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The Neuroscience of Religious/Spiritual/Mystical Experiences

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Abstract

Reports of religious/spiritual/mystical experiences (RSMEs) are found throughout history and across different cultures and religions. The experience is commonly described as a content-free consciousness, or a feeling of oneness with the universe, and has been proven to positively influence ones mental and physical health. Yet what happens in the brain that causes these experiences is still largely a mystery. This literary review discusses all neuroimaging studies currently existing on RSMEs with the aim of discovering a neural correlate and explanation for the subjective experiences. The existing research suggests activation in the prefrontal cortex, decreased activation in the posterior parietal cortex, and a possible relation between the two. These changed activations could be the result of the sensory deprivation used to achieve RSME or could be the cause of certain aspects of the experience. Much is still unclear as many of the studies have significant methodological issues. It is thus not possible to establish a neural correlate yet. Further research can however learn from these experimental studies in this new field to achieve methodological sound setups, which will advance the field further.

Keywords: religious experience, mystical experience, meditation, neural correlates, prefrontal cortex, posterior parietal cortex,

Contents

1. Introduction

A mystical experience is a state of consciousness defined by a sense of oneness with the universe, or the experience of content-free consciousness (Stace, 1960). These feelings are commonly accompanied by the feeling of ecstasy or intense joy and unexplainable meaningfulness. This mystical experience is said to be at the core of all religions (Bucke, 1901; James, 1902). The Cristian will say the experience is ‘union with god’, the Hindu might explain it as though the individual is at one with Brahman or the universe, while the Buddhist might not speak of a supreme being at all (Stace, 1960). Behavioral and psychological research from the past century has analyzed reports of mystical experiences from different cultures and religions, and concluded that at the core, these experiences are all the same (James, 1902; Stace, 1960). As a result of the different interpretations, mystical experiences carry different names and different values between religions and cultures; Enlightenment (western cultures), Nirvana (Buddhism), Rigpa (Tibetan cultures), ein sof (Judaism), Moksha (Hinduism), kensho or satori (Zen), Dzogchen (Tibetan Buddhism), etcetera. Psychology has thus recognized the mystical experience as a mental state, this implies that there could exist a neural correlate. Neurological research of last two decades have attempted to discover such a pattern, with different intentions among the researchers. Some scientists believe all human behavior is reducible to neuronal activation (Persinger, 1983). Regardless of whether this is true, establishing a neural correlate of mystical experiences does not lesser or demean their spiritual significance, meaning or value. To date, there is however no consensus on the neural correlate of such an experience, as many experiments have encountered numerous methodological difficulties and sometimes show contradicting results.

This literary review will critically analyze the different neuroimaging studies performed on mystical experiences. Many researchers have speculated and hypothesized on neural correlates, yet neuroimaging studies can give evidence for any hypothesis, and are thus of more interest to the actual discovery of neural correlates. A critical examination of these neuroimaging studies and some of their methodological flaws will thus help to answer the question, what is the neural correlate of a mystical experience? And how does this neural correlate result in the described experience?

As mentioned, the experience goes by many different names, in empirical science it has most often been called either a religious, spiritual or mystical experience. Thus, for the purpose of this review the umbrella term, RSME, will be used. A consensus on the name of the experience not existing, neither does a definition. Yet, many researchers refer to the first philosophical papers written on the topic. These will also be used for this review.

The Varieties of Religious Experience (1902) by the psychologist and philosopher W. James was among the first to scientifically describe and discuss RSME. James realized that the experience stretched wider than just religion and thus defined it without religious terms, being the first to do so. These qualities are ineffability, a noetic quality, transiency and passivity. Ineffability refers to how the experience defies expression and no adequate report of its contents can be given in words. Secondly, the experience seems to contain a state of insight and knowledge, this is the noetic quality. Transiency refers to that the experience cannot be sustained for long. This quality has been under discussion as some cultures report a version that can last years (Powers, 2007), but for the purpose of this review the transient version will suffice. And lastly, passivity as the experiencer does not feel like he is in control, rather it appears one's own will is in abeyance.

James' book sparked a wave of philosophers and theologians to discuss and define the matter further or slightly differently. Among these was the influential book *Mysticism and Philosophy* (1960) by W. Stace, who analyzed many first-hand reports of RSMEs. From these he derived a set of characteristics with some overlap to those of James. These include a sense of the disappearance of mental objects or ordinary consciousness, also described as experiencing pure or unitary consciousness, a sense of objectivity or reality, a feeling of blessedness, joy, happiness or peace, transcendence of time and space, and ineffability.

It is worth noting that any person can experience an RSME, and many have reported them throughout history. The ways through which people have experienced them varies greatly, although a few categories have been established. A state of sensory deprivation and extreme focus have been known to commonly be used, this includes practices such as meditation and prayer. The opposite, sensory overload combined with emotional arousal has also been used, this manner is found in shamanic rituals involving rhythmic drumming, or by whirling dervishes (Beauregard, 2012). A third category involves specific physiological changes, such as triggered by certain drugs or as can be onset by extreme fasting. As the last category is considered dangerous, and the first two have been reported to require dedication and practice (Stace, 1960), the complexity of these triggers show how difficult the study of RSMEs is. Many researchers thus rely on a last possibility, which is that these experiences sometimes occur randomly. The question of whether they really experienced an RSME then remains difficult as this is subjective and could be influenced by later interpretations.

Relevance to AI

If there indeed exists a neural correlate responsible for such a life changing event as an RSME, this would have great consequences. The experience has been shown to significantly positively impact both mental and physical health (Sloan, Bagiella & Powell, 1999; Kass et al., 1991; Koenig, 2009), yet it is currently not entirely understood how. An understanding of the neural mechanisms underlying RSMEs might shed some light on its effects, which might then help to improve current understanding of mental and physical health, possibly significantly changing medical help, and changing human health worldwide. Additionally, if a neural correlate exists, this might create the possibility for stimulating these experiences in humans. Which might yield even greater consequences if their effects are taken into account. Additionally, as an RSME is an altered state of consciousness, it could further the understanding of the neuroscience of consciousness. A field that is also of importance to artificial intelligence (AI) as one of its goals is to create an artificially intelligent and sentient being which might or might not involve a consciousness. The further purpose of AI is to model after and learn from the human brain, which would also be aided greatly by a more thorough understanding of the human brain. The link between RSME and AI will be further elaborated on in the discussion.

Structure

As psychologists and philosophers have started researching RSMEs in the 1900s, only a handful of neuroscientists have studied the field. This review will go through all the neuroimaging studies performed on RSMEs. These different studies have resulted in different hypotheses or the support of these. Therefore, the papers will be structured based on the hypotheses they support. Starting with the temporal lobe hypothesis in part 2, as it might be among the first hypotheses on the subject, it still receives support. It will be followed by support of the involvement of the dorsolateral prefrontal cortex in part 3. Then the suggested involvement of the posterior parietal cortex will be discussed and its possible connection to the prefrontal cortex in part 4. Lastly, two experiments have found a complex activation pattern with no area being seemingly of more importance than others, in part 5. Finally, all discussed papers and theories will be summarized in part 6, finishing with a conclusion regarding the findings. Further insights into this reviews relevance to AI will also be given here, as well as suggestions for further research.

2. Temporal lobe hypothesis

The temporal lobe is a relatively well studied area of the brain and includes areas responsible for auditory perception, speech comprehension and production and the encoding and retrieval of long-term memory (Smith, Kosslyn & Barsalou, 2007). Although it might not initially be clear how this region could relate to RSMEs, the link with temporal lobe epilepsy (TLE) might make this more evident. The characteristics of temporal lobe seizures are quite similar to those of RSMEs both of which, according to reports, have regularly resulted in a sudden religious conversion (Dewhurst & Beard, 1970). More recently, a distinct syndrome has been discovered among TLE patients, of which 'hyperreliosity' is a characteristic (Waxman & Geschwind, 1975). These points combined can make one see the similarities.

M. A. Persinger was among the first to try to uncover a neural correlate for RSMEs using the similarities with temporal lobe seizures as a basis. After describing his initial hypothesis in 1983, he and many others have tried to prove his theories, some still going. Since Persinger was the first to study RSMEs from a neurological perspective, both his hypothesis and first experiment will be discussed here

2.1 The Temporal Lobe Hypothesis (Persinger, 1983)

In 1983 Persinger published a paper explaining a possible theory for the neural activation of RSMEs. He explains that such an experience "is evoked by a transient (a few seconds), very focal, electrical display within the temporal lobe" (Persinger, 1983, p.1257), thus paralleling them to electrical micro seizures without the motor components. This neurological activation is hence referred to as temporal lobe transients or TLTs. Persinger presses that RSMEs are 'normal' consequences of TLTs, interpreted and shaped by culture and religion. The involvement of the amygdaloid-hippocampal structures located in the temporal lobe is also noted, although not specified. Consequently, according to Persinger, the state of one's temporal lobe will predict one's susceptibility to such an experience. Predisposing factors, such as a proneness to membrane fusion and a recurrent low-level epileptogenic foci in the temporal lobe, would make a person particularly sensitive to the experience. Yet there are certain triggers to precipitate a TLT at any time.

Although this article has been quite influential due to its new implications and its subject not previously having been studied by neuroscientists, its explanations tend to be vague but the claims strong. The explanations given for certain characteristics for RSMEs will presently be discussed.

According to the paper, cortical and deep structures, primarily amygdaloid and hippocampal complexes, are responsible for the sense of self in relation to time and space. The claim of 'cortical and deep structures' seems vague as it encompasses the entire brain, yet in a later paper he specifies, stating that the relative metabolic activity of the left hemisphere is responsible for this sense of self (Persinger, 1993). How this might occur during a TLT remains unsure however. He continues, stating that if a sudden amygdaloid stimulation where to take place during an altered sense of self in relation to time and space, this could result in a momentarily altered hippocampal function. Which could in turn alter memory reference, resulting in the conviction that something meaningful had happened, or the noetic quality of RSMEs. A connection between the amygdaloid complex, important for emotional processing, and the hippocampal complex, involved in memory consolidation, has been shown when emotional stimuli require processing (Phelps, 2004). It is thus possible to imagine how these areas would be connected during such an emotional feeling. How a sense of meaningfulness results from the activation of the hippocampal complex however, is not further specified.

Additionally, the paper states that the direct connections of the temporal lobe to the dorsomedial portions of the thalamus and orbital frontal lobes is the cause for perceived time distortions during an RSME. While he does not give any substantiation for this claim, further research indeed suggests a temporal lobe - thalamus connection (Voets, 2015) as well as temporal lobe - prefrontal lobe connection (Simons & Spiers, 2003). Both being involved in memory, the latter specifically in long-term memory retrieval, there is no relation found between these connections and time perception. Further research gives an indication of which areas might be involved in time perception, pointing to the supplementary motor area (Coull, Nazarian & Vidal, 2008; Kononowicz, van Rijn & Meck, 2018). Concluding, Persingers claim that connection between the temporal lobe and other areas are the cause for perceived time distortions seems unlikely given the lack of a consensus on the localization of time perception, and recent research pointing to a different area.

It is further stated in the article that RSMEs are influenced by “the rich imagery-evoking sequences of metaphorical language” (Persinger, 1983, p.1256). Persinger states that this is due to the various language centers being in the temporal lobe. However, it seems hard to imagine how a micro seizure in or near a language center might result in the experience being influenced by language if it is not processed at that moment. The activation of a memory might influence the experience, yet it seems unlikely that a remembered sentence is processed afresh, resulting in the involvement of the language centers.

Persinger stated that the micro seizures responsible for RSMEs are not paired by any obvious motor components, yet later in his paper he states that a facial expression of ecstasy and automatisms such as lip smacking might be noticeable. Including these characteristics, both Persingers hypothesis and characteristics used to define RSMEs come very close to an exact definition of focal temporal lobe seizures. The only characteristic of these seizures not shared by Persingers hypothesis is the possibility of auras, unusual sensations warning of a seizure, and hallucinations, both not mentioned in RSME reports (NINDS, 2015). As RSMEs in their original definition as given in the introduction are not so similar to focal temporal lobe seizures, Persingers definition seems quite different.

To summarize, in one of the first attempts to neutrally explain RSMEs, Persinger hypothesizes that the experiences are caused by transient micro seizures in the temporal lobe. Their noetic quality is supposedly caused by the connection between the amygdaloid and hippocampal complexes. Yet as these areas involve emotional processing and memory consolidation, it remains unsure how they would create this feeling. Additionally, the neural cause for an altered time perception is suggested to involve certain temporal - thalamus and temporal - orbitofrontal cortex connections, yet it is unclear how exactly. The involvement of the influence of language also remains large unspecified. To conclude, Persingers hypothesis and definition of RSMEs are perhaps a little too similar to that of temporal lobe epilepsy.

2.2 The 'God-Helmet' Experiment (Ruttan, Persinger & Korren, 1990)

In 1990, seven years after Persingers original hypothecation, Ruttan, Persinger and Koren publish an experiment to test the hypothesis. They apply weak magnetic fields to the temporal lobes of participants using an adapted motorcycle helmet. The participants reported such strange phenomena that the media has dubbed the helmet the 'God-Helmet'. The participants were told they were participating in a relaxation experiment, and where seated in an acoustic chamber with opaque goggles. They received pulsed magnetic fields of either 4 Hz, 9 Hz or 16 Hz (-0.3 mG to 1.0 mG), or sham field, for five minutes in three sets. The researchers hypothesized that with these field patterns, the normal discharge pattern of deep limbic structures could be altered, resulting in alterations over the temporal lobe. Through responses during and after the experiment, the researchers concluded that vestibular ('I feel like I can't move'), depersonalization ('I felt as if I were somewhere else') and imagining ('I saw vivid images') experiences where reported more frequently in the exposed group than in the control group. They thus concluded this was due to weak magnetic field.

Replications

Persinger has worked together to perform this same study numerous times with subtle variations. The strange reports have resulted in increasing media attention and critique from other researchers. A few have attempted to replicate the experiment, whose findings will now be shortly discussed.

Granqvist et al. (2005) borrowed Persingers original magnetic field device and software, only changing the setup and questionnaires. They did not find a relation between the application of the weak magnetic fields and the experience of mystical or somatosensory experiences. The researchers did however find a personality characteristic indicative of suggestibility to consistently predict the previously mentioned experiences. They suggest the lack of a double-blind protocol and the suggestibility of the participants to have caused Ruttan, Persinger and Korens (1990) results.

French et al. (2009) attempted to artificially construct a 'haunted' room using weak complex electromagnetic fields, as inspired by Persinger. Although they found that many participants reported experiencing mildly anomalous sensations, the degree to which these sensations were reported was completely unrelated to the experimental conditions employed. They also suggest the suggestibility of the participants to be correlated with the experience reports.

Gendle and McGrath (2012) used a commercially available version of the 'god-helmet', namely the '8-coil Shakti'. It is claimed to produce the exact same results, stimulating the deep limbic structures, having many effects among which mood enhancement. Although the researchers checked the devices proper functioning, they found no effects on subjective emotional responses, nor did the participants report any anomalous experiences. They thus suggest the device is not able to stimulate the claimed structures.

Tinoca and Ortiz (2014) recreated the stimulation helmet in order to perform their study. They analyzed the valence and complexity of the words spoken by the participants after the session and found a significant difference between subjects and controls. It should however be noted that these researchers did not use a blinded design, allowing for the influenceability of their participants, and a small participant group. Nonetheless, Tinoca and Ortiz found confirming results in their partial replication study.

Simmonds-Moore et al. (2017) performed a sham experiment, using only a sham helmet. Using a condition without the helmet, and two with, including a self-described 'believers of the paranormal' and a skeptics group, they found that believers where significantly more likely to report anomalous experiences that skeptics. Finding also the wearing of the helmet to have influenced the participant, the researchers conclude sensitivity, synesthesia and individual beliefs to affect the participants reports of anomalous experiences significantly.

To summarize, of all the attempted replication studies, only Tinoca and Ortiz (2014) succeeded in reaching a similar conclusion to Ruttan, Persinger and Koren (1990). Yet, their experiment did not use a blinded design, while both Granqvist et al. (2005) and French et al. (2009) suggest great influence of the suggestibility of participants in these types of experiments, indicating the importance of a blinded design for reliable results. Thus, it can be concluded that no successful replication has been conducted, which suggests that the methodology of Ruttan, Persinger an Koren (1990) might not have been enough.

Ruttan, Persinger and Koren (1990) where the first to perform an experiment related to RSMEs, setting the stage for this kind of research and any other experiments trying to uncover the neural correlate for the experience. The criticism this article has received created a discussion around how these studies should rather be performed, allowing for great methodological progress. These methodological criticisms have not been unfounded however and shall presently be discussed.

The researchers hypothesize that they should be able to alter the normal discharge pattern within deep limbic structures, by altering the ordinary pathways of operational neuronal ensembles. Their method is similar to transcranial magnetic stimulation (TMS), a well-known clinical technique for triggering neuronal activity by inducing currents in the brain but should be differentiated based on the strength of their fields. Where TMS delivers short pulses in the range of 1 Tesla (Granqvist et al., 2005), those of Ruttan and colleagues are in the range of 1 microTesla, a strength comparable to that of a hair dryer and about 5000 times weaker than a typical fridge magnet. This has led many researchers to wonder whether these field are even able to penetrate the cranium, let alone reach structures deep within the brain. The researchers give no substantiation for the chosen strength of their magnetic field. They do state that they have chosen the characteristics of their magnetic field to be similar to that of the hippocampus and amygdala, hoping to match the endogenous discharge patterns in those regions. Yet they also note that this might prove difficult, as these field disperse quickly when exiting their poles of origin. Their hypothesized circumvention involves the rotation of a magnetic field around the surface of the scalp, which they further explain in an unpublished paper by Persinger and Makarec. This would involve a setup using four solenoids on either side of the head as shown in figure 1. However, their apparatus description in the current paper mentions only two solenoids, points of origin of the magnetic field, on either side of the participants head, meaning they did not apply their rotational technique, leaving the mentioned difficulty unsolved.

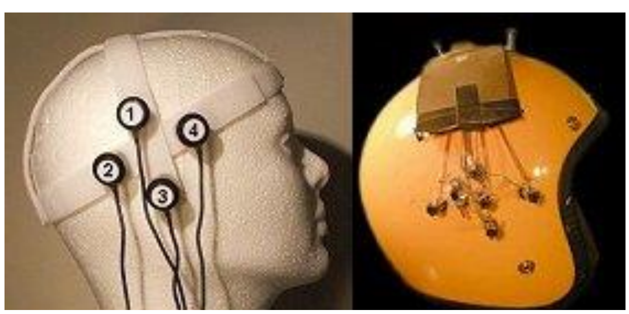

Figure 1. The 'God helmet' (right), adapted to make use of the rotational field technique such as used in Persinger, Tiller & Koren (2000) and Baker-Price & Persinger (2003). Image on the left shows the placement of the solenoids. Retrieved from https://www.god-helmet.com

Apart from the magnetic field inducing helmet, participants also had four electrodes attached to their head in an attempt to measure the electrical activity of the temporal and occipital lobes trough electroencephalography (EEG). As EEG measures voltage fluctuations as a result of electrical activity within neurons of the brain (Niedermeyer & da Silva, 2005), it has proven a good measure of brain activation. Yet, when placed on the scalp, it has a poor spatial resolution, meaning it is practically impossible to deduce anything below the upper layers of the brain (Srinivasan & Ramesh, 1999). Thus Ruttan, Persinger and Koren cannot verify their hypothesis of the alteration of discharge patterns in deep limbic structures on the basis these electrodes. Additionally, these electrodes where placed very close to the location the solenoids emitting the magnetic field where located. It is thus possible that the spikes the researchers found in temporal lobes are mere artifacts of their own equipment. The researchers defend by stating that artifacts are usually quite strong, unlike their found activation. Not mentioning whether they have considered that their fields are also significantly weaker than ordinary TMS, thus possibly resulting in weaker artifacts. Secondly, they mention that they found a correlation between subjective pleasantness of the experience and temporal lobe activity spikes, which would have been unexpected if they were measuring artifacts. This statement is relatively weak however, as ‘unexpected’ does not mean impossible, and it is difficult to see how, if their hypothesis where correct, the artifacts would not correlate with the subjective experience of the participants.

What seems like the biggest criticism however, is that Ruttan, Persinger and Koren did not use a double-blind protocol in their experiment, nor any randomization. The participants could thus have been influenced by the researchers who new exactly whether it concerned a control group or not, having a particularly great impact on participants prone to suggestibility as has been suggested by Granqvist et al. (2005) and French et al. (2009). In a sensory deprivation room especially, such small differences as the treatment of researchers can have great influences. Additionally, the participants could have been primed by the pre-experiment questionnaires, containing questions concerning possible past RSMEs. Furthermore, the control group contained only three participants, where the other groups each consisted of at least nine participants, resulting in difficulties of the reliability of any found statistical differences.

To summarize, Ruttan, Persinger and Koren applied weak magnetic fields to the temporal lobes of participants in this first ever experimental study related to RSMEs. However, their chosen field strength raises question as to whether these will reach the limbic structures as the researchers intend to. They further used EEG to assess if this is the case, yet these electrodes are unable to detect activation in such deep areas. Additionally, it is unclear whether these electrodes measured equipment artifacts. Furthermore, due to the lack of a double-blind protocol and a poor control group, both the data and the analyses appear to be unreliable. And lastly, a successful replication has not been performed, indeed indicating insufficient methodology.

2.3 Summary temporal lobe hypothesis

The similarities between RSMEs and focal temporal lobe seizures have been noticed by a few researchers, among whom was Persinger. His hypothesis localizing the origin of RSMEs to the temporal lobe remains unfounded due to the lack of evidence. When investigated further, an important difference with RSMEs are the hallucinations that appear an essential part of the seizures. This, and that RSMEs are triggerable where seizures are not, define important distinctions, suggesting that perhaps Persingers hypothesis was not at the essence of RSMEs. His further experiments using weak magnetic fields to attempt to stimulate the limbic regions have a few methodological issues, resulting in that it is unsure whether their experimental hypothesis can be confirmed. Yet it can be established that the temporal lobe is probably not at the core of the neural correlate of RSMEs

3. Dorsolateral Prefrontal Cortex

The dorsolateral prefrontal cortex (dorsolateral PFC or dlPFC) is an area ordinarily involved in higher cognitive functions. This includes tasks such as switching attention, working memory, maintaining abstract rules, inhibition of thoughts, etc. (Hoshi, 2006). Multiple researchers contemplate its involvement in the occurrence of RSMEs, yet due to almost all cognitive tasks involving attention or the working memory, it seems near impossible to establish this using neuroimaging studies. Furthermore, recent research into believing and religious belief shows activation of dlPFC for those phenomena (Sugiura, Seitz & Angel, 2015; Harris et al., 2009), suggesting its involvement in the interpretation of RSMEs rather than its actual occurrence. In this section, two experiments providing neuroimaging evidence for the involvement of the dlPFC in RSMEs will be discussed. Afterwards, the discussions will be summarized and the involvement of the dlPFC in RSMEs will be concluded.

3.1 A Cognitive Process (Azari et al. 2001)

Azari et al. (2001) performed the first neuroimaging study on RSMEs by attempting to have religious individuals experience an RSME while in a positron-emission tomography (PET) scan. As this had never been attempted before, their findings drew a lot of attention from religious groups. Azari et al. tested a hypothesis suggested by Proudfoot (1985) which stated that rather than a preconceptual and affective event, as RSMEs were commonly thought of, they where a purely cognitive phenomenon. Religious and non-religious individuals read and recited Psalm 23, a nursery rhyme, a set of instructions, and simply lay quiet during a PET scan in which their neural activity was recorded. The researchers found a significant activation of the right dlPFC during the religious recitation in the religious participants, and in other frontal areas with great functional or anatomical connectivity to the dlPFC. They also found no activation in the limbic areas, confirming Proudfoots (1985) hypothesis. Azari et al. further hypothesize that RSMEs are anomalous or ambiguous states yet are interpreted by religious schemas that are activated in the frontal areas, activated by a religious cue, in this case the Psalm. This is in line with the hypothesis by Granqvist & Larsson (2006). They thus conclude RSMEs are a purely cognitive phenomenon, mediated by a pre-established neural circuit, consisting of the dorsolateral prefrontal, dorsomedial frontal and medial parietal cortex.

As the first neuroimaging study on RSMEs, the research performed by Azari et al. is ground breaking. Yet since it was the first, some methodological issues are inevitable. These and other issues will presently be discussed.
The researchers found that the limbic areas, responsible for affect and other emotional processes, do not seem to be involved in RSMEs. They assessed through a questionnaire the emotional affect of the participants post- and pre-scan and found that the religious subjects were positively affected by the recital

of Psalm 23. They continue to state that religious experience is entirely a cognitive process, not providing an explanation for the noted changed affect in the religious participants.

For this experiment, Azari et al. selected their two participant groups from quite different backgrounds. Where the religious individuals were teachers at a private secondary school, the non-religious individuals were students of the natural sciences. Although the participants were matched on education level, an age difference of mean five and maximum nine years remains. The participants additionally had a non-significant difference on a life satisfaction test. Although these differences might not be of great importance, they should be taken into account as not being a perfect representation. Further research might additionally use participants from various religious backgrounds, as this could have an effect on how or where their religious schemas could be stored.

As mentioned, this study involved six different conditions. These are, silently reading or reciting with eyes covered biblical Psalm 23 (1. religious-read; 2. religious-recite) and the children's nursery rhyme 'happy' (3. happy-read; 4. happy- recite), silently reading the set of instructions (5. neutral-read), and lying quietly with eyes covered (6. rest). The biblical Psalm was chosen since all the religious individuals had had a documented conversion experience to which the first verse of this specific Psalm was essential. All participants had to recite the Psalm and the rhyme for the experiment, raising an initial difference between the participant groups as the religious individuals probably already knew the psalm by heart. This effort exerted by the non-religious participant to recite 20 lines could have shown in the PET images. Additionally, the dlPFC is responsible for both working memory and attention, two cognitive tasks required for these conditions. This complicates the task of analyzing the results while taking into account this areas activation for these different reasons.

Moreover, as prayer has been found a technique for achieving RSMEs, the recital or reading of religious texts has not been established as such. Azari et al. notes that "... the religious subjects regarded the induction of repeated, transient religious states in a single scanning session as antithetical to religious experience (and disrespectful to their faith)" (Azari et al., 2001, p 1650). The participants suggested to invoke in themselves 'a unique religious state' during the religious conditions, yet what this entails is not specified. Since the participants did have a documented conversion experience, a way RSMEs are commonly interpreted, in which Psalm 23 played a major role, this Psalm might bring back their experience and make the participants relive it to a certain extent. All participants were asked to assess whether or not they reached the target state, from which the researchers concluded that the religious individuals achieved the target state significantly more than the non-religious individuals. Without specifying what this state exactly involves however, and since the achievement of the state was judged through self-assessment, all this data really states is that self-defined religious people think of themselves as religious significantly more than non-religious people think this of themselves.

Azari et al. have chosen to use a positron-emission tomography (PET) scan to analyze the neural activity in the brains of their participants. PET measures positrons emitted from a radioisotope, in this case butanol-15, which is injected directly into the bloodstream. It thus measures the regional cerebral blood flow of the brain with great spatial resolution. Every subject was scanned six times, once in every condition, separated by 10 minutes, resulting in the participants being in the scanner for roughly an hour. This could have very feasibly influenced their ability to concentrate, perhaps especially for the non-religious individuals as none of the conditions were of importance to them, and thus influenced their neural activity

The researchers specify a procedure for when they started scanning on the reading condition. They state that the first half of the text was shown on the screen, which the subjects were asked to read out loud. Then the second half of the text was shown on screen, which the participants were asked to read silently. At the time the second half was displayed, the injection took place and the scan was started. This ensured that the subjects were fully engaged in the task at the time of the scan. This does however also mean the participants have to switch from reading out loud to reading silently which could result in altered brain activation compared to just reading silently, as the latter does not involve the activation of muscle controlling brain areas. What might alter the accuracy of their findings more however, is that no such procedure was used for the recitation condition, as scanning was started when the condition was started. Even though religious participants stated they reached and maintained the target state during the religious-recite condition, it is not stated if they reached this state immediately in the beginning of this condition or only near the end. Thus, it is quite possible that the neural activation recorded during the religious-recite condition is only the neural activation associated with remembering and reciting the text, rather than being in a specific religious state as they might have only reached this much later during the condition.

To summarize, Azari et al. (2001) performed the first neuroimaging study into RSMIs, paving the way for other researchers as well as giving some first insights in the possible neural correlates of RSME. They concluded the importance of the dlPFC in the experience, noting it a purely cognitive phenomenon, yet leaving the found change in affect unexplained. Their participants further did not actually experience a RSME during the experiment, but rather an unspecified suggested ‘unique religious state’, making the possibility to draw conclusions on RSMEs harder. Furthermore, the scanning of the different conditions did happen in the same way across the conditions, and the total task length might have influenced the participants ability to focus. To conclude, Azari et al. might have researched a state related to RSMEs or not, leaving the reliability of the found involvement of the dlPFC and excluding the involvement of the limbic system, open to questioning.

3.2 RSME in lesion patients (Cristofori et al., 2016)

Studying the behavioral effects of brain lesions can give great insights into the workings and causality of brain regions that other studies are unable to give. Cristofori et al. had this opportunity with a large sample of lesion patients, allowing for good statistical analysis. Their aim was to assess the causal contributions of brain regions that may underpin mystical experiences. Cristofori et al. compared 116 patients who suffered penetrating traumatic brain injury (pTBI) with 32 matched healthy controls (HC), both groups were Vietnam war veterans. Using a computed tomography (CT) scan and voxel-based lesion-symptom mapping analysis they attempted to confirm the executive inhibition hypothesis. According to this hypothesis, inappropriate inhibitory control can lead a person to interpret a certain sensory experience as being a supernatural phenomenon, or something other than a simple sensory experience. As the dlPFC is crucial in cognitive control and has subsequently been considered a key brain structure for inhibition, the researchers suggest this area to be of great importance. Cristofori et al. found, in line with their hypothesis, that selective dlPFC lesions where linked to greater RSMEs in participants, both when compared to other lesion patients and when compared to the healthy controls. Additionally, they found that lesions to the temporal cortex (TC) where associated with fewer RSMEs. Thus Cristofori et al. conclude that their findings support a model in which executive disinhibition has at least a partial causal relation to RSMEs and the TC might be required to generate the experience. However, studying lesion patients has some great disadvantages and limits the conclusions one can draw from the study. Limitations of this study will be discussed after a discussion of how Cristofori et al. interpreted their results.

Cristofori et al. conclude their paper by stating that they found support for the executive inhibition hypothesis. However, in their neuropsychological measures they tested a few aspects involving inhibition. One of these was a neurobehavioral rating scale for disinhibition, a well-tested and verified scale (Levin et al. 1987), in which they found no significant difference between the participants with dlPFC lesions, other lesions or the healthy controls. This lack of significance on a verified scale suggests inhibition might not be malfunctioning in these participants. In a different test the researchers used a subset of the Card Sorting assessment, which in itself is a subset of the verified and well tested D-KEFS set (Homack, Lee & Riccio, 2005). These results indicate a significant difference between pTBI and HC with a P value of 0.003. Regardless, the researchers indicate that these results are still within the normal range for the test and thus conclude no found difference in the participants inhibition skills. Any other tests measuring executive function also did not show a relation to the occurrence of RSMEs, even though the hypothesis would suggest one. As a result, their support for the executive inhibition hypothesis is weak due to the lack of correlation on neuropsychological measures.
The authors further find a correlation between lesions in the right middle and superior TC and fewer RSMEs. They state that this is due to the TCs role in generating RSMEs, referring to papers comparing temporal lobe epilepsy with RSMEs. However, as discussed earlier in this review, the relation between temporal lobe seizures and RSMEs has not been well established. Furthermore, when comparing the characteristics of the two, a clear distinction is found. It is thus unclear what the role of the temporal cortex might be in the enabling or generating of RSMEs, something which this research could have further explored.

Studying brain lesions gives researchers interesting new insights into the causal relation of brain structures and behavioral phenomena. These studies however also come with some major disadvantages. The participants of the current study have been assessed 40-45 years post injury. For 39% of the participants who experienced an RSME in this study, it occurred directly after their injury took place. A CT scan of their brain lesion 40 years after they experienced the RSME might not be representative of their lesions right as they occurred. One of the reasons for this is that the human brain is able to recover some of the functioning that was originally lost due to the lesion, due to brain plasticity. Additionally, as a CT scan uses X-ray measurements from different angles, it is only able to detect morphological changes. It is impossible to see if a morphologically intact region is functioning correctly using a CT scan, and vice versa.
Furthermore, there are a lot of contextual factors for these participants that might make their reports of RSMEs unreliable. As many of them reported having experienced one 40-45 years,
the time gap might have made the participants reconsider their experiences over the years, and interpret them differently, possibly incorrectly ascribing certain qualities to them only afterwards. Additionally, these participants experienced war, a contextual factor that might have also influenced their interpretations as this a very extreme experience. Reported experiences are most accurately studied if the

report is given immediately after the experience, minimizing the time for interpretation and external influences.

Cristofori et al. measured whether participants have had an RSMEs through two means. The first was an open-ended question interview, resulting in a binary answer set. According to an example question given, these questions required the participant themselves to first having identified the experience as a religious experience. This can cause problems as this leaves the participant to interpret what that would entail or be like themselves, not controlling for any between participant differences.
The second way through which the researchers measured whether participants have had an RSME was with the use of the Mysticism-scale (M-scale). This M-scale is based on Stace's (1960) definition of RSMEs as a universal experience, as also noted in the introduction, and was created with the purpose of encouraging empirical research into the subject (Hood, 1975). This scale has been among the most widely used measures of RSMEs and is thus often one of the most critical parts, warranting a look into its validity. Studies examining its validity note the stable structure of correlated factors (Caird, 1988), but also state that evidence for validity of the factors is weak (Reinert & Stifler, 1993). The nature of the subject, mainly the vagueness, makes it difficult to conduct validity tests. Statements such as 'I have had an experience which was both timeless and space-less' could refer to a sleeping state, and 'I have had an experience which was incapable of being expressed in words' could be interpreted as referring to dreams. The accuracy and validity of the M scale thus remains highly questionable and this should be taken into account.

To summarize Cristofori et al. (2016), their paper studying the relation between brain lesions and RSME occurrence allowed for some unique functional insights. They found support for the executive inhibition hypothesis, claiming the malfunction of inhibition, due to a lesion in the dlPFC, to result in more reported RSMEs. Yet the conducted neuropsychological measures show no functional inhibition in participants with these lesions, weakening their conclusion. Additionally, as this study took place many years after the injury occurred, and often after the RSME too, the data collected about the both of these will have some inaccuracies.

3.3 Summary dlPFC

Both the study by Azari et al. (2001) and Cristofori et al. (2016) hypothesize the involvement of the dlPFC in RSMEs in quite different ways. As mentioned, the area is important for its role in executive functioning, and is thus involved in inhibition, attention and working memory. Azari et al. (2001) found it activated while their participants where in a unique religious state, concluding that the dlPFC must be involved in the religious attribution of these experiences. Cristofori et al. (2016) found almost the opposite, as they found a correlation between selective dlPFC lesion and great RSMEs, suggesting a malfunctioning dlPFC might result in more RSMEs. Yet the research conducted by Cristofori et al. had some methodological issues, as well as the disadvantages associated with lesion studies. A different study by Newberg et al. (2001), which will be discussed shortly, showed increased blood flow in the dlPFC during their peak experience associated with an RSME. This finding supports those of Azari et al., yet due to the different religion and lack of strong religious feelings, might not support their hypothesis.

4. Posterior Parietal Cortex

As one of the four main cortices of the brain, the parietal cortex has a variety of functions. The posterior parietal cortex (PPC) is located posterior to the primary somatosensory cortex and consists of the superior and inferior parietal lobules as shown in figure 2. It being adjacent to the somatosensory area however, it has an important role in the higher-order processing and intermodal integration of sensory inputs (Lynch, 1980). The area additionally is crucial to the higher-order processing of visual input and as a result, any lesions in this region often result in spatial neglect in the patient (Vallar, 207). Further, the PPC is often divided in an inferior and superior part, yet the exact separation of functions does not seem to be agreed upon (Olsen & Colby, 2013; Johns, 2014). How this area might be involved in RSMEs is mainly due to its function in visual-spatial processing. The subjective experience of an altered sense of space during RSMEs could be caused by an alteration in the normal activation patterns of this area. This and other relations between the two will be further examined in the following two papers.

Figure 2. The posterior parietal cortex consists of both the superior (left) and inferior (right) parietal lobules. (Image retrieved from H. Gray (1918) Anatomy of the Human Body, illustrated by H. V. Carter)

4.1 Tibetan Buddhists brains (Newberg et al., 2001)

As mentioned in the introduction, a common way to achieve an RSME is through meditation. One of the main aims in Tibetan Buddhism is reaching Buddhahood, an ultimate form of RSME, to which meditation is a means (Powers, 2007). Newberg et al. (2001) choose these Buddhists as participants for his study, partly because the peak of their meditation session they describe as having a sense of absorption, experiencing a loss of the usual sense of space and time, and as having a special clarity of thought. These characteristics are identical to some of the characteristics of RSMEs, and as such must be an experience very closely relating to RSMEs. By being able to able to analyze the neural activity of these participants during their peak of meditation, much can be learned.

Newberg et al. collected single-photon emission computed tomography (SPECT) data from eight practitioners of Tibetan Buddhism, once in a baseline condition, and once during the peak of their meditation. They found a significant increase in activity in the frontal lobe similar to that found in participants performing a focused attention task. The authors thus associate this activation with the focused attention required for this type of meditation. Correlated with this frontal lobe activation was found a decreased activation of the posterior parietal lobes, which they attribute to the experience of an altered sense of time and space, as other experiments have shown this connection. Additionally, significant activation was found in the thalami, sensorimotor cortex, and midbrain, suggesting the involvement of the central nervous system. Some methodological issues have been found however, as well as some unexplained findings which will be discussed now.

When analyzing their findings, the researchers found most significant activation, normalized to the whole brain, in the anterior cingulate, cingulate body, dlPFC, inferior frontal, orbital frontal and sensorimotor areas. However, as they discuss their hypotheses and associated findings, they neglect to expand on the area with the most significant activation, the cingulate body. In fact, they do not mention any possible explanation for its activation. The area being an integral part of the limbic system, this finding contradicts with those of Azari et al. (2001) who found no activation of any limbic areas during their scan of the recital of a religious text. Yet, as mentioned, such a recital and an RSME are quite different experiences, indicating that perhaps the findings by Newberg et al. might in this case be more reliable. Saver and Rabin (1997) have hypothesized that every element of an RSME is explainable through the Limbic Marker Hypothesis. Indicating that the limbic system has an important evolutionary role of marking external stimuli as important or not, if this system were hyper activated it could incorrectly mark the current experience as very important. This feeling of importance can consequently be named, yet not communicated in their full visceral intensity, resulting in the feeling of ineffability. Similarly, its importance in complex emotion formation could result in the experience of blessedness or intense joy when hyper activated. Although Newberg et al. did not mention this hypothesis, they did seem to have found some evidence for it.

Additionally, the authors found a significant positive correlation between the thalamus and the dlPFC which they also neglect to explain further. The thalamus being an additional part of the limbic system, this further supports the limbic marker hypothesis. The thalamus further serves as a relay system in the brain, transmitting information to the cerebral cortex (Murray Sherman, 2006). Newberg et al. propose that this last function is why it has been found to be activated during the peak meditation experience, it serves a communicative purpose to the overall complex processes associated with meditation, including cognitive and affective responses. They further compared the baseline neural activation of the Tibetan participants to a healthy control group, and found a significantly different thalamic laterality index. These two results suggest a high involvement of the thalamus in RSMEs, possibly resulting in a lasting neural change. However, this is still speculative as this change could have also been due to regular meditation practice or a genetic distinction, predisposing the individuals to meditation or Buddhism, rather than as a result of RSMEs. Nonetheless, the thalamic activity in addition to the activation in the cingulate body suggests evidence for the limbic marker hypothesis.

Newberg et al. (2001) have further found a negative correlation between the dlPFC and the superior parietal lobe, which they suggest is involved with the performing of visual-spatial tasks, such as found in the study by Cohen et al. (1996). Yet what the study by Cohen et al. found was a relation between an area controlling oculomotor function, used for moving their eyes to scan a complex stimulus, and the superior parietal lobe, probably used for its spatial abilities. These results are seemingly of minimal use to Newberg et al. as their Tibetan participants had their eyes closed during the meditation session, and where thus probably not moving them. More recent research suggests the frontoparietal network to be involved in the interaction with other brain networks (Marek & Dosenbach, 2018), others suggest a function related to spatial processing of the parietal lobe (Scolari, Seidl-Rathkopf & Kastner, 2015; Ptak, Schnider & Fellrath, 2017). The function of this connection thus remains vague,

Since Newberg et al. required highly experienced meditators for this study, they only managed to find eight participants. This complicated their statistical analysis, yet they state it was enough to reveal statistically meaningful results, comparing this study to other meditation studies with a limited number of participants. However, they also noted that in the SPM analysis they encountered a false-negative result, which makes one wonder how many other incorrect results due to a small participant number they did not notice, and where thus included in the results.

The participants meditated for approximately one hour, after which they provided a signal, incorporated as part of their session, to communicate that they were about to begin the most intense part of the meditation. Several minutes later the participant was injected with the required radioisotope for the SPECT study through an already attached IV from outside the meditation room. Whether the participants reached their self-described peak meditation experience however, was not noted as the researchers did not analyze the questionnaires the participants filled in. They state they found it impossible to quantize or analyze that data in a useful manner.

SPECT imaging is very similar to PET scans in that they both use radiopharmaceuticals, yet in the former a radioactive tracer that emits gamma rays is used, rather than a positron emitting one (Rahmim & Zaidi, 2008). Newberg et al. substantiate their choice for using SPECT as a measuring technique, by naming an important disadvantage of fMRIs in this case being too noisy for a participant to be able to focus on meditation. A PET scan would have been too impractical as they performed their research outside of regular hours to avoid any other noises, at which time the required radioactive tracer would be no longer available. As a result, their scans have less contrast and spatial resolution than both mentioned alternatives, leaving the researcher unable to be more specific in their conclusions. To supplement this, the researchers used a validated template to differentiate between different areas, yet this might result in a slightly biased perspective as the templated areas are merely those they hypothesized activation, or lack thereof, in. Additionally, the participants where only scanned during one moment of their meditation. It is quite possible that the researchers did not measure the peak of the meditation sessions, but rather some other component. Resulting in them not measuring what they intended to.

Franciscan nuns (Newberg et al. 2003)

Newberg et al. performed practically the same experiment on three Franciscan nuns, whose peak of meditation, or centering prayer, was very similar to that of the Tibetan Buddhists. Since this 2003 study only included three participants and was set up completely the same as their 2001 study, their findings will be shortly discussed here. A discussion of their methods will not be necessary due to the similarities, yet it is worth noting, as the researchers do too, that no statistical conclusions can be derived from this papers due its minimal participant group. Most findings are similar to those of the 2001 paper, including the prefrontal cortex activation, the negative correlation between prefrontal and superior parietal regions, and the positive correlation between prefrontal cortex and thalamus. Unexpected was the found activation in the inferior parietal lobes, which the researchers associated with language, explained through the verbal basis of the meditation. The researcher did expect sensorimotor abnormalities due to the participants describing decreased sensory awareness, yet none was found. Additionally, Newberg et al. do not note any limbic areas activation, as was found in their previous study. However, nothing can be deduced from these findings due to the methodological issues, yet it does give an interesting additional insight.

To summarize, Newberg et al. (2001) have found a neural image of an experience as close to RSMEs as has yet been studied. The researchers found dlPFC activation, which they associate with focused attention, as well as a negative correlation between this area and the superior parietal lobe, which they associate with an altered experience of space and time. This negative correlation was also found in the research by Azari et al. (2001), yet to a lesser extent. Newberg et al. do not further analyze the found activations in the limbic areas, which seem to support the limbic marker hypothesis proposed by Saver and Rabin (1997). Further, it is unclear whether the participants reached their desired peak of meditation due to the lack of subjective reports. Lastly, since the study only recorded during one moment of the meditation session, combined with the limited spatial resolution of a SPECT scan, the accuracy of their results remains debatable.

4.2 Personalised guided-imagery (Miller et al., 2018)

Miller et al. (2018) created an individualized guided imagery task to investigate the neural correlate of personally experienced RSMEs or personally meaningful spiritual experiences. The participants thus re-lived their own experience through a personalized script, played on tape to them while they were in an fMRI scan. Even though the participants did not experience an RSME in a scanner, re-living or remembering them is close, especially with the uses of a personalized guided imagery tape, and might thus result in relevant findings.
All 27 participants were scanned twice on each of the three conditions, neutral, spiritual and stressful. Each condition lasted 5 minutes and were, as mentioned, accompanied by a personalized guided imagery. Miller et al. found significantly reduced activity in the inferior parietal lobule (IPL) when comparing the spiritual to the neutral condition, which they state may contribute to perceptual processing and self-other representations during the experience. During spiritual conditions compared to stress cues, decreased activation in the medial thalamus expanding to the caudate was found, regions which they associated with sensory and emotional processing.

Both the significant changes in activity the researchers found in this study, where reduced activations found in areas that can be related to sensory processing. The participants being deprived of sensory input, these findings are easily explained. Yet the researchers hypothesize that activation in the (right) parietal cortex might be contributing to the sense of self, as suggested by research such as that by Kjaer, Nowak and Lou (2002). Although it should be mentioned that this mentioned research has some flaws, it suggests that an altered activation of this area thus might result in an altered sense of self. The thalamus being a relay structure for many other brain areas, as well as a part of the limbic system, no alternate explanation for its decreased activation can be found.
Additionally, while the researchers used three conditions, a spiritual, stressful, and a relaxed/neutral condition, they neglected to create a baseline condition. The relaxed condition being a guided imagery

task of a participants most relaxed experience in the past year, it is more relaxing than a neutral baseline condition. Any conclusion can thus only be drawn on the comparisons of these quite extreme conditions, and no statements can be made on the neural activation of the spiritual condition alone.
The reduced activation found in the medial thalamus and caudate are significant when the spiritual condition is compared to the stress condition. However, this simply indicates that increased activation is found in these areas in a stressful situation and implicates nothing about the spiritual condition except for its un-likeliness to stress. These areas have indeed been found relevant to emotional processing additional to sensory processing, and this would explain its increased activation in a stressful situation. In the relaxed condition, the researchers found increased activity in the inferior parietal lobule, which is thus significantly decreased in the spiritual condition. Which in turn says little about the spiritual condition except for its un-likeliness to a relaxed situation.

As mentioned, for each participant, two personalized scripts were created for every condition based on questionnaires and interviews conducted a week earlier. The scripts where created using a standardized procedure for the provoking of personal experiences. Spiritual scripts where created only for the experiences the participants rated with an 8 or higher on a 10-point scale where 1 equals not at all spiritual, and 10 equals the most spiritual experience in the past year. Excluded where also food, sexual or drug-related scenarios. First of all, it is not noted what happened to the participants whose experiences were excluded from script creation, it can only be assumed those participants were excluded from the experiment. Additionally, as can be derived from these methods, these experiences were not tested for whether they actually classify as an RSME. While the authors do mention the definition for these experiences as proposed by James (1902), they do not take caution to make sure their participants are only re-living those that qualify as an RSME. As a result, the participants are free to interpret and be misled by questions including statements as ‘felt a strong connection with a higher power or spiritual presence’.

To summarize Miller et al. (2018), they performed accessible new study on RSME, using fMRI to obtain highly detailed and images during the entire experiment. The spiritual condition they used was based on a personal experience for every participant yet was not checked for whether it concerned an RSME or not. They found a significant decrease in activation in the inferior parietal lobule and the thalamus, the latter directly opposing one of the findings by Newberg et al. (2001). Yet, these results are noted on a basis of comparison with a stressful condition and a relaxed condition, lacking a baseline condition these findings are only relevant in the context of comparison with each other.

4.3 Summary Posterior Parietal Cortex

The posterior parietal cortex has been ascribed many functions, among which the sense of self (Kjaer, Nowak & Lou, 2002), and its role in visual-spatial processing (Lynch, 1980). The results of the experiment by Miller et al. (2018) seem to be of little use for finding the neural correlate of RSMEs, due to their lack of a baseline condition and verification of the experiences. The experiment performed by Newberg et al. (2001), although not being perfect, resulted in some interesting findings. The negative correlation between the dlPFC and the superior parietal lobe he found seems to be in line with other research performed by Azari et al. (2001) who also found an activated connection between the dlPFC and the parietal cortex, indicating that this area, or the connection, might indeed be of importance. How this area is involved in the experience is unclear however. Other findings by Newberg et al. include a significant activation of the thalamus and cingulate body, suggesting affirmation of the limbic marker hypothesis, but directly opposing the other findings of Azari et al. (2001) who did not find any limbic activation.

5. Complex activation

The wide variety of characteristics of RSME might suggest that a variety of brain areas are involved. Strong positive emotions, a change of consciousness, a change of perception of the self and reality, all are associated with different brain areas. It thus does not seem strange to implicate that a wide range of brain areas might be involved in creating such an experience, rather than a single area being solely responsible. This is exactly what Beauregard & Paquette do.

5.1 RSME in Carmelite nuns (Beauregard & Paquette, 2006)

Beauregard and Paquette (2006) designed an experiment with a setup similar to that of Miller et al. (2018), where participants were reliving a past spiritual experience while in an fMRI scanner. What contrasts the studies is that Beauregard and Paquette have a participant group consisting of 15 nuns of the Carmelite order, who place great emphasis on prayer and contemplation, two means commonly used to achieve RSMEs. They describe their mystical experience mainly as a sense of union with god, yet some of the other common characteristics are also mentioned, ensuring the same RSME definition as used in this review. The participants informed the researcher that ‘god cannot be summoned at will’, thus the researchers asked the participants to relive their most intense RSME, as classified using a selected set of Mysticism Scale questions (Hood, 1975), during an fMRI scan.

Comparing their findings of re-living these experiences with a baseline condition of resting and a control condition in which the participants relived an experience of a state of union with another human, the researchers found a lot of significant changes in activations. Among these where a lot of areas the researchers indicated to be involved in (positive) emotions and the awareness of these emotions. These areas included the right medial orbitofrontal cortex, caudate nucleus, left medial prefrontal cortex, left anterior cingulate cortex, left insula and left brainstem. However, many of these areas are also involved in a variety of functions themselves, making it unclear what their involvement in this case might be. Additionally, they found a significant decrease in activation in the inferior and superior parietal lobules, which the researchers state might be involved in the processing of visuospatial information as well as storing a representation of the self, both of which are commonly experienced altered during RSMEs. The researchers further note a significant activation of the right medial temporal cortex, which they associate with the subjective impression of contacting a spiritual reality, due to the cortex’s found link with spirituality and religiosity as Persinger (1983) and Devinsky (2003) have shown. Beauregard and Paquette thus conclude that a variety of brain regions and systems interact to create the various aspects of mystical experiences.

When looking at their data, the researchers simply state the complexity of their findings, without relating their findings to confirm or disprove any currently existing hypotheses. When looking at the previously discussed hypotheses however, the found activation does seem to support the involvement of the temporal lobe as suggested by Persinger (1983). As the researchers further find a significant activation in the medial prefrontal and medial orbitofrontal cortex, the involvement of cognitive processes can also be derived, thus a partial affirmation of the executive inhibition hypothesis as suggested by Cristofori et al. (2016). Additionally, a decreased posterior parietal cortex activation is found, which is partly in line with Newberg et al. (2001) and Miller et al. (2018). The activation of limbic areas seems also to support the mentioned limbic marker hypothesis of Saver and Rabin (1997). What Beauregard and Paquette do not analyse their data for however, is possible correlations between areas or possible lateralizations. As such, some crucial information could have been obtained from this detailed fMRI study, yet none is revealed.

The control and baseline condition in addition to the mystical condition allowed for a good comparison of activation. Since in the control condition the participants were asked to relive their most intense experience of union with another human being, and they described their RSME they were re-living during the mystical condition as mainly a sense of union with god, the researcher expected these conditions to show some similarities. Yet they found mainly differences between the conditions implicating that RSMEs are unlike the feeling of union with another human.
The researchers further state that the participants experienced a genuine RSMEs during their experiment, yet their findings indicate differently. Beauregard and Paquette conducted an interview as well as asked the participants to rate the intensity of their experience when concluding their scans. From the first, the authors concluded that the experiences where actual RSMEs, although it is not specified how, yet the second indicated simply a re-living, as the scoring averaged on a 3.06 on a scale of 1 through 5. The scans should thus not be directly interpreted as of an RSME, but rather approached with this information in mind.

5.2 EEG activity in RSME in Carmelite nuns (Beauregard & Paquette, 2008)

In 2008, Beauregard and Paquette published a study with exactly the same setup and participants, only now they used an electroencephalography (EEG) to monitor the electrical activity of their participants brains. Since the methodology is practically identical, only the relevant differences will be discussed here. EEG being quite different from previously mentioned neuroimaging techniques, it measures voltage fluctuation in the brain related to the electrical activity within neurons (Niedermeyer & da Silva, 2005). Since the electrodes are placed on the scalp, this neuroimaging method has quite a limited spatial resolution, resulting in its limited usage outside of anesthesia, sleep disorders, epilepsy and coma (Chernecky & Berger, 2012). At the time of this study there indeed existed no other EEG studies on RSMEs, yet a few on different types of meditation. This thus limits the conclusions the researchers can draw based upon their findings. Nonetheless, they found increased gamma1 power over the right temporal and parietal regions and increased theta power over frontal and parietal regions. These areas and activations are loosely associated with functions such as positive emotions, focused attention and modification of the body schema according to the researchers.
In contrast with their 2006 study, the researchers measured coherence between different brain areas, giving an indication of the functional coordination and information exchange of various brain regions. As such, they found theta connectivity between left frontal and central areas, which they associate with

positive emotional experience. And general long-distance alpha connectivity in the right hemisphere, which the researcher state is related to the reduction of sensory processing.

The intensity of the subjective experience as indicated by the participants was only slightly higher presently as compared to the fMRI study, indicating that the sound and surroundings of an fMRI scanner will not have distracted the participants too much in the 2006 fMRI study. This suggests that the participants performed the task comparatively in both studies.

Beauregard and Paquette, similar to their 2006 study, do not mention any expected findings or hypotheses they intend to test. Yet the coherence findings of both theta and alpha suggest a confirmation of the Newberg et al. (2001) findings regarding a connection between the frontal and parietal regions.

5.3 Summary complex activation

Beauregard and Paquette have attributed greatly to the neuroimaging research on RSMEs as they performed two imaging techniques on a participant group who have devoted their lives to these experiences. Both their studies show a variety of activation patterns over the brain, suggesting a complex activation pattern to be responsible for RSMEs. Although the researchers did not note a hypothesis or expected findings beforehand, they deduce that for a multidimensional experience such as an RSME, a variety of functions must be involved, such as emotion, self-consciousness, mental imagery, body representation, and the perception of contacting another reality (Beauregard, 2012). Further relations or interactions between brain areas might have been found if their fMRI data would have been analyzed further. However, the coherence analysis of the EEG data from the Beauregard and Paquette study (2006) does suggest a confirmation of the frontal - parietal connection Newberg et al. (2001) found. Additionally, it should be noted that these participants did not actually experience in RSME during these experiences, yet simply remembered and re-lived them.

6. Discussion

The purpose of this literary review was to critically analyze the different neuroimaging studies that currently exist on RSMEs, with as aim was to find a neural correlate of the experience. The reviewed articles have suggested a variety of hypotheses, starting with the temporal lobe hypothesis, the involvement of the dorsolateral prefrontal cortex (dlPFC), decreased activity of the parietal cortex, and a complex activation pattern over the whole brain.

Persinger (1983) was among the first to create a theory on the neurological basis of RSMEs. He noticed the similarities between temporal lobe epilepsy and RSME, and proposed that micro seizures in the temporal lobe might be responsible for the latter. In his experiments starting in 1990 he attempted to provide evidence by applying weak magnetic field to the temporal lobes. Yet these experiments where flawed and disputed by the lack of successful replication studies, invalidating his hypothesis.

Azari et al. (2001) furthered the biological foundations of RSMEs as they successfully provided evidence for a popular theory by Proudfoot (1985), suggesting the events to be purely cognitively mediated. They invented a way to perform neuroimaging studies of the experiences, allowing for a major leap forward in the field. Their results indicated the dlPFC to be of importance to the experience, as well as other frontal and parietal regions. Their explanation for these involvements rested on the activation of religious schemas and the religious interpretation of the otherwise ambiguous events. However, their methodology involved a variety of aspects that could have influenced the participants. Additionally, the participants did experience an RSME in the experiment as they found this religiously antithetical. It is thus unsure what Azari et al. actually measured.

Cristofori et al. (2016) additionally added new findings to the field, as they compared brain lesion patients and their religious experiences. Such a lesion study gives unique insights into the workings of brain areas that are otherwise impossible to achieve. They found a significant correlation between lesions in the dlPFC and the amount of RSMEs experienced among their participants. Yet this lesion study has some disadvantages influencing the reliability of their findings, such as the time passed between the injury and the study, and the unreliable measure of testing for RSMEs in patients.

Newberg et al. (2001) studied the brains of Tibetan Buddhists, whose peak of meditation is very similar to, if not the same as, RSMEs. This has provided the field with possibly the most accurate findings so far. The researchers found a significant negative correlation between the dlPFC and the superior parietal lobe, which they state could be responsible for the altered sense of space during the experience. Additionally, some prefrontal activation was noted. These new findings are only mediated by the limited spatial resolution of their chosen scanning method and their small participant group.

Miller et al. (2018) attempted a new study design for researching RSMEs, using personally guided imagery tasks in this new context for the first time. Using the high-resolution fMRI scanner, they found reduced activity in the inferior parietal lobule and medial thalamus, suggesting a changed sensory and emotional processing, as well as a change in the self-other representations. Whether their participants re-lived an RSME in their experiment is unclear however, suggesting uncertainty in what they measured.

Lastly, Beauregard and Paquette (2006, 2008) researched the neural correlate and electrical activity during an RSME in the brains of Carmelite nuns, another religious group that have devoted their lives to these experiences. Their findings show the complexity of the experience, as a wide variety of brain regions are described to be involved, which matches with the multifaceted nature of the experience. These participants, however, did not actually experience an RSME in the fMRI scan, they re-lived a past experience, yet where compared with a similar non-RSME experience, complicating the conclusions once again.

6.1 Conclusion

A common component among the more reliable of these studies seems to be the activation of prefrontal regions and the deactivation of the posterior parietal cortex, and possibly a relation between the two, as found by Newberg et al. (2001), Beauregard and Paquette (2006, 2008), and Azari et al. (2001). This frontal region might include or exist solely of the dlPFC as has been suggested by Azari et al (2001), Cristofori et al. (2016) and Newberg et al. (2001) yet might be more general as Beauregard and Paquette (2006) suggest.

The posterior parietal cortex is specialized in sensory and visual-spatial processing (Culham & Valyear, 2006), the former of which will undoubtedly be decreased in activation during meditation or prayer, which has been found a common method for achieving RSMEs. An altered activation in the posterior parietal lobe has additionally been associated with a changed sense of self (Kjaer, Nowak & Lou, 2002) and a changed sense of space, due to its involvement in spatial processing (Lynch, 1980). The dlPFC and other prefrontal areas are involved in higher order functions such as attention and inhibition. Many meditation and prayer techniques involve focused attention, making for an easy explanation of the involvement of this region. Yet other researchers have suggested it is responsible for the religious feelings and interpretations of the experience (Azari et al., 2001; Newberg et al., 2001). A relation between the frontal and parietal areas has also been found in multiple studies, yet some found a negative correlation (Newberg et al., 2001; Azari et al., 2001) and others a positive (Beauregard & Paquette, 2008). The function of this (de)activation of this connection in the context of RSME is unestablished however.

To conclude, due to the complexity of RSMEs and their study, no neural correlate can yet be established. However, the involvement of the posterior parietal lobe and prefrontal cortex, and a relation between them, is suggested. The explanation for their involvement can lie in the experience of RSMEs, or in their function in the means of achieving one, which means they would not be part of a neural correlate of the core of RSMEs.

Studies like those of Newberg et al. (2001) and Beauregard and Paquette (2006) come very close to providing an accurate image of the neural activity during an RSME. However, experiments like these need to be performed with more participants from a varied range of religions and cultures, to achieve the neural correlate of the core of RSMEs.

This review has covered all existing neuroimaging studies on RSMEs. Yet the reviewing of these articles as well as the hypothesizing of the underlying neuronal structures is critical to uncover an eventual neural correlate. Therefore, the following authors have provided important additional theories that have not been discussed in the current review: Fulford and Jackson (1997), Joseph (2001), Newberg and Iverson (2003), Previc (2006), Ott (2013), Barrett and Griffiths (2017), and Castro et al. (2017). Many have also critiqued the field and its methodologies, such as Slors and Azari (2007), Schjoedt (2009), Anderson et al. (2014), Ladd et al. (2015) and Jones (2018). Psychological and philosophical research on RSME has also continued yet shall not be mentioned here. In an ideal situation, all theories on the neural basis of these experiences would also be assessed and considered, yet that would result in a very time intensive project.

6.2 Relevance AI

As has been briefly mentioned in the introduction, this field of study carries relevance to the study of artificial intelligence (AI). An important discussion since the beginning of computer technology has been whether it is possible to build machines that can compete with human intelligence. As current technology has been rapidly advancing, many people see this is a concrete possibility (Buttazzo, 2001). This opens up some important philosophical questions concerning whether machines are able to think or just calculate, which if positive, regards the question of whether machines can obtain a consciousness, which has great ethical and moral consequences. To this extent, the defenders of weak AI, the believe that machines cannot have a consciousness, mind and sentience, and strong AI, the believe that a programmed computer really is a mind and can be understood as having cognitive states (Hildt, 2019), both benefit from a further neuroscientific study of consciousness. Consciousness is often considered an epiphenomenon, yet it can be argued that this is concluded due to the lack of understanding of the phenomenon (Davidson, 1976). The recent surge in the multidisciplinary studies of altered states of consciousness suggests their might actually exist a neural correlate (Boly et al., 2008; Rees, Kreiman & Koch, 2002). The current review has shed some light on the topic as it has tried to uncover the neural correlates of a specific altered state of consciousness. When compared to other states of consciousness, this could help uncover a possible neural correlate of consciousness.

Additionally, the field of AI might be of great benefit to the study of RSMEs. As had been mentioned in the discussion of multiple articles, the data analysis in neuroimaging studies is of great importance and has sometimes been found to be lacking. Statistical machine learning has great value in modeling high-dimensional datasets, using both supervised and unsupervised learning to uncover hidden structures in sets of images such as those of function MRI scans (Abraham et al., 2014). Recent uses of deep learning algorithms in classifying MRI data have additionally shown promising results (Plis et al., 2014). These studies suggest that any neuroimaging study could benefit from statistical machine learning in the analysis of their findings, and in the future, even deep learning algorithms could be applied.

Lastly, creating models of the hypothesized involved brain regions in RSMEs might help the understanding of how these regions contribute to the experience.

6.3 Further research

As has been noted, the study of RSMEs is a complicated one as the result of a few factors. These can be categorized intro three problems: definition, achievement, and core. The first being an obvious lack of consensus on the definition of RSMEs. While many researchers have quoted James (1902) and Stace (1960), none have stated the specific characteristics that need to be met for the experience to qualify as an RSME. Even the Mysticism scale developed by Hood (1975) does not result in a binary answer. Herein also lies the problem of subjectivity, participants can only describe or classify the experience themselves, yet they might not interpret words the same. One way to get around this problem is to use participants of whom one can be as sure as possible that they have experienced an RSME, such as those of religious groups that devote their lives to these experiences, which is what Newberg et al. (2001, 2003) and Beauregard and Paquette (2006, 2008) have done. The next problem is that of achieving an RSME on command during an experiment. Participants have refused to achieve an RSME in a scanner because it is disrespectful to their faith (Azari et al., 2001, Beauregard and Paquette, 2006, 2008). Others have noted that the noise of an fMRI scanner is too loud to focus on meditation (Newberg et al. 2001) or have stated the experiences cannot be summoned at will (Azari et al., 2001; Beauregard et al., 2006, 2008). These obstacles are hard to get around, although some researchers have already noted some ways this might be circumvented or helped. Newberg et al. 2001 have suggested that a close working together of participant and researchers will aid both, as the participant can understand the aim is not to disprove their religion, possibly allowing for more willingness to participate, and the researcher can understand what the participant is capable of and what might aid him or her. Other researchers have circumvented by accepting a remembering and reliving of an RSME, allowing for an estimation of the experience with thus a limitation on the conclusions. Lastly, as the previous research has shown, the areas that have been found activated are often easily explainable through the means the participants have used to try to achieve the RSME. Focused attention in meditation, language and memory in prayer, and sensory deprivation in meditation and prayer all seem to refer to the means used to achieve the RSME rather than the core of the RSME. It thus seems necessary that studies are performed on RSME using different means to achieve them and different religions and culture backgrounds, to be able to find the neural correlate of the core of these experiences.

As the field of the study of RSMEs is still quite young, all discussed papers are attempting something quite new and there are no standardized methods for the researchers to fall back on. As the current review is quite inconclusive in its findings, more research is required to confirm any of the paper’s findings. Yet, given the progress that has already been made, future research looks promising. The critique the field and papers have received additionally help the field and methodology grow as new ideas are suggested regularly. As a result, perhaps one day the neural underpinnings of RSMEs will be completely understood, having far reaching consequences. It could greatly impact how mental and physical health is viewed and treated today, as RSMEs have significant but not yet understood effects on both mental and physical health.

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