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A LORETA study of mental time travel: Similar and distinct electrophysiological correlates of re-experiencing past events and pre-experiencing future events

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ABSTRACT

Previous studies exploring mental time travel paradigms with functional neuroimaging techniques have uncovered both common and distinct neural correlates of re-experiencing past events or pre-experiencing future events. A gap in the mental time travel literature exists, as paradigms have not explored the affective component of re-experiencing past episodic events; this study explored this sparsely researched area. The present study employed standardized low resolution electromagnetic tomography (sLORETA) to identify electrophysiological correlates of re-experience affect-laden and non-affective past events, as well as pre-experiencing a future anticipated event. Our results confirm previous research and are also novel in that we illustrate common and distinct electrophysiological correlates of re-experiencing affective episodic events. Furthermore, research from this experiment yields results outlining a pattern of activation in the frontal and temporal regions is correlated with the time frame of past or future events subjects imagined.

1. Introduction

Previous research on mental time travel into the past and imagining the future has yielded very interesting results; however, an exploration of ecphory of affect-laden past events is not well covered in the mental time travel literature. Few studies explicitly focus on positive and negative affective past events. Furthermore, although some studies provide a specific temporal focus for subjects to mentally time travel to, few studies have attempted to allow subjects to mentally time travel to an event without temporal restrictions. We were also interested in determining quantitative electroencephalographic (EEG) spectral power that is associated with a temporal frame of remembering the past and imagining the future to provide insight into how the brain processes events within a temporal sequence. Thus, the rationale for this study was to determine intracerebral source generators for when an affect-laden past event (either positive or negative) is remembered and when a future event is imagined, as well to explore associations between spectral power and the time frame in which events were imagined.

It has been debated that the ability to mentally represent oneself throughout space and time is an attribute or characteristic unique to humans (Suddendorf & Corballis, 1997). This ability has been coined "mental time travel" and reflects the humans' capacity to re-experience or relive previous events or situations in their personal past, as well as pre-experience future anticipated events through imagination (Wheeler, Stuss, & Tulving, 1997). The ability to pre-experience events has

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been termed ''episodic future thinking'' and reflects the ability to project one's self forward in time (Atance & O'Neill, 2001). It has been proposed that the ability to mentally time travel is a function of the episodic memory system of the brain, where episodic memory represents the individuals' personal experiences and is linked to particular autobiographical events in one's personal past, which are spatially and temporally located (Tulving, 1972, 1983).

Although autobiographical memory, by definition, contains episodic memories relevant to ones' past, the constructive episodic simulation hypothesis argues that a critical function of autobiographical memory includes the ability to imagine possible future events (Addis, Wong, & Schacter, 2007; Schacter & Addis, 2007). The ability to generate elaborations on future plans may be an adaptive function, as suggested by Suddendorf & Busby (2005), in that the ability to remember events evolved from the need to generate actions for the future.

Recent research from developmental fields has demonstrated a link between episodic memory (i.e. autobiographical past) and episodic future thinking. Research from developmental studies has identified that episodic memory formation and episodic future thinking (i.e. mental time travel abilities) emerges at approximately 3–4 years of age (Suddendorf & Busby, 2005), although the causal factors are not well known, parental talk and the role of language may play an important factor in the emergence of these abilities (Atance & O'Neill, 2005). These studies demonstrate that there is some fundamental link between episodic memory and imagining future events.

Qualitatively different memory subsystems may differ in the type of conscious awareness that is necessary for its operation, because according to Tulving (1985), different types of memory systems are linked to different levels of knowing or awareness and their associated representation of the ''self''. For example, non-declarative memory is anoetic (i.e. non-knowing), semantic memory is noetic, where ''knowing'' or awareness is a requirement; however, autonoetic (self-knowing) consciousness is necessary for episodic memory. Autonoetic consciousness is the capacity that provides adults the ability to mentally represent and become aware of their existence across time (Tulving, 1985; Wheeler et al., 1997). This provides humans the possibility to apprehend subjective experiences throughout time and to perceive the present moment as both a continuation of the past and prelude to one's future.

Tulving used the term ''ecphory'' to describe the automatic retrieval process when a specific cue interacts with information previously stored in memory, whereby the retrieval cue reactivates and recovers the stored information (1983). Previous studies have identified both common and distinct neural correlates of remembering or ecphorizing the past and pre-experiencing the future with various neuroimaging techniques (Addis et al., 2007; Botzung, Denkova, & Manning, 2008). It has been speculated that these abilities, which share common neural associations, rely on a common set of processes whereby past experiences are utilized adaptively to envision future events or perspectives (Buckner & Carroll, 2007; Quoidbach, Hansenne, & Mottet, 2008).

The purpose of the present study was to demonstrate the electrophysiological correlates of ecphory of autobiographical material. To evaluate the episodic system, subjects were to think back to a specific moment in their personal subjective past to consciously recollect a personally experienced episode or event (Wheeler et al., 1997). In addition to this, we were also interested in the electrophysiological activation associated with mentally projecting oneself into the future via ''mental time travel.'' Since there is a gap in the literature on studies researching affect-laden past events, this study will also cover positive and negative affective past experiences. Furthermore, since cognitive processes such as emotional processing serve to maintain accurate information about ones' environment by highlighting events of significance (Pollak, Cicchetti, Klorman, & Brumaghim, 1997), it would be prudent to identify the cortical structures that are involved in the recreation or imagination of these emotional events. This study is novel in that it combines imagination of future events and ecphory of past events (affective and non-affective), where affect-laden past events have not been well-researched in the mental time travel literature. Furthermore, to the authors' knowledge, the literature does not outline quantitative EEG correlates between regional (lobe/hemisphere) electrical activity and the time frame in which both past and future events are imagined.

2. Materials and methods

2.1. Participants

Ten volunteers were recruited for participation in the study; however, only nine subjects' records were utilized for analysis as one EEG record had to be discarded due to artifact. Nine subjects were utilized for analysis (six males, mean age = 23.7 range 22–31; three females, mean age = 21.3, range 20–22). Subjects were undergraduate students in psychology at Laurentian University. All subjects were right handed and subjects had no known illnesses/diseases that would affect their EEG record or ability to imagine future events or recall past events. Subjects were informed about the nature of the procedure as they had to prepare (prior to the EEG session) a brief write-up of the events they would think about during the experimental procedure. Written informed consent was obtained from all subjects and the ethics protocol for the experiment was approved through Laurentian University's Research Ethics Board.

2.2. Tasks and experimental design

Participants were instructed to write a paragraph on each of the following events: a future upcoming event that they had planned, a non-affect laden event in their personal past, the happiest moment in their past, as well as the saddest moment previously experienced. Subjects were not limited to focusing on events within a given time period, however, the temporal frame in which these events occurred was recorded. Data was collected individually for each subject; the participant was asked to recall either one of the past, happy, sad or future events (repeated measures) while quantitative EEG records were taken. The order of the events to be re-experienced or pre-experienced was randomized for all subjects. As a reference point, eyes-closed baseline EEGs were taken, as well as instructing subjects to think about the present, where they were asked to focus on the current EEG measurements being taken. Subjects were instructed by the experimenter to think of one of the events they had written about and to imagine themselves in the same spatial and temporal context in which the re-experienced events had occurred or pre-experienced events will be anticipated to occur. The experimenter provided verbal cues from the written reports for the participants when they were instructed to begin "mental time travel." All quantitative EEG records were taken with the subjects' eyes closed.

2.3. Data acquisition

Quantitative EEG recordings were taken with a Mitsar 201 system amplifier which samples at 250 Hz. WinEEG version 2.82 software was utilized for data collection and the electrode cap (Electro-Cap International) utilized 19 AgCl electrodes, employing the International 10–20 standard method of electrode placement. Electrode sites included: Fp1, Fp2, F7, F3, Fz, F4, F8, T3, C3, Cz, C4, T4, T5, P3, Pz, P4, T6, O1 and O2, where electrodes were linked to ears (A1 and A2) as reference for monopolar recordings. Impedance for all electrodes was maintained under 15 kΩ. The low cut band filter was 1.6 Hz with a high cut filter at 30 Hz and a 50–70 Hz notch filter was employed in WinEEG v2.82 software for all subjects to filter high frequency noise during recording. The EEG record was visually inspected for artifacts and the principal component analysis (PCA) method of artifact correction within winEEG v2.82 software was used where appropriate. One minute EEG epochs were utilized and were divided into three 20 s segments for analysis.

2.4. Data processing and statistical analysis

Spectral analysis, utilizing the fast Fourier transform (FFT) method, was completed with WinEEG v2.82 software, which determined absolute power output for all 19 electrode sites. The delta (1.5–4 Hz), theta (4–7.5 Hz), alpha (7.5–14 Hz), Beta1 (14–20 Hz), Beta2 (20–30 Hz) and gamma (30–40 Hz) bands were analyzed for this portion of the data. These values were correlated with the number of days away from the testing session the past events occurred or future events were anticipated to occur. All statistical analysis was completed on SPSS software.

Source localization analysis of the multi-channel EEG was completed with Standardized Low Resolution Electromagnetic Tomography (sLORETA; Pascual-Marqui, Esslen, Kochi, & Lehmann, 2002). sLORETA uses standardized current density to calculate intracerebral generators and has low resolution but ideally zero localization error in the presence of measurement and biological noise (Pascual-Marqui et al., 2002). sLORETA software has received cross-modal validation for use with a 19-channel EEG montage in previous studies (Lehmann, Pascual-Marqui, Strik, & Koenig, 2010; Mulert et al., 2004; Winterer et al., 2001). Cross-spectral analysis was completed on all epochs and paired *t*-tests without normalization were utilized with the sLORETA software to determine source localization throughout the telencephalon within each of the software's defined frequency bands, which include delta (1.5–4 Hz), theta (4–7.5 Hz) Alpha1 (7.5–10 Hz), Alpha2 (10–12.5 Hz), Beta1 (12.5–18 Hz), Beta2 (18–21 Hz), Beta3 (21–30 Hz). The statistical images generated by sLORETA were statistically tested for source localization differences during the different experimental conditions with non-parametric correction for multiple testing (Holmes, Blair, Watson, & Ford, 1996), which is a feature selected for within the sLORETA (Pascual-Marqui et al., 2002).

3. Results

3.1. Behavioral results

Although the groups for comparison were not divided based on the reported temporal distance (in days) of their event from the test session, the means and corresponding standard error of the mean (SE) and range are reported in days in Table 1. Oneway analysis of variance with post hoc testing employing the Tukey method, indicated that the mean number of days away from the testing session was significantly lower for the future condition compared to the past thought induction conditions ($F_{(3,8)} = 9.22$, $\Omega^2 = 0.37$, $p < .01$).

Table 1
Mean and SE in days for each of the experimental conditions.

Condition	Mean	SE	Range
Past	2573.44	783.96	186–8030
Future	187.22	78.01	1–730
Past happy	2356.44	691.55	458–6205
Past sad	1398.44	465.54	124–4015

3.2. Temporal frame and spectral power

To determine if there was any quantitative change in the subjects' EEG activity associated with the distance in time from the recording session of the imagined event, spectral power was correlated with the temporal frame (in days) from the recording session. Table 2 outlines significant correlations (Spearman's rho) demonstrated between the two variables. Electrode site is labeled according to the 10–20 International Standard electrode mapping.

3.3. sLORETA

During the future thought induction, when compared to the eyes-closed baseline recording, an increase in Beta2 activity within the left medial frontal gyrus (see Fig. 1) was observed ($t = -0.772$, $p < .05$), as well as when compared to mental time travel into the past ($t = -0.706$, $p < .05$) (refer to Table 3 for summary). When subjects mentally time travelled to the saddest moment in their personal past, increased Alpha2 activity was observed in the left superior frontal gyrus ($t = -0.957$, $p < .05$) when compared to baseline and similarly when compared to thinking about the present ($t = -0.738$, $p < .05$) (see Fig. 2). Compared to when subjects focused their thoughts on the present moment, activation in the left middle temporal gyrus was observed in the Beta3 band when subjects were instructed to mentally time travel to a non-affect laden event in their past ($t = -0.810$, $p < .05$) (see Fig. 3), as well as an anticipated future event ($t = -0.688$, $p < .05$) (see Fig. 4). When mental time travel to subjects' happiest ($t = -3.72$, $p < .05$) (see Fig. 5) or saddest moment ($t = -3.94$, $p < .05$) in their personal past was compared to mentally traveling to a non-affect-laden past event, increased activation was observed in the right inferior frontal gyrus. Increased activation in the Beta3 band was observed in the right middle temporal gyrus when mental time travel to the happiest moment in the subjects' episodic past was compared to the saddest moment ($t = 1.06$, $p < .01$) in their personal past, as well as when focusing on the present ($t = -0.748$, $p < .01$).

4. Discussion

The results presented in Table 2 illustrate that a fundamental network consisting of the frontal and temporal lobes is activated when imagining events within a certain temporal period or time frame, whether they be episodic past events which were highly emotive, non-affect-laden past events or a future anticipated event. Although multiple comparisons (i.e. correlations) were made for the results presented in Table 1, a Bonferroni adjustment was not conducted as it may not be necessary (Pernegger, 1998). In lieu of a Bonferroni correction (Aickin, 1999; Bender & Lange, 1999), a chi square analysis was utilized to determine if the correlations within the five regions (prefrontal, frontal, temporal, parietal and occipital) observed were due to chance alone. The calculated chi square value ($x_4^2 = 140$) is significant at the $p < .0001$ level, indicating that the pattern of correlations observed is not due to random chance based on the observed and expected correlations for the different lobes. In the past condition, right frontal (F4) and mid frontal (Fz) theta power is positively correlated with number of days passed from the event and the testing session. Furthermore, right (T4, T6) and left (T5) temporal activity in the delta band is negatively correlated with the number of days, suggesting that an increase in delta power in these regions would result in a smaller temporal frame (i.e. Less days) for the events mentally time travelled to. In the future condition, subjects' left (F3, F7) and mid (Fz) frontal gamma power was negatively correlated with number of days away the event was

Table 2
Correlations between spectral power and temporal distance (days) from testing session.

Condition	Electrode	Frequency band	Rho
Past	Fz	Theta	0.60†
	F4	Theta	0.60†
	T4	Delta	$-0.63^{\dagger}$
	T5	Delta	$-0.68^{\dagger}$
	T6	Delta	$-0.75^{\ddagger}$
	T6	Beta2	$-0.67^{\dagger}$
Future	F7	Gamma	$-0.77^{\ddagger}$
	F3	Gamma	$-0.80^{\ddagger}$
	Fz	Gamma	$-0.60^{\dagger}$
	T3	Alpha	0.77‡
	T4	Beta	$-0.59^{\dagger}$
Past happy	F3	Delta	0.82‡
	T3	Delta	0.93*
	T4	Delta	0.67†
	T5	Beta2	$-0.78^{\ddagger}$
Past sad	T6	Alpha	0.78‡

† $p < .05$.
‡ $p < .01$.
* $p < .001$.

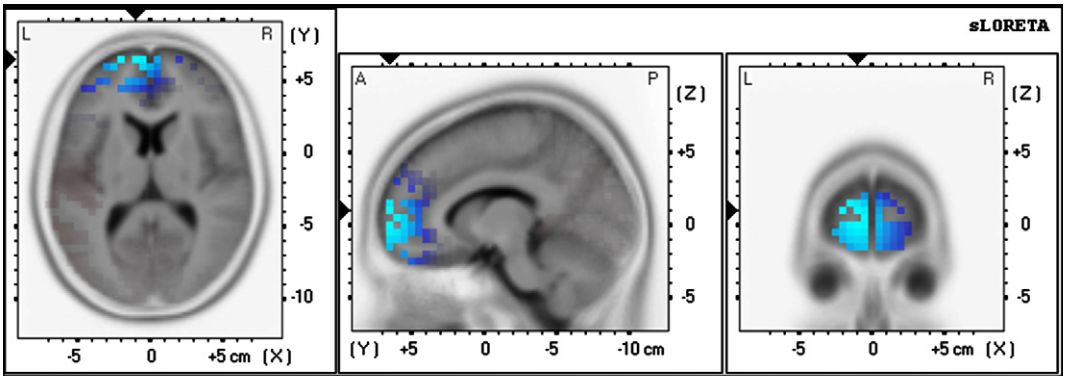

Fig. 1. Increased Beta2 activity in the medial frontal gyrus when thinking about future events when compared to the baseline.

Table 3
Summary of significant findings with sLORETA.

Comparison	Region (Gyri)	Broadmann's area	Side	Band	*X*	*Y*	*Z*
Future > baseline	Med. frontal	10	L	Beta2	−10	65	10
Past sad > baseline	Sup. frontal	10	L	Alpha2	−25	65	−5
Past > present	Mid. temporal	21	L	Beta3	−65	−40	−10
Future > present	Mid. temporal	21	L	Beta3	−65	−45	−10
Past sad > present	Sup. frontal	11	L	Alpha2	−15	65	−10
Future > past	Sup. frontal	10	L	Beta2	−15	65	15
Past happy > past	Inf. frontal	47	R	Beta1	55	30	0
Past sad > past	Inf. frontal	47	R	Gamma	55	30	0
Past happy > past sad	Mid. temporal	21	R	Beta3	60	−30	−15
Past happy > present	Med. temporal	21	R	Beta3	65	−35	−15

Co-ordinates are based on the Montreal Neurological Institute (MNI) system (Collins, Neelin, Peters, & Evans, 1994).

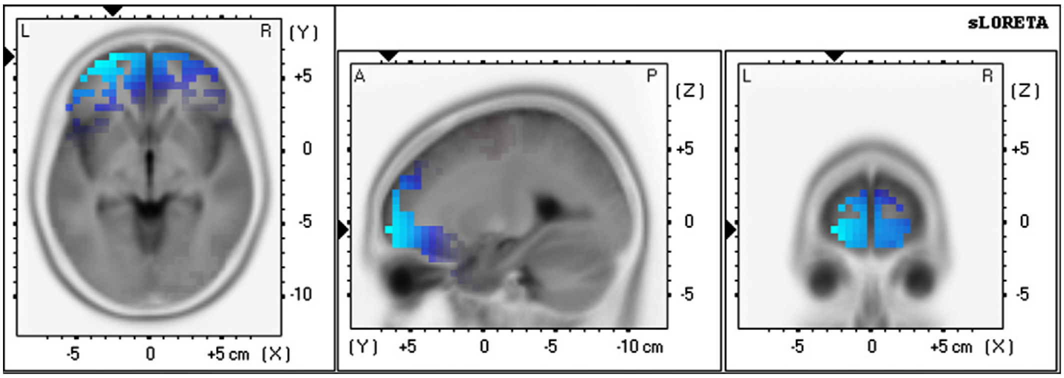

Fig. 2. Increased Alpha2 activity in the superior frontal gyrus when thinking about a sad past event compared to thinking about the present.

in the prospective future. This suggests that as gamma power in these regions increase, the future anticipated event mentally travelled to would be closer to the actual day of testing rather than further away. When subjects were instructed to mentally time travel to a non-affect laden event in their personal past, negative correlations between temporal lobe delta and days was observed; however, when subjects were instructed to mentally time travel to the happiest moment in their personal past, the delta power in the left (T3) and right (T4) temporal lobes demonstrate a positive correlation with the temporal frame of previous events. Although these results are correlational in nature and do not indicate causality, it appears that a pattern of electrical activation within the temporal and frontal lobes, as measured by quantitative EEG, are associated with a temporal period of imagining or mentally time travelling to previously experienced or future anticipated events.

To the author's knowledge, there are no published results involving quantitative EEG and a temporal frame of imagined events; thus, the interpretation of these results is speculative in nature and will hopefully provide insight for future researchers. Previous literature has implicated the role of the frontal lobes in imaging possible future events and engaging in mental

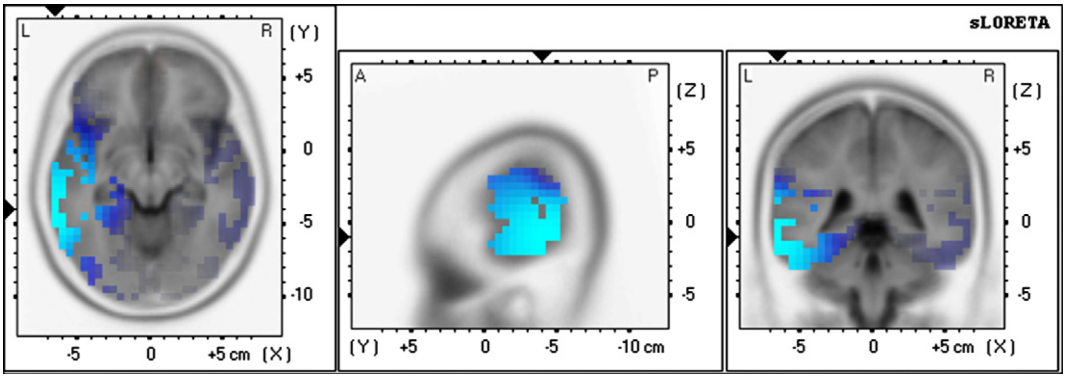

Fig. 3. Increased Beta3 activity in the middle temporal gyrus when thinking about the past compared to thinking about the present.

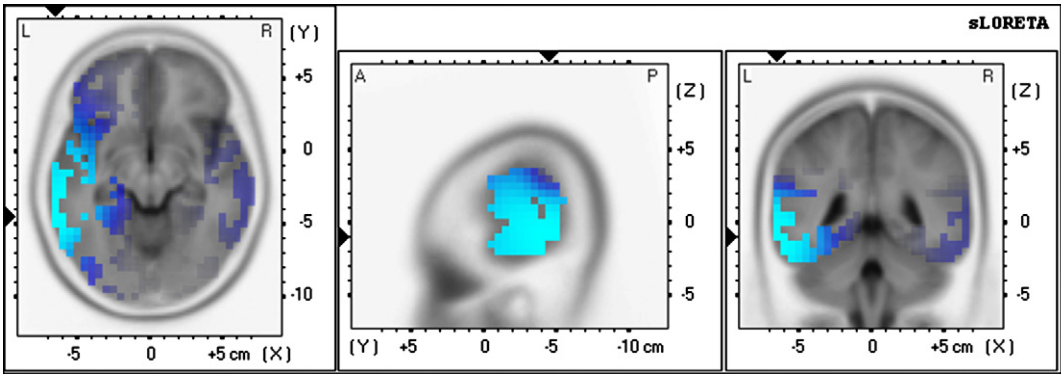

Fig. 4. Increased Beta3 activity in the middle temporal gyrus when thinking about the future compared to thinking about the present.

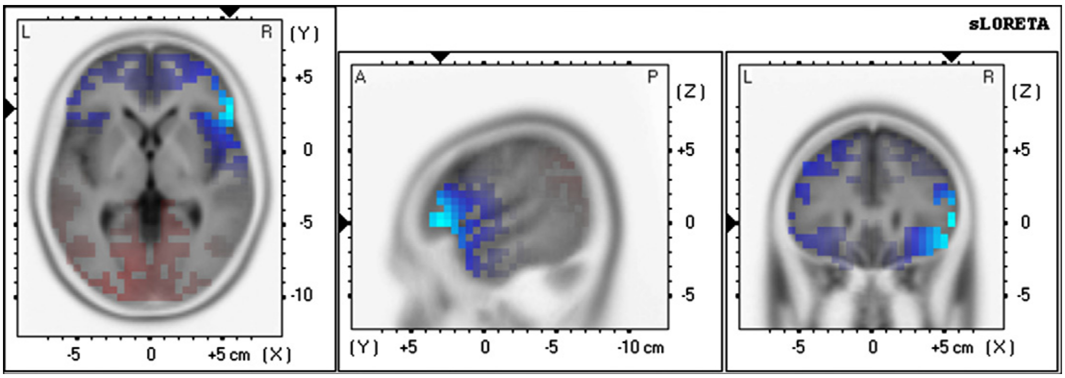

Fig. 5. Increased Beta1 activity in the inferior frontal gyrus when thinking about happy past event compared to a non-affect-laden past event.

time travel (Wheeler et al., 1997). Perhaps the correlations (Table 2) between frontal regions and the temporal frame of events are related to ones' ability to process and attend to events in some temporal sequence.

The increased Beta2 activity in the medial and superior frontal gyrus (BA 10) when subjects were instructed to pre-experience a future event, compared to the resting baseline (Fig. 1) and the past event evocation was consistent with previous findings with functional magnetic resonance imaging (fMRI). FMRI has demonstrated increases in the left superior/middle frontal regions when subjects were instructed to think about an upcoming future anticipated event (Botzung et al., 2008). Since Beta2 activity is associated with alertness and focus (Zillmer & Spiers, 2001), we have hypothesized the increased left frontal activation during pre-experiencing a future event as a possible feature of autonoetic consciousness. Projecting oneself into the subjective future must be accomplished through a sophisticated representation of the self and the integrity of the frontal lobes (Wheeler et al., 1997). Both sense of self and projection into the future are thought to be features of autonoetic consciousness. This may be reflected in the increased Beta2 activity in the frontal regions observed in this study. Furthermore, Addis, Wong & Schacter have also demonstrated the left prefrontal regions to play a role in prospective thinking (2007).

Increased activation of the right inferior frontal gyrus in gamma was observed when both the happy (Fig. 5) and sad thought inductions were compared to the non-affect-laden past. Although in the happy and sad conditions, subjects are thinking about a highly emotive affect-laden previous event, the increased right hemispheric activation when compared to a non-affect-laden previous event, illustrates that the emotive component of remembering the emotional past, whether it be positive or negative, is associated with increased gamma activation in the right BA 47. Increased activation in the middle temporal gyrus (BA 21) is also observed in the right hemisphere when the happy thought induction condition is compared to the sad condition as well as when subjects were instructed to focus their thoughts on the present (see Table 3). Although the activation may merely reflect experiencing an emotion, and have nothing to do with memory, this pattern of activation supports previous findings wherein the right hemisphere was implicated in retrieval of emotional autobiographical memory (Fink et al., 1996). Gamma activity is of low amplitude but fast activity, and has been associated with peak performance states and hyperarousal (Zillmer & Spiers, 2001); the gamma activity may be a function of the highly emotive condition subjects were experiencing. These results may be, in whole or part, due to the neuroanatomical structure of the right hemisphere, as the right hemisphere appears to subserve emotional expression as it has a greater abundance of reciprocal interconnections with the limbic system (Lecours, 1975).

Previous research has demonstrated that valence or emotional affect as well as temporal distance of the event to be re-experienced or pre-experienced may influence the phenomenal characteristics provided by the subject. Sensorial, contextual and emotional representations of past and future events were greater when the event was temporally close and emotionally valent, as compared to distant and low valence events (D'Argembeau & Van der Linden, 2004). Although the paradigm of the current study did not restrict subjects to past or future events within any given temporal frame or quantitatively assess the phenomenological characteristics of their personal events, it is possible that this may have an influence on results and future studies may wish to accommodate these variables.

The results from the current study outlining a decrease in left frontal activity, demonstrate that transient sadness produced a similar pattern of electrical activation in controls (i.e. non-depressed subjects) when compared to previously established findings in depressed individuals (Fig. 2), specifically the work of Henriques and Davidson. Although the current study did not observe depressed patients in the paradigm, previously conducted research has illustrated left frontal hypoactivation in the EEG records of subjects with clinically diagnosed unipolar depression compared to a group of control subjects. Depressed subjects demonstrated less left-hemispheric activation (i.e. increased alpha activity) than the controls (Henriques & Davidson, 1991). As suggested by previous research, activation paradigms may represent a useful way of delineating functional correlates of various symptoms that characterize major depression (Beauregard et al., 1998). Furthermore, this may provide insight into how individuals with certain personality types may actually "learn" to become depressed as constant rumination or reminiscing over sad or negatively affective events could potentially become the baseline state of brain activity.

Future studies employing a similar paradigm of mental time travel with affect-laden and affectively neutral events may consider measuring personality traits as the quantity and affective quality of mental time travel may be in part due to one's unique personality characteristics. It has been demonstrated that the amount of neuroticism and harm avoidance, measured in personality tests, is associated with the content of past and future events imaged (Quoidbach et al., 2008). As our findings suggest that just thinking about a sad event can mimic the previously established pattern of electrical activity in depressed patients (Henriques & Davidson, 1991), this would imply that people who constantly ruminate or reminisce on negatively affective events may 'learn' to become depressed as this activity could potentially become the set point or baseline brain activity.

The results of this study outlining increased activation in the left middle temporal gyrus (BA21) for both the past and future conditions (as compared to focusing on the present) suggest that the basis of mental time travel into the past and/or future may rely on activation of similar areas, as compared to baseline recordings. This would support the constructive episodic simulation hypothesis, which contends that a critical function of autobiographical memory includes the ability to imagine possible future events (Addis et al., 2007; Schacter & Addis, 2007). Similarly, our study demonstrated distinct and common regions of activation when subjects mentally time travel to affect laden events in their past, where activity in the right inferior frontal gyrus reflects the commonality of ecphorizing happy and sad memories. These results further support the notion that two tasks can rely on similar neuronal functions and cognitive capacities (Addis et al., 2007), in that past experiences are used adaptively to imagine perspectives and events beyond the current moment (Buckner & Carroll, 2007). Beyond supporting research previously conducted, we have also illustrated that this pattern of activation of distinct and similar areas may also be established for mentally time travelling to affect laden events in ones' episodic memory.

5. Conclusion

In summary, the results from this study, although using a completely different tool of measurement, yield similar results to studies using functional neuroimaging techniques. Our results illustrate that there are common and distinct neural correlates activated when thinking about the past and imagining the future. Furthermore, common and distinct patterns of electrophysiological activation are also present when subjects are engaging in thought about a highly emotive (happy/sad) episodic event, which has not previously been demonstrated in the literature through past research. Therefore, common and distinct neural correlates not only exist for mental time travel into the personal past and prospective future, but are also present when mentally time travelling to a highly emotive (positive or negative) event.

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