectual level represents a significant part of the relationship between extraversion and EP-measures of cortical activation, raising a question whether the observed individual differences in cortical arousal could be mainly ascribed to personality traits or to the intelligence level of subjects.

For the purpose of exploring the role of general intelligence ability (G) in the EP-extraversion relationship, in this study it was operationalized by the construct of abstract thought. This ability to manipulate ideas and symbols has often been investigated using the nonverbal problem solving tasks. Therefore, the aim of this study was to examine the relationship among latency and amplitude of the EPs (N1, P2, N2, P3 and SW), measured by a simple visual oddball task, extraversion, and abstract thought. This relationship will be studied separately for the EP-amplitudes measured in the first and second trial, and for each of the electrodes. Taking into account the previous findings, it was assumed that the EP-extraversion relationship would be affected by the level of abstract thinking in subjects, especially in the context of late EP-components.

METHOD

Participants

Forty-three female psychology students from the Department of Psychology, Faculty of Humanities and Social Sciences in Rijeka, within the age range 19-23 years (M = 20.5, SD = 1.32), participated in the study. They were all naive to electrophysiological studies, right-handed and reported no visual or neurological/psychiatric problems. The subjects received course credits for their participation in the study.

Extraversion and abstract thought measurement

Extraversion was measured by the extraversion scale from the standardized version of the Eysenck's Personality Questionnaire (Eysenck & Eysenck, 1994), consisting of 23 items on which subjects answered choosing between *Yes* or *No*. This study confirmed the earlier satisfactory levels of reliability–Cronbach alpha for extraversion was .89. Abstract thought was measured by the Abstract Thinking Test, ATT (Kulenović, 2003), which is a nonverbal test, designed for measuring the level of symbol manipulation and inductive reasoning. It consists of 60 items divided in three subscales with different complexity level. The result on each of the subtests is the sum of the correctly solved problems. The internal consistency of ATT showed satisfactory levels: Cronbach Alpha for the total ATT result was α = .83 (Kulenović, 2004), and in this study α = .79.

EP-measurement and procedure

After completing the personality and intelligence testing, all subjects were engaged in the evoked brain potentials measuring. The visual oddball paradigm has been used in two trials for evoking brain potentials: N1, P2, N2, P3, and SW. The measurement took place within a 3-months period, always at the same time, using the device Medelec/TECA SapphireII 4E (Medelec, Vickers Medical, & Teca Vickers Medical, 1996) with five Ag/AgCl disc electrodes. According to 10-20 system, two occipital (O1 & O2) and two parietal (P3 & P4) electrodes referred to Fz were used. The electrode impedance was kept below 5 kΩ and the filter bandpass was 0.1-50 Hz.

A pattern reverse binocular full-field stimulation was performed in a dark, quiet room using a 16x16 checkerboard pattern, 70 cm away from the nasion, with 1 Hz frequency and 100% contrast. Subjects were instructed to look at the centre of the monitor and to react to the rare (target) stimuli (checkerboards consisting of the smaller quadrangles) by pressing the pen, and to ignore frequent (nontarget) stimuli (checkerboards consisting of the larger quadrangles).

The marking procedure of the amplitudes and latencies of the EPs (N1, P2, N2, P3, and SW) was performed manually, using a cursor, by the same medical technician for both trials. To provide a higher quality of data, the effect of the latency jitter should be avoided for the EPs to be more stable over trials (Coles, Gratton, Kramer, & Miller, 1986; Hoormann, Falkenstein, Schwarzenau, & Hohnsbein, 1998). Therefore, in the second trial they were marked by the same latencies as those from the first trial, resulting for each participant with a same EP-latency for both trials, but different EP-amplitudes.

RESULTS AND DISCUSSION

Extraversion, abstract thinking, and event-related potentials measurement

The group average for the extraversion results (M = 15.5; SD = 5.4) was a little higher than the average obtained on the Croatian standardization group (M = 14.2; SD = 4.7). This result was expected since the subjects in this study were psychology students. Considering the ATT results, the determined group average (M = 39.6; SD = 5.8) was higher than the one obtained on the standardization group (M = 33.5; SD = 8.2). The comparison among mean results on the three ATT-subtests showed that students achieved the highest result in the first ATT-subtest (M = 14.4; SD = 2.6), the medium in the second one (M = 13.2; SD = 2.9), and the lowest in the third ATT-subtest (M = 12; SD = 2.7). This finding is logical since the task complexity level rises from the first to the third ATT-subtest. The Kolmogorov-Smirnov test of conformity (K-Sz) showed the distributions of extraversion and ATT variables to be normal. Finally, the mean amplitudes and latencies of all EPs (N1, P2, N2, P3 and SW), measured in two trials, were determined according to their points of maximum negativity or positivity. All the mean EP-amplitudes and EP-latencies were within the expected range (for details see Tatalović Vorkapić, Tadinac, Kulenović, & Buško, 2008).

The relationship among extraversion, EPs, and abstract thought

To analyze the complex relationship among extraversion, intelligence, and brain potentials, zero order correlation analyses were performed. Furthermore, to analyze the role of abstract thinking within the extraversion-EP relationship, the partial correlations were calculated. In most cases the Pearson coefficient correlation was calculated. However, because of the significant deviations of some EP-distributions from the normal distribution, Spearman coefficient of correlation was used in these cases: N2-latency on P3 (K-Sz = 1.93, p = .01), N2-latency on P4 (K-Sz = 1.94, p = .01), N2-amplitude in the first trial on O1 (K-Sz = 1.43, p = .03), N2-amplitude in the first trial on O2 (K-Sz = 1.46, p = .03), and N2-amplitude in the second trial on O2 (K-Sz = 1.35, p = .05). As none of the correlations of P2 and P3 with other variables were significant, they were omitted from the following tables.

Extraversion–abstract thinking relationship. Zero order correlations of extraversion with first, second, and third ATT-subtest, and the total ATT-result, were .19, .22, -.17 and .12, respectively. Generally, it was determined that there was no significant correlation between students' level of extraversion and their level of abstract thinking. This result was expected since a great number of previous studies of intelligence-personality relationship had obtained similar findings (Sternberg & Ruzgis, 1994). They pointed out that intelligence is not related to personality in any meaningful way. Those rare differences that had been found were explained by the different pathways in introverts and extraverts use regarding their actual performance on various kinds of tests. In another words, since the performance on the intelligence tests was used for measuring intelligence, personality might have influenced the performance itself rather than the abstract intellect. Therefore, other factors such as vigilance, fatigue, arousal, etc., may play a significant part and must be taken into consideration within the research of personality-intelligence relationship (Eysenck, 1994). The working speed is another important factor found to be significantly positively correlated with extraversion (Eysenck, 1967). Furthermore, in the replication of Furneaux's experiment, Eysenck (1959) analyzed the performance parameters of extraverts and introverts using a nonverbal intelligence test. He found that extraverts showed a greater work decrement on the intelligence test by taking longer to obtain the correct solution towards the end of the test as compared to introverts, and by giving up more easily towards the end. Overall, the differences between extraverts and introverts might be more apparent in the performance parameters than in the total score. Since extraverts tended to be faster but less accurate than introverts (Eysenck, 1947), their different features were mutually compensated, as reflected in their equal total scores. Besides, our sample was small and proved to be very homogeneous in both extraversion and abstract thinking, which could be another reason contributing to lower correlations. Therefore, in the future studies it would be wise to use subjects with a wider range of personality traits and abstract thinking level. Finally, it is interesting to attract attention to opposite patterns of relationship determined between extraversion and average results on ATT3–the first two subtest of ATT (also the ATT total result) showed positive relationship with extraversion while ATT3 showed negative. Therefore, it would be very interesting to explore their relationship within future experimental design of task difficulty and test duration manipulation.

Table 2
Correlations between extraversion and evoked potentials (N1, N2, SW)

Evoked potentials		Extraversion: Zero order correlations	Partial correlations controlled for: ATT1	ATT2	ATT3	ATTΣ
N1-component	LO1	-.19	-.13	-.22	-.18	-.18
	LO2	-.19	-.13	-.22	-.18	-.18
	LP3	-.10	-.10	-.10	-.13	-.09
	LP4	-.10	-.10	-.11	-.13	-.09
	A1O1	.01	.01	.02	-.03	.03
	A1O2	-.14	-.16	-.17	-.14	-.15
	A1P3	.20	.19	.16	.20	.19
	A1P4	.12	.10	.08	.12	.10
	A2O1	-.06	-.05	-.03	-.10	-.04
	A2O2	-.20	-.22	-.22	-.19	-.21
	A2P3	.17	.13	.13	.16	.15
	A2P4	.23	.20	.16	.22	.21
N2-component	LO1	.00	.02	-.01	.00	.00
	LO2	.00	.02	-.01	.01	.00
	LP3	-.29	-.08	-.04	-.08	-.08
	LP4	-.30*	-.09	-.05	-.08	-.08
	A1O1	-.08	-.05	-.03	-.05	-.05
	A1O2	-.04	-.11	-.06	-.06	-.07
	A1P3	.22	.24	.23	.19	.24
	A1P4	.26	.28	.25	.26	.26
	A2O1	-.15	-.11	-.11	-.15	-.13
	A2O2	-.19	-.20	-.15	-.19	-.18
	A2P3	.20	.21	.20	.18	.21
	A2P4	.39**	.38**	.38**	.37*	.40**
SW-component	LO1	-.35*	-.42**	-.39**	-.34*	-.39**
	LO2	-.35*	-.40**	-.38**	-.34*	-.38**
	LP3	-.28	-.29	-.30	-.25	-.30*
	LP4	-.28	-.29	-.30	-.24	-.30*

Note. ATT1 = the first ATT-subtest; ATT2 = the second ATT-subtest; ATT3 = the third ATT-subtest; ATTΣ = ATT total; A = amplitude; L = latency; O1, O2, P3, P4 = two occipital and two parietal electrodes sites.
* $p < .05$. ** $p < .01$.

Extraversion–EP relationship. Zero order and partial correlations between extraversion and EPs are shown in Table 2. Analyzing the zero order correlations between extraversion and EPs it can be seen that N2-latency measured on one parietal electrode P4 (r = -.30, p > .05) and SW latencies measured on both occipital electrodes O1 (r = -.35, p >

.05) and O2 (r = -.35, p > .05) showed significant negative correlations with extraversion. More extraverted students showed shorter N2- and SW-latencies, i.e., they needed a shorter time for automatic extraction and determination of stimulus' properties target detection, shorter reaction time and shorter time before they were ready for the next task. It could be proposed that precognitive N2-component and the resting SW activity reflect the specific performance parameters of extraverts/introverts: greater working speed (Eysenck, 1967) and the characteristic of "geared to react" (Brebner & Cooper, 1985) being specific for extraverts. No significant correlations were found between extraversion and P3-component, which is contrary to our expectations and the results from our previous study, where significant negative correlations between extraversion and P3-latencies were determined (Tatalović Vorkapić, 2009; Tatalović Vorkapić et al., 2010). As the methodology was the same, the only explanation lies in the smaller sample used in this study, leading to a very restricted variability.

Table 3
Correlations of the ATT total and ATT subtests with evoked potentials (N1, N2, SW)

Evoked potentials		Abstract thinking test			
		ATT1	ATT2	ATT3	ATTΣ
N1-component	LO1	-.38**	.12	.04	-.08
	LO2	-.38**	.12	.04	-.08
	LP3	-.04	.00	-.17	-.09
	LP4	-.02	.02	-.15	-.07
	A1O1	.00	-.05	-.22	-.13
	A1O2	.10	.13	-.02	.10
	A1P3	.11	.26	-.03	.16
	A1P4	.13	.19	-.02	.14
	A2O1	-.06	-.12	-.20	-.18
	A2O2	.10	.07	.05	.10
	A2P3	.25	.24	-.08	.19
	A2P4	.20	.35*	-.05	.24
N2-component	LO1	-.11	.05	.03	-.01
	LO2	-.11	.05	.03	-.01
	LP3	-.01	-.19	.06	-.07
	LP4	-.01	-.19	.06	-.08
	A1O1	-.03	-.13	.03	-.06
	A1O2	.24	.01	-.03	.10
	A1P3	-.06	-.05	-.20	-.14
	A1P4	-.05	.09	-.04	.00
	A2O1	-.23	-.21	.05	-.18
	A2O2	.05	-.20	.01	-.07
	A2P3	-.06	.02	-.16	-.09
	A2P4	.11	.07	-.22	-.02
SW-component	LO1	.24	.11	.10	.21
	LO2	.20	.08	.09	.17
	LP3	.04	.05	.26	.16
	LP4	.04	.05	.26	.16

Note. ATT1 = the first ATT-subtest; ATT2 = the second ATT-subtest; ATT3 = the third ATT-subtest; ATTΣ = ATT total; A = amplitude; L = latency; O1, O2, P3, P4 = two occipital and two parietal electrodes sites.
* p < .05. ** p < .01.

Abstract thinking–EP relationship. The results of abstract thinking-EP relationship are presented here (Table 3) only briefly to enable the easier understanding of the complex personality–EP–intelligence relationship, as they are explained in detail in our earlier study (Tatalović Vorkapić et al., 2008). Contrary to our expectations, only three significant correlations between abstract thinking and EPs were determined. Those students who showed higher abstract thinking level also needed a significantly shorter time for selective attention (N1-latency on O1 and on O2), and had a significantly higher N1-amplitude on one parietal electrode. As we have emphasized earlier (Tatalović Vorkapić et al., 2008), further research into the relationship between EPs and abstract thinking is needed, using more trials, more complex tasks within different oddball paradigms, and more adequate electrophysiological apparatus.

Extraversion–EP relationship controlled for abstract thinking: Partial correlation analyses. Finally, trying to answer our main question, it can be seen (Table 2) that abstract thinking played a significant role within the extraversion–EP relationship, especially in the relationship of extraversion and late EP-components. Firstly, analyzing the relationship of N1-component and psychological variables (Table 2), it was determined that significant negative correlations between averages on N1-latency and the first ATT-subtest lowered the negative correlation between extraversion and N1-latency when the ATT1 was singled out or partialized. In another words, a part of the N1 latency-extraversion relationship could be ascribed to abstract thinking. A similar pattern could be observed in the correlation analyses of extraversion-N1-amplitude in the second trial on P4-electrode after partializing for the effect of average results on ATT2, which showed a significant positive correlation with N1-amplitude on P4-electrode.

Furthermore, this pattern could be observed within the relationship of extraversion with N2-component and SW activity latency. However, before analyzing the extraversion–SW latency relationship when partialized for abstract thinking, an interesting finding must be emphasized. Even though a significant negative correlation was determined between extraversion and N2-latency on P4-electrode (r = -.30, p > .05), implying the shorter time for automatic extraction and determination of stimulus' properties target detection, including shorter reaction time in extraverts, when analyzing the same relationship partialized for abstract thinking, it ceased to be significant. Even more interesting is that this change in the extraversion-N2 latency relationship could not be ascribed to the direct partializing effect of abstract thinking, as its correlations with N2-latency were rather small. Possible explanations for this effect could be the variability effects, the measurement effect, or could be related to the earlier mentioned effort system (Beauducel et al., 2006; Brocke et al., 1996, 1997). The observed changes within the extraversion-N2-intelligence relationship could be explained within the effort system context, where changes in the subjects' functioning level of cognitive engagement significantly influence and moderate the relationship between extraversion and N2-latency. However, since the authors who have proposed the system effort model dealt only with P3-component, its applicability to other EP components could only be hypothesized (Beauducel et al., 2006; Brocke et al., 1996, 1997), and further research is necessary to examine the possibility of widening of this model.

Finally, the greatest changes could be observed in the extraversion-SW latency relationship on all the electrodes when partializing for abstract thinking. Extraverts showed shorter latencies while waiting for the stimulus presentation or between trials while resting, and this negative correlation was even higher when partialized for abstract thinking. It is interesting to notice that this change did not happen when partializing for the effect of the ATT3 subtest–the one with the highest task difficulty. This is in accordance with the idea from previous studies (Stenberg, 1994; Tatalović Vorkapić et al., 2010) that task difficulty is a very important variable in analyzing the extraversion–EP relationship. Based on this finding it could be speculated that abstract thinking moderates the extraversion-SW relationship in the monotonous situations, but not in the situations when a more difficult task is used. This idea has its roots in the neural efficiency hypothesis (Fink et al., 2002), i.e., the assumption of more efficient use of the brain in high IQ individuals. Fink et al. (2002) found significant IQ by extraversion interactions during rest and cognitive activity in the lower alpha band. They proposed that during certain cognitive activities extraverts were more likely to produce activation patterns in line with the neural efficiency hypothesis (i.e., less activation in more intelligent participants), whereas at rest the introverted group displayed this inverse relationship between IQ and cortical activation. This neural efficiency hypothesis was confirmed only during the task performance and only in the group of brighter individuals, which could be related to our finding. There were no changes in the extraversion–SW latency relationship after partializing for abstract thinking in the situation of longer engagement in the task and the situation of greater task difficulty. This finding suggests the need for further studies that would vary task difficulty in different modalities and use different operationalizations of intelligence or other tests. Furthermore, this implies a need for larger samples and greater heterogeneity in both extraversion and intelligence range of the subjects.

CONCLUSION

As it was shown, no significant correlations between students' level of extraversion and their level of abstract thinking were found in this study, which was in accordance with our expectations based on previous findings. However, although it seems that intelligence is not related to personality in any meaningful way, their relationship with evoked brain potentials seems to be rather significant. The zero order and partial correlation analyses showed that some part of the N1 latency-extraversion relationship could be ascribed to abstract thinking. A similar pattern could also be observed in the analyses of correlation between extraversion and N1-amplitude, N2-component and SW activity latency. Furthermore, extraverts showed shorter latencies while waiting for the stimulus presentation or between trials while resting, and this negative correlation was even higher when partialized for abstract thinking.

Despite the limitations of this study, such as low task difficulty, one task modality, small number of electrodes, and sample homogeneity in both extraversion and abstract thinking, there are clear indications that subjects' intelligence level can moderate the relationship between extraversion and EPs. In the interdisciplinary field of investigating evoked brain potentials and psychological variables similar studies are very scarce, which adds to the novelty and importance of our results. In conclusion, as it seems that the intellectual level of subjects has a significant role within the extraversion-EPs relationship, especially in the SW-latency parameters, our findings imply a need for analyzing and interpreting individual differences in cortical arousal by using the measures of both personality and intelligence.

REFERENCES

Barrett, P. T., & Eysenck, H. J. (1994). The relationship between evoked potential component amplitude latency, contour length, variability, zero-crossing, and psychometric intelligence. *Personality and Individual Differences, 16*(1), 3-32.

Bates, T., & Eysenck, H. J. (1993). String length, attention and intelligence: Focused attention reverses the string length–IQ relationship. *Personality and Individual Differences, 15*(4), 363-371.

Beauducel, A., Brocke, B., & Leue, A. (2006). Energetical bases of extraversion: Effort, arousal, EEG, and performance. *International Journal of Psychophysiology, 62,* 212-223.

Brebner, J., & Cooper, C. (1985). A proposed unified model of extraversion. In J. T. Spence & C. E. Izard (Eds.), *Motivation, Emotion, and Personality* (pp. 219-227). Amsterdam: Elsevier Science Publishers B. V.

Brocke, B., Tasche, K. G., & Beauducel, A. (1996). Biopsychological foundations of extraversion: Differential effort reactivity and the differential P300 effect. *Personality and Individual Differences, 21,* 727-738.

Brocke, B., Tasche, K. G., & Beauducel, A. (1997). Biopsychological foundations of extraversion: Differential effort reactivity and the state control. *Personality and Individual Differences, 22,* 447-458.

Bruneau, N., Roux, S., Perse, J., & Lelord, G. (1984). Frontal evoked responses, stimulus intensity control, and the extraversion dimension. *Annals of the New York Academy Sciences, 425,* 546-550.

Coles, M. G. H., Gratton, G., Kramer, A. F., & Miller, G. A. (1986). Principles of signal acquisition and analysis. In M. G. H. Coles, E. Donchin, & S. W. Porges (Eds.), *Psychophysiology: Systems, processes and applications* (pp. 183-221). New York: The Guilford Press.

Donchin, E., Karis, D., Bashore, T. R., Coles, M. G. H., & Gratton, G. (1986). Cognitive psychophysiology and human information processing. In M. G. H. Coles, E. Donchin & S. W. Porges (Eds.), *Psychophysiology: Systems, processes and applications* (pp. 244-267). New York: The Guilford Press.

Doucet, C., & Stelmack, R. M. (2000). An event-related potential analysis of extraversion and individual differences in cognitive processing speed and response execution. *Journal of Personality and Social Psychology, 78,* 956-964.

Eysenck, H. J. (1947). *Dimensions of personality.* London: K. Paul Trench Trubner.

Eysenck, H. J. (1959). *Manual of the Maudsley Personality Inventory.* London: University of London Press.

Eysenck, H. J. (1967). *Biological basis of personality.* Springfield, IL: Charles C Thomas Publisher.

Eysenck, H. J. (1987). Speed of information processing, reaction time, and the theory of intelligence. In P. A. Vernon (Ed.), *Speed of Information-Processing and Intelligence* (pp. 21-67). Norwood, NJ: Ablex.

Eysenck, H. J. (1994). Personality and intelligence: psychometric and experimental approaches. In R. J. Sternberg & P. Ruzgis (Eds.), *Personality and Intelligence* (pp. 3-31). New York, USA: Cambridge University Press.

Eysenck, H. J., & Eysenck, S. B. G. (1994). *Priručnik za Eysenckove skale ličnosti: EPS-odrasli* [The Handbook for use of Eysencks' personality scales: EPS-adults]. Jastrebarsko: Naklada Slap.

Fink, A., Schrausser, D. G., & Neubauer, A. C. (2002). The moderating influence of extraversion on the relationship between IQ and cortical activation. *Personality and Individual Differences, 33*, 311-326.

Haier, R. J., Robinson, D. L., Braden, W., & Williams, D. (1983). Electrical potentials of the cerebral cortex and psychometric intelligence. *Personality and Individual Differences, 4*(6), 591-599.

Hoormann, J., Falkenstein, M., Schwarzenau, P., & Hohnsbein, J. (1998). Methods for the quantification and statistical testing of ERP differences across conditions. *Behavior Research Methods, Instruments, & Computers, 30*(1), 103-109.

Josiassen, R. C., Shagass, C., Roemer, R. A., & Slepner, S. (1988). Evoked potential correlates of intelligence in nonpatient participants. *Biological Psychology, 27,* 207-225.

Kulenović, A. (2003). *Abstract reasoning test* (*TAM 2003*). Manuscript, Faculty of Humanities and Social Sciences, University of Zagreb, Croatia.

Kulenović, A. (2004, May). *Izabrano netočno rješenje u zadacima višestrukog izbora kao osnovica za poboljšanje dijagnoze mjerenog atributa?* [Selected incorrect answer in multiple choice items as a basis for improvement of the assessment of the construct]. Paper presented at Psychology Days in Zadar, Zadar, Croatia.

Ladish, C., & Polich, J. (1989). P300 and probability in children. *Journal of Experimental Child Psychology, 48*(2), 212-223.

Lindín, M., Zurrón, M., & Díaz, F. (2007). Influences of introverted/extraverted personality types on P300 amplitude across repeated stimulation. *Journal of Psychophysiology, 21*(2), 75-82.

Matthews, G., & Gilliland, K. (1999). The personality theories of H. J. Eysenck and J. A. Gray: A comparative review. *Personality and Individual Differences, 26,* 583-626.

Medelec, Vickers Medical, & Teca Vickers Medical (1996). *SapphireII user manual 003W009A*. England: Author.

Mulder, G. (1986). The concept and measurement of mental effort. In G. R. J. Hockey, A. W. K. Gaillard, & M. G. H. Coles (Eds.), *Energetical issues in research on human information processing* (pp. 175-198). Dordrecht, The Netherlands: Martinus Nijhoff.

Osaka, M., & Osaka, N. (1980). Human intelligence and power spectral analysis of visual evoked potentials. *Perceptual and Motor Skills, 50,* 192-194.

Picton, T. W., Bentin, S., Berg, P., Donchin, E., Hillyard, S. A., Johnson, R. Jr., Miller, G. A., Ritter, W., Ruchkin, D. S., Rugg, M. D., & Taylor, M. J. (2000). Guidelines for using human event-related potentials to study cognition: Recording standards and publication criteria–Committee report, *Psychophysiology, 37,* 127-157.

Polich, J. (1993). Cognitive brain potentials. *Current Directions in Psychological Science, 2,* 175-179.

Polich, J. (1998). P300 clinical utility and control of variability. *Journal of Clinical Neurophysiology, 15*(1), 14-33.

Polich, J., & Herbst, K. L. (2000). P300 as a clinical assay: Rationale, evaluation, and findings. *International Journal of Psychophysiology, 38,* 3–19.

Rhodes, L. E., Dustman, R. E., & Beck, E. C. (1969). The visual evoked response: A comparison of bright and dull children. *Electroencephalography and Clinical Neurophysiology, 27,* 364-372.

Shagass, C., Roemer, R. A., & Straumanis, J. J. (1981). Intelligence as a factor in evoked potential studies of psychopathology: II. Correlations between treatment-associate changes in IQ and evoked potentials. *Biological Psychiatry, 16,* 1031-1040.

Soskis, D. A., & Shagass, C. (1974). Evoked potential tests of augmenting-reducing. *Psychophysiology, 11*(2)*,* 175-190.

Stelmack, R. M., Achorn, E., & Michaud, A. (1977). Extraversion and individual differences in auditory evoked response. *Psychophysiology, 14*(4), 368-374.

Stelmack, R. M., & Campbell, K. B. (1974). Extraversion and auditory sensitivity to high and low frequency. *Perceptual & Motor Skills, 38*(3), 875-879.

Stelmack, R. M., & Geen, R. G. (1992). The psychophysiology of extraversion. In A. Gale & M. W. Eysenck (Eds.), *Handbook of individual differences: Biological perspectives* (pp. 227-254). New York, USA: John Wiley & Sons.

Stelmack, R. M., & Houlihan, M. (1995). Event-related potentials, personality, and intelligence: Concepts, issues, and evidence. In D. H. Saklofske & M. Zeidner (Eds.), *International handbook of personality and intelligence* (pp. 349-365). New York: Plenum Press.

Stelmack, R. M., & Michaud-Achorn, A. (1985). Extraversion, attention, and habituation of the auditory evoked response. *Journal of Research in Personality, 19*(4), 416-428.

Stenberg, G. (1994). Extraversion and the P300 in a visual classification task. *Personality and Individual Differences, 16*(4), 543-560.

Stenberg, G., Rosen, I., & Risberg, J. (1988). Personality and augmenting/reducing in visual and auditory evoked potentials. *Personality and Individual Differences, 9*(3), 571-579.

Stenberg, G., Rosen, I., & Risberg, J. (1990). Attention and personality in augmenting/reducing of visual evoked potentials, *Personality and Individual Differences, 11*(12), 1243-1254.

Sternberg, R. J., & Ruzgis, P. (1994). *Personality and Intelligence.* New York, USA: Cambridge University Press.

Tatalović Vorkapić, S. (2005). *Moždani val P300 i ličnost u vidnoj oddball paradigmi* [Brain wave P300 and personality in the visual oddball paradigm] (Unpublished master thesis). Faculty of Humanities and Social Sciences, University of Zagreb, Croatia.

Tatalović Vorkapić, S. (2009). Biological correlates of P300 and its relationship with extraversion. *Collegium Antropologicum, 33*(4), 1215-1222.

Tatalović Vorkapić, S. (2010). *Odnos između temperamenta, temeljnih dimenzija ličnosti i evociranih mozgovnih potencijala* [The relationship between temperament, basic personality traits and evoked brain potentials] (Unpublished doctoral dissertation). Faculty of Humanities and Social Sciences, University of Zagreb, Croatia.

Tatalović Vorkapić, S., Tadinac, M., Kulenović, A., & Buško, V. (2008). Evoked potentials and abstract thinking. *Review of Psychology, 15*(1-2), 67-76.

Tatalović Vorkapić, S., Tadinac, M., & Rudež, J. (2010). P300 and extraversion in the visual oddball paradigm. *Studia Psychologica, 52*(1), 3-14.

Widaman, K. F., Carlson, J. S., Saetermoe, C. L., & Galbraith, G. C. (1993). The relationship of auditory evoked potentials to fluid and crystallized intelligence. *Personality and Individual Differences, 15*(2), 205-217.

Zurron, M., & Diaz, F. (1998). Conditions for correlation between IQ and auditory evoked potential latencies. *Personality and Individual Differences, 24*(2), 779-287.