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Review

Review of EEG and ERP studies of extraversion personality for baseline and cognitive tasks

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ABSTRACT

According to psychological studies, the most fundamental personality is the extraversion personality. Most studies looking at differences between extroverts and introverts are pen and paper based studies. However, in a few studies, electrophysiological signals were involved. In this paper, we reviewed studies examining extraversion personality using electroencephalography (EEG) and event-related potentials (ERP). It was found that some of the EEG studies claimed that extroverts and introverts can be differentiated using baseline EEG, while some others claimed otherwise. Conflicting findings were also observed in the ERP studies; higher/lower P300 amplitude in extroverts compared to that of introverts in visual stimuli tasks. These various findings are probably due to differences in their experimental protocols, sample size, or age of subjects. Other possible reasons include no consideration given on the main feature of extraversion and the studies only focused on EEG power spectral analysis. We are thus suggesting for future investigations to involve the main feature such as sociability and/or to incorporate more EEG features in the analysis to produce more robust and reliable results. This review constitutes a guidance for research on brain-related conditions of extroverts and introverts and shall be useful in many areas.

1. Introduction

Everyone exhibits a combination of common and unique personality characteristics, which gives each person individuality. This complex combination of characteristics means that individuals possess a unique set of traits, with their own strengths and weaknesses, comprising their personality. A number of studies have highlighted the importance for individuals to know and explore their own personalities (Littauer, 1992; Long, 2002; Roberts, Kuncel, Shiner, Caspi, & Goldberg, 2007) to enhance their strengths and improve their weaknesses. For instance, when a person understands his or her ability to influence people through communication, this may lead him or her to choose a career that involves communication skills.

A number of studies have contributed to the development of a general taxonomy of personality traits, known as the “Big Five” (John & Srivastava, 1999; Wright et al., 2006). The five broad dimensions included in this taxonomy are openness to experience, conscientiousness, agreeableness, neuroticism and extraversion. Extraversion is considered the most fundamental dimension of personality (Costa & McCrae, 1992; Hutcherson, Goldin, Ramel, McRae, & Gross, 2008). Individuals with a high level of extraversion personality, also known as extroverts, can typically be described as chatty, outspoken, active and sociable (John & Srivastava, 1999; Komarraju, Karau, & Schmeck, 2009), while individuals with a low level of extraversion, also known as introverts, can typically be described as quiet, reserved, passive, and less sociable (John & Srivastava, 1999; Zelenski, Santoro, & Whelan, 2012).

Much research has been conducted to explore extraversion in various areas, such as in the measurement of personality via questionnaires (Eysenck & Eysenck, 1975), creativity (O'Connor, Gardiner, & Watson, 2016), intelligence (Wolf & Ackerman, 2005) and group learning (Nussbaum, 2002). Although there were many studies that were interested in the differences between extroverts and introverts, these are the pen and paper based studies, which mainly focused on the behavioural responses. Studies on investigation of extraversion personality in terms of biological basis are still lacking (Lei, Yang, & Wu, 2015) especially in the neuroscience area. Lei et al. (2015) reviewed studies that are related to the extraversion personality on several functional brain imaging modalities, such as the functional magnetic resonance imaging (fMRI), positron emission tomography (PET) and electroencephalography (EEG). Particularly on the EEG modalities, the studies reviewed have been relatively limited and lack a comprehensive understanding of the personality. There also exists discordant findings (Korjus et al., 2015; Lei et al., 2015) regarding EEG and resting state condition. Lei et al. (2015) stated

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that personality could be assessed by the resting state scanning, while Korjus et al. (2015) mentioned otherwise. Although the arguments by Lei et al. (2015) conflicted with Korjus et al. (2015), there exist several studies that have similar suggestions (Hagemann et al., 2009; Tran et al., 2006). Thus, future work needs to be done to investigate the reason behind these diverse conclusions.

In this work, we would like to focus on reviewing the EEG and its derivative event-related potentials (ERP) studies of extraversion personality. The EEG approach could complement the findings because it could measure the brain electrical activity directly and has an excellent temporal resolution as compared to the fMRI and PET (Sanei & Chambers, 2013). Although EEG has certain limitations (i.e. poor spatial resolution), EEG is reasonably priced and is easier to use as compared to the fMRI and PET. It also has been applied in neurofeedback which is one of the brain-based therapies that has been used to enhance cognitive performance (Gruzelier, 2014a, 2014b). This work aims to concentrate on reviewing the studies of EEG baseline or resting condition and cognitive tasks in relation to extraversion personality. First, because discordant findings exist in several studies regarding the EEG resting condition and extraversion personality. Second, the review on cognitive tasks was chosen to be emphasised because it could assist in improving the biological theories of personality traits (Matthews & Gilliland, 1999). Third, comprehensive understanding of different personality traits with their respective electrophysiological signals may assist in finding ways to improve individual's cognitive aptitudes. For instance, individuals who have low working memory performance (Klimesch, 1999) could have neurotherapy (Escolano, Aguilar, & Minguez, 2011; Gruzelier, 2014a) explicitly tailored to their personality traits and brain signals. After reviewing the previous studies, we summarise the findings and provide some suggestions that may be valuable for future work.

1.1. Extraversion personality

In 1921, Jung became the first person to introduce the term extraversion and introversion (Jung, 1923). Based on Jung's work, extroverts are defined as individuals who prefer the external world of things, people, and activities, while introverts prefer the internal world of their own thoughts and feelings (Jung, 1923). Since then, many studies have investigated the characteristics of extroverts and introverts (Cattell, Eber, & Tatsuoka, 1980; McCrae & Costa, 1987). For instance, McCrae and Costa (1987) defined extroverts as friendly, talkative, sociable, fun-loving, affectionate and spontaneous, while introverts were defined as aloof, quiet, retiring, sober, and inhibited (McCrae & Costa, 1987). Cattell et al. (1980) defined extroverts as outspoken, warm, lively, bold and self-reliant, while introverts were defined as reserved, serious, shy, and group-oriented. As it can be seen, the definitions are slightly different but all studies provide a clear understanding in the characteristics of extroverts and introverts (Cattell et al., 1980).

After >90 years, the main feature of extraversion is still debatable. Some studies mentioned that sociability is the main feature (McCrae & Costa, 1987), while other studies mentioned otherwise. In the late 20th century, Depue and Collins (1999) investigated several important characteristics of extraversion personality including sociability based on various studies (Cattell et al., 1980; Costa & McCrae, 1985; Depue & Collins, 1999; Eysenck & Eysenck, 1975). The characteristics were interpersonal engagement, activation, impulsivity-sensation seeking, positive emotions and optimism (Depue & Collins, 1999). Among the characteristics, the authors suggested interpersonal engagement was one of the main characteristics of extraversion, which consists of two components, namely sociability and agency (Depue & Collins, 1999). They defined sociability or affiliation as an embodiment of friendly and warmth interpersonal bond, while agency as a motivational character that includes social dominance, determination, supremacy, efficacy, and accomplishment. The authors also suggested that extraversion is closely associated with positive incentive motivation based on their findings (Depue & Collins, 1999).

In 2000, a study found that sociability was not the main feature of extraversion (Lucas, Diener, Grob, Suh, & Shao, 2000). They argued that sensitivity to reward is the central characteristic of extraversion rather than sociability, although sociability is certainly a vital part of extraversion. However, this study did not investigate enjoyment of rewarding and non-rewarding of extraverts and introverts in social and non-social conditions. Some researchers have supported the statement by Lucas et al. (2000) that claimed sociability is not the main feature of extraversion (Ashton, Lee, & Paunonen, 2002). However, their suggestion is contrary to Lucas et al. (2000), which reward sensitivity as not the main feature of extraversion, but social attention. The contradiction arose as Lucas et al. (2000) did not include the assessment of social attention in their study.

The argument on the main characteristics of extraversion is still ongoing. In 2008, a study investigated the reason behind a strong correlation between the positive affect and extraversion that leads to social participation (Srivastava, Angelo, & Vallereux, 2008). The study claimed that extroverts perform greater in social interaction than introverts, which increases the positive affect of extroverts. This result is supported by Pavot, Diener, and Fujita (1990) that mentioned extroverts might be happier simply because they spend a greater amount of time in social contact with others (Pavot et al., 1990). The explanation for higher happiness levels among extroverts is parallel to a study that claimed extroverted moments are typically more enjoyable than introverted moments (Fleeson, Malanos, & Achille, 2002). Therefore, based on these studies (McCrae & Costa, 1987; Pavot et al., 1990; Srivastava et al., 2008), it shows that sociability or social participation could be the main feature of extraversion personality.

Due to the substantial differences in social participation between extroverts and introverts, researchers have conducted many studies to explore this differentiation in various domains, such as collaborative learning and creativity (Nussbaum, 2002; O'Connor et al., 2016). In the area of collaborative learning, previous studies have reported that introverted students have higher levels of hesitation to share their ideas or solutions than extroverted students during group discussions (Antonenko, 2014; Nussbaum, 2002). This situation might lead to introverts being rarely contradicting with other group members and preferring to redesign the ideas or solutions, whereas extroverts tend to be providing more contradictory ideas and engaging in more confrontational language (Nussbaum, 2002). In the area of creativity, O'Connor et al. (2016) investigated the effectiveness of ideation skills and relaxation-focused creativity training on short-term improvement among introverts and extroverts (O'Connor et al., 2016). They found that relaxation training was mostly beneficial for introverts, whereas ideation skills training was more effective for extroverts. This is because introverts preferred quiet and generally non-arousing environment, while extroverts sought stimulating environments (O'Connor et al., 2016).

1.2. Extraversion and electrophysiological approach

Neuropsychology is part of psychology that focuses on how the brain and the rest of the nervous system influences an individual's cognitive and behaviours. By understanding how the brain influences individual differences in cognition and behaviour, it will possibly help in finding ways to develop their cognitive aptitudes according to their personality type. For instance, if a healthy person was found having weak working memory skills by referring to their personality type and brain signals, that person could have a neurofeedback training (Escolano et al., 2011; Gruzelier, 2014a) to enhance their working memory skills.

In the neuropsychology area, the concept of brain arousal has been widely used (Duffy, 1957; Eysenck, 1967; Wickens, Hollands, Banbury, & Parasuraman, 2015) in investigating extraversion personality and brain signals. In this area, arousal denotes a person's level of systematic change in their brain activity that can also be obtained through an electroencephalography (EEG). For example, a calm person who had a high amplitude of low frequency alpha waves (EEG result) showed a less cortical arousal (Duffy, 1957). In contrast, a nervous person who had a low amplitude of high frequency alpha waves displayed a high cortical arousal. One of the most influential theories of extraversion based on the cortical arousal was proposed by Eysenck (1967), which is related to the ascending reticular activating system in the brain (Cox-Fuenzalida, Angie, Holloway, & Sohl, 2006; Eysenck, 1967). According to this theory, extroverts tend to exhibit lower levels of ascending reticular activating system activity as compared to that of the introverts (Eysenck, 1967). Consequently, extroverts exhibit lower levels of cortical arousal, while introverts exhibit a greater cortical arousal. In the EEG domain, high and low arousal are defined in terms of the alpha amplitude and frequency (Golan & Neufeld, 1996; Schmidtke & Heller, 2004; Tran et al., 2006). For instance, a high frequency alpha wave activity with a low amplitude represents a high level of cortical arousal, while a low frequency alpha wave activity with a high amplitude represents a low level of cortical arousal (Tran, Craig, & McIsaac, 2001).

In 1974, Brebner and Cooper investigated extraversion personality with respect to the stimulus analysis and response organisation (Brebner & Cooper, 1974). They mentioned that extroverts grow their characteristic of low arousal from response organisation, while introverts' characteristic of high arousal makes them tend to derive inhibition from response organisation and prefer stimulus analysis. In other words, they described “extrovert is geared to response” and “introvert is geared to inspect” (Brebner & Cooper, 1974; p. 273). This description is similar to Gale, Coles, and Blaydon (1969) that mentioned extroverts are easily adapted to response as compared to introverts (Gale et al., 1969).

Other than the arousal theory, Gray used the behavioural inhibition system (BIS) and the behavioural activation system (BAS) in describing extroverts and introverts (Gray, 1970 & 1981). The author explained BIS relating to the response of introverts and extroverts towards punishment and non-reward condition, while BAS relating to the responses towards reward sensitivity (Gray, 1981 & 1987). In terms of the punishment condition, introverts displayed a higher level of fear towards punishment and non-reward as compared to the extroverts (Gray, 1970). This suggestion is associated with Eysenck's theory that mentioned introverts to have higher arousal than extroverts, therefore it leads to introverts having high sensitivity to punishment and non-reward conditions. For the BAS interpretation, extroverts are found to be more motivated by incentives than introverts (Gray, 1981).

Matthews and Gilliand prepared a comparative review between Eysenck's and Gray's personality theories (Matthews & Gilliland, 1999). The authors claimed both theories are still applicable in the neuropsychology area but it is limited only to certain events. For instance, Gray's theory could be used in studies related to motivation, while Eysenck's theory is beneficial in interpreting the individual's differences in connection with the brain function (Matthews & Gilliland, 1999). They suggested that the development of a methodology could provide an improvement in the biological theories, specifically where the research should focus more on the cognitive or social bases of personality.

2. Methods

A literature search was performed using the database Google Scholar. The following search terms were entered with regards to extraversion personality: “EEG”, “ERP”, “extraversion”, and “introversion”. The EEG and ERP studies of extraversion personality based on baseline and cognitive tasks were selected. Web of Science was used to check the quality of the literature's publication. Only journals written in the English language with a 2015 ranking of quartile 2 (Q2) and above were included.

3. Results

A total of 21 studies fulfilled the inclusion criteria. For the method of data acquisition, four studies utilized EEG and baseline, while five and twelve studies utilized EEG and ERP studies, respectively, in various cognitive tasks for extraversion personality. The detailed information on the included studies are presented in Tables 1 and 2 for EEG studies of extraversion during baseline condition and cognitive tasks, respectively, and Table 3 for ERP studies of extraversion during cognitive tasks.

3.1. EEG studies

A number of EEG studies have examined the extraversion – introversion dimension (Gale, 1983; Gale et al., 1969). The studies can be divided into two categories, which are extraversion and EEG during baseline condition and extraversion and EEG during cognitive tasks. Thus, in this section, we divided the studies based on these two categories.

3.1.1. EEG and baseline condition

Tran et al. (2001) used EEG to investigate the relationship between brain activity and extraversion personality (Tran et al., 2001). EEG was recorded while participants performed a series of eyes open (EO) for 20 s, followed by alert (A) for 20 s, eyes closed (EC) for 20 s and alert for 20 s (EO-A-EC-A), repeated three times (Tran et al., 2001). The results revealed that extroverts were three times more likely to exhibit greater amplitude of alpha wave (8–13 Hz) than that of introverts (Tran et al., 2001). These results supported the Eysenck's theory of extraversion (Eysenck, 1967) that claimed the high amplitudes of alpha wave represented the low level of arousal and vice versa (Schmidtke & Heller, 2004).

Tran et al. (2006) investigated the relationship between resting brain activity and personality (Tran et al., 2006); measuring four frequency bands over the whole cortex using EEG spectral magnitude under EC condition. The results indicated that greater low-frequency activities (delta and theta) during the resting state were associated with higher levels of extraversion in males. The authors concluded that at least some personality traits (e.g. extraversion) are connected with resting brain activity (Tran et al., 2006). This conclusion is similar to Tran et al. (2001) that suggested extraversion personality can be assessed using resting brain activities (EO and EC).

The arousal hypothesis of extraversion was further examined by Hagemann et al. (2009) using EEG alpha activity as a measure of cortical arousal (Hagemann et al., 2009). They recorded four baseline measurements under EO condition and four under EC condition, in a counterbalanced order e.g., EO-EC-EC-EO – EC-EO-EO-EC. Importantly, this method of baseline recording is unlikely to evoke self-regulating behaviour or transmarginal inhibition (i.e. individual response to overwhelming stimuli), facilitating the assessment of cortical arousal (Gale, 1983). Following the baseline recording, the participants were made to complete tasks involving presentation of visual stimuli and a reaction time task. In addition, the skull thickness of each participant was also measured using magnetic resonance imaging (MRI). The results revealed that neither external factors nor skull thickness affected the positive correlation between alpha activity and extraversion. This result is consistent with the arousal hypothesis, and suggests that external factors do not account for the inconsistency of empirical findings.

In 2015, Korjus et al. (2015) investigated the feasibility of predicting personality characteristics based on resting state EEG, using EC and EO conditions (Korjus et al., 2015). They used resting state of EEG data (EC and EO) between 1 to 3 min as their experimental tasks. In addition, they applied a machine learning algorithm to build a classifier for predicting individual differences in the Big 5 personality traits from power spectral of the recorded EEG data. The results provided no support for the notion that personality traits can be predicted from resting state EEG data (Korjus et al., 2015). This finding is contrary to the findings of Hagemann et al. (2009) and Tran et al. (2006). They, on the other

Table 1
Summary of EEG studies of extraversion personality during baseline condition.

Study	N	Age (years)	Personality test	Stimuli	Findings
Tran et al. (2001)	50 (26 M; 24 F)	22–60	16PF	EO for 20 s, alert for 20 s, EC for 20 s and alert for 20 s; repeated three times.	Extroverts were three times more likely to exhibit greater amplitude in the 8–13 Hz range. Conversely, introverts were more likely to exhibit lower levels of 8–13 Hz waves.
Tran et al. (2006)	699 (340 M; 359 F)	18–82	NEO-FFI	EC	Delta and theta activities were consistently mildly significantly associated with extraversion personality in the whole cortex in males.
Hagemann et al. (2009)	49 (24 M; 25 F)	Mean age: 24	EPQ-R	EO-EC-EC-EO – EC-EO-EO-EC	Skull thickness and other external factors did not affect the positive correlation between alpha activity and extraversion.
Korjus et al. (2015)	289 (102 M, 187 F)	18–42	EE.PIP-NEO inventory and FFM	1–3 min of EC and EO	Personality traits including extraversion could not be predicted from the resting state EEG data

Note: M = males; F = females; 16PF = 16 Personality Factors; NEO-FFI = Neuroticism-Extraversion-Openness Five-Factor Inventory; EPQ-R = Eysenck Personality Questionnaire-Revised; EE.PIP-NEO inventory = Estonian Personality Item Pool NEO inventory; FFM = Five Factor Model; EC = eyes closed; EO = eyes open.

hand, claimed that resting state EEG could be used to differentiate between extroverts and introverts. These contradictory findings could be due to the differences in the experimental protocol of the baseline recordings adopted in these studies (as described earlier).

3.1.2. EEG and cognitive tasks

A number of researchers, including Matthews and Amelang (1993), reported that they found no clear proof that extroverts show low arousal on EEG measures (Matthews & Amelang, 1993). They conducted some studies to investigate the performance of individuals exhibiting extraversion personality in various tasks such as information-processing ability, psychomotor function and perception using EEG variables (Matthews & Amelang, 1993). In their studies, EEG power spectral were examined while participants with different levels of extraversion performed the given tasks (Matthews & Amelang, 1993). The results revealed that extroverts exhibited superior performance when alpha activity was low, while introverts exhibited superior performance when alpha activity was high (Matthews & Amelang, 1993). This means that extroverts prefer high arousal condition, and introverts prefer low arousal condition (e.g. silence environment) (Bates & Rock, 2004).

Fink, Schrausser, and Neubauer (2002) investigated the relationship between the level of cortical activation, IQ, and extraversion (Fink et al., 2002). The researchers used an elementary cognitive task modified from Posner and Mitchell's (1967) classic letter matching task (Posner & Mitchell, 1967). EEG in form of an event-related desynchronization (ERD) was measured during the task performance (Fink et al., 2002). ERD refers to the desynchronization of alpha activity or a decrease in alpha power associated with cortical activation (Fink et al., 2002; Pfurtscheller, 2001). The results revealed a significant relationship between IQ and extraversion in the lower alpha band, with an inverse relationship between IQ and cortical activation during resting conditions in introverts (Fink et al., 2002). However, during cognitive tasks, extroverts with low IQ exhibited greater cortical activation (Fink et al., 2002). Thus, these results provide mixed support for Eysenck's (1967) arousal theory; during the resting condition, only low-IQ individuals exhibited Eysenck's predicted pattern of lower cortical arousal in extroverts compared to introverts. However, during cognitive tasks, only high-IQ individuals exhibited activation levels in accord with Eysenck's (1967) hypothesis (Fink et al., 2002).

Fink and Neubauer (2004) investigated the effect of task complexity on extraversion personality and the level of cortical activation (Fink &

Table 2
Summary of EEG studies of extraversion personality during various cognitive tasks.

Study	N	Age (years)	Personality test	Stimuli	Findings
Matthews and Amelang (1993)	181 (79 M; 102 F)	50% of the subjects were students; the other 50% were working people, housewives or underemployed.	EPI, EPQ and EIS.	Tests of perception, information-processing, ability and psychomotor function.	Extroverts performed better when low in alpha while introverts performed better when high in alpha.
Fink et al. (2002)	60 (29 M; 31 F)	18–49	NEO-FFI	Matching task.	Introverts exhibited an inverse relationship between IQ and cortical activation during resting conditions. During cognitive tasks, extroverts with low IQ exhibited more activation than those with high IQ.
Fink and Neubauer (2004)	65 (33 M; 32 F)	18–52	NEO-FFI	A modified version of Stankov's Triplet Numbers Test. It consists of five increasingly complex condition.	In the less complex condition, introverts exhibited lower cortical activation than extroverts. But, in the more complex condition, higher cortical activation was found in introverts as compared to that of extroverts.
Fink et al. (2005)	62 (30 M; 32 F)	18–52	NEO-FFI	Short-term memory task (STM task); working memory task (WM task); central executive (CE) task; reaction time (RT) task.	Introverts exhibited stronger event-related desynchronization than extroverted individuals.
Fink and Neubauer (2008)	34 (17 M; 17 F)	Mean age: 34.9	NEO-FFI	Insight (IS), utopian situations (US), alternative uses (AU), word ends (WE).	Extroverted individuals who produced highly original ideas during task performance exhibited the highest level of alpha power, while introverted individuals who produced fewer original ideas exhibited the lowest level of alpha power.

Note: M = males; F = females; EPI = Eysenck Personality Inventory; EPQ = Eysenck Personality Questionnaire; EIS = Eysenck Impulsiveness Scale; NEO-FFI = Neuroticism-Extraversion-Openness Five-Factor Inventory.

Table 3
Summary of ERP studies of extraversion personality during various cognitive tasks.

Study	N	Age (years)	Personality test	Stimuli	Results: P300
Ditraglia and Polich (1991)	32 (16 introverts; 16 extroverts)	20.5 ± 2.2	MBTI and EPQ	Two-tone auditory with two trial blocks (1000 and 2000 Hz tones presented at 60 dB SPL)	Extroverts and introverts produced similar P300 patterns in block 1. However, during block 2, for extroverts, the amplitude decreased, and for introverts there was no change between the two blocks.
Cahill and Polich (1992)	48 (24 M; 24 F)	19.9 (undergraduate students)	MBTI and EPQ	Two-tone auditory (1000 and 2000 Hz tones) with four levels of probability of the target stimulus (0.2, 0.4, 0.6, 0.8).	P300 amplitude smaller for introverts than extroverts, but extroverts dropped across target stimulus probability (0.2, 0.4, 0.6 and 0.8).
Polich and Martin (1992)	54 (27 M; 27 F)	19.4	MBTI and EPQ	Two-tone auditory stimuli.	Male subjects with high introversion personality induced larger amplitude of P300 than male subjects with high extraversion personality.
Ortiz and Maojo (1993)	20 (9 introverts; 11 extroverts)	18–22 years old	EPI	Auditory oddball task (mentally count the 2000 Hz tones from series of 420 tones)	Introverts showed larger amplitude than extroverts
Stenberg (1994)	40 (22 M; 18 F)	24.7 (18–46)	EPI	Visual stimuli: click of mouse button when a photo in assigned category appear.	P300 amplitude was greater for extroverts than ambiverts, and greater for ambiverts than introverts.
Brocke et al. (1996)	Study 1: 23 Study 2: 31	University students	EPI	Auditory oddball task with vigilance condition.	Introverts exhibited significantly greater P300 amplitude under conditions of vigilance, compared with extroverts.
Brocke et al. (1997)	18	University students	EPI	Visual vigilance task under three different conditions of white noise: baseline (0 db SPL), 40 db SPL, and 60 db SPL.	In the baseline and 40 db condition, introverts displayed greater P300 amplitudes. In the 60 db condition, extroverts displayed greater P300 amplitudes.
Doucet and Stelmack (2000)	67	18–30	EPQ-R	Auditory stimuli: constantly click the home button and response to certain tone by pressing different button located in different location (0, 7, 15, 23 cm).	No significant difference in P300 amplitude and P300 latency between extroverts and introverts
Rammsayer and Stahl (2004)	28 (F only)	19–47 (undergraduate students)	EPQ-R	Auditory stimuli: response to certain tone by pressing two different buttons.	No significant difference in P300 amplitude between extroverts and introverts. But, introverts exhibited shorter P300 latency than extroverts.
Gurrera et al. (2005)	33 (28 M; 15 F)	18–51	NEO-FFI	Standard oddball auditory discrimination paradigm.	Extroverts exhibited greater P300 amplitude than introverts.
Beauducel et al. (2006)	81 (41 M; 40 F)	18–31 (students)	EPQ-R	60-min binaural presentation of a series of 1 kHz tone bursts at 79 dB SPL, at a rate of one every 3 s via NeuroScan STIM earphones.	Introverts exhibited larger P300 amplitude than extroverts.
Stauffer et al. (2012)	100 (F only)	18–30	EPQ-R	Visual short-term memory task.	Extroverts exhibited greater P300 amplitude than introverts.

Note: M = males; F = females; MBTI = Myers-Briggs Type Indicator; EPQ = Eysenck Personality Questionnaire; EPI = Eysenck Personality Inventory; EPQ-R = Eysenck Personality Questionnaire-Revised; NEO-FFI = Neuroticism-Extraversion-Openness Five-Factor Inventory.

Neubauer, 2004). The authors used a modified version of Stankov's Triplet Numbers test where the participants needed to answer correctly the number of mental operation task. The test consists of five increasingly complex conditions. The results revealed that in the more complex condition tasks, a higher cortical activation was found in the introverts as compared to the extroverts. But in the less complex condition tasks, the introverts exhibited lower cortical activation than the extroverts. It showed that the result of the more complex condition supported the theory by Eysenck (1967), but the less complex condition showed otherwise (Fink & Neubauer, 2004). These findings indicated that task complexity plays an important role in the extraversion personality.

In another study, Fink, Grabner, Neuper, and Neubauer (2005) examined the effects of extraversion personality during a working memory task (Fink et al., 2005). In this study, participants were asked to perform a counting span task, in which 10 digits containing values between 2 and 7 were displayed in a random arrangement on a screen. The digits were displayed in either blue or red, and were a mixture of odd and even numbers. On each trial, participants were instructed to calculate a specified subgroup of digits (e.g., "blue even", "blue odd", "red even" or "red odd", respectively) as accurately and quickly as possible. The results indicated that introverts exhibited greater ERD than extroverts (Fink et al., 2005). Since alpha power is known to be prominent in the state of relaxation and inhibition (SAVAGE, 1964; Tran et al., 2001), these results supported that introverts tend to think carefully before delivering their answer (Eysenck, 1981).

In another EEG study, Fink and Neubauer (2008) investigated the relationship between extraversion personality and performance on four different creative idea generation tasks: 1) insight, 2) utopian situations, 3) alternative uses and 4) word ends (Fink & Neubauer, 2008). The results revealed that extroverts, who demonstrated highly original ideas during task performance exhibited the highest level of alpha power, while introverts, who produced fewer original ideas exhibited the lowest level of alpha power (Fink & Neubauer, 2008). This could be due to introverts tend to think carefully before giving their ideas (Eysenck, 1981) and therefore leading to produce fewer original ideas during the task given.

In these EEG studies, variation of results was noticed. This is probably due to certain causes that will be discussed further in Section 4. For the next section, we discuss on the derivative of EEG, event-related potentials (ERP), as ERP based studies might assist us in the investigation of extroverts' and introverts' cognitive capability.

3.2. Event-related potentials (ERP) studies

Event-related potentials (ERP) are EEG signals that are measured as cortical responses to specific cognitive, sensory or motor events (Luck, 2005; Sanei & Chambers, 2013). The ERP provide a versatile technique for studying diverse populations, and can provide information about a broad range of affective and cognitive processes (Luck, Woodman, & Vogel, 2000; Raz, Dan, Arad, & Zysberg, 2013). The ERP are typically generated by responses that are directly related to external stimulation, and are elicited as somatosensory, auditory, or visual brain potentials that can be either positive or negative. The results of ERP are represented by the letter P (i.e., the P100 or P300) for positive voltage whereas negative voltage is represented by the letter N (i.e., the N170 or N400). The digits in the name indicate the number of milliseconds after stimulus presentation at which the potential typically appears.

In 1991, some researchers examined ERP in response to auditory stimuli in a group of extroverted and introverted students (Ditraglia & Polich, 1991). The researchers used the Eysenck Personality Questionnaire (EPQ) and Myers-Briggs Type Indicator (MBTI) to divide the students into the two categories (extroverts and introverts). Participants were required to perform a two-tone auditory task with two trial blocks (1000 and 2000 Hz tones presented at 60 dB SPL). The results showed that extroverts and introverts produced similar P300 patterns in block 1. However, during block 2, for extroverts, the P300 amplitude was significantly smaller than that in block 1, and for introverts there was no change in the P300 amplitude between the two blocks. Based on the results obtained, the authors mentioned that the P300 could be an indicator for attention to the tasks (Ditraglia & Polich, 1991).

Cahill and Polich (1992) also investigated the relationship between the P300 and extraversion personality using a two-tone auditory task as their experiment stimuli (Cahill & Polich, 1992). The experimental paradigm involved a sequence of 1000 Hz standard tones and 2000 Hz target tones. The target tone appeared at random with a probability of 0.20, 0.40, 0.60, or 0.80 in different conditions. The results revealed that P300 amplitude showed a significant interaction with personality difference and target probability, and that these interaction effects were smaller for the introverted students than the extroverted students. They claimed that the extroverts are more sensitive to the target stimuli probability than that of the introverts. They found that for extroverts, the P300 amplitude decreased as probability increased (0.2, 0.4, 0.6 and 0.8). In contrast, introverts tended to display larger P300 components than extroverts across all conditions. This may be a result of extroverts tending to react more strongly at the beginning but decreasing more rapidly with repeated presentations, while introverts sustained greater electrophysiological responsivity across trials (Cahill & Polich, 1992; Eysenck, 1967). The authors concluded that the effect of personality differences on the P300 can provide valuable information about this ERP component and its connection to both the physiological and the psychological factors that affect its normal variation (Cahill & Polich, 1992).

Polich and Martin (1992) conducted a study using a similar paradigm to that used in two earlier studies (Cahill & Polich, 1992; Ditraglia & Polich, 1991), and additionally examined the relationship between ERP and Raven's Matrices performance (Polich & Martin, 1992). The results revealed no relationship between ERP values and Raven's Matrices scores, although participants' grade point average was negatively correlated with P300 latency (delay between stimulus and response). In addition, they reported that male subjects tended to exhibit a correlation between ERP and extraversion personality. They claimed that male introverts exhibited greater P300 amplitude than male extroverts (Polich & Martin, 1992). However, female subjects did not demonstrate this relationship between ERP and extraversion personality. The cause for this variation was not really clear but probably due to the influence of other personality dimension (Polich & Martin, 1992).

In addition to auditory stimuli, Ortiz and Maojo (1993) investigated P300 amplitudes for extroverts and introverts using auditory stimuli (Ortiz & Maojo, 1993). In the experiment, they used auditory stimuli that contained 420 tones and the subjects needed to count silently the 2000 Hz tones in the series. The results showed introverts displayed greater amplitudes than extroverts at Fz, Cz and Pz. These results indicated that an increase of P300 amplitude equal to an increase in the cortical response, thus supported the theory of extraversion personality by Eysenck where introverts has greater cortical arousal than extroverts.

In 1996, some researchers examined the relationship between the P300 and extraversion personality using the auditory oddball task, with a condition involving the typical duration of a vigilance task (40 and 32 min for low-difficulty and high-difficulty-tasks, respectively) (Brocke, Tasche, & Beauducel, 1996). Unlike an earlier study by Ditraglia and Polich (1991), task duration was included as an experimental variable, because task duration can be used to manipulate effort and arousal (Brocke et al., 1996). In addition, an auditory vigilance task with two levels of difficulty was used. The results revealed that, for a low-difficulty auditory vigilance task, introverts exhibited greater P300 amplitude than that of extroverts. However, no differences in terms of performance parameters was observed for low-difficulty tasks. During a more difficult task, greater P300 amplitude was observed among introverts compared to extroverts, and with the strongest activation at frontal regions. Unlike the low-difficulty tasks, there were significant differences in some performance parameters, including a lower decision criterion among extroverts, indicating that they displayed greater readiness to respond. The authors concluded that introverts exhibited significantly greater P300 amplitude under conditions of vigilance, compared with extroverts (Brocke et al., 1996). This means that vigilance task influences the performance of extroverts and introverts.

Other than auditory stimuli, some studies have investigated the P300 using visual stimuli (Brocke, Tasche, & Beauducel, 1997; Stenberg, 1994). These studies usually focused on the P300 since it could be produced when the subjects were involved in cognitive processing of stimuli (Stenberg, 1994). For instance, Stenberg (1994) investigated the relationship between extraversion personality and the P300 using a visual task involving picture stimuli (Stenberg, 1994). In this study, participants were divided into three categories: low (introverts), medium (ambiverts) and high (extroverts) levels of extraversion. In the experimental task, participants were asked to view visual stimuli and to click the mouse button as soon as a picture in the designated target category appeared. There were three categories: color, semantic, and both (color and semantic). The results revealed that the amplitude of the P300 was greater for extroverts than ambiverts, and greater for ambiverts than introverts, in posterior regions. However, it should be noted that this study did not include task duration as a variable.

In another study, Brocke et al. (1997) investigated the relationship between extraversion personality and the P300 using visual stimuli and three conditions of sound pressure level stimuli (SPL) (Brocke et al., 1997). This paradigm was designed to involve tasks of different levels of difficulty in order to investigate the level of performance of extroverts and introverts when the extra pressure was added. In this experimental paradigm, the baseline simulation (0 db) was measured, followed by applying 40 db SPL and 60 db SPL of white noise. The results revealed that the P300 amplitudes of introverts were increased between the baseline and 40 db, then were decreased between 40 db and 60 db; while the P300 of extroverts were increased in all three conditions. Between the introverts and extroverts, introverts exhibited greater P300 amplitudes during the baseline and 40 db SPL conditions as compared to extroverts, whereas extroverts exhibited greater P300 amplitudes in response to 60 db SPL (Brocke et al., 1997). These results suggested that the P300 amplitudes could be an indicator where individuals with different levels of extraversion exhibited different P300 amplitudes. It gives support to the theory that introverts have a high level of cortical arousal and extroverts have a low level (Eysenck & Eysenck, 1985), where it is thought that individual with high arousal is easier to be influenced by additional pressure.

In 2000, ERP has been used to investigate the differences between introverts and extroverts in the cognitive processing speed and response execution (Doucet & Stelmack, 2000). These researchers used simple reaction time task where the participants were required to respond to different cue words by pressing a different button located in different location. The results showed that the P300 amplitude increased when the distance of the response button from the home button was increased. However, there was no significant difference in the P300 amplitude between extroverts and introverts. Regarding the P300 latency, it increased when the intensity of auditory stimulus was increased. Also, there was no significant difference in the P300 latency between extroverts and introverts (Doucet & Stelmack, 2000). Therefore, the P300 results of this simple task could not differentiate between introverts and extroverts in terms of cognitive processing speed.

Rammsayer and Stahl (2004) investigated the differences between introverts and extroverts in stimulus analysis and response organisation (Rammsayer & Stahl, 2004). The auditory stimulus was used and the participant needed to response to the certain tones in the experiment tasks. The results revealed that the average response time for introverts was 412 $\pm$ 47 ms and for extroverts was 404 $\pm$ 53 ms. However, there was no significant effect on extraversion in terms of response time ($p > 0.1$). Regarding the ERP results, there was no significant difference in the P300 amplitude between the extroverts and introverts. However, for the P300 latency, an indicator of speed in the stimulus analysis showed that the introverts and extroverts significantly exhibited mean P300 latencies of 320 $\pm$ 32 ms and 351 $\pm$ 38 ms, respectively.

Gurrera, Salisbury, O'Donnell, Nestor, and McCarley (2005) investigated the relationship between the P300 and personality, using a range of neuropsychological tasks, including the auditory oddball paradigm, the Wechsler Adult Intelligence Scale Revised (WAIS-R) and the Trail Making Test (Gurrera et al., 2005). The WAIS-R comprises four types of test that cover tasks on information, vocabulary, digit span, and digit symbol. These tests were chosen because they provide standardized measures of semantic memory or working memory, and because they would be expected to differ in their relationship to P300 latency, which is the time elapsed from stimulus onset to peak amplitude of P300. The results revealed that P300 amplitude positively related to extraversion, openness, agreeableness and conscientiousness, and negatively related to neuroticism. Based on these results, the authors concluded that greater P300 amplitude was associated with more typical personality scores (someone behaviour fall under society's norm) and better neuropsychological performance (Gurrera et al., 2005).

In 2006, some researchers investigated effort of extroverts and introverts based on Eysenck theory by using 60-min binaural presentation of a series of 1 kHz tone bursts at 79 dB SPL, at a rate of one every 3 s via NeuroScan STIM earphones. (Beauducel, Brocke, & Leue, 2006). During the given task, the participants were required to indicate how many tones were present. Participants were required to perform 10-min pre- and post-test with feedback, and the 40-min central block without feedback. All related performance parameters including hits were analyzed, together with the EEG data. The results revealed P300 for hits parameter, introverts exhibited larger P300 amplitude than extroverts. This indicated that a lower performance (hits) of extraverts were obtained. This result support previous suggestion that mentioned these P300 amplitudes could be an effort indicator.

Stauffer, Indermühle, Troche, and Rammsayer (2012) used ERP to investigate the relationship between extraversion and short-term memory (Stauffer et al., 2012). This study used a visual short-term memory task in which participants were presented with color stimuli. In each trial, a color appeared on a screen, and participants were instructed to press the appropriate key to indicate whether the stimulus was the same or different in color to the previously presented stimulus. Participants were instructed to respond as quickly and as accurately as possible. The results revealed no differences in P300 amplitude between introverts and extroverts when there was no color-change. However, extroverts were found to exhibit greater P300 amplitude under the color-change condition. These findings indicated that extroverts were more responsive to the occurrence of a context change than introverts.

4. Discussion

This review sought to explore the relationship between measures of extraversion personality and electrophysiological signals measured with EEG and ERP techniques. In particular, this work aimed to identify areas of consistency in EEG and ERP findings regarding extraversion personality, and to discuss potential avenues for future research. Tables 1 and 2 show a summary of EEG studies of extraversion personality during baseline and cognitive tasks, respectively, while Table 3 shows a summary of ERP studies of extraversion personality during cognitive tasks.

There were several personality assessments that have been used to distinguish between introverts and extrovert, such as Eysenck Personality Inventory (EPI), 16 Personality Factors (16PF), Neuroticism-Extraversion-Openness Five-Factor Inventory (NEO-FFI), Myers-Briggs Type Indicator (MBTI) and more (Tables 1–3). It can be seen in all tables that most studies favoured the personality assessment provided by Eysenck (Tables 1–3). It is due to its capability to appraise factorial validity along with construct and concurrent validity (Simpson, 2007).

As mentioned in Section 1.1, the definitions of extroverts and introverts by numerous studies are slightly different. For example, MBTI exclusively measures a continuous bipolar manner, which are introversion-extraversion, sensation-intuition, thinking-feeling and judging-perceiving (Myers, McCaulley, Quenk, & Hammer, 1998), while NEO-FFI measures neuroticism, extraversion, openness to experience, agreeableness and conscientiousness (Costa & McCrae, 1989). Furnham, Moutafi, and Crump (2003) mentioned that extraversion in NEO-FFI is unsurprisingly linked with the introversion-extraversion dimensions in MBTI (Furnham et al., 2003). For introversion in MBTI, it is linked with neuroticism in NEO-FFI (Furnham et al., 2003). MBTI measurement also slightly different with EPQ, where EPQ measures extraversion, neuroticism, psychoticism and lie (Eysenck, 1968). However, Steele and Kelly (1976) found a positive relation between extraversion and introversion scales of the MBTI and EPQ that display similarity at the self-report questionnaire level in dealing with extraversion and introversion (Steele & Kelly, 1976). Although the definitions are slightly different, all studies provided a clear difference in the characteristics of extroverts and introverts. Therefore, in obtaining a more reliable and robust result of an individual personality, the use of two personality tests is highly recommended. For instance, Ditraglia and Polich (1991) only included subjects for their experiment if the subjects scored the same results from MBTI and EPQ (Ditraglia & Polich, 1991). If the subject scored lower than 15% from EPQ but higher than 15% from MBTI, then the subject will be excluded from the experiment.

Among the large number of studies investigating the neural correlates of extraversion personality, some researchers have reported that baseline or resting state EEG can distinguish between extroverts and introverts (Hagemann et al., 2009; Tran et al., 2001; Tran et al., 2006) (see Table 1). However, a recent study produced a surprising and conflicting result, reporting that it was not possible to predict personality traits from the power spectral of resting state EEG data (Korjus et al., 2015). Unlike the studies by Hagemann et al. (2009), Tran et al. (2006), and Tran et al. (2001) that only applied EEG feature extraction, Korjus et al. (2015) applied machine learning algorithms to build a classifier to predict personality differences from power spectral of the resting state EEG data. After the classification stage, they found that personality difference could not be predicted from resting state EEG data as the power spectral of resting state EEG is extremely noisy (Korjus et al., 2015). Based on these studies, we could not make a solid conclusion regarding the EEG baseline and the extraversion personality as different methods of analysis were used. Thus, using other EEG features in future investigation regarding the EEG baseline and extraversion is highly recommended in order to produce more reliable results. For example, other than focusing only on EEG power spectral analysis, EEG coherence (Achermann & Borbély, 1998) could be included in the analysis of the study. Some researchers used EEG coherence to investigate different arousal level in the rapid eyes movement and the wakefulness condition (Cantero, Atienza, Salas, & Gómez, 1999). As the Eysenck theory stated that introverts and extroverts have different arousal level, the EEG coherence therefore can be suitable for EEG studies of extraversion personality as well. We hypothesised that exploring more EEG features would assist us in enhancing the outcomes of EEG studies of the extraversion personality.

Regarding the studies of EEG and cognitive tasks, the present review revealed that the previous studies have consistently reported a superior performance of the extroverts on a range of cognitive tasks (working memory and idea generation) as compared to the introverts (Fink & Neubauer, 2008; Fink et al., 2005) (Table 2). In the cognitive tasks studies, the EEG evidence suggests that alpha activity during cognitive task performance is inversely related to mental effort (Jaušovec, 2000). It means that less alpha power indicates a greater mental effort, whereas more alpha power indicates a less mental effort. The increase in alpha activity during cognitive task performance may also reflect a state of enhanced alertness or concentration in relation to neural pathways (Knyazev, Savostyanov, & Levin, 2006). In the EEG study of memory performance between extroverts and introverts, Fink et al. (2005) found that the introverts exhibited a larger ERD (refers to a decrease in alpha power) as compared to the extroverts (Fink et al., 2005). The results were observed in two memory performance tasks, which are working memory task and short-term memory (such as temporary maintenance of information) task. Similarity was found during creative task, which the introverts exhibited less alpha power while the extroverts exhibited more alpha power (Fink & Neubauer, 2008). However, in the EEG study of extraversion and IQ task, high IQ introverts showed a decrease of more alpha power (larger ERD) than high IQ extroverts, while low IQ introverts tended to exhibit smaller ERD as compared to that of low IQ extroverts (Fink et al., 2002). It shows that only high IQ introverts and high IQ extroverts supported the Eysenck theory. This result suggests that IQ variable is less suitable in the making of extraversion personality assessment via the EEG as low IQ result did not support the Eysenck theory. However, further study need to be done in order to support this suggestion.

Among a wide range of previous ERP studies, we found contradictory findings regarding extraversion and visual stimuli, where some studies reported that extroverts had larger P300 amplitude (Stauffer et al., 2012; Stenberg, 1994) and existed a study that reported extroverts exhibited lower P300 amplitude (Brocke et al., 1997) (see Table 3). This discrepancy might be a result of differences in the experimental protocols. Differences in subjects' age may have also influenced the results, since Brocke et al., (1997) only tested university students, while other studies involved subjects with a greater range age. Regarding auditory stimuli, we also found contradictory findings where one study reported that introverts exhibited similar patterns to extroverts (Ditraglia & Polich, 1991) and several other studies reported that introverts exhibited greater P300 amplitude (Brocke et al., 1996; Ortiz & Maojo, 1993; Polich & Martin, 1992). Moreover, two studies (Cahill & Polich, 1992; Gurrera et al., 2005) reported that introverts exhibited smaller P300 amplitudes compared with extroverts (see Table 3). These discrepancies may be related to the slight differences in experimental protocol between the studies. Another possible explanation is that the sample size of the studies may have been too small to represent the general population of introverts and extroverts. Regarding the response organisation, several studies found that there is no significant effect of extraversion on the P300 amplitude and response time (Doucet & Stelmack, 2000; Rammsayer & Stahl, 2004). However, Rammsayer and Stahl (2004) found that introverts and extroverts significantly exhibited the mean P300 latencies of 320 ± 32 ms and 351 ± 38 ms, respectively. This result is different than the study done by Doucet and Stelmack (2000) that found no significant difference in the P300 latency between the extroverts and introverts. These discordant findings might be related to the differences in the experimental protocol between these two studies (Table 3).

As mentioned earlier, the results of the EEG and ERP studies of the extraversion personality in the baseline condition and cognitive tasks lead to various findings. The various findings could be due to the differences in experimental protocol, sample size, and age of subjects. Another possible reason could be that the studies did not consider the main feature of extraversion (e.g. sociability) in their task design. However, the argument on the main feature is still ongoing. As discussed in 1.1, we found that sociability or social participation could be the main feature of extraversion personality. It could lead to a positive effect, one of the criteria that is strongly associated with extraversion (Srivastava et al., 2008). Therefore, in the future, we suggest that sociability concept could be involved in the EEG experiment task to distinguish between the introverts and extroverts. This thought to be due to the theory of Brebner and Cooper claimed that "extrovert is geared to response" and "introvert is geared to inspect" (Brebner & Cooper, 1974; p. 273). Based on this theory, we believe extroverts participate in social interactions more than introverts. It is also supported by recent studies that mentioned shyness and sociability could be differentiated by measuring their brain signals (Tang, Santesso, Segalowitz, & Schmidt, 2016). Moreover, this suggestion could help us in investigating the main feature of extraversion using different approach (other than pen and paper based). We also believe by involving this criterion, we could develop an assessment tool for the extraversion personality. Therefore, we provide some ideas of sociability concept that could be applied in the EEG experiment tasks involving extraversion personality (Fig. 1).

5. Conclusion

This work was devoted to reviewing several studies involving extraversion personality and neuro-electrophysiological signals (i.e., EEG and ERP). It was found that there exist some areas of inconsistency among EEG and ERP studies of extraversion personality. However, it should be noted that this does not indicate that any of the studies reviewed are incorrect in terms of neuro-electrophysiological approach. Rather, the diversity of evidence reviewed here suggests that the majority of these studies are unable to generalize their results to settle on a single

Fig. 1. Social participation: one possible concept that could be applied in the EEG experiment task to distinguish between introverts and extroverts.

conclusion about the neural basis of extraversion. Overall, differences in the experimental protocols used in these studies are likely to have caused differences in the results. This inconsistency in research findings may have prevented the development of assessment tools for extraversion personality via brain signals, even though the theories of extraversion has been used for more than four decades (Brebner & Cooper, 1974; Eysenck, 1967; Gray, 1970). Other possible reasons are that the studies did not focus on the main feature of extraversion and the analysis of the studies only focused on EEG power spectral analysis. We propose that future investigations need to involve the main feature of extraversion (sociability) or to use more EEG features in the analysis to produce more reliable results.

We believe this paper could help others to understand the electrophysiological signals of extroverts and introverts and to be a guidance for individuals who are interested in improving their cognitive performance based on their personality traits and brain signals. For instance, individuals who have low performance in working memory based on their personality type and brain signals could apply the neurofeedback (Escolano et al., 2011; Gruzelier, 2014a) to improve their working memory performance. This work could also assist in finding the assessment tools for extraversion personality that might be useful in many areas, such as education, communication, and occupation.

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