GOLDSMITHS, UNIVERSITY OF LONDON

DOCTORAL THESIS

Mechanisms and outcomes of Autonomous Sensory Meridian Response

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A thesis submitted in fulfillment of the requirements
for the degree of Doctor of Philosophy

in the

Banissy Lab
Department of Psychology

Declaration of Authorship

I, Thomas SWART, declare that this thesis titled, "Mechanisms and outcomes of Autonomous Sensory Meridian Response" and the work presented have not been and will not be, submitted in whole or in part to another University for the award of any other degree.

The current thesis is presented in the 'scientific article format', with Chapters 3 to 6 consisting of distinct research papers, which were written in a style appropriate for publication in peer-reviewed journals. Publications titles and author contributions for these chapters are as follows:

- **Chapter 3:** Swart, T.R., Bowling, N.C. and Banissy, M.J. (2021). ASMR-Experience Questionnaire (AEQ): a data-driven step towards accurately classifying ASMR responders. *British Journal of Psychology*.
- **Chapter 4:** Swart, T.R., Poerio, G.P., Edgar, C., Banissy, M.J. (*Under Review*). ASMR responders score higher in emotion perception tasks compared to non-responders.
- **Chapter 5:** Swart, T.R., Banissy, M.J., Hein, T.P., Bruña, R., Pereda E., Bhattacharya J. (2022). ASMR amplifies low frequency and reduces high frequency oscillations. *Cortex*
- **Chapter 6:** Swart T. R., Banissy, M. J. (In Prep.). The stochastic resonance model of ASMR.

Signed: Swart

Date: October 12, 2022

"He didn't answer but reached over and put his hand at the root of my hair and ran his fingers out slowly to the tip ends like a comb. A little electric shock flared through me and I sat quite still. Ever since I was small I loved feeling somebody comb my hair. It made me go all sleepy and peaceful."

Sylvia Plath, 1971 - The Bell Jar

"'K. . . R. . . ' said the nursemaid, and Septimus heard her say "Kay Arr" close to his ear, deeply, softly, like a mellow organ, but with a roughness in her voice like a grasshopper's, which rasped his spine deliciously and sent running up into his brain waves of sound which, concussing, broke. A marvellous discovery indeed that the human voice in certain atmospheric conditions (for one must be scientific, above all scientific) can quicken trees into life!"

Virginia Woolf, 1925 - Mrs. Dalloway

Abstract

People who experience autonomous sensory meridian response (ASMR) report a complex emotional response of calming, tingling sensations that originate around the crown of the head in response to a specific subset of somatosensory and/or audio-visual triggers. Recently, the authenticity of these experiences has been established. This thesis aimed to build on prior work to further characterise both state and trait ASMR in terms of classification, empathic abilities and electrophysiological neural correlates. In Chapter 1 a brief review of the current literature is described, followed by an introductory methodology chapter.

Chapter 3 introduces a novel data-driven tool that is able to capture both state and trait ASMR, whilst also identifying potential respondents who report experiencing ASMR but who would otherwise fail a follow-up confirmation (e.g., negative associated affect). Using this data-driven approach in respondent classification allows a more comprehensive profiling of how participants respond to ASMR stimuli. This raises the potential to better understand mechanisms and broader traits associated with sub-groups of ASMR-responders in the future.

I further unpack the relationship between ASMR and empathy in Chapter 4. Results show that ASMR-responders perform better at tasks designed to measure emotion identification capabilities. These findings systematically delineate the relationship between ASMR and empathy and show the importance of investigating subcomponents of the empathic process in order to fully explain the nature of individual differences in empathic response.

In Chapter 5 I sought to provide source-level signatures of oscillatory changes induced by this phenomenon and investigate potential decay effects — oscillatory changes in the absence of self-reported ASMR. Altogether, I showed the robust changes in the patterns of dynamical brain oscillations associated with an ASMR tingling experience. Further, I demonstrated the long-lasting effects of ASMR across a wide range of brain regions and oscillatory powers.

Together, I propose a neural model of ASMR based on the principles of stochastic resonance and synchronisation in Chapter 6. Using testable hypotheses, I hope this model builds on prior work and progresses our understanding of the neurological basis of ASMR and the role neural noise in sensory processing in general.

Acknowledgements

I'd like to thank my supervisor Professor Michael Banissy first and foremost, for being an excellent mentor and teacher throughout these last three years. His kindness, experience and huge wealth of knowledge has been invaluable and I cannot thank you enough! I would also like to thank Professor Joydeep Bhattacharya for all his EEG expertise and knowledge, I couldn't have done it without you. Dr Giulia Poerio has also been tremendously supportive during my doctorate and I have learnt so much much from you through our numerous successful collaborations - you've been an unofficial tertiary supervisor to me so thank you ever so much Giulia!

To the entire Banissy lab group, thank you for being a wonderful team that I'm lucky and proud to have been a part of - I have learnt so much from all of you! In particular, Nat & Chris thank you for all your help with my clustering woes; Chris & Tegan thank you for all your advice on the various statistical dilemmas throughout the doctorate; Mal thank you for all your help with the EEG data collection, you made it much more enjoyable and efficient; Katalena thank you for your constant support and advice throughout all of my presentations and questions. Special thanks to Thomas & Jasmine for all your extensive support for the EEG cleaning and analysis.

A huge thanks to my partner Rebecca for putting up with my ASMR talk throughout the years (especially as someone who doesn't experience ASMR) and for the constant moral support. Thank you to all my flatmates and family for supporting me throughout the doctorate as well.

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Chapter 1

Introduction

1.1 Background

Autonomous sensory meridian response (ASMR) is an atypical spontaneous sensory experience, which is characterised by tingling sensations in response to social visual and auditory stimuli (Barratt & Davis, 2015). Typically these tingling sensations arise at the back of the head and neck and then radiate down the spine and into the limbs in periods of greater intensity (Barratt & Davis, 2015). ASMR-Responders often report first noticing the experience in their pre-adolescent childhood, describing the sensations as 'electric' (Barratt & Davis, 2015). To date there have been no studies investigating the origins of ASMR since the term was first coined in the previous decade. Therefore, it is unclear how old of a phenomenon ASMR really is. However, ASMR has been found in English literature as far back as the early 20th century (Woolf, 1925).

Trait ASMR is only prevalent in a proportion of the population, although exact figures have not yet been explored. In addition to these tingling sensations from ASMR stimuli, ASMR-Responders also report an elation of mood and relaxation, thus showing a cross-modal modulation of affect (Barratt & Davis, 2015). Consequently, many ASMR-Responders watch ASMR videos to aid mood regulation, including alleviating pain, insomnia, anxiety and depressive symptoms (Barratt & Davis, 2015). Such videos have accrued trillions of views on YouTube and are becoming increasingly popular and widespread to induce state ASMR voluntarily.

The online ASMR community is growing rapidly: from YouTube alone, as of May 2018, the top 10 ASMRtists (creators of ASMR media) have accrued more than 1.7 trillion views across their combined 3500 videos. Comparing these figures again in December 2019, the top 10 ASMRtists have now accrued more than 5.7 trillion views across their combined 4450 videos, with over 24 million subscribers to their collective channels. According to Ahrefs in October 2019 ASMR was the 4th most common keyword search on YouTube worldwide, up from 8th most common 8 months prior (Hardwick, 2019).

It is important to note that, without the internet and widespread use of video hosting websites such as YouTube, day-to-day (state) ASMR occurrences happen spontaneously without much control by ASMR-Responders. Of course, there are certain scenarios that are commonly more indicative of being ASMR-inducing such as the environment of a quiet library (the sounds of turning pages, whispered voices, writing of pen and paper etc), or going for a haircut (close proximity of the hairdresser, scissor/shaver sounds panning around the ASMR-Responder). Through the creation and sharing of intentional ASMR videos, more control has now been provided to the ASMR-Responder to experience this involuntary, spontaneous experience at will.

One question to consider is whether trait ASMR is a binary concept, or rather lies on a scale. To date there have been no studies attempting to estimate the prevalence of ASMR. However, given a lack of consensus of ASMR definition, any such estimation would likely be inaccurate. Given the idiosyncratic nature of ASMR triggers, it is possible that everyone is capable of experiencing ASMR and simply requires the correct trigger in the correct environment. It is also possible that everyone individual is capable of experiencing ASMR at a young age, and ASMR is a developmental phenomenon requiring persistent stimuli (e.g., care-giving, lice combing) in a pleasant and relaxing environment. These are speculations which require investigation however it is important to the reader to understand the infancy of this topic and what little we scientifically know about ASMR. Audio-visual ASMR-inducing triggers have received considerable attention due to their relative ease of testing in online questionnaires (e.g., YouTube videos). As such, these will be covered in the next section.

1.1.1 ASMR-inducing triggers

A combination of certain themes help to reliably identify auditory and visual stimuli as ASMR-inducing: (1) close proximity; (2) social communication; (3) soft voices or whispers; (4) focused activities (Barratt & Davis, 2015; Barratt et al., 2017). These ASMR stimuli (so called 'triggers' in the community) often consist of personal attention, whispering, tapping, scratching of objects around the microphone, slow movements or delicately executed movements performed with precision (Barratt et al., 2017). However, trigger preference appears to be idiosyncratic which relies on the subtle nuances in the possible variety of different ASMR triggers. The possibilities grow exponentially when considering the combined preference of these triggers with other layered triggers from the same or other modalities (e.g., slow vs fast whispering possibly layered with tapping on wooden objects vs metal objects).

Whilst auditory and visual triggers are the dominant form of recreating the environment to induce ASMR, it is also thought that other modalities can also induce ASMR, specifically touch. This has been discovered anecdotally, through unpublished qualitative data and also through the increasing appearance of ASMR-oriented spa treatments. Indeed, there are striking similarities between the properties and modalities associated with ASMR and social grooming. There is very little evidence towards explaining why ASMR exists, and what biological or social function such a phenomenon could provide. Poerio and colleagues (2018) have suggested a tentative role for ASMR and social grooming due to the strong touch component of ASMR in both inducing stimuli and experienced somatosensation. Furthermore, ASMR-Responders report greater social connectedness following ASMR induction, as well as greater levels of calm and pleasantness (elaborated further in Section 1.2). Future work could explore whether there a change in neuropeptides associated with social touch and grooming following ASMR (Poerio et al., 2018). Naturally this is only one theory, and the biological function, if any, may differ or be driven through multifaceted selection pressures.

Now that a brief overview of the characterisation of ASMR, possible evolutionary functions, and what stimuli induces this state has been provided, the following sections will outline current knowledge of state ASMR and trait ASMR respectively.

1.2 State ASMR

There have been a number of investigations into how the ASMR experience affects the individual in the moment. Changes in affect, somatosensation, cognition and physiology have all been recorded, which will be discussed below.

1.2.1 A complex emotional state

Affect

The first scientific characterisation of state ASMR was by Barratt and Davis as a euphoric and calming experience coupled with short-lasting positive effect on mood (even in the absence of tingling sensations) and chronic pain symptoms (Barratt & Davis, 2015). Since then, a few studies have replicated and built on these findings to develop a more nuanced picture of the effect of state ASMR on affect. To my knowledge, three studies (two in Poerio et al., 2018) have investigated changes in affect using items from the Multi-affect indicator (Poerio et al., 2018; Scofield, 2019). Whilst some keywords differed between the studies all three studies showed significant increases in positive emotions (calmness, relaxation, excitement, joy) and two studies showed reductions in negative emotions (stress, sadness, anxiousness) between ASMR-Responders and controls (Poerio et al., 2018) and between control and ASMR stimuli (Poerio et al., 2018; Scofield, 2019). Furthermore, reinforcing the high proportion of ASMR-Responders (86%) reporting that consuming ASMR stimuli was not sexually stimulating, no differences in sexual arousal were found between ASMR-Responders and controls in two studies (Poerio et al., 2018).

Two studies found ASMR stimuli to enhance self-report scores of being connected to others induced by whispering or spoken triggers (Poerio et al., 2018; Scofield, 2019). This link has also been reinforced in a separate study investigating social connectedness with the actor in the ASMR video and ASMR-15 scores (Williams-Wilson, 2021). In this study a strong positive correlation was found between social connectedness and ASMR-15 scores. In addition, this study revealed that when successfully attenuating state absorption (through repeated exposure to an alarming sound during an ASMR video) the self-reported scores on social connectedness to the ASMRtist were not significantly diminished in ASMR-Responders. Therefore, it is possible that state absorption is not a moderator for social connectedness (Williams-Wilson, 2021). However, there was no control for ASMR propensity (i.e., how strong of an ASMR-Responder) between the test and control stimulus cohorts and thus these results may have been explained by underlying individual differences present prior.

Overall, ASMR appears to be characterised by a complex emotional state, where both positive activating and de-activating processes are reported simultaneously (e.g., excited, engaged and relaxed). The physiological correlates to support this are discussed below in Section 1.2.4.

1.2.2 Somatosensation

Pleasant tingling sensations are a hallmark feature of ASMR, yet different types of sensory-emotional tingling sensations have been characterised more generally into two distinct concepts: goosetingles (goosebumps and tingles) and coldshivers (coldness and shivers; Maruskin et al., 2012).

Goosetingles are associated with positive affect and approach-related motivations, whilst coldshivers are associated with negative affect and avoidance-related motivations (Maruskin et al., 2012). In the context of these two distinct concepts, ASMR tingles would be classified as goosetingles since the experience is often associated with higher levels of engagement and social connectedness. Furthermore, ASMR-Responders actively seek out the experience by watching the intentionally (or unintentionally) created ASMR videos online. This is an important distinction to address, since the lack of conformity in terminology between similar phenomena (such as aesthetic chills, musical chills etc) can lead to misconceptions. For example, according to the goosetingles and coldshivers distinction the term musical chills implies a negative affect and avoidance-motivated phenomenon. However, more research is required into whether ASMR tingles fits neatly into the goosetingles construct or whether certain overlapping features are present. The chills literature may benefit greatly from an unsupervised classification study (e.g., as employed in Chapter 3) in an attempt to normalise the nomenclature used in the field, without adding researcher bias to the terms. Such a study may be able to address these contradictions of terminology by using a data-driven approach and setting a framework for future studies.

Whilst it would be superfluous to list all the studies that showed group-level differences in ASMR tingling sensation scores, it would be prudent to note that there is wide variation of what the most 'effective' stimuli type to induce ASMR is. For example, Poerio and colleagues found spoken-based ASMR videos to produce higher effect sizes than sound-based (with no speech components) videos 2018. Conversely, another study has found no-whisper videos to elicit a greater number of reported tingles in contrast to whispered videos in ASMR-Responders (Liang, 2019). This variation is most likely as a result of individual differences in stimuli preference, but this has yet to be proven. Similarly, there is a scarcity of data on whether the presence of a face in ASMR videos elicits a more intense and reliable ASMR experience. The only study found revealed no effect of videos containing a full face, partially showing a face, or showing no face at all on the number of tingles elicited (Liang, 2019).

Tingle Location

Three studies to date have investigated the self-reported tingle location of ASMR (Barratt & Davis, 2015; Roberts et al., 2021c; Scofield, 2019). Whilst the regions delineated do not exactly match between all of the studies, general trends can be observed. Only one study has specifically investigated the origin of the tingling sensations, which typically originated towards the back of the scalp (Barratt & Davis, 2015). One of the two remaining studies support that the top or the back of the head/scalp is the most selected region (Roberts et al., 2021c), where the remaining study indicated the back of the neck to be the most likely region (followed marginally by the top of the scalp; Scofield, 2019). Roberts and colleagues are the only study to distinguish between front and back body maps and thus provide further insight into the tingle topology. For example, the front of the head was the second most endorsed in this study (2021c). Interestingly, the total number of body regions reported correlated positively with total ASMR-15 scores (Roberts et al., 2021c), with the Altered Consciousness subscale appearing to drive this trend. Crucially, ASMR-Responders who report tingling sensations in only one location compared to multiple tend to report comparable levels of sensation, relaxation and changes in affect. This may be explained by higher Affect scores being associated with ASMR sensations in the back of the head (Roberts et al., 2021c), which appears to be the epicentre of tingles for most ASMR-Responders (Barratt & Davis, 2015).

The midline from the middle of the forehead wrapping round down the back of the head and into the spine seems to be a hotspot for tingles (Roberts et al., 2021c). However, Roberts and colleagues noted that there were often 'jumps' or splitting of the path of sensation, where participants reported a low endorsement for the neck region (2021c). Conversely, the back of the neck was one of the most endorsed regions from both other studies (Barratt & Davis, 2015; Scofield, 2019). The variable region labelling framework (e.g., differing body map picture used, number of pixels allocated per region) could explain this discrepancy. In addition, these data may also suggest the role of certain sensory receptors in the skin being involved in the ASMR tactile response. For example, it is thought that low threshold mechanoreceptors with unmyelinated afferents (CT-afferents) are responsible for pleasant touch during slow movements on specific skin cell types (e.g., see the review Olausson et al., 2010). Whilst no studies to date have investigated the relationship between CT-afferents and ASMR, it is possible given the similar pleasant and socially relevant biological roles there is a link.

Results from the three studies consistently show ASMR as a head-oriented experience with additional body engagement when intense in some experiencers and/or some individuals, where reporting multiple tingling regions was common.

1.2.3 Cognition & motivation

Expectancy effects & priming

A single experiment has attempted to modulate the ASMR experience through providing either encouraging or discouraging instructions prior to watching ASMR stimuli in ASMR-Responders and naïve controls (Cash et al., 2018). The ASMR-Responder cohort were unaffected by the instruction manipulation, however naïve participants were significantly affected. These findings support the veracity of ASMR, where ASMR-Responders were able to distinguish authentic ASMR stimuli from foil stimuli, despite prior manipulation. In addition, this study highlights the importance of the placebo effect of naïve participants who may think they feel something due to the manipulation, but that something is distinct from the canonical ASMR experience. These findings highlight the importance of a data-driven tool to distinguish these 'false-positive' cases (see Chapter 3.

One experiment to date has investigated whether the ASMR experience can be altered through positive visual or auditory stimuli immediately preceding novel ASMR auditory stimuli. No effect was found (L.-J. Lee, 2019).

Executive function

Two studies to date have investigated the effect of state ASMR on cognitive function, either immediately following self-report state ASMR (Wang et al., 2020) or simultaneously tested with ASMR stimuli (Fredborg, 2015).

The earlier study used the attention networks task (ANT; Fan et al., 2009) to explore how ASMR affects the alerting, orienting and executive control aspects of attention (Fredborg, 2015). Their task ran over two days, where participants would complete the task either in silence or after 2 minutes into a 20 minute ASMR audio clip played concurrently. The only significant difference reported was a slower reaction time in ASMR-Responders compared to controls during the ASMR condition of the ANT for invalidly cued trials.

Wang and colleagues compared the performance (reaction time and accuracy) of three executive function processes (working memory, set shifting, and inhibitory control) between ASMR-responders and controls following either ASMR audio stimuli, normal speech stimuli or no stimuli (baseline; 2020). No significant differences were seen in the working memory task, nor were any intrinsic differences in all three tasks (e.g., baseline/normal speech conditions). ASMR triggered by auditory stimuli significantly slowed the reaction time of ASMR-responders in both set shifting and inhibitory control tasks. The authors also reported a trend level decrease in reaction time between groups for these two tasks. Since all ASMR-responders reported experiencing ASMR during the ASMR audio stimuli block the authors concluded that these differences were a result of state ASMR (Wang et al., 2020).

Overall, both studies provide some evidence that state ASMR may slow down the reaction times of ASMR-responders during certain cognitive tasks. However, since the differences present in the first study are minimal, further investigation is needed to unpack this discrepancy.

1.2.4 Neurophysiological effects of ASMR

Ocular, galvanic and cardiac effects

One study to date has investigated the effects of ASMR on pupil diameter using a mixed study design (Valtakari et al., 2019). ASMR stimuli were found to significantly increase pupil diameter in both ASMR-responders and controls compared to control videos. This increase was comparable between groups across the video generally. In epochs where tingling sensations were reported by ASMR-responders the authors reported a significant increase in pupil diameter (Valtakari et al., 2019). These results suggest that ASMR is linked to a release of norepinephrine in the locus coeruleus-norepinephrine (LC-NE) system (Eckstein et al., 2017; Valtakari et al., 2019), as previously shown during musical chills (Laeng et al., 2016).

Another study has measured changes in heart rate and skin conductance in response to ASMR stimuli (Poerio et al., 2018). ASMR-responders showed significantly greater reductions in heart rate following ASMR video presentation, in contrast to controls. In addition this cohort also showed a significantly greater increase in skin conductance in contrast to controls (Poerio et al., 2018). The authors concluded that the combination of these findings support the notion that ASMR is a complex affective state comprising of both activating (skin conductance increase) and de-activating (heart rate reduction) physiological components.

1.2.5 Neurobiology

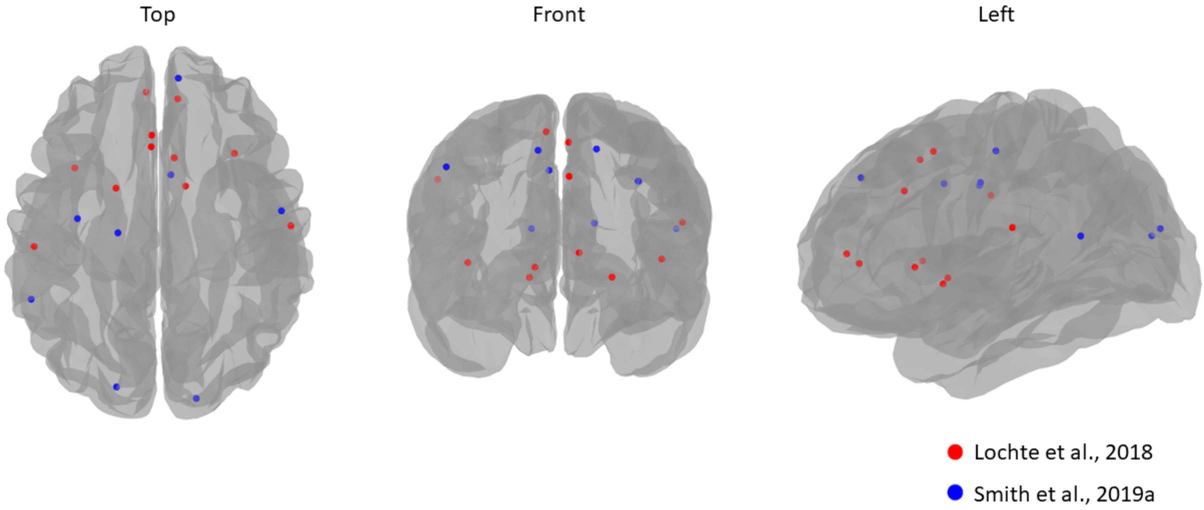
To date, two fMRI studies (Lochte et al., 2018; S. D. Smith et al., 2019a) and two EEG studies (Fredborg et al., 2021; Mackintosh, 2020) have investigated state ASMR.

The first fMRI study was a within-group comparison of brain region activation relative to an individual baseline during state ASMR (Lochte et al., 2018). Ten participants reported three states: no change 'Baseline', Relaxation or ASMR (e.g., the tingling sensations). When Relaxation was compared to Baseline, there was an increased activity in the medial prefrontal cortex. When ASMR was compared to Baseline there was increased activity in the media prefrontal cortex, bilateral nucleus accumbens, bilateral insula/inferior frontal gyrus, ventral premotor cortex, dorsal anterior cingulate cortex, left inferior parietal lobule, bilateral supplementary motor area and the left secondary somatosensory cortex. Reassuringly, the processes associated with these regions such as reward responses (e.g., see review Schultz, 2000), interoception (e.g., see review Craig and Craig, 2009) and emotional arousal (e.g., Oliveri et al., 2003) were all implicated, thus supporting the reported phenomenology of ASMR (Barratt & Davis, 2015).

In a task-based fMRI study where ASMR-responders and controls watched ASMR stimuli and control stimuli, differential activation of regions was shown through group comparisons (S. D. Smith et al., 2019a). Specifically, episodes of ASMR were associated with increased activity in medial prefrontal regions, bilateral precentral gyri, the right superior prefrontal cortex, the left superior temporal cortex, and midline occipito-parietal structures (precuneus and cuneus), whereas control participants showed only a decrease in activity in the cuneus (S. D. Smith et al., 2019a). The results indicate changes in sensorimotor, emotion and attention regions, however, surprisingly there was a lack of differential activity in reward centres such as the nucleus accumbens. A collation of these implicated regions is depicted in Figure 1.1.

Both EEG studies to date have investigated the changes in oscillatory frequencies induced by state ASMR (Fredborg et al., 2021; Mackintosh, 2020). Fredborg and colleagues employed a mixed design with audio and audiovisual ASMR and control stimuli (2021). Finally, Mackintosh employed a small mixed design study, where only one participant experienced ASMR and

Figure 1.1: *3D Brain Plot of fMRI ASMR-associated regions*



Brain areas activated during ASMR. fMRI brain regions reported as significantly different during state ASMR have been combined in this plot from two studies (Lochte et al., 2018; S. D. Smith et al., 2019a). Specifically, the regions depicted are the bilateral medial prefrontal cortex, bilateral nucleus accumbens, bilateral supplementary motor area, bilateral insula/inferior frontal gyrus, dorsal anterior cingulate cortex, left secondary somatosensory cortex, ventral premotor cortex (Lochte et al., 2018); left medial frontal gyrus, bilateral precentral gyrus, right superior frontal gyrus, left superior temporal gyrus, bilateral cuneus and right cingulate gyrus (S. D. Smith et al., 2019a). Plots have been generated using nilearn.

focused solely on alpha where the results were variable and inconclusive (2020). Changes in oscillatory alpha power have been recorded in all 3 studies. For the audio ASMR trials in the study reported by Fredborg and colleagues, a between-group contrast revealed significantly enhanced alpha power at frontal, parietal and precuneus electrodes. Only the enhanced alpha precuneus effect was replicated for the audiovisual contrast. An exploratory analysis for the audio trials also revealed significant enhanced alpha power at occipital, parietal and temporal regions in ASMR-responders compared to non-Experiencers. Moreover, an enhancement of gamma power was seen at central electrodes for the audio trials only. An increase in sensorimotor rhythm power was seen at sensorimotor regions (C3, Cz, C4) for ASMR-responders during audio trials (Fredborg et al., 2021).

Within-subjects contrasts of ASMR-inducing stimuli against control stimuli in the audio trials revealed a similar significant enhancement of alpha power in frontal and cuneus electrodes as well as at P3 and P4 for ASMR-responders only (Fredborg et al., 2021). Baseline within-subjects contrasts of audio trials in ASMR-responders revealed enhancements of alpha power in frontal and medial frontal regions. Conversely, the same contrasts in controls (using the times from the matched ASMR-responders) reported decreases in alpha power in frontal, medial frontal and precuneus regions. Furthermore, sensorimotor rhythm power increased for ASMR-responders in audio trials only, whilst decreased for controls (Fredborg et al., 2021). For the video trials for ASMR-responders there was a trending increase in alpha power near the precuneus (Fredborg et al., 2021). Further replication and expansion of electrophysiological state ASMR data would be an important next step in ASMR research.

1.3 Trait ASMR

1.3.1 Personality & altered mental states

Broader personality traits

To date, four studies have used the BFI (John et al., 1991) to capture personality differences between ASMR-responders and non-Experiencers. Openness-to-Experience was found to be significantly enhanced in ASMR-responders in three of these studies (Fredborg et al., 2017; McErlean & Banissy, 2017; Roberts et al., 2020). Roberts and colleagues, investigated further using the ASMR-15 and found that in particular this effect was driven by the Altered Consciousness and Affect subscales of the ASMR-15 (2020; e.g., "It feels like a different state of mind" and "The experience is blissful" respectively). The Neuroticism subscale of the BFI was also found to be significantly higher in ASMR-responders in two of the four studies (Fredborg et al., 2017; Wang et al., 2020). Conscientiousness was found to be lower in ASMR-responders in 75% of the studies (Fredborg et al., 2017; McErlean & Banissy, 2017; Roberts et al., 2020). In fact, both Conscientiousness and Openness-to-Experience were found to be independent predictors of ASMR-15 scores (along with heightened sensory sensitivity scores; explaining 12.6% of variation in ASMR propensity; Roberts et al., 2020). Finally, both Extraversion and Agreeableness were only found to be lower in ASMR-responders in one study (Fredborg et al., 2017).

Propensity for altered mental states

Since a reliable effect of heightened Openness-to-Experience scores in ASMR-responders has been shown, it is also logical that ASMR-responders also exhibit higher scores in transliminality (Roberts et al., 2021b). Indeed, both effects have been shown to be significantly correlated by the Altered

Consciousness subscale of the ASMR-15. In the same study, Roberts *et al.*, investigated the propensity for ASMR-responders to experience Unusual Experiences (e.g., synaesthesia, dreams and fantasy; from Hartman's 1991 145-item Boundary Questionnaire; 2020). A significant positive correlation was found between Unusual Experience subscale scores and both ASMR-15 and Altered Consciousness scores. In fact, both mindfulness (assessed by the Mindful Attention and Awareness Scale; MAAS; K. W. Brown and Ryan, 2003) and transliminality were significant predictors of ASMR-15 scores.

ASMR has also been speculated to share certain facets of the state of flow (e.g., altered temporal perception; Barratt and Davis, 2015). Consequently, there have been several studies investigating the propensity of flow as well as state absorption in ASMR-responders. Considering absorption first, three studies have found links between ASMR and heightened trait absorption. One study found group level differences (higher absorption scores) compared to matched non-responders (McErlean & Osborne-Ford, 2020), and two studies found significant correlations between ASMR-15 scores and absorption using the Tellegen Absorption Scale (Williams-Wilson, 2021) and a significant predictor of ASMR-15 scores using the absorption subscale of the Curious Experiences Scale (CES; Roberts et al., 2019).

Compared to the clear trend seen for absorption & ASMR, the relatedness of trait flow to ASMR is more varied. Two of the three studies indicated a significant positive relationship between flow (as measured by a reduced version of the Flow State Scale; Jackson and Marsh, 1996) and the number of ASMR triggers (Barratt & Davis, 2015) and scores of the ASMR-20 (a previous iteration of the ASMR-15) total and all respective subscales scores except Sensation (Roberts et al., 2019). Conversely, McErlean and Osborne-Ford found no group-level differences between ASMR-responders and non-Experiencers using the Flow Experiences Scale (Schwartz and Waterman, 2006; 2020).

1.3.2 Emotion processing & cognition

Cognitive reappraisal of emotion regulation & wellbeing

One recent study has reported group level differences using the emotion regulation questionnaire (J. J. Gross & John, 2003), where ASMR-responders scored higher in the cognitive reappraisal subscale (Morales et al., 2021). This finding supports the regulatory emotional effect that the ASMR experience appears to exhibit in ASMR-responders. Interestingly, reappraisal has been shown to correlate positively to well-being (J. J. Gross & John, 2003), where Flourishing (a marker of wellbeing) has been shown to also correlate significantly with the ASMR-15 total score, Altered Consciousness and Affect subscales (Roberts et al., 2021c).

Mixed self-report differences

ASMR-responders have been assessed, to date, across five different studies using a variety of self-report empathy measures. Three of these studies have found significant group differences. Using the IRI (Davis, 1980), two (McErlean & Banissy, 2017; Roberts et al., 2020) of three (Wang et al., 2020) studies have reported ASMR-responders scoring higher on at least one of the IRI subscales, in particular the Fantasizing subscale. Roberts *et al.*, also found using the total ASMR-15 score a significant correlation with the Personal Distress subscale 2020. Furthermore, the Sensation subscale of the ASMR-15 correlated significantly with the Fantasizing, Personal Distress, as well as Empathic Concern subscales, the latter of which was also found to be higher in ASMR-responders (McErlean & Banissy, 2017). Therefore, the authors concluded it is possible that the sensory component of ASMR is associated with an altered cognitive and affective empathy profile (Roberts et al., 2021a). In contrast, Poerio and colleagues have found no significant differences using the Toronto Empathy Questionnaire 2018.

Attachment styles

Whether or not these enhanced emotion identification skills have positive downstream consequences for interpersonal relationships is an open question. The attachment styles of ASMR-Responders may also differ to non-Responders, especially if the evolutionary function of ASMR is related to social grooming as discussed in Section 1.1.1. Moreover, a contrast could be made with the prominent roles portrayed in ASMR videos as a motherly figure who cares for you with ample platonic personal attention. Frequent exposure to these scenarios, especially pre-adolescence, could predispose ASMR-Responders to exhibit altered values within their adult relationships. However, one study found no significant differences in overall ASMR propensity (ASMR-15) and different attachment styles (Roberts et al., 2021a). However, respondents categorised as Fearful Avoidant (high anxiety and high avoidance in romantic relationships) scored significantly higher in the Sensation subscale than those in the Dismissive group (low anxiety, high avoidance in romantic relationships). This may suggest the sensory component of ASMR is associated with anxiety in close relationships. Indeed, 16.1% of the variance in Sensation scores was significantly predicted from relational constructs (Roberts et al., 2021a).

1.3.3 Altered (multi)sensory processing

Determining whether ASMR-responders possess an altered sensory processing profile has been the aim of many recent studies (e.g., Keizer et al., 2020; McErlean and Banissy, 2018; Poerio et al., 2021; Roberts et al., 2020), and was first suggested by Barratt & Davis in terms of a suggestion association between ASMR and synaesthesia with possible links to misophonia (2015), a disorder where certain sounds can elicit disgust and intense anger.

ASMR & misophonia

The association between ASMR and misophonia in particular has received a great deal of interest, with seven studies providing insights (Del Campo, 2019; Ditchburn & Bedwell, 2019; McErlean & Banissy, 2018; Roberts et al., 2019; Rouw & Erfanian, 2018; Scofield, 2019; Tada et al., 2021). In the two studies that used single-item measures, a significant group level difference of higher self-reported misophonia in ASMR-responders was found (Del Campo, 2019; Ditchburn & Bedwell, 2019). However, this effect was nullified in one study when only considering ASMR-responders that experienced ASMR during the stimuli presentation within the survey itself (Del Campo, 2019). Nonetheless, 68% of these responders identified as experiencing misophonia (Del Campo, 2019). In a study investigating misophonia more generally, almost half (49%) of participants with misophonia also self-reported as ASMR-responders (Rouw & Erfanian, 2018). Interestingly, the presence of trait ASMR did not significantly decrease the negative effects of misophonia in this cohort.

In the four remaining correlational or group-level difference studies, three reported a significant association between misophonia and ASMR (McErlean & Banissy, 2018; Scofield, 2019; Tada et al., 2021). Using the Misophonia Questionnaire (MQ; Wu et al., 2014) ASMR-responders scored significantly higher than age and gender matched non-Experiencers on all subscales of the MQ (including the Misophonia Symptom Scale, the Misophonia Emotions and Behaviours Scale and the Misophonia Severity Scale; McErlean and Banissy, 2018). Similarly, Kondo *et al.,* found a positive correlation between ASMR scores and MQ scores including Symptom scale and Emotional and Behavioural Scale 2021, as did Scofield with mean ASMR Checklist scores and total MQ scores (2019).

ASMR & synaesthesia

Only two empirical studies have investigated the link between synaesthesia and ASMR. Barratt & Davis noted that the prevalence of synaesthesia was trending higher in ASMR-responders than non-Experiencers (5.9% within the sample; 2015; vs 4.4% estimated general population; Simner et al., 2006). Self-reporting ASMR-responders in another study also were associated with reporting as experiencing "other" (e.g., sounds evoking a particular taste or particular emotions with tactile forms).

ASMR & similar experiences

Two empirical studies to have reported associations between musically-induced aesthetic chills (frisson) and ASMR (Del Campo, 2019; Ditchburn & Bedwell, 2019). Using self-report scales ASMR-responders scored significantly higher in self-reporting propensity to experience musical chills (Ditchburn & Bedwell, 2019). Moreover, using the Aesthetic Experiences Scale and its respective 3 item frisson subscale (AES-FR), ASMR-20 scores positively correlated on both (Roberts et al., 2019). This effect was driven by the Movement subscale of the ASMR-20, which has been subsequently merged with the Sensation subscale of the ASMR-15. Finally, 65% of self-reporting ASMR-responders agree that ASMR and (aesthetic) chills are distinct experiences (Del Campo, 2019).

ASMR-responders exhibit altered environmental sensitivity

There has been one behavioural study to date that has investigated sensory processing in ASMR-responders using the Sensory Suggestibility Scale (SSS; Gheorghiu et al., 1994). The SSS involves a number of experimental exercises and control exercises. For experimental exercises the experimenter hints to the participant verbally that they should feel a particular sensation (e.g., shining an LED torch and hinting heat). ASMR-responders scored equally in sensation scores in both control and experimental exercises indicating a high propensity to experience illusory sensory events compared to non-Experiencers (Keizer et al., 2020). Another study has linked ASMR-responders to heightened illusory sensory events by looking at the relationship between ASMR and symptoms of Alice in Wonderland Syndrome (AIWS). Bedwell & Butcher report a significant negative correlation between the number of visual symptoms of AIWS (e.g., inability to appreciate the size of objects or the exaggeration of depth and detail of objects) and the age of onset of ASMR (2020). The number of visual symptoms of AIWS was found to be a significant predictor of the age of onset of ASMR. Indeed, just under half of self-reporting ASMR-responders also reported experiencing symptoms of AIWS (Bedwell & Butcher, 2020).

Two studies to date have investigated sensory-processing sensitivity (SPS) more broadly using the highly sensitive persons scale (HSPS; Aron and Aron, 1997). SPS refers to innate heightened psychobiological sensitivity to social and environmental stimuli (Acevedo et al., 2014; Aron & Aron, 1997). Both studies found ASMR-responders to score significantly higher in the HSPS than non-experiencers (Poerio et al., 2021; Roberts et al., 2020). Further analyses showed that these significant differences were present in all three subscales of the HSPS: ease of excitation (measuring the tendency to be easily overwhelmed by internal and external stimuli), low sensory threshold (measuring sensitivity to subtle external stimuli) and aesthetic experiences (measuring openness for, and pleasure of, aesthetic experiences and positive stimuli; Poerio et al., 2021). In particular, both studies found significant correlates between HSPS scores and total ASMR-15 scores as well as the ASMR-15 Sensation subscale scores. Despite Neuroticism (and Openness to experience) also correlating with HSPS scores, this significant relationship between ASMR-15 and SPS persisted even when controlling for the Neuroticism BFI subscale (which has been shown to correlate with SPS scores previously; Roberts et al., 2020). Indeed, HSPS scores were found to be a significant predictor of ASMR-15 scores (Roberts et al., 2020) or more intense ASMR trigger responses (Poerio et al., 2021). In particular, the aesthetic experiences subscale of the HSPS was found to be driving this effect (alongside higher emotional awareness). The authors concluded that "more intense ASMR trigger responses were predicted by higher awareness of the connection between body sensations and emotional states and higher appreciation for aesthetic experiences". Furthermore, one of the two studies found HSPS scores to be a significant predictor for the Relaxation and Affect subscales of the ASMR-15 (Poerio et al., 2021), an effect again shown to be driven by the aesthetic experiences subscale. In addition, scores collected using the Glasgow sensory questionnaire have also shown to be a significant predictor of ASMR response intensity, which are perhaps predicted by both overactive and underactive sensory processing (Poerio et al., 2021).

ASMR-responders exhibit altered interoceptive processing

In addition to heightened exteroceptive processing present in ASMR-responders, investigations into an altered interoceptive processing profile have also been conducted. Interoceptive sensibility, the self-evaluated assessment of subjective interoception (Garfinkel et al., 2015), has been assessed twice to date using different scales. Poerio and colleagues reported that scores on the Multidimensional Assessment of Interoceptive Awareness Scale (MAIA-2; Mehling et al., 2018) positively predicted the intensity of ASMR trigger responses, driven primarily by the emotional awareness subscale (measuring awareness of the connection between body sensations and emotional states). MAIA-2 scores also predicted all subscales of the ASMR-15 apart from Relaxation (Poerio et al., 2021). Furthermore, the non-distracting component (the tendency not to ignore or distract oneself from sensations of pain or discomfort) was reported to be a negative predictor of the Sensation subscale; the Trusting subscale (the experience of one's body as safe and trustworthy) was also reported to be a predictor of the Affect subscale. ASMR-responders were reported to have scored higher on the Noticing (the awareness of uncomfortable, comfortable, and neutral body sensations) and Emotional Awareness subscales and lower on the Not Worrying (the tendency not to worry or experience emotional distress with sensations of pain or discomfort) subscale compared to controls (Poerio et al., 2021). Conversely, another study found no relationship between ASMR and interoceptive sensibility using the Private Body Consciousness Subscale (self-evaluation of perceived internal bodily sensations; Miller et al., 1981) of the Body Consciousness Questionnaire (Roberts et al., 2021b).

The propensity for ASMR-responders to experience alexithymia, the impairment of interoception, has also been investigated in one study using the Toronto Alexithymia Scale (TAS-20; Bagby et al., 1994). No relationship between alexithymia and ASMR was found, however a very weak correlation was present between the Altered Consciousness subscale of the ASMR-20 and TAS-20 scores (Roberts et al., 2019). Similarly, the relationship between autistic traits, as measured by the autism-spectrum quotient (AQ), and ASMR has been investigated once (Tada et al., 2021). Again, no significant correlation was present between ASMR and any of the AQ subscales.

Since the first mention of the similarities between ASMR and mindfulness (Barratt & Davis, 2015), there have been 6 studies to date that have investigated further (Del Campo, 2019; Fredborg et al., 2018; McErlean & Osborne-Ford, 2020; Poerio et al., 2021; Roberts et al., 2021b; Scofield, 2019). Of those studies, three of which used the Five-Facet Mindfulness Questionnaire (FFMQ-15) to measure trait mindfulness. All three studies found a positive association between trait ASMR and the Observing facet of the scale (e.g., "I notice how foods and drinks affect my thoughts, bodily sensations, and emotions"; Del Campo, 2019; Poerio et al., 2021; Scofield, 2019). In addition, Del Campo reported that the frequency of ASMR occurrences (e.g., daily vs yearly) positively predicts scores on the Observing facet, proposing that the ASMR experience acts as a mindfulness strengthening exercise of bodily awareness (2019). Moreover, one study revealed a negative correlation between trait misophonia and the Non-reactivity (e.g., "When I have distressing thoughts or images I just notice them and let them go") and Non-judgement to Inner Experience facets (e.g., the reverse scored item "I think some of my emotions are bad or inappropriate and I shouldn't feel them"; Scofield, 2019).

The remaining 3 studies used the MAAS to assess trait mindfulness. Comparing total group scores between ASMR-responders and controls, one study found ASMR-responders to score higher (Fredborg et al., 2018), and one found no difference (McErlean & Osborne-Ford, 2020). Roberts *et al.*, report a negative correlation between ASMR-15 scores and MAAS scores, which was specifically driven by scores on the Altered Consciousness subscale (2021b). Indeed, they also reported mindfulness to be a significant negative predictor of ASMR-15 scores. One study has also used the Toronto Mindfulness Scale, where ASMR-responders scored higher on the curiosity subscale (a measure of one's mindful curiosity about any thoughts, emotions, and sensations) but not the decentering subscale (measures people's awareness of their own experiences; Fredborg et al., 2018). Positive associations between Curiosity scores and ASMR checklist intensity scores were also reported for the Touching and Repetitive sounds subscales.

1.3.4 Functional neurobiological differences

Functional connectivity differences in resting state networks

There are two fMRI studies investigating functional connectivity differences in (eyes closed) resting state networks between ASMR-responders and controls (S. D. Smith et al., 2017, 2019b). The more recent study built on the dataset of the former study, including additional analyses. Compared to controls ASMR-responders showed significantly less connectivity among the key nodes of the DMN (e.g., sensory/attentional processing of precuneus, parietal cortex and mPFC; S. D. Smith et al., 2017) and atypical relationships between resting state networks (S. D. Smith et al., 2019b). This finding led the authors to speculate that ASMR-responders may have a reduced ability to inhibit sensory-emotional responses that are typically suppressed in controls. The authors also speculated that ASMR may involve a blending of resting-state networks due to prior work showing associations between atypical perceptions and undifferentiated networks (Alderson-Day et al., 2015; S. D. Smith et al., 2017). ASMR-responders were also shown to exhibit greater DMN functional connectivity compared to controls in regions associated with executive control and visual resting state networks (S. D. Smith et al., 2017). Conversely, in the latter paper the DMN of ASMR-responders recruited a smaller cluster in the cuneus, which is a visual region that is adjacent to the precuneus (S. D. Smith et al., 2019b). In addition, control participants showed greater functional connectivity both within the visual network and between the visual network and motoric regions.

Another example of atypical connectivity in ASMR-responders is a stronger correlation between sensorimotor network regions and reward-sensitive regions (orbital gyrus - part of the frontal lobe reward valuation network; S. D. Smith et al., 2019b). This finding might provide evidence for a stronger tendency for ASMR-responders to experience rewarding tingling sensations. In contrast, controls showed greater functional connectivity in many motoric areas of the sensorimotor network (S. D. Smith et al., 2019b).

When examining the central executive network, controls were found to show increased bilateral connectivity in frontal and occipitotemporal regions compared to ASMR-responders. Furthermore, ASMR-responders showed increased functional connectivity between regions associated with negative valence emotional motoric responses (midcingulate cortex; S. D. Smith et al., 2019b). A further finding was the greater synchronisation of the central executive network and regions associated with speech processing (posterior and middle temporal lobes). In contrast, controls showed greater synchronisation between regions associated with the salience network and more general auditory perception regions (S. D. Smith et al., 2019b).

A third study has investigated the functional connectivity associated with five different ASMR triggers as assessed by the ASMR Checklist (Watching, Touching, Repetitive sounds, Simulations and Mouth sounds; Fredborg et al., 2017; S. D. Smith et al., 2020). Overall the authors reported and hypothesised a general trend of greater trigger sensitivity being correlated with weaker functional connectivity relevant to the processing of the respective stimuli. For example Watching trigger scores were associated with weaker functional connectivity of the Salience and Visual networks in regions associated with attention (left posterior cingulate cortex and bilateral anterior cingulate cortex respectively). Touching trigger scores were associated with decreased functional connectivity within the DMN (right middle frontal gyrus, right angular gyrus, left supramarginal gyrus and left precuneus). Touching trigger scores were positively correlated with the functional connectivity of regions involved in the dorsal attention network including the precentral gyrus (primary motor cortex) and the supramarginal gyrus (processing tactile information and self-other control; Baeken et al., 2014). Individual differences in Repetitive sounds trigger scores were also associated with a weaker functional connectivity between the DMN and the right temporal pole (an area associated with emotional contagion; Sturm et al., 2013), right amygdala (detection of dynamic emotional stimuli; Baeken et al., 2014) and posterior orbitofrontal cortex (response inhibition and impulse control; S. D. Smith et al., 2020; Zikopoulos et al., 2017). Simulation trigger scores were associated with weaker connectivity between the frontoparietal network and left superior frontal gyrus (working memory and processing spatial information), left postcentral gyrus (touch processing; Roland, 1981) and left lateral occipital cortex (object perception; Erdogan et al., 2016) and between the sensorimotor network and left postcentral gyrus. Mouth sound trigger scores were also associated with weaker connectivity between the frontoparietal network (right inferior temporal gyrus) and sensorimotor network (left lateral occipital cortex). Furthermore a positive correlation was found between the dorsal attention network involving the left occipital pole. Taken together these results suggest a distinct trigger-dependent neurobiological profile for trait ASMR when assessing resting state networks (S. D. Smith et al., 2020).

Table 1.1: Summary of Trait ASMR differences between ASMR-Responders and non-Responders

Cognitive	Affective	Sensory	Biological	Developmental
↑ Propensity for altered mental states	△ Personality traits	↑ Sensitivity	△ MRI resting state functional connectivity	?
↑ Cognitive reappraisal of emotion regulation	△ Empathy	↑ Misophonia	? EEG connectivity	
? Intelligence	?/= Attachment styles	↑/? Synaesthesia		
		↑ Musical chills		
		↑ Suggestibility		
		↑ Illusory		
		↑/=/? Interoception		
		△/? Mindfulness		

Note. All trends reported above are respective to ASMR-Responders compared to non-responders. '△' = varied or complex differences, '↑' = enhanced,, '?' = unknown, '=' = no difference

1.4 Summary

Table 1.1 summarises the significant findings related to ASMR to date. It is prudent to note that many of the studies reported above rely on self-report measures and often recruit from the same restricted population pools (e.g., the ASMR subreddit). This sampling bias limitation is inherent to ASMR research, where ASMR-Responders will more readily volunteer to participate, whereas in contrast non-Responders tend to be more aversive to ASMR stimuli. This tendency to recruit via self-report measures as an easy and essential start to study such sensory phenomenon. However, quantitative psychometric tools to classify how participants respond to ASMR will be greatly beneficial to the field. Furthermore, it would be useful for ASMR research for a participant database to be created to monitor and prevent oversampling of the same individuals, anonymised where possible.

1.5 Aims and overview of the thesis

While these studies provide an important first step in objectively verifying ASMR, further work is required to develop quantitative measures to validate and measure the presence of trait and state ASMR in an individual. Indeed, before potential relationships between ASMR and broader experiences (e.g., mental health and well-being) can be fully explored one firstly needs to be able to characterise and explain ASMR itself. There are a number of gaps in the literature that have been outlined above. This thesis aims to address, at least in part, these gaps.

The first major gap that will be prioritised is the creation of a data-driven tool to identify participants who are ASMR-responders, who are not ASMR-responders and individuals who think they experience ASMR but are in fact experiencing something separate (e.g., see Cash et al., 2018). Consequently, in Chapter 3 the development and testing of the ASMR-Experience Questionnaire (AEQ) will be described, which will be the first data-driven tool to cluster and identify participants using unsupervised clustering techniques. This is particularly important due the inaccuracies inherent in self-report measures, and an online tool can eliminate the need for independent participant verification. An additional gap identified is the inconclusive indication of an effect of trait ASMR and empathic processing. Whilst some studies have found group-level differences, others have not. In order to address this gap Chapter 4 will use behavioural measures of empathy that have been designed to independently measure subcomponents of the empathic process and, thus identify where potential differences may reside. Thirdly, the electrophysiological correlates of state ASMR have largely been unexplored. Chapter 5 will build on the work presented by Fredborg and colleagues, and expand on their findings using a novel experimental design, coupled with source localisation of the signals, to estimate the cortical origin of identified differences (2021). Finally, the results from Chapters 3 to 5 will be discussed in the broader context of a proposed model that will aim to explain both state and trait ASMR in Chapter 6.

The specific questions addressed are:

- **Chapter 3:** Can participants be characterised using data-driven methods through their responses to a series of sensory-affective questions presented following a variety of ASMR stimuli?
- **Chapter 4:** Is trait ASMR associated with enhanced empathy and, if so, is there a particular subcomponent that is driving these effects?
- **Chapter 5:** What oscillatory correlates of state ASMR can be detected using EEG methodologies, and can, with the aid of source-localisation, speculations be made about possible reason certain brain regions are implicated?
- **Chapter 6:** Can both state and trait ASMR be explained using a novel model that incorporates the findings outlined in Chapters 1 and 3 to 5?

First, Chapter 2 will briefly introduce the more advanced methodologies used in the subsequent chapters.

Chapter 2

General Methods

2.1 Introduction

The primary aims of this thesis is to effectively characterise how participants can be classified in their responses to ASMR stimuli, and if classified as an ASMR-R, in what physiological, behavioural and neural ways do differences exhibit to non-responders. This chapter provides a brief overview of the hardware used, data acquisition, data processing and data analysis steps of the methodologies used, as well as the biophysical principles relevant to any neuroimaging techniques adopted in the process (specifically EEG - detailed further in Chapter 5). The cheap, and non-invasive nature of EEG permits itself to being used world-wide as a tool to identify spatio-temporal specific patterns of a plethora of phenomena. The combined high temporal resolution present in EEG, on the order of milliseconds, and with advanced analyses a respectable spatial resolution too has resulted in major breakthroughs in cognitive neuroscience.

This chapter will provide a brief overview of all the general methods used throughout this Ph.D, however where relevant more specific methodological details can also be found in the respective sections. Overall, the methodologies behind the development of psychometric measures (the ASMR-Experience Questionnaire detailed in Chapter 3 and respective refinement techniques (such as k-means clustering), EEG acquisition & analysis (detailed in Chapter 5 and heart-rate acquisition & analysis).

2.2 Current ASMR measures

2.3 Data clustering

Data clustering techniques are used to uncover inherent patterns in the structure of large multivariate datasets. They are very useful in exploratory data analysis, where no prior knowledge or interpreter bias can be applied to the distribution of the dataset. As such, data clustering is a form of unsupervised classification (where no labels are assigned initially). Instead, clusters are determined by evaluating similarities and dissimilarities across a number of variables both within and between every case. Consequently, the groupings formed are driven by emergent similarities and not any externally applied criterion (however, it should be noted that external criterion can be applied to variants of *k*-means clustering such as constrained *k*-means Wagstaff et al., 2001). Data clustering is especially useful for large multivariate datasets where visualisation of the variables on Nth dimensional space is difficult to comprehend.

There are numerous types of clustering techniques, however partitioning-based techniques such as *k*-means was used in this thesis in Chapter 3 and thus will be described in more detail here.

2.3.1 *K*-means clustering

K-means clustering relies on the iterative relocation of data points between clusters, where the center of each cluster is derived from the mean of all the data points within that cluster (it should also be noted that there is also a variant of clustering which relies on a median value being assigned as a cluster center called *k*-medoid). Each case is partitioned into non-overlapping clusters, or groups, so that each case can only belong to one cluster. The goal of *k*-means is to group cases together that share a high degree of similarity across the input variables with each other, whilst keeping a low degree of similarity with cases assigned to other clusters (Likas et al., 2003). In fact, the centroid of a cluster (the center) represents the mean used to describe each cluster, as the creator of the technique originally intended (MacQueen et al., 1967).

Within clustering there a many different ways to calculate the distance between data points, the most common of which is the Euclidian distance.

$$d\left(x,c\right)=\sqrt{\sum_{i}^{n}\left(c_i-x_i\right)^2}$$

Here, c is the cluster center to which x is compared, k is the total dimensions, and i is the dimension of x being compared.

Clustering algorithms - Hartigan & Wong

The *k*-means clustering algorithm used in this thesis was the Hartigan & Wong algorithm (Hartigan & Wong, 1979). The aim of this algorithm is to identify partitions in the data space that have the locally optimal within-cluster sum of squares of errors (SSE). The cluster centres are first initialised, typically by randomly assigning the initial k centroids. Each case is then assigned to the closest centroid. The centroid is subsequently calculated as the mean of the assigned points as measured by Euclidian Distance. Then, assuming the value for the centroids has been updated, this process repeats iteratively, where cases are reassigned to the new centroid position, and new means are calculated. These iterations continue until no cases change cluster, and thus fully optimised.

The biggest drawback of *k*-means clustering is the high sensitivity of the algorithm to the initial centroids has on the final solution (due to the gradient descent nature of the algorithm, e.g., see Celebi et al., 2013). However, to compensate for this drawback a technique called *k*-means seeding can be adopted by running *k*-means several times with different initial values and then picking the best (lowest SSE) result. Another drawback is how best to determine how many clusters to determine within the dataset. This is covered in the next section.

Determining k number of clusters

Usually there is no correct number of clusters to use for a dataset, however there are methods to guide the user in choosing the most appropriate number. The simplest method is to use the elbow plot, where the within-cluster sum of squares of errors is plotted against the number of clusters k. As k increases the SSE tends to zero. For example in the extreme scenario where k is equivalent to he number of cases the SSE will be zero. Therefore, it is more appropriate to look for the reduction in SSE between subsequent values of k to determine the greatest benefit of including an additional cluster to the algorithm. Of course, this optimum value is dependent on the clustering aim, and if the aim of the clustering is to determine a more granular characterisation of the dataset then values of k can be greater.

Whilst k-means is an example of non-hierarchical clustering, hierarchical clustering can also be used to aid in determining k.

Finally, a statistical approach can also be taken towards determining k. Namely, the Gap Statistic (Tibshirani et al., 2001) has been used in Chapter 3. This technique relies on the change in within-cluster dispersion contrasted against what would be expected under a null distribution. The reference dataset is generated using Monte Carlo simulations of the sampling process. For the observed data and the the reference data, the total intracluster variation is computed using different values of k. Therefore, the Gap Statistic selects the number of k where the biggest jump in within-cluster distance occurred, against the expected value.

2.4 Electroencephalography (EEG)

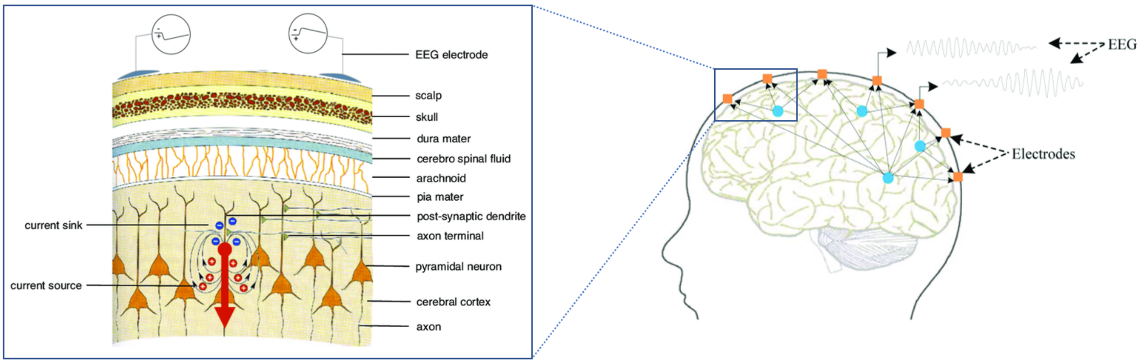
The potential for EEG to measure the activity of the brain was first realised in the late 19th century by pioneers such as Adolf Beck (Beck, 1890). The technique has since developed significantly through the advent of small electrodes which can be placed at very specific loci on the scalp, dedicated to specific standardised regions. Indeed, the field has advanced to the extent where scientists have with a high degree of success been able to facilitate thought sharing between three participants (Jiang et al., 2019).

Before the fundamental principles of EEG are outlined below, the suitability of the technique in investigating ASMR will be assessed. EEG is low cost and requires relatively little training in order to use and crucially is non-invasive. The temporal resolution is high, where the sampling rate can be as high as 20,000 Hz. The precise temporal resolution combined with the appropriate paradigm can facilitate the uncovering of specific stages of processing (Sereno et al., 1998). Movement artefacts are tolerated relatively well compared to other neuroimaging techniques, where various algorithms have been developed to rescue data from movement artefacts (e.g., independent component analysis correcting for eye-blinks; Delorme and Makeig, 2004; Hyvärinen and Oja, 2000). Covert processing, such as that is predominant in ASMR can also be detected by EEG, even where stimuli are unattended to (Mcguigan, 2012). The silent nature of EEG, allows for less interference for ASMR auditory stimuli to induce ASMR, where other techniques such as fMRI are at a severe disadvantage. However, it should be noted there is anecdotal evidence in some ASMR-R that pressure to the head reduces ASMR induction.

On the other hand, the setup for EEG can be lengthy, which with longer paradigms could result in attrition faster than other techniques. This is particularly problematic with inconsistent and involuntary phenomena such as ASMR. Therefore, is it possible participant data might be useless if no ASMR induction was successful. There is also evidence reported by participants tested in this thesis, as well as other studies (Fredborg et al., 2021) that the setup process of the EEG equipment itself was sufficient to induce ASMR, thereby possibly influencing the data downstream. Furthermore, the signal to noise ratio with EEG data is quite poor, requiring more advanced data analysis techniques and/or a greater number of participants (confounding with the previous point). Finally, the spatial resolution is relatively poor, but can be rescued somewhat with more advanced analyses.

2.4.1 Fundamental principles of EEG

Figure 2.1: *Fundamental principles of EEG generation*



The potential presenting on the surface of the cerebral hemispheres is generated by the summed activity of hundreds of nerve cells. The bio-electrodes (black points) placed on the cerebral cortex are used to collect these potentials. Sourced from https://www.researchgate.net/figure/Fundamental-principles-of-EEG-generation-The-potential-prevsenting-on-the-surface-of_fig1_334042877.

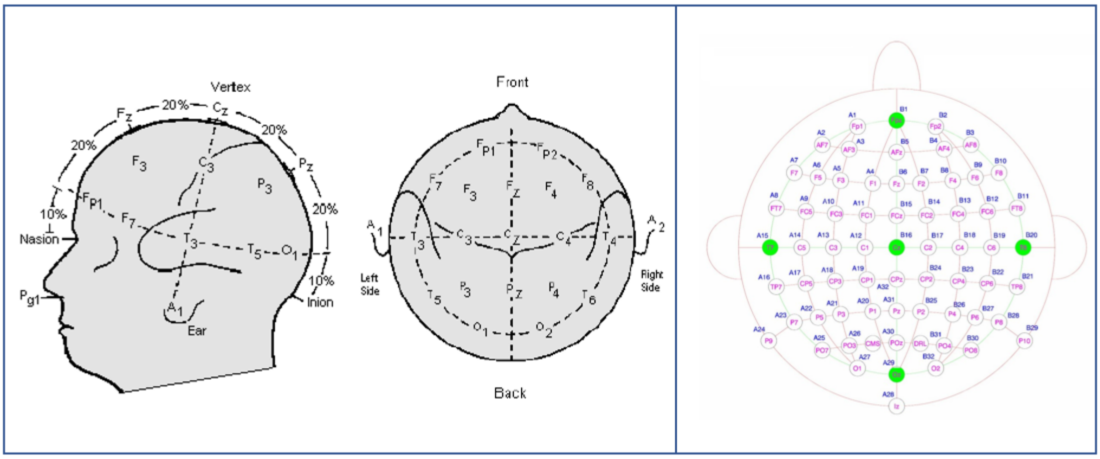
EEG captures the electrical potential between two sites, in this instance on the scalp. As shown in Figure 2.1 the summed activity of thousands of nerve cells from the surface of the cerebral hemispheres is what results in the electrical potential recorded by the EEG electrodes. Specifically, EEG recordings are primarily due to the synchronous firing of large numbers of similarly oriented pyramidal neurons in the cortex. These pyramidal neurons are the main contributors to the captured signal since their collective structure represents a series of dipoles, where the stacked layers provide a large distance between a source (where current flows from; negative potential) and sink (where current flows to; positive potential). Furthermore, the pyramidal neurons are spatially aligned perpendicular to the cortical surface and thus create a dipole layer in the cortex. Indeed, it is the summed post synaptic activity of these large cell ensembles closest to the electrode that generates the electrical potential recorded.

This electrical potential is conducted through several conductors in order to reach the electrodes on the scalp: the skull, scalp, brain and CSF, where the skull is the worst conductor. Subsequently, the potential can be distorted as it passes through the layers, and thus spherical models with layers can be used to attempt to correct for these distortions.

2.4.2 Electrode placement systems

As shown in Figure 2.2, a position system ensures consistent placement of electrodes across individuals of varying skull size. The are numerous systems based on the number of electrodes that are distributed across the scalp; the 10-20 system for 64 electrodes is illustrated in Figure 2.2. Crucially, the symmetry and measurements of the scalp, for example the distance from the inion to nasion can be used to standardise EEG electrode placement.

Figure 2.2: *10-20 system of EEG electrode placement*



10-20 system of EEG electrode placement. Image was modified from (Teli, 2007).

Consistent electrode placement is vital for comparable results between subjects. Once the data have been collected the next step is to preprocess the data in order to remove artefacts and to facilitate any analyses.

2.4.3 Preprocessing methods

The raw EEG recording not only consists of the relevant signal to the cognitive process in question, but also irrelevant signals due to a variety of sources. These sources can be external or internal in nature ranging from signal noise from electrical devices (e.g., from the power source, mobile phones) to irrelevant bodily functions (e.g., eye-blinks, heartbeat, muscular movements). Preprocessing is the process used to remove as much noise from the signal, whilst preserving the original signal as much as possible. Another stage of preprocessing is the organisation of the data into comparable blocks termed epochs. These epochs can then be compared against one another, and also can be excluded from analyses when failing certain data quality checks (e.g., a simple voltage threshold of $\pm 80\mu$V). Below a list of all preprocessing stages will be outlined.

Artefact removal using artifact subspace reconstruction (ASR)

Artifact subspace reconstruction (ASR) is a statistical anomaly detection method. Specifically, ASR examines the statistical properties of the signal which has been decomposed into the principal component analysis (PCA) subspace. Large variance identified is assumed to be of a non-neural origin and can be removed. The data containing artefacts are thus reconstructed using an unmixing matrix to recover the artefactless EEG data (Blum et al., 2019). This PCA-based adaptive method allows for online or offline correction of artefacts (Blum et al., 2019; Mullen et al., 2015). In the component subspace ASR uses covariance matrices to detect artefacts based on their statistical properties contrasted against clean calibration data. For example, ASR allows for noisy channels to be detected automatically, which can then be spherically interpolated before running independent components analysis (ASR from the clean_rawdata EEGLAB plugin, Mullen et al., 2015).

Artifact removal using independent component analysis (ICA)

Independent component analysis (ICA) is a signal processing technique that separates linearly mixed sources, which facilitates artifact identification that spans across multiple electrodes (Delorme et al., 2007). The main assumptions of ICA is that the signal recorded on the scalp are a combination of independent sources related to artefacts and brain activity, and that these signals propagate linearly. Therefore, in the case of channel interpolation (e.g., see Section 2.4.3), the level of signal independence, termed the rank, is modified to reflect the number of fully independent sources.

Specifically, ICA linearly decomposes the EEG signal (X) by identifying a set of weights (W) into a set of independent components. Each component exhibits specific spatiotemporal features that can be used to identify the origin of the component. In this manner, classical component profiles can be used to identify and label components in the dataset which reflect common artefacts such as eye-blinks (large frontal amplitude) or heartbeats (amplitude spikes coinciding with heartbeat R peaks; e.g., see Delorme et al., 2007).

In this thesis, electro-oculogram (EOG) signals were identified using ICA, facilitated primarily by two electrodes placed at the outer canthi of each eye for horizontal EOG (HEOG) signals, as well as two electrodes placed above and below the left eye to capture vertical EOG (VEOG) signals. The difference was calculated for each signal respectively to calculate the micro eyelid movements (VEOG) and the small eye rotations (HEOG; e.g., for a review see Croft and Barry, 2000). Topograph and power spectrum plots can be visualised in aiding ICA component labelling and thus the subsequent cautious removal of these artifact-containing components.

Semi-automatic artifact removal using voltage thresholds

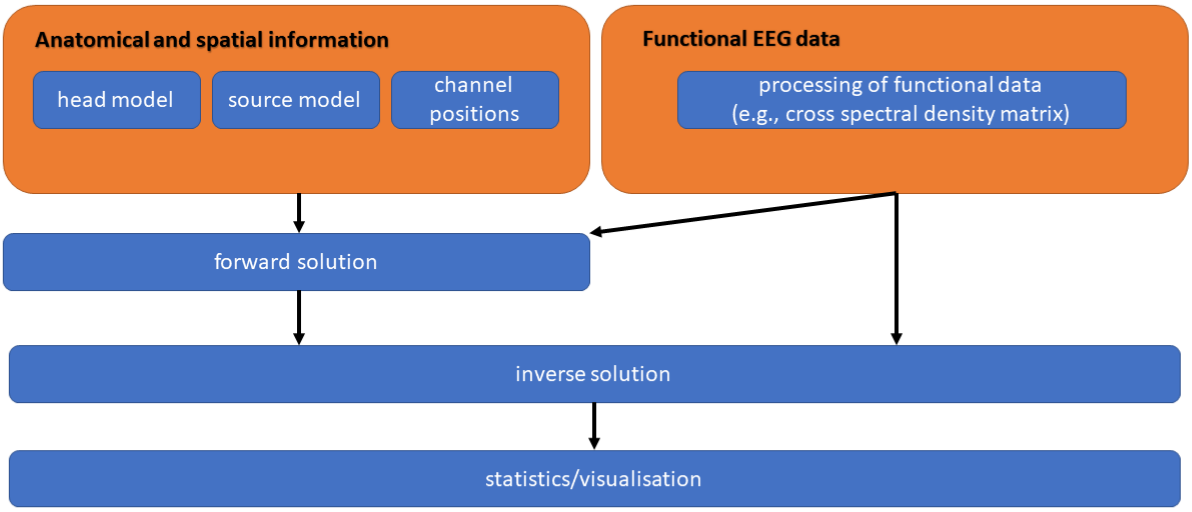
Another form of data cleaning can involve a simple voltage threshold rejection of noisy segments (epochs) of data. For example, in this thesis, a stringent threshold of $\pm 80\mu$ V was used, however large values can also be used for more noisy data. Finally, visual inspection of all remaining epochs is advisable to identify any artefacts that have not been identified using the above methods.

2.4.4 Time-frequency analysis

The EEG activity measured in the brain is far from static; signals are ever-changing in varying speeds and fluctuations over time in network-related rhythms or neural oscillations. These neural oscillations are modulated by both excitatory and inhibitory populations of neurons and thus the firing pattern, or frequency of oscillatory fluctuations, vary dramatically. These variations in frequencies have been subdivided into different bands: delta (δ, 1-4 Hz), theta (θ, 4-8 Hz), alpha (α, 8-13 Hz), beta (β, 13-30 Hz) and gamma (γ, >30 Hz). Since these oscillations are rhythmic the particular phase of an oscillation (the point along the waveform) is important information. Alongside the phase, and the frequencies mentioned above (the speed of the oscillation), the power (the amount of energy) can also be calculated. By using this time-frequency oscillatory approach to data analysis, neuroscientists try to understand and infer contextually-relevant cognitive and perceptual processes.

There are a number of parameters that are important to consider when estimating time-frequency representations (TFRs). The most important parameter is the type of tapering/windowing function to use. In short, a tapering function allows a segment of data to be analysed at a chosen interval and is thus multiplied with the EEG data. This is important because an appropriate taper minimises spectral leakage (i.e., where the energy in one frequency band can influence the estimation of the energy in other frequency bands). Another important aspect of the taper is the

Figure 2.3: *Major steps in source reconstruction*



smoothing function, which simply removes localised variation in the raw EEG (and thus smooths out an output waveform).

In this thesis the multitaper discrete prolate spheroidal sequence (DPSS; e.g., see Zemen and Mecklenbrauker, 2005) was used. A multitaper is a more advanced taper that takes the average over a small ensemble of orthogonal tapers that yields a more stable spectra yield with lower variance than single taper methods. In particular the DPSS function is optimised to minimise spectral leakage at the edges of a window (e.g., see van Vugt et al., 2007). Multitaper methods are particularly good at preventing spectral leakage and are designed to detect oscillations with large-amplitude transients without changing the time window length.

2.4.5 Beamformer source reconstruction

Using more advanced techniques it is also possible to estimate the sources responsible for producing oscillatory effects in the sensor space. One such techniques is called beamforming, which is a form of spatial filtering that can be applied to EEG data to estimate the amount of activity at any given region in the brain (for a more comprehensive read on EEG source localisation measures please see Mahjoory et al., 2017). In brief, the 3D structure of the brain and skull are computed to be aid in calculating relevant electrical data that can subsequently be overlaid onto the structure image of the subject's brain.

The procedure for reconstructing oscillatory activity requires anatomical (i.e., spatial) and functional information (outlined in Figure 2.3). First, the functional EEG data must be processed. In this thesis, the adaptive spatial filter used for beamforming was the dynamical imaging of coherent sources (DICS), which relies on estimates calculated in the frequency domain (J. Gross et al., 2001). In particular, the DICS spatial filter uses the cross-spectral density (CSD) matrix, which is the frequency component from the covariance matrix. The CSD is computed for all sensor combinations from the Fourier transformed data. Second, the brain must be divided into a regular 3D grid, upon which the source strength for each grid point is computed. For the anatomical and spatial information, the volume conduction model of the head (head model) needs to be calculated from the participant's MRI scan. In this thesis, obtaining individualised structural MRI scans was not possible and thus an average template on MNI space was used instead for all participants. A single template-based forward model was constructed based on the default average MNI brain coordinates. The head model consisted of a three-layer boundary element (BEM) model, generated using the whole-head tissue probability map provided with the NY Head (Huang et al., 2016). In short, the voxels of the anatomical MRI are segmented (i.e., separated) into different tissue types (e.g., gray matter, white matter and the cerebrospinal fluid). Next the source model, or leadfield matrix is calculated, where dipoles are assigned to a regular grid. The lead field is a matrix with as many rows as EEG channels and thrice as many columns as source positions (since each source position has three different orientations). Each entry in the matrix is filled independently, thereby allowing the removal of undesired sources or channels without affecting other data. Next the inverse solution can be calculated using the source model and spatial filter. The inverse filter is based on minimising the source power (or variance) at a given location. Importantly, if contrasting between conditions this filter must be calculated using data from both conditions and subsequently applied to each condition separately.

Generally speaking, EEG systems with 64 or more electrodes provide the most accurate data in terms of source reconstruction (where the jump from 32 to 64 electrodes is most impactful; e.g., see Lantz et al., 2003). Consequently, as described in more detail in Chapter 5, a source reconstruction approach has been taken to analyse the EEG data collection from 64 electrodes.

2.5 Electrocardiography (ECG)

Heart rate data can be collected in a number of ways including using a pulse oximeter (relying on photoplethysmography, measuring levels of light reflection) or more directly using electrodes placed on the skin (ECG). Using ECG, the electric activity of the heart can be captured by an electrode placed below the left clavicle and a reference electrode placed either below the right clavicle or above the right hip bone. A difference waveform can then be calculated from the two ECG electrode to obtain a QRS complex. This QRS complex can then be used to calculate heart rate variability (HRV).

2.5.1 Heart rate variability (HRV)

HRV is a metric that reflects how much the heart rate varies, where, generally, a higher HRV is associated with good health (seen as the propensity of the central nervous system to rapidly react to a stimulus ; for a comprehensive review please see Shaffer and Ginsberg, 2017; Shaffer et al., 2014). HRV has been shown to be sensitive to changes to autonomic nervous system activity associated with stress, and thus has often been used in psychology as a biomarker for parasympathetic activity (Kim et al., 2018). Each letter in the QRS complex represents a different action of the heart. Of particular interest, and the most prominent point in the waveform, is the R peak. The time between consecutive R peaks, otherwise known as the RR interval, or the normal-to-normal for clean RR peaks (NN), can then be used to calculate HRV. There are a number of different ways to calculate HRV in both the time-domain and the frequency-domain (e.g., see Umetani et al., 1998).

HRV Time-domain methods

The most common method for analysing HRV in the time-domain is to use the Root Mean Square of Successive Differences (RMSSD) between each heartbeat or to take the standard deviation of all NN intervals (SDNN). For the RMSSD the each successive time different between heartbeats in ms is calculated, each of which is then squared. The square root of this number is the final value. RMSSD is the primary time-domain method used to estimate vagally-induced changes in HRV and can be used reliably on shorter duration epochs (optimally at 5 minutes; Shaffer et al., 2014). SDNN on the other hand is less reliable in shorter durations and typically is used over 24 hr recording periods.

HRV Frequency-domain methods

Using fast Fourier transformations (FFT) HRV signals can be separated into component rhythms that are range from ultra low frequency (ULF; $\leq$0.003 Hz), very low frequency (VLF; 0.0033–0.04 Hz,; low frequency (LF; 0.04–0.15 Hz) to high frequency (HF; 0.15–0.40 Hz). ULF band requires a recording period of at least 24 hr to be accurate (Shaffer et al., 2014) and thus was not considered in Chapter 5. The VLF rhythm may be fundamental to health (Shaffer et al., 2014), since, for example, it has been associated with high inflammation in several studies (Carney et al., 2007; Lampert et al., 2008). LF on the other hand seems to reflect baroreceptor activity during resting conditions and not not cardiac sympathetic innervation (McCraty & Shaffer, 2015). The HF band is often called the respiratory band since it demonstrates phasic HR changes. HF also reflects parasympathetic activity, where lower HF power is correlated with high activation negative emotions (e.g., worry, stress; Shaffer and Ginsberg, 2017).

2.6 Summary

There are various methods used in the upcoming chapters, the most technical of which have been discussed in more detail in this chapter. This overview should allow the reader to understand in greater detail the methodology used in projects described later, and thus be able to interpret the results in a more meaningful way. The subsequent chapter will detail the creation of the ASMR-Experience Questionnaire, an online psychometric tool to accurately classify how we respond to ASMR stimuli in a data-driven way.

Chapter 3

ASMR-Experience Questionnaire (AEQ)

Abstract

Autonomous sensory meridian response (ASMR) describes an atypical multisensory experience of calming, tingling sensations that originate in the crown of the head in response to a specific subset of audio-visual triggers. There is currently no tool that can accurately classify both ASMR-responders and non-responders, while simultaneously identifying False-Positive cases that are similar sensory-emotional experiences. This study sought to fill this gap by developing a new online psychometric tool - the ASMR-Experiences Questionnaire (AEQ). Participants watched a series of short ASMR videos and answered sensory-affective questions immediately afterwards. Using a k-means clustering approach, I identified five data-driven groupings, based on tingle- and affect-related scores. ASMR-responders differentiate based on ASMR propensity and intensity (ASMR-Strong; ASMR-Weak); non-responders differentiate based on response valence (Control+; Control-; False-Positive). Recommendations for how the AEQ and the respective output groups can be best utilized to enhance ASMR research are discussed.

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[0] Note: this chapter has been published: Swart, T.R., Bowling, N.C. and Banissy, M.J. (2021). ASMR-Experience Questionnaire (AEQ): a data-driven step towards accurately classifying ASMR responders. *British Journal of Psychology*.

3.1 Introduction

3.1.1 Background

Autonomous sensory meridian response (ASMR) is a spontaneous sensory experience, which is characterised by tingling sensations in response to social visual and auditory stimuli (Barratt & Davis, 2015). Typically these tingling sensations arise at the back of the head and neck; they are then thought to radiate down the spine and into the limbs in periods of greater intensity (Barratt & Davis, 2015). ASMR induction is largely thought to be involuntary and heavily dependent on environmental setting and individual mood (Barratt & Davis, 2015; Poerio et al., 2018).

While ASMR has wide popular appeal (e.g., over 24 million subscribers to ASMR channels on YouTube), our scientific understanding of the experience is at early stages. There are some studies that provide evidence of physiological correlates of ASMR. For instance, altered heart rate and skin conductance response when viewing ASMR videos in individuals that reported experiencing ASMR versus those who did not (Poerio et al., 2018). There is also neuroimaging work showing that ASMR experience is associated with neural correlates in brain regions associated with social cognition and self-awareness (Lochte et al., 2018; S. D. Smith et al., 2019a).

ASMR has also been linked to wider traits such as personality differences and empathy (Fredborg et al., 2017; McErlean & Banissy, 2017). ASMR-responders have reported increased relaxation and an elevation in mood (Barratt & Davis, 2015) following ASMR induction. There is also an interest in studying the effects of ASMR on wellbeing (Barratt & Davis, 2015). In this context, there is increasing focus on ASMR to help us to understand human psychological function in a wider context. For example, in the context of the social impacts of ASMR (e.g., empathy), the experience can offer a unique experimental window to help us to understand individual differences that contribute to our perception of the social world. This is important because if we are to build a complete understanding of factors that contribute to human perception I need to understand the normative and the variation between (Happé et al., 2017).

3.1.2 Current ASMR-responder validation limitations

While prior studies provide an important first step in objectively verifying ASMR, further work is required to develop quantitative measures to validate and measure the presence of ASMR in an individual. Indeed, before potential relationships between ASMR and broader experiences (e.g., mental health and well-being) can be fully explored, I first need to be able to better characterise and explain ASMR itself.

Most ASMR research relies upon self-described groupings for ASMR-responders that are assigned by an individual researcher based on binary responses of whether the participants indicate that they do or do not experience ASMR. While this is a useful first step, more objective classification criteria are required. In particular, there is a crucial need for the development of tools that can help with sub-grouping participants based on how they respond to ASMR inducing material. For example, one obstacle is understanding whether there are ASMR-specific biases in non-Responder recruitment (e.g., whether individual differences in perceived pleasantness or calmness of ASMR stimuli influences non-responders' likelihood of participation in research).

A further hindrance in ASMR research is identifying ASMR-responders with a high reliability of ASMR induction. In particular, identifying ASMR-responders who are able to reliably and strongly experience ASMR while under experimental conditions (i.e., in an unfamiliar environment). Unpublished and anecdotal evidence suggest environmental context can also play a role in the reliability of ASMR induction. The inconsistent and involuntary nature of ASMR has been supported by the notion of ASMR 'tolerance', i.e., the inability to experience ASMR from certain stimuli despite previous success (Kovacevich & Huron, 2019). A classification of ASMR trait (the capability of experiencing ASMR generally) and ASMR state (the propensity to experience ASMR at a given moment at a given intensity) has been suggested (Hostler et al., 2019).

Another limitation in participant classification is the presence of false positives in terms of ASMR-responders. An individual would be deemed a false positive when they report experiencing something, however that something does not align to the hallmark features of ASMR (e.g., pleasant, calming, head-dominant tingles; henceforth termed False-Positive). There are broad similarities between ASMR and other phenomena that result in induced somatosensory responses, for example emotional piloerection in response to visual and/or auditory cues such as aesthetic chills (Grewe et al., 2011; Laeng et al., 2016; Sumpf et al., 2015); fear-induced responses (Phillips & LeDoux, 1992); or even non-specific vicarious somatosensory responses (Gillmeister et al., 2017). A recent study provided evidence for expectancy effects present in non-responders (Cash et al., 2018). In this study, the experimenters manipulated the described effectiveness of ASMR stimuli prior to participants watching the stimuli and reporting on the experience. Whilst ASMR-responders remained unaffected by expectancy manipulation (encouraging vs discouraging instructions), the responses (ASMR Rating) of non-responders were significantly modulated (Hostler et al., 2019). Therefore, the ability to distinguish and exclude these cases from genuine ASMR-responder groupings will facilitate clearer analyses and interpretations.

The recent development of the ASMR-15 (Roberts et al., 2019) as an individual differences score for ASMR has been extremely useful in furthering the characterisation of ASMR-responders. Here, it was shown that ASMR-responders lie on a spectrum and thus there is a propensity for weaker and stronger ASMR-responders. While useful, the ASMR-15 relies on retrospective self-reporting of various ASMR-related measures and carries some limitations: 1) there are no clear data-driven threshold scores used to differentiate groups or sub-groups; 2) the ASMR-15 appears to lack the capability to reliably identify False-Positives; 3) the measure asks participants to reflect on previous ASMR experiences with an unknown lag (i.e., they do not watch ASMR inducing material). In light of these limitations, a useful counterpart would be the creation of a measure assessing ASMR-related items immediately after ASMR-induction, thereby capturing ASMR-state and minimising inaccuracies introduced through prolonged memory recall. This study sought to achieve this. In addition, I sought to adopt a data-driven approach (a *k*-means cluster analysis, (Zhang et al., 1996) to identify groupings that reflect individual differences inherent in the data. This is important because it circumvents issues surrounding setting arbitrary cut-off scores and can support identification of sub-groupings of responders (e.g., see Grice-Jackson et al., 2017; J. Ward et al., 2018) for use of such approaches in other domains).

With the above factors in mind, I, therefore, sought to develop a new web-based psychometric tool to assess ASMR that uses a data-driven approach (*k*-means) – ASMR-Experiences Questionnaire (AEQ). The measure sought to:

1. produce diagnostic groupings (e.g., ASMR-responder, non-Responder), which reflect individual differences inherent in the data rather than being set by the experimenter.
2. identify sub-groupings in the population to facilitate False-Positive identification, as well as sub-groupings present in ASMR-responder and non-Responder populations.
3. capture ASMR state through immediate retrospective ASMR-related measures.

3.2 Methods

3.2.1 Participants

Participants who were familiar and unfamiliar with ASMR were recruited for participation ($N = 282$). Participants were either recruited by word of mouth, on social media websites targeted at ASMR-responder populations (e.g., www.reddit.com/r/ASMR/), by advertisement on university premises, or via Prolific. All participants received remuneration for their time in the form of course credits ($n = 232$) or financial payment ($n = 50$).

Table 3.1: *Demographic Characteristics of Screened Participants*

Gender	Frequency	age
	n	*M (SD)*
Female	197	24.0 (8.1)
Male	82	26.5 (9.9)
Non-binary	2	28.5 (2.1)
Undisclosed	1	18.0 (*NA*)
Total	**282**	**24.7 (8.7)**

Note. Age is shown in years.

3.2.2 Materials

The materials consisted of 5 short videos (~3 minutes), which depicted ASMR stimuli based on 5 different ASMR-inducing categories. These were: 1) visually dominant triggers without whispering; 2) visually dominant triggers with whispering; 3) auditory dominant triggers without whispering; 4) auditory dominant triggers with whispering; 5) personal attention simulations. In order to successfully capture as many ASMR-responders and their respective idiosyncratic preferences in ASMR triggers multiple different one minute clips (respective to the category) were presented in videos 1-4. For the sake of brevity only one three minute personal attention simulation video was used, where it has been assumed (due to a lack of data) that a greater duration of time is needed to induce ASMR from simulation videos. This video is a simulation of a haircut and was one of the highest rated ASMR videos on YouTube at the time of creation in December 2018. Table A.1 depicts the precise triggers, authors and URLs (accessible December 2018).

3.2.3 Procedure

The questionnaire was hosted on an online survey platform (Qualtrics). Consent and demographics were recorded and a description of ASMR was given.

Prior to watching any videos respondents were asked: "Based on your own experience and the description you've just read, would you consider yourself capable of experiencing ASMR?" [Definitely yes/Probably yes/Might or might not/Probably not/Definitely not]. Questions related to the content of general ASMR videos were then asked: "Do you feel like certain voices or accents have a calming effect on you? (0 = completely disagree, 5 = neutral, 10 = absolutely agree)." and "How do you feel about watching other people draw/colour in? (0 = very unpleasant, 5 = neutral, 10 = very pleasant).". Then a self-report question pertaining to misophonia was asked: "Are you made extremely uncomfortable by certain sounds, even if these sounds are quiet? e.g., polystyrene, ceramic, chalk. (0 = no discomfort, 10 = absolute discomfort)." A question querying the capability of frisson/aesthetic chills was then asked: "Are you capable of experiencing frisson/aesthetic chills? i.e., goosebumps down the spine and a surge of energy when listening to profoundly moving music? (0 = not capable, 10 = very capable).". Subsequently respondents were asked to self-report traits related to empathy and emotional sensitivity: "Do you consider yourself an empathetic person? (0 = not at all empathetic, 10 = highly empathetic)." and "Do you consider yourself an emotionally sensitive person. i.e., are you easily upset? (0 = not emotional, 10 = highly emotional).". The propensity of ASMR induction for that given moment was then queried: "Given the presentation of your ideal ASMR videos/sounds, how primed/ready do you feel right now to experience ASMR? (Many ASMR-responders report a high degree of variation in their ability to experience ASMR in their day-to-day).". Finally, a baseline state of calm question was gauged: "How calm do you feel right now? (-5 = not calm at all, 0 = neutral, 5 = extremely calm)."

The ASMR videos were categorised into three trigger types: visual, auditory, or simulation. The videos were presented in a fixed order (see Table A.1) with similar triggers together to create blocks of trials for each trigger type. This was done with a view to maximising the likelihood of ASMR induction, by lengthening the duration of each trigger type (e.g., by presenting two visual stimuli blocks consecutively). These main trigger types appeared in a fixed order: 1) visual, 2) auditory, 3) simulation. Immediately after each video was played participants were asked: “Did you experience ASMR (any tingling sensations in your head/scalp) whilst watching this video?” [Yes/No/No, but I did feel a precursory ASMR-conducive state (a background feeling where ASMR is more likely to occur)]. Regardless of the answer participants were queried on a scale between -5 to 5: “How pleasant did you find the experience of watching this video? (-5 = not pleasant, 0 = neutral, 5 = highly pleasant).” and “How calm do you feel right now? (-5 = not calm at all, 0 = neutral, 5 = extremely calm).” Participants who reported experiencing ASMR tingling sensations were then asked a series of questions: “Where did you feel these tingling sensations? Please indicate as many areas as you like using the body map below.” (see Figure 3.3). The responses on the body map were later recoded as either head tingles or body tingles for use in the *k*-means clustering. Furthermore, a score out of 1 was calculated representing the per video likelihood of body part selection. Subsequently two questions aimed to assess the intensity of the transient wave-like sensations associated with ASMR: “On average, how intense were the tingling sensations throughout the video? (1 = very weak, 10 = very strong).” and “How intense was your strongest period of tingling sensations during the video? (1 = very weak, 10 = very strong).”.

3.2.4 Clustering

A *k*-means approach was used to ascertain grouping membership of respondents in a data-driven method. In *k*-means clustering, data is partitioned into *k* number of groups (Khan & Ahmad, 2004). *K*-means is an unsupervised learning algorithm which can solve the clustering problem. An unsupervised learning approach has been chosen over a supervised learning approach because I wanted to avoid bias through assigning labels. This exploratory approach instead automatically identifies structure in the data, which can be subsequently labelled using qualitative data on the ASMR experience.

For an unsupervised learning approach such as *k*-means, it is vital that the input variables are completely reflective of the desired clustering goal. To achieve this, variables that represent the core qualities of ASMR must only be used. Whilst the definition of ASMR is nuanced, certain qualities appear to be universal to the phenomenon. The sensation has been repeatedly reported to be (1) calming and involves (2) pleasurable (3) tingling sensations, which originate in the (4) head and often radiate down the midline to the rest of the (5) body (Barratt & Davis, 2015; Fredborg et al., 2017; Kovacevich & Huron, 2019; Poerio et al., 2018). Subsequently, labels are assigned to the outcome groups post-clustering and are deduced from patterns in the group data, unlike a supervised learning approach where labels are assigned pre-analysis.

The *k*-means algorithm consists of two separate steps. The first step is to calculate the centroid respective to each *k* group (where a centroid is roughly the average of a shape's vertices). Secondly, the Euclidian distance between each data point and the nearest centroid is calculated, where the minimum Euclidian distance is the goal. Once this process has occurred for all *k* number of centroids, the process repeats iteratively to recalculate the best fitting centroid positions (i.e., the position with the smallest sum of Euclidian distances to all of the member data points). Therefore, this iterative process optimises the shape of each *k* group as defined by the data. The initial centroid position is randomly allocated multiple times to identify the optimum starting position. In this way data points from numerous variables can be clustered to identify *k* number of groups. *k* itself can be identified using a number of methods, of which the gap statistic (Tibshirani et al., 2001), and Wards dendrogram (J. H. Ward, 1963) methods are commonly used.

Clustering was performed in R using the *stats* package version 3.6.1 with the containing *kmeans* function (iter.max = 50, nstart = 10). Standardised variables used in clustering were derived from ASMR stimuli response scores: frequency of head tingles, body tingles, pleasant scores, intensity scores, and relative calm scores (calculated as the mean relative change in calm from baseline to Video 5 calm responses). Cluster confirmation and the respective labels were then created and assigned based on group-specific scores in all of the above variables. The estimate for the number of clusters was determined using Ward's dendrogram clustering method (*stats* package, *hclust* function, method "ward.D2", and by calculating the gap statistic for values of k from 2 to 10 (*cluster* package, *clusGap* function). Two clusters were predicted a-priori: ASMR-responders vs non-responders.

3.3 Results

3.3.1 Participants

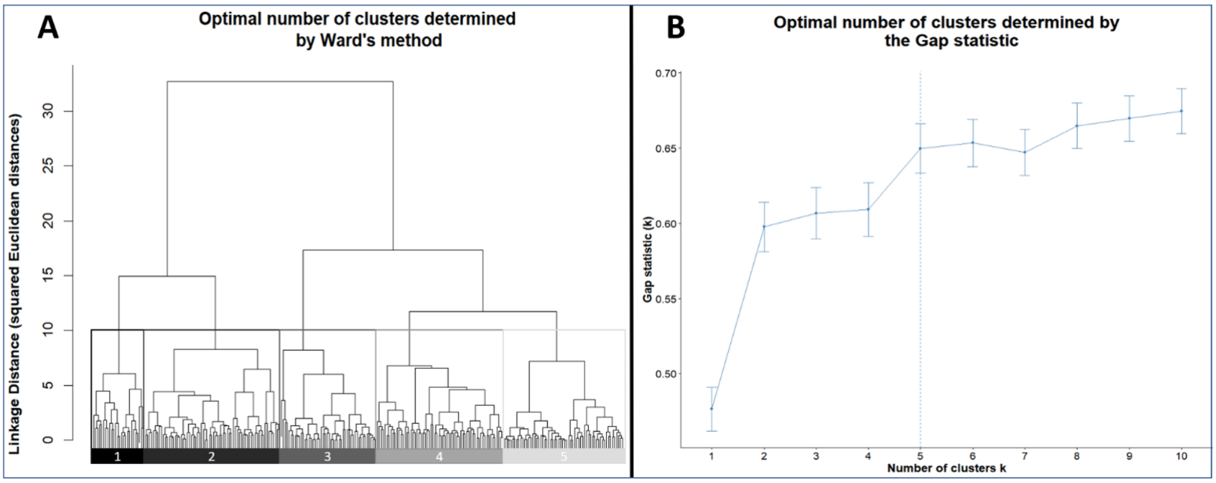
16 participants were omitted from the analysis ($N = 266$, range = 18-67; 76 males, age in years $M = 26.5$, $SD = 10$; 187 females, age $M = 24.1$, $SD = 8.3$; 1 undisclosed gender). The reasons for omission were incomplete responses; responses with a duration of less than 20 minutes; and responses with a duration of more than 2 hours.

3.3.2 Clustering

The optimum number of clusters was five. The threshold linkage distance used to determine the number can vary, however a Euclidean distance of 10 has been effective in previous studies (Grice-Jackson et al., 2017) and indicated five groups in our study. These five branches stem from two main branches, thus supporting our a-priori hypothesis that there are two main types of responders to ASMR content: those who experience ASMR; those who do not experience ASMR.

The gap statistic also supports the 5-Cluster approach (see Figure 3.1). It therefore seems that two approaches can be taken to group the data: a simplified 2-cluster view or a more detailed 5 cluster view depending on the subsequent usage.

Figure 3.1: *Determining k number of clusters*



Using hierarchical clustering via Ward's method (A) and the Gap statistic (B) to determine an appropriate k number of clusters. A) Ward's method, a hierarchical clustering method, showing the linkage distance between the data-derived groups. A linkage distance threshold of 10 was used. The five clusters identified can be seen to be derived from two main clusters. B) The appropriate number of clusters were also modelled and confirmed using the Gap statistic.

3.3.3 Cluster Labelling

The 5-group cluster labelling and demographics are as follows: ASMR-StrongResponder (ASMR-S; $n = 46$, age in years M = 28.1=, SD = 11.4, 35 females); ASMR-WeakResponder (ASMR-W; $n = 55$, age in years M = 26.1, SD = 8.7, 38 females); non-responders with positive affective responses to ASMR (Control+; $n = 77$, age in years M = 25.9, SD = 9.7, 54 females); non-responders with negative affective responses to ASMR (Control-; $n = 68$, age in years M = 21.3, SD = 5.1, 47 females); Responders reporting negative tactile sensations (False-Positive; $n = 18$, age in years M = 20.7, SD = 3.6, 14 females). These labels were assigned post-clustering based on the results described below (e.g., tingle-related and affect-related scores).

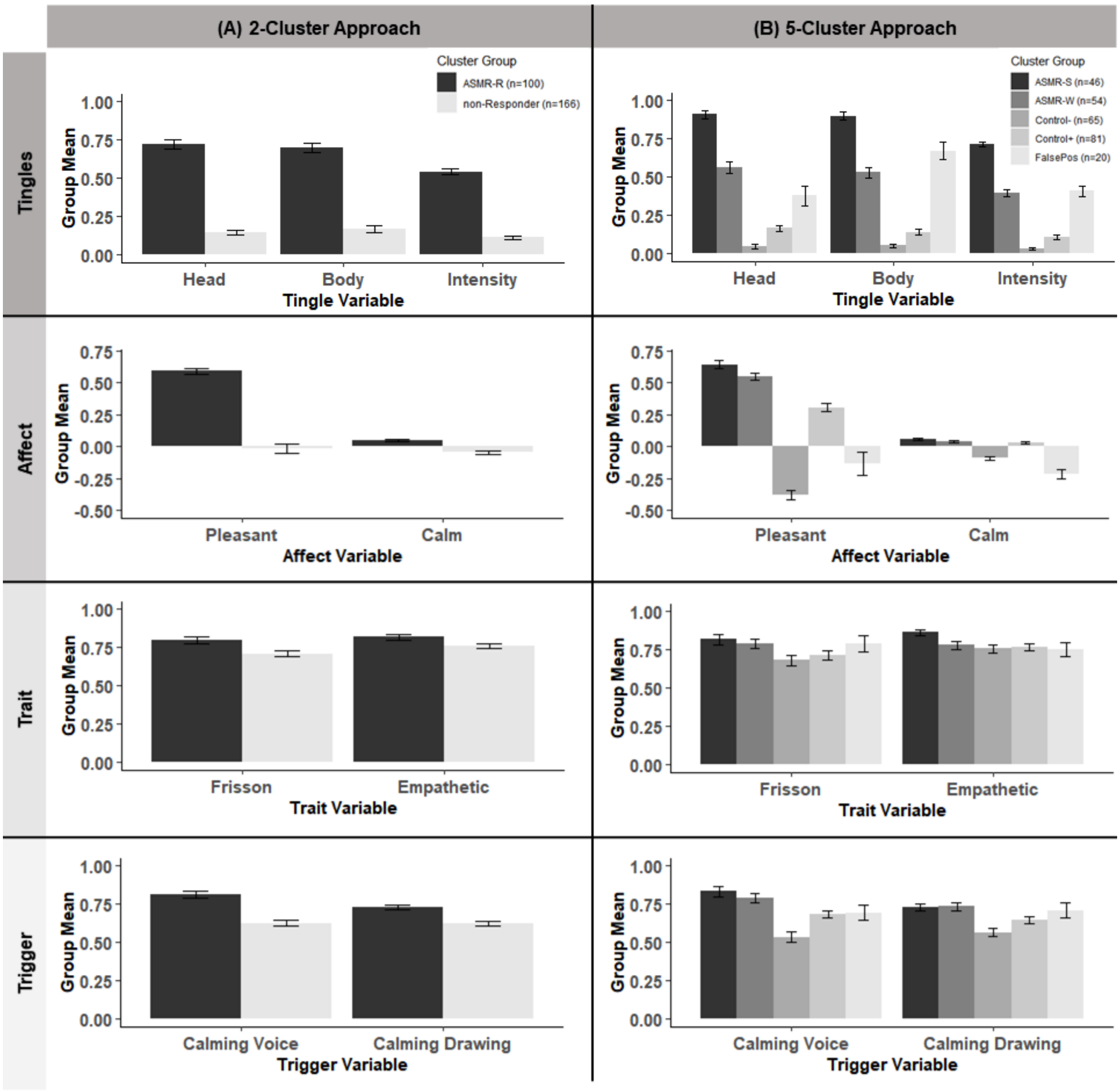
When specifying two clusters into the k-means function, the group memberships were not representative of the hypothesised populations (i.e., Control+ clustering with ASMR-S). Therefore, the two-cluster groups membership were determined from the five-group clusters, where groups ASMR-S and ASMR-W have been collapsed into ASMR-responders ($N = 101$, age in years M =

27.1, *SD* = 10, 73 females); Control+, Control- and False-Positive have been collapsed into non-responders ($N = 166$, age in years M = 23.4, *SD* = 7.8, 101 females).

For all ANOVAs reported below, assumptions of equality and normality were violated thus Welch's method was used, followed by Games-Howell post-hoc tests. Tables showing more detailed post-hoc comparisons for the 5-cluster analyses are provided in Tables A.2 to A.6. Furthermore, 5-group cluster scores of each of the five individual videos are illustrated in Figure A.1.

3.3.4 Cluster Variables - Tingles

Figure 3.2: *Mean scores of the cluster variables (Tingles & Affect) and general questions (Trait & Trigger) compared within 2-cluster (A) and 5-cluster (B) groupings*



Tingles: Mean scores of the cluster variables Head (presence of tingles in the head), Body (presence of tingles anywhere in the body except the head) and change in Calm are presented. **Affect**: Mean scores of the cluster variables Pleasantness and Intensity (mean score of Peak and average intensity scores). **Trait**: Frisson represents the self-report capability of experiencing musical chills. Empathetic represents the degree of self-report empathic traits. **Trigger**: Calming Voices represents the self-reported effectiveness of one's voice on calming the individual. Calming Drawing represents how pleasant the individual feels when watching one draw or colour. ASMR-Strong (ASMR-S) experience tingles more intensely and more frequently in the Head and Body compared to all other groups ($p < 0.001$). Affect scores can be used to differentiate Control subgroupings as well as False-Positives from ASMR-responders. Error bars represent SEM. 2-Cluster groupings are ASMR-responders (ASMR-S, ASMR-W) and non-Responder (Control+, Control-, False-Positive). ASMR-R represents ASMR-responders; ASMR-S represents ASMR-Strong; ASMR-W represents ASMR-Weak.

2-Cluster

As shown in Figure 3.2A an independent t-test (Welch's) revealed ASMR-responders scored significantly higher than non-responders on mean Head tingle scores, $t(162) = 17.2$, $p < 0.001$, $d = 2.36$. ASMR-responders also scored significantly higher than non-responders on mean Body tingle scores, $t(195) = 16.0$, $p < 0.001$, $d = 2.07$. Finally, ASMR-responders also scored significantly higher than non-responders on mean Intensity scores, $t(172) = 17.7$, $p < 0.001$, $d = 2.38$.

5-Cluster

Across all tingle-related cluster variables (Figure 3.2B) a one-way between ANOVA (Welch's) showed a significant difference between all 5 cluster groups in mean Head tingles scores ($F(4, 82.6) = 233$, $p < 0.001$, $est\ \omega^2 = 0.986$), Body tingles ($F(4, 82.4) = 250$, $p < 0.001$, $est\ \omega^2 = 0.987$) and tingle intensity ($F(4, 82.5) = 320$, $p < 0.001$, $est\ \omega^2 = 0.990$).

Post-hoc group comparisons on Head data performed by Games-Howell tests showed no significant differences between False-Positive and Control, or False-Positive and ASMR-W. Significant differences were found between Control- and Control+ ($p < 0.01$), and between Control- and False-Positive ($p < 0.01$). All other group comparisons were also significant ($p < 0.001$).

Post-hoc group comparisons on Body data performed by Games-Howell tests showed no significant differences between False-Positive and ASMR-W, as well as between Control+ and Control-. Significant differences were found between False-Positive and ASMR-S ($p < 0.05$), and all other group comparisons were also significant ($p < 0.001$).

Post-hoc group comparisons on Intensity data performed by Games-Howell tests showed no significant differences between False-Positive and ASMR-W. Significant differences were found between Control+ and Control- ($p < 0.01$), and all other group comparisons were also significant ($p < 0.001$).

3.3.5 Tingle Location

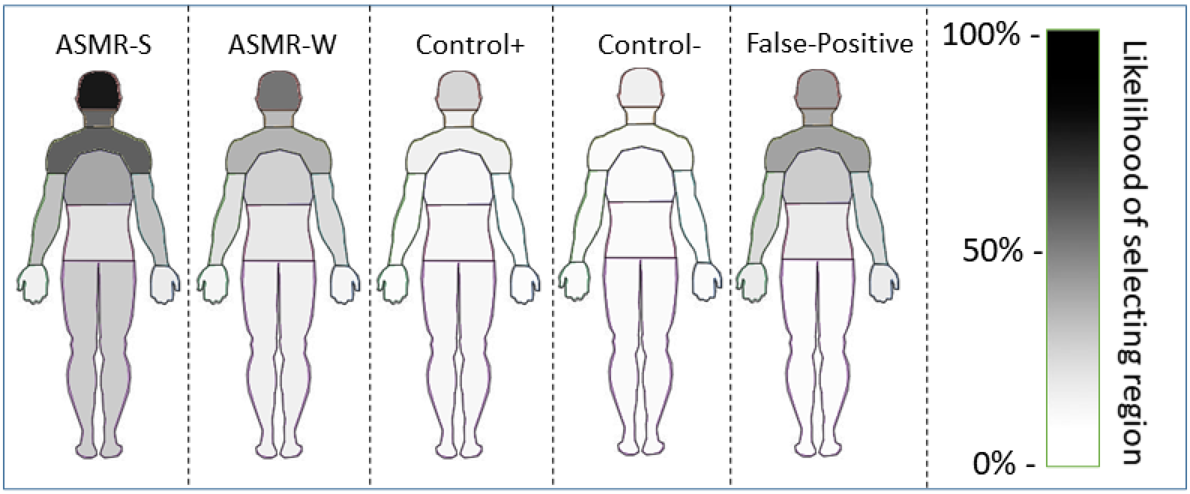
As shown in Figure 3.3, Games-Howell post-hoc tests reveal that ASMR-S scored significantly higher compared to all other groups in the Head ($p < 0.001$) and Neck ($p < 0.05$) regions. Further information is provided in Tables A.2 and A.6.

3.3.6 Cluster Variables - Affect

2-Cluster

As shown in Figure 3.2A an independent t-test (Welch's) revealed ASMR-responders scored significantly higher than non-responders on mean Pleasant scores, $t(255) = 13.6$, $p < 0.001$, $d = 1.51$. ASMR-responders also scored significantly higher than non-responders on mean Calm scores, $t(264) = 7.55$, $p < 0.001$, $d = 0.86$.

Figure 3.3: *Heatmap of the likelihood of associating tingling sensations to a body region based on 5-cluster groupings*



Scores have been calculated as likelihood of selecting a region per video where black is 100% and white is 0% likely. ASMR-S represents ASMR-Strong; ASMR-W represents ASMR-Weak.

5-Cluster

Across all tingle-related cluster variables (Figure 3.2B) a one-way between ANOVA (Welch's) showed a significant difference between all 5 cluster groups in mean Pleasant tingles scores ($F(4, 82.6) = 144$, $p < 0.001$, $est\ \omega^2 = 0.978$) and relative Calm ($F(4, 83.2) = 40.2$, $p < 0.001$, $est.\ \omega^2 = 0.925$).

Post-hoc group comparisons on Pleasant mean data performed by Games-Howell tests showed significant differences between False-Positive and Control- ($p < 0.05$), as well as between False-Positive and Control+ ($p < 0.05$) and also between ASMR-S and ASMR-W ($p < 0.05$). Significant differences also were found between ASMR-W and Control+ ($p < 0.01$) as well as between ASMR-W and False-Positive ($p < 0.01$). All other group comparisons were significant ($p < 0.001$).

Post-hoc group comparisons on relative Calm mean data performed by Games-Howell tests showed no significant differences between ASMR-W and ASMR-S or between ASMR-W and Control+. Similarly there were no significant differences between Control+ and ASMR-S. All other group comparisons were significant ($p < 0.001$; see Table A.3).

3.3.7 General Questions - Trait

2-Cluster

As shown in Figure 3.2A an independent t-test (Welch's) revealed ASMR-responders scored significantly higher than non-responders on Frisson scores, $t(229) = 2.67$, $p < 0.01$, $d = 0.33$. ASMR-responders also scored significantly higher than non-responders on Empathetic scores, $t(221) = 7.55$, $p < 0.05$, $d = 0.29$. Finally, ASMR-responders also scored significantly higher than non-responders on Emotionally Sensitive scores, $t(207) = 2.48$, $p < 0.05$, $d = 0.32$.

5-Cluster

Across both self-report trait variables (Figure 3.2B) a one-way between ANOVA (Welch's) showed a significant difference between all 5 cluster groups in mean Frisson ($F(4, 88.6) = 3.35$, $p < 0.05$, $est\ \omega^2 = 0.439$) and Empathetic ($F(4, 86.6) = 2.74$, $p < 0.05$, $est\ \omega^2 = 0.362$) scores.

Post-hoc group comparisons on Frisson mean data performed by Games-Howell tests showed significantly higher scores in the ASMR-S group compared to the Control- group only ($p < 0.05$).

Post-hoc group comparisons on Empathetic mean data performed by Games-Howell tests showed significantly higher scores in the ASMR-S group compared to Control+ ($p < 0.05$) and Control- ($p < 0.05$) groups only. However, it should be noted that Emotionally Sensitive self-report scores were trending to significance ($p = 0.083$), driven by the difference between ASMR-S and Control- ($M_{diff} = 0.121$, $p = 0.069$; see Table A.4)

3.3.8 General Questions - Trigger

2-Cluster

As shown in Figure 3.2A an independent t-test (Welch's) revealed ASMR-responders scored significantly higher than non-responders on mean Calming Voices scores, $t(229) = 6.09$, $p < 0.001$, $d = 0.76$. ASMR-responders also scored significantly higher than non-responders on mean Calming Drawing scores, $t(251) = 4.87$, $p < 0.001$, d = 0.58.

5-Cluster

Across both self-report trigger variables (Figure 3.2B) a one-way between ANOVA (Welch's) showed a significant difference between all 5 cluster groups in mean Calming Voices ($F(4, 90.4) = 13.57$, $p < 0.001$, $est\ \omega^2 = 0.810$) and Calming Drawing ($F(4, 87.5) = 8.94$, $p < 0.05$, $est\ \omega^2 = 0.723$) scores.

Post-hoc group comparisons on Calming Voices mean data performed by Games-Howell tests showed significant differences between Control- and ASMR-S, Control- and ASMR-W, Control- and False-Positive ($p < 0.001$). Furthermore, Control+ differed significantly from ASMR-S and from Control- ($p < 0.01$). Finally, Control+ differed significantly to ASMR-W ($p < 0.05$).

Post-hoc group comparisons on Calming Drawing mean data performed by Games-Howell tests showed significant differences between Control- and ASMR-S ($p < 0.001$), Control- and ASMR-W ($p < 0.001$), as well as Control- and False-Positive ($p < 0.05$). Finally, Control+ differed significantly to ASMR-W ($p < 0.05$; see Table A.5).

3.4 Discussion

Prior research into ASMR has mainly relied on participants self-disclosing their capability of experiencing ASMR. The present work has built on this to establish a new online psychometric tool to effectively classify respondents based on their response to ASMR stimuli using a data-driven approach. The basis of this new tool relies on an unsupervised learning algorithm which clusters data derived from the core features of ASMR: pleasant tingling sensations, tingle intensity, tingle loci and enhanced levels of calm. Respondents can be classified in either 2- (ASMR-responder vs non-Responder) or 5-cluster approaches (ASMR-Strong, ASMR-Weak; Control+, Control-, False-Positive) depending on the desired aim of the research study.

There are a number of benefits that the AEQ provides over existing tools to the ASMR research community. Firstly, and most importantly, the groups derived by the AEQ are data-driven and thus are derived with less implicit bias (e.g., Abrams et al., 2007; Mayberry and Espelage, 2007). Taken together with the score from the ASMR-15, a fully comprehensive profile of the participant is now possible. Secondly, retrospective ratings of the ASMR experience are given immediately after watching a variety of ASMR-inducing videos and experiencing the ASMR sensations. This is an improvement over other measures where participants are able to or asked to reflect on ASMR experiences that may have happened some time ago (e.g., months, days) rather than in the immediate past. In addition, the location of tingles is considered in the clustering algorithm, which enhances False-Positive identification.

The presence of both ASMR-S and ASMR-W supports the notion that ASMR-trait and -state lie on a spectrum with idiosyncratic potential for ASMR induction. False-Positives appear to differ most from ASMR-responders by reporting a more homogenous concentration of tingles in the upper body, where the tingles are generally unpleasant and reduce levels of calm. The categorisation of non-responders who do not report feeling tingles show that there are two groups differing in their attitude towards ASMR content: Control+, who enjoy and feel calmer; Control- who do not enjoy and feel less calm. Self-report scores of Frisson capability, being emotionally sensitive and empathetic were significantly higher in ASMR-responders compared to non-responders. Proposals on utilising these sub-groups effectively will be outlined below.

One key contribution of the newly developed AEQ is to provide the capacity to differentiate Control+ and Control- respondents. A major caveat in prior literature is the difficulty in identifying whether any difference between ASMR-responders and non-responders, physiological or otherwise, is a consequence of a change in the ASMR group rather than the non-Responder group. By having a better characterisation of the control group more valid conclusions can be drawn. For example, ensuring the recruitment of an equal balance of Control- and Control+ will help to reduce individual differences inherent in the control group and thus prevent masking of effects seen between ASMR-responder and non-Responder groups. When considering experiments involving watching ASMR stimuli, Control+ may be more likely to be recruited due to the inherent aversion and dislike to ASMR stimuli exhibited by Control-. Therefore, it is possible that effects seen in some studies may be as a result of the inherent traits of Control+ alone. Thus, the ability to stratify participants into Control+ and Control- would aid the researcher in interpreting the results and permit the ability to exclude Control- a priori if required.

Furthermore, given an appropriate paradigm, future studies can more effectively disentangle the tingling properties of ASMR from the affective modulatory properties. For instance, a comparison between Control+ only and ASMR-responder is more likely to indicate a change in tingling alone, due to a degree of shared affective modulation between the two groups. In contrast, a comparison between Control- and ASMR-responder is more likely to indicate a change in both affective and tingling properties between the two groups.

Another key finding of our current results is the presence of False-Positives, namely that some individuals experience tingling sensations that are unpleasant and are not calming. This finding draws into question whether there is a valence spectrum with respect to ASMR, where ASMR is at the most positive end, and other phenomena might lie on the opposite end. Furthermore, False-Positives appear to not emphasise the head as the most prominent site of induced tingling. Ideally, False-Positives would be identified in screening, and thus excluded from testing. The result also demonstrates how inclusion of False-Positives may influence differences in outcome measures when comparing ASMR-responder groups to controls. For example, if False-Positives are grouped with non-responders then, as shown in Figure 3.2A, the scores for Tingles are enhanced. Conversely, if False-Positives are grouped with ASMR-responders then Affect scores would be diminished. By being able to better characterise False-Positive responses the AEQ offers the potential to better constrain the recruitment of ASMR participants in the future. This will help to provide more refined insights into the mechanisms and broader consequences associated with ASMR.

In terms of recruitment, the ability to differentiate ASMR-S and ASMR-W offers the potential to maximise experimental time and help to clarify observed effects in ASMR research. Specifically, prioritising ASMR-S over ASMR-W in the recruitment stage of a study may reduce the likelihood of unsuccessful ASMR induction in an experimental environment (see Figure 3.2: Tingles & Affect). This is particularly the case when ASMR-responders can be further screened with the ASMR-15 (Roberts et al., 2019) to provide an individualised ASMR score. I am currently investigating the relationship between ASMR-15 scores and ASMR-responder clusters identified with the AEQ. However, it should be noted that it is possible that ASMR-S and ASMR-W participants represent different ASMR sub-types and thus exhibit differing neural responses. In this scenario experiments run on both ASMR-S and ASMR-W separately could yield interesting differences. Further research is required.

The AEQ is not without limitations. The current measure of Calm appears to exhibit a ceiling effect, where the initial calm rating of ASMR-responders was already tending to the maximum score. Therefore, subsequent ASMR videos had little capacity to enhance calm scores. Adopting a larger scale for comparisons in future work will be an important next step. Future adaptations may also wish to consider affective descriptors derived from the circumplex affect model to hopefully further hone in on sub-groupings and enhance accuracy (Russell, 1980). The measure, like other questionnaire measures of ASMR, suffers from a limitation implied by prior findings. Namely, that people can show short changes in set shifting and inhibitory control following ASMR induction (Wang et al., 2020). These changes may influence responses to questionnaires. There is also a limitation of scope of this tool - whilst a large proportion of ASMR-responders are captured by this tool, certain cases will be overlooked due to preferences in ASMR stimuli type or inherent aversion to such stimuli. A future development of the tool could include the addition of an unintentional ASMR video, such as that of a cranial nerve exam. Another future development could be the integration of the AEQ with the ASMR checklist (Fredborg et al., 2017) and the recently compiled and validated ASMR digital video library (Liu & Zhou, 2019b). The videos presented to each participant could be tailored based on trigger preferences from the ASMR checklist, and then sourced from associated labels contained in the digital ASMR library. In this way a wider range of idiosyncratic ASMR preferences can be captured with the tool, thus reducing the number of false negative cases.

In addition to considering ASMR identification, our study also examined broader traits associated with ASMR. In line with previous investigations of the relationship between ASMR and empathy (Fredborg et al., 2017; McErlean & Banissy, 2017), ASMR-responders showed significantly higher scores of self-report empathy compared to non-responders. Our data extend these prior findings by providing greater insights into the granularity of this relationship. When assessing the 5-cluster approach this was driven by ASMR-S against Controls. Frisson, the multisensory experience frequently contrasted with ASMR (del Campo & Kehle, 2016; Kovacevich & Huron, 2019), was also found to be reported higher in ASMR-responders compared to non-responders. Again this effect was driven by ASMR-S compared against Control-. This further supports the notion suggested by Smith *et al.* that ASMR-responders are more prone to sensory-emotional experiences, perhaps mediated by atypical thalamic connectivity (2017).

A further trait of interest was misophonia. Here, I did not replicate previous finding from our lab that indicated enhanced misophonia in ASMR-responders (McErlean & Banissy, 2018). This requires further investigation. One possibility for the difference may be measurements used. Here, I used a single question, however in our prior work full psychometric measures were used. I am now exploring this question in ongoing projects.

The introduction of this tool will augment research on the relationship of ASMR with more general theoretical frameworks by improving characterisation of participants. As noted, thus far ASMR-responders have reported to show differences to non-responders in a range of domains including: personality traits (Fredborg et al., 2017; McErlean & Banissy, 2017; Roberts et al., 2019), brain connectivity (S. D. Smith et al., 2017), social cognition (Lochte et al., 2018), and sensory sensitivity (Poerio et al., under review). These findings, and the inherent multisensory nature of ASMR, means that the experience provides a unique experimental window to explore how multisensory interactions shape our perception of the world (Lochte et al., 2018). In this regard being able to better identify ASMR-responders can help to improve studies that seek to better understand individual differences that contribute to sensory processing, social cognition, and multisensory interaction. In doing so this will help with endeavours, and theory, that seeks to understand not only normative mechanisms but also factors that contribute to individual variation in how we all perceive and interact with the world around us.

3.4.1 Conclusion

To summarise, here I provide a new psychometric tool that adopts a data-driven approach to aid in the identification of sub-groups of ASMR responders. In doing so, the AEQ provides promise to differentiate how participants respond to ASMR videos, and categorise each respondent into one of five groups: ASMR-Strong; ASMR-Weak; Control+; Control-; False-Positives. Both ASMR state and trait can also be captured using the tool, as well as an overview of the types of preferred triggers for each respondent. Using this data-driven approach in respondent classification allows a more comprehensive profiling of participants for ASMR response. This raises the potential to better understand mechanisms and broader traits associated with sub-groups of ASMR responders in the future.

Given the mixed self-report findings of enhanced empathy discussed in Chapter 1, I aim to use the AEQ in conjunction with two behavioural measures of empathy in the subsequent Chapter to further unpack the relationship between trait ASMR and empathy. I hope to build on prior work, by using behavioural measures that are both ecologically valid and able to measure subcomponents of the empathic response.

Chapter 4

ASMR-responders exhibit enhanced empathic accuracy

Abstract

People who experience autonomous sensory meridian response (ASMR) report a complex emotional response of calming, tingling sensations that originate around the crown of the head in response to a specific subset of audio-visual triggers. Recently, the authenticity of these experiences has been established. There is now growing interest in studying how ASMR is linked to wider aspects of perception and cognition. One example is the relationship between ASMR and empathy, where there is currently mixed evidence suggesting enhanced empathy in ASMR-responders compared to non-responders. To date, prior work on this topic has focussed on self-report measures of empathy that do not investigate sub-components (e.g., emotion identification, affect sharing) of the empathic process. Here, I conducted three experiments to examine how ASMR is linked to empathy. Two different groups of ASMR-responders and non-responders completed a variety of behavioural tasks measuring emotion identification and affect sharing: (1) Geneva Emotion Recognition Test (Experiment 1); (2) Continuous Affective Rating and Empathic Response task

(Experiment 2). Results show that ASMR-responders perform better at tasks designed to measure emotion identification capabilities (across both studies). This superior emotion identification was linked to greater empathic accuracy, however ASMR-responders and non-responders did not differ in how much they shared what they thought other people were feeling (Experiment 2). These findings systematically delineate the relationship between ASMR and empathy and show the importance of investigating subcomponents of the empathic process in order to fully explain the nature of individual differences in empathic response. Future work focussed on generating a greater understanding of the factors contributing to superior emotion identification in ASMR will be important for this emerging field and have the potential to reveal insights into mechanisms that can contribute to inter-individual variability in emotion identification in us all.

4.1 Introduction

4.1.1 Background

Autonomous sensory meridian response (ASMR) is a complex positive emotional experience reported by some people in response to a core set of triggers. The feeling (state ASMR), is described as a pleasant and calming involuntary tactile sensations (e.g., tingling) originating at the back of the head, which can radiate down the spine to other limbs (Barratt & Davis, 2015; Poerio et al., 2018). ASMR is most commonly induced by so-called 'triggers' encompassing: affective touch (e.g., tracing fingers on the back) and specific auditory (e.g., whispering, tapping, and brushing), visual (e.g., precisely executed hand movements, repetitive actions) and interpersonal cues (e.g., close personal attention, caring; Barratt et al., 2017; Fredborg et al., 2017).

Although ASMR research is still in its infancy, evidence has shed light on both the ASMR state (i.e., what occurs when an individual experiences ASMR) and the ASMR trait (i.e., what perceptual, cognitive, and broader psychological characteristics make ASMR-responders different from non-responders). Neuroimaging and physiological studies have helped to characterise the ASMR state by exploring correlates of the ASMR experience. ASMR appears to induce a distinct physiological profile characterised by reduced heart rate and increased skin conductance (Poerio et al., 2018), as well as differential activity in the cingulate gyrus and cortical regions associated with audition, movement and vision (S. D. Smith et al., 2019a). Another fMRI study examining ASMR tingling specifically, shows differential activity in the medial prefrontal cortex and regions associated with somatosensation, reward and interoception (Lochte et al., 2018). Recent electrophysiological work also shows that state ASMR is associated with increased alpha wave activity and increases in frequency bands associated with movement (Fredborg et al., 2021).

A complementary set of studies has started to describe broader factors connected to trait ASMR by identifying the psychological characteristics that distinguish ASMR-responders from non-responders. In terms of personality as indexed by the Big Five (BFI; John et al., 1991), ASMR-responders typically score higher than controls on dimensions of openness to experience Janik (McErlean & Banissy, 2017; S. D. Smith et al., 2017), and neuroticism (S. D. Smith et al., 2017) and lower on conscientiousness (McErlean & Banissy, 2017; S. D. Smith et al., 2017). There is also evidence that ASMR-responders have higher sensory suggestibility (Keizer et al., 2020), a greater tendency towards absorption and immersive experiences such as flow (McErlean & Osborne-Ford, 2020; Roberts et al., 2019), and higher self-reported sensory sensitivity particularly to interoceptive cues and positive affective appraisals of sensory stimuli ((Poerio et al., 2021; Roberts et al., 2020).

4.1.2 Enhanced empathic traits may be related to ASMR responsiveness

One intriguing but inconsistent difference between ASMR-responders and non-responders is the idea that those with ASMR may be more empathetic. ASMR-responders score significantly higher on two components of trait empathy measured by the Interpersonal Reactivity Index (Davis, 1980); specifically they self-report higher levels of empathic concern (other-orientated feelings of sympathy) and fantasizing (the tendency to immerse themselves in imagination, fantasy, and fiction (McErlean & Banissy, 2017). However, no significant differences emerge for dimensions of perspective taking or personal distress (McErlean & Banissy, 2017), or emotional empathy more generally when assessed with a different scale, the Toronto Empathy Scale (Poerio et al., 2018). Whether or not trait ASMR is characterised by enhanced empathy is therefore an open question and one that I address here in a series of studies.

Recent advances in the conceptualisation and measurement of individual differences in empathy highlight the need to distinguish between two related components of the empathy process: emotion identification (an aspect of cognitive empathy) and affect sharing (affective or emotional empathy (Coll et al., 2017). Emotion identification describes the degree to which an individual can accurately detect the emotional state of another person from perceptual cues or based on contextual information. Classic examples of emotion identification tasks therefore involve participants (the perceiver/empathiser) accurately identifying the affective experience of the target's state from information presented (e.g., facial expression, tone of voice). Affect sharing, on the other hand, describes the extent to which the perceiver experiences the same emotional state they attributed to the target (which may or may not match what the target is actually feeling).

According to this conceptualisation, the combination of accurate emotion identification and subsequent affect sharing are necessary to produce an appropriate empathetic response. Importantly, the accuracy of affect sharing will be influenced by the perceiver's emotion identification. High empathic accuracy is observed when emotion identification is correct and the perceiver also shares a corresponding amount of what the other person is feeling However, low empathic accuracy can be observed in cases where affect sharing is high, but emotion identification is incorrect (Santiesteban et al., 2021). Thus, individuals high in affective empathy are described by the extent to which a perceiver's state matches the state of the target (which comprises both accurate emotion identification and affect sharing).

Across two studies, I test whether ASMR-responders are indeed more empathetic than control participants, distinguishing between emotion identification and affect sharing, and using a range of established tasks. Study 1 examines performance differences in emotion identification between ASMR-responders and non-responders. Study 1 used the Geneva Emotion Recognition Test (GERT-S; Schlegel and Scherer, 2015), which requires the accurate identification of emotional expressions from audio-visual stimuli portraying the face, voice and body of actors (thus portraying dynamic, multimodal emotion expressions). Study 1 also measured self-reported empathy differences between groups using the 15-item short form of the Empathy Quotient (EQ; Muncer and Ling, 2006) and a questionnaire derived from the IRI, the Questionnaire of Cognitive and Affective Empathy (QCAE; Reniers et al., 2011). In Study 2, I used The Continuous Affective Rating and Empathic Response task (CARER task; Santiesteban et al., 2021), a novel method allowing the overall assessment of empathic accuracy by separately assessing emotion identification and affect sharing. This allowed us to test whether any potential empathy enhancements in ASMR-responders were driven by emotion identification and/or affect sharing abilities more directly.

4.2 Study 1 – ASMR-responders have enhanced GERT-S task performance

4.2.1 Methods

Participants

Participants were 100 individuals recruited through a UK University student mailing list and by word of mouth. Three participants were excluded for failing my data quality checks (insufficient or excessive duration): 2 ASMR-responders, 1 non-responder. The final ASMR sample consisted of 29 participants (M_{age} = 20.14, SD = 3.41; Range: 18-35; 93% female) who were predominantly

South Asian (36%). The final non-responder sample consisted of 62 participants *M*($_{age}$ = 20.18, *SD* = 3.15; Range: 18-37; 90% female) who were predominantly South Asian (39%). Ethical approval was provided by the local ethics committee at Goldsmiths, University of London.

Assessing ASMR-responders vs. non-responders

Participants were classified using the ASMR-Experience Questionnaire (AEQ; Chapter 3). The AEQ first provides a written description of ASMR encompassing its key characteristics (pleasurable tingling originating at the head), typical elicitors (example triggers) and distinction from frisson/musical chills. Subsequently, participants watched five ASMR videos portraying a wide range of ASMR triggers (visual, auditory, interpersonal) and rate their pleasantness, relative calm, tingle intensity and tingle location to each video.

The AEQ determines group status in a data-driven fashion facilitated by an unsupervised k-means clustering algorithm (Zhang et al., 1996). Five possible groupings are determined using the AEQ, ASMR-Strong (Responders with a greater propensity of ASMR induction/intensity), ASMR-Weak (Responders with a weaker propensity of ASMR induction/intensity), Control+ (non-responders who don’t experience tactile tingling sensations, but do experience a calming effect), Control- (non-responders who don’t experience tactile tingling sensations, and also find ASMR stimuli upsetting) and False-Positives (non-responders who experience tactile sensations which are not head-dominant and are unpleasant and upsetting). ASMR-Strong (n = 9) and ASMR-Weak (n = 19) were combined into one group, as were Control+ (n = 21) and Control- (n = 41). False-Positives were excluded from the analysis. In addition to the five cluster variables used in the AEQ, a sixth variable defined by affirmative tingles at both the head and body was used to augment False-Positive identification.

Emotion identification

Participants completed the Geneva Emotion Recognition Test (GERT-S; Schlegel and Scherer, 2015. Participants watched 42 short (a few seconds) video clips of actors expressing 14 different emotions in a pseudo-linguistic language: Anger, Pride, Joy, Amusement, Pleasure, Relief, Interest, Surprise, Anxiety, Fear, Despair, Sadness, Disgust and Irritation. Each emotion was described to the participant in the practice instructions. The audiovisual stimuli include the shoulders, and entire face of the actor and the videos were presented in a fixed order. Participants selected the emotion that they thought was expressed in the clip from the 14 emotion choices. Responses were scored into correct and incorrect categories, thus a total of 42 is the maximum score, with higher scores indicating greater emotion identification ability.

Self-reported empathy

Participants completed the 15-item short form of the Empathy Quotient (EQ; Muncer and Ling, 2006), rating their agreement to items (e.g., "I can tune into how someone else feels rapidly and intuitively") on 4-point Likert scales from 'strongly disagree' to 'strongly agree'. Values were recoded so that participants received 0 for a 'non-empathetic' (disagree) response and 1 or 2 for an 'empathetic' (agree or strongly agree, respectively) response. Recoded values were used to compute an overall score out of 30 where higher scores indicated greater self-reported empathy (α = .83). EQ subscales were also computed (each comprising five items, and a score out of ten) for Cognitive Empathy (α = .81), Social Skills (α = .65), and Emotional Reactivity (α = .70).

Participants also completed the 31-item Questionnaire of Cognitive and Affective Empathy (QCAE; Reniers et al., 2011). Items were rated on 4-point Likert scales from 1 (Strongly disagree) to 4 (Strongly agree). Negatively worded items were reverse scored, and items were summed to provide an overall score out of 124 where higher scores indicated greater self-reported empathy

(α = .91). QCAE subscales were also computed for Perspective Taking (10-items e.g., "I can easily tell if someone else wants to enter a conversation"; α = .81), Online Simulation (9-items e.g., "Before I do something I try to consider how my friends will react to it"; α = .82), Emotion Contagion (4-items e.g., "People I am with have a strong influence on my mood"; α = .73), Proximal Responsivity (4-items e.g., "I often get emotionally involved with my friends' problems"; α = .73) and Peripheral Responsivity (4-items e.g., "It is hard for me to see why some things upset people so much"; α = .75).

4.2.2 Results

I conducted a series of Welch Tests to examine differences within my emotion identification (GERT-S) and self-report empathy (EQ, QCAE) measures between ASMR-responders and non-responders. Results show that ASMR-responders performed significantly better on the GERT-S (M = 25.00, SD = 4.88) compared to non-responders (M = 21.77, SD = 6.32), Welch's t(63.52) = 2.61, p = .006, d = .57.

Table 1 displays the means and standard deviations for self-reported empathy levels for the EQ and QCAE. Although ASMR participants report higher levels of self-reported empathy on average, none of the differences in means were statistically significant. ASMR-responders and non-responders did not differ significantly in their EQ self-reported empathy overall, M_{diff} = -.23, Welch's t(50.48) = -.15, p = .56, d = -.04 or in any of the EQ subscales (Cognitive Empathy: M_{diff} = -.15, Welch's t(49.43) = -.22, p = .59, d = -.05; Social Skills: M_{diff} = .17, Welch's t(56.10) = .33, p = .37, d = .07; Emotional Reactivity: M_{diff} = -.25, Welch's t(56.37) = -.43, p = .67, d = -.10). ASMR-responders and non-responders did not differ significantly in their QCAE self-reported empathy overall, M_{diff} = .50, Welch's t(53.86) = .20, p = .42, d = .04 or in any of the QCAE subscales (Perspective taking: M_{diff} = -.45, Welch's t(53.14) = -.46, p = .67, d = -.10; Online simulation: M_{diff} = -.32, Welch's t(62.95) = -.36, p = .64, d = -.08; Emotion contagion: M_{diff} = .28, Welch's t(56.58) = .58, p = .28, d = .13;

Table 4.1: *Means and standard deviations of self-reported empathy for Study 1*

QUESTIONNAIRE	ASMR-responder (N = 28)	non-responder (N = 62)
	M (SD)	M (SD)
EQ	15.43 (6.43)	15.66 (6.19)
Cognitive Empathy	5.57 (3.13)	5.73 (2.95)
Social Skills	4.29 (2.24)	4.11 (2.42)
Emotional Reactivity	5.57 (2.49)	5.82 (2.70)
QCAE	94.46 (10.93)	93.97 (11.31)
Perspective Taking	31.50 (4.32)	31.95 (4.41)
Online Simulation	26.50 (3.63)	26.82 (4.43)
Emotion Contagion	12.39 (2.06)	12.11 (2.25)
Proximal Responsivity	12.61 (2.28)	12.00 (2.54)
Peripheral Responsivity	11.46 (1.64)	11.08 (1.99)

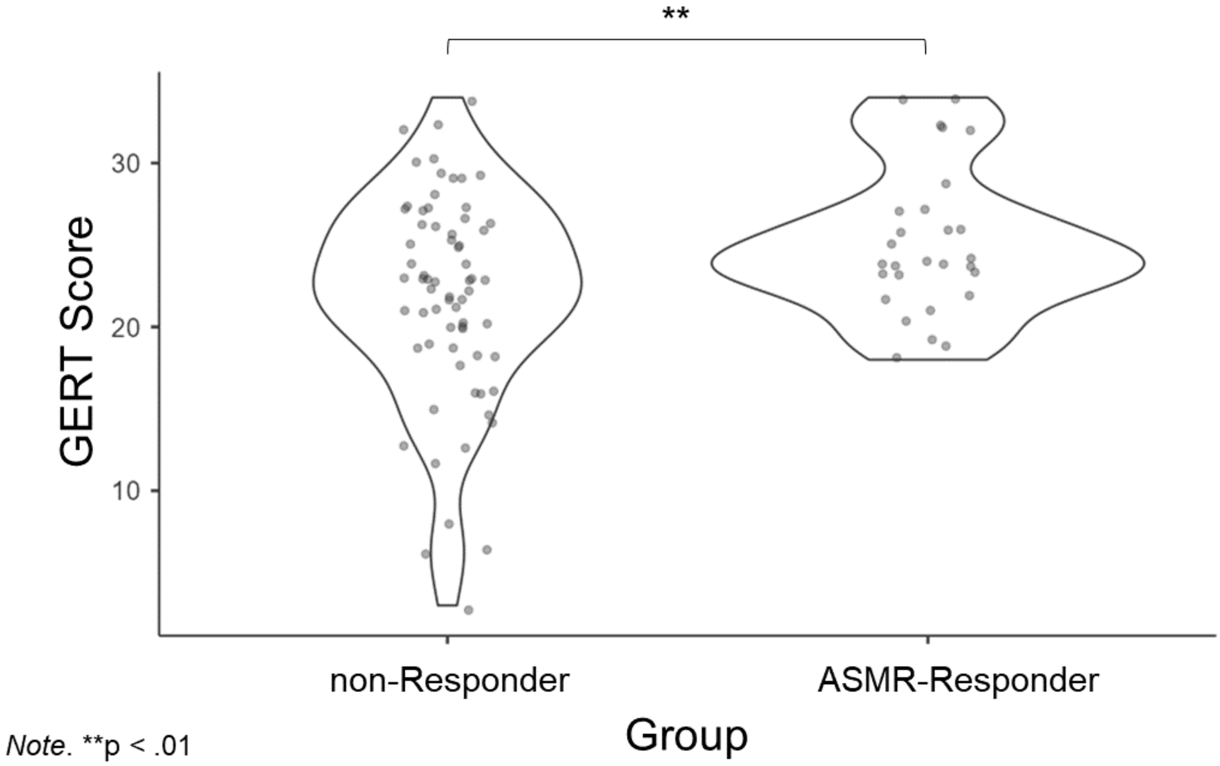
Note. EQ = Empathy Quotient; QCAE = Questionnaire of Cognitive and Affective Empathy.

Proximal responsivity: M_{diff} = .61, Welch's t(57.55) = 1.13, p = .13, d = .25; Peripheral responsivity: M_{diff} = .38, Welch's t(62.34) = .96, p = .17, d = .21.

ASMR-responders perform better than non-responders at an emotion identification task (GERT-S; see violin plots depicted in Figure 4.1). Although average levels of self-reported empathy were higher in the ASMR group, differences were not statistically significant. Thus, using both emotion identification tasks and measures of self-reported empathy I found evidence that ASMR-responders have enhanced task-specific skills in emotion identification but similar self-reported trait empathy.

While Study 1 provide complimentary insights into emotion identification and self-reported trait empathy in ASMR, the empathy measures used do not enable us to distinguish subcomponents of the empathic response (e.g., emotion identification and affect sharing) and their relative contributions to empathetic accuracy. In Study 2 I use a novel task to measure and distinguish between these constructs (emotion identification, affect sharing, and empathetic accuracy) in ASMR participants relative to controls. The Continuous Affective Rating and Empathic Response (CARER task; Santiesteban et al., 2021) task allows an individual assessment of: (1) emotion identification (the accuracy of the Empathiser's judgement of the Target's affective state), (2)

Figure 4.1: *Mean scores derived from the Continuous Affective Rating and Empathic Response (CARER) task comparing ASMR-Responder vs non-Responders*



ASMR-Responders score higher on the GERT compared to non-Responders. Group level differences were revealed using Welch tests due to violations of normality. Higher scores on the GERT represent a greater emotion identification accuracy.

affective empathy as classically defined (the extent that the Empathiser's affective state matches that of the Target, i.e., empathic accuracy) and (3) affect sharing (the degree of similarity between the Empathiser's affective state to the Target's affective state). Studies 1 and 2 showed that ASMR-responders have enhanced emotion identification, and thus I predict ASMR-responders to be more accurate at identifying the target's affective state. As a result of this enhanced emotion identification, I would also expect a closer correspondence between the empathiser and target affective state (affective empathy/empathic accuracy) in ASMR-responders, but not necessarily closer correspondence for affect sharing.

4.3 Study 2 – ASMR-responders perform more accurately in the CARER task

4.3.1 Method

Participants

Participants were 40 individuals recruited through a UK University student mailing list and by word of mouth, which comprised of 20 ASMR-responders and 20 non-responders (73% females; *M* = 20.49, *SD* = 4.41). Participants had been previously classified independently using the ASMR-Experience Questionnaire (AEQ; Swart et al., 2021), as described in Study 1. Consequently, no False-Positives were tested. Ethical approval was provided by the local ethics committee at Goldsmiths, University of London.

Assessing Empathy (CARER Task)

I used an adaption of the CARER task (Santiesteban et al., 2021) coded in Python using the PsychoPy software (Peirce et al., 2019). Participants (Empathisers) watched 32 videos (approximately 30s each) describing real life events (told by actors – called Targets); half were emotionally intense (i.e., upsetting; Emotional) and half were emotionally neutral (Neutral). A total of 32 trials (16 Emotional and 16 Neutral) were presented in two blocks of 16 trials each in a pseudorandomised order, where no more than three trials of the same type were presented in succession. There were two types of blocks. In Continuous Self blocks participants were instructed to rate how they (the Empathiser) felt while watching each video (Online Self rating), whilst also providing a subsequent rating of how they thought the Target felt throughout the story (Offline Other rating) after the video. Both ratings ranged from 0 (very calm) to 100 (very upset). The Online Other blocks consistent of the participant rating the Target continuously throughout the video, whilst also providing an offline rating for the self. The self/other rating order was counterbalanced across participants, who completed blocks in succession. Comparable ratings from each actor reporting how they actually felt after telling each story were also used.

Three dependent variables were calculated as follows: (1) Emotion Identification (Target's self rating—Empathiser rating of the Target's state) (2) Affective Empathy (Target's self rating—Empathiser's self rating), i.e., how accurate participants were at sharing what the other person actually felt (empathic accuracy); and (3) Affect Sharing (Empathiser's rating of the Target's state—Empathiser's self rating, i.e., how much participants shared what they thought the other person was feeling. Lower scores on all three measures indicate better performance in the respective measures. All three values were calculated from both online and offline ratings.

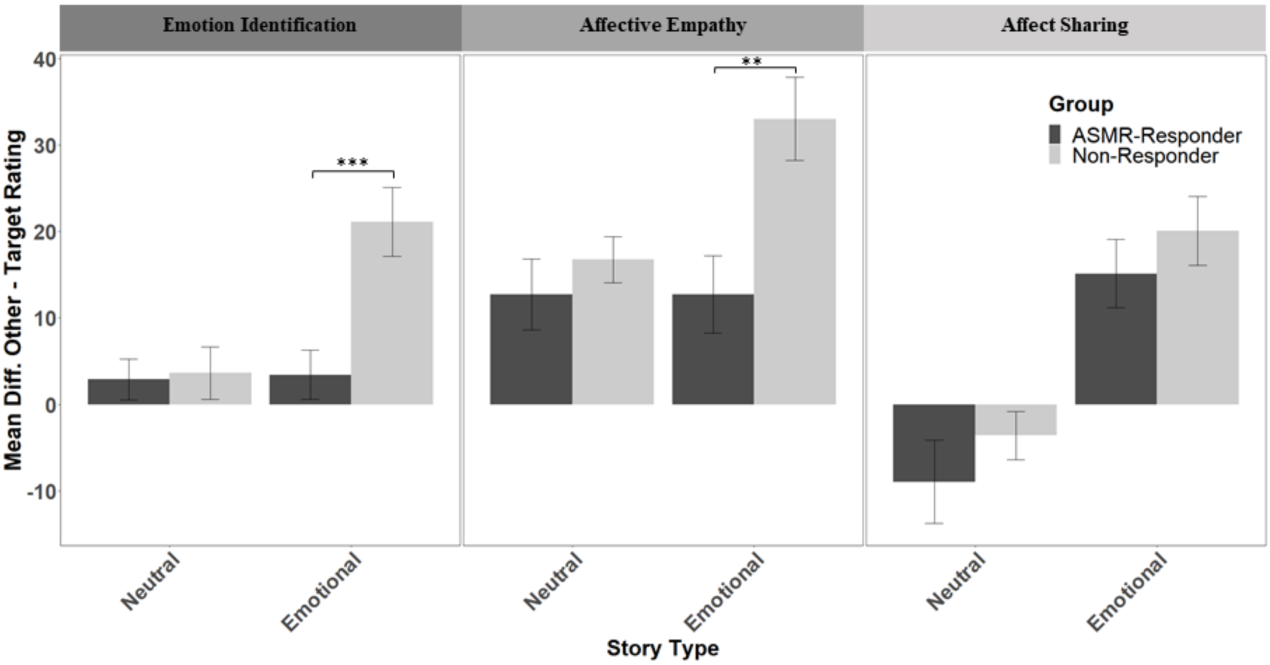
4.3.2 Results

The data were analysed using ANOVA with Story type (Emotional vs Neutral) as within-subject factors, Group (ASMR-responder vs non-responder) as a between-subjects factor. Bonferroni corrections were used for post-hoc multiple comparisons. Cohen's *d* was calculated using the pooled *SD* approach.

Emotion Identification Offline

Figure 4.2 (left panel) shows the offline data for Emotion Identification. I found significant main effects of Story Type ($F(1, 33) = 10.28$, $p = .0030$, $\eta^2p = .24$) and Group ($F(1, 33) = 7.27$, $p = .011$, $\eta^2p = .18$). A Story Type × Group interaction was also significant ($F(1, 33) = 10.24$, $p = .003$, $\eta^2p = .24$). Post-hoc tests revealed that this was driven by an enhancement (lower score) in emotion identification in the ASMR-responder group on Emotional trials ($M = 2.77$, $SEM = 3.29$), compared

Figure 4.2: *Mean scores derived from the Continuous Affective Rating and Empathic Response (CARER) task comparing ASMR-Responder vs non-Responders*



Note. *p < .05, **p < .01, ***p < .001

Offline data for Emotion Identification (calculated by subtracting participants' ratings of how the Targets feels from the Targets' own ratings), Affective Empathy (calculated as the difference between participants' self ratings and the Targets' own ratings) and Affect Sharing (calculated by subtracting the Empathiser's own state (self ratings) from Empathiser's judgement of the Target's state (other ratings). In all measures, lower scores indicate better performance. ASMR-Responders show greater emotion identification and affective empathy abilities, but equivalent affect sharing abilities. Error bars represent 95% CI.

to non-responders (M = 21.91, SEM = 3.32; t(1,62.29) = 4.09, $p < 0.001$, d = 1.38). The Group contrast on Neutral trials was not significant, p = .87.

Emotion Identification Online

I found a significant main effect of Story Type ($F(1, 38) = 8.21$, $p = .0067$, $\eta^2 p = .18$), indicating better emotion identification on the Emotional than the Neutral trials. Neither the main effect of Group ($F(1, 38) = 2.82$, $p = .10$, $\eta^2 p = .07$) or the Story Type × Group interaction ($F(1, 38) = 2.39$, $p = .13$, $\eta^2 p = .06$) were significant.

Affective Empathy Offline

Figure 4.2 (middle panel) shows the offline data for Affective Empathy. I found a significant main effect of Group ($F(1, 35) = 6.19$, $p = .018$, $\eta^2 p = .15$) and a non-significant trending effect of Story Type ($F(1, 35) = 3.68$, $p = .063$, $\eta^2 p = .10$). A Story Type × Group interaction was also significant ($F(1, 35) = 5.66$, $p = .023$, $\eta^2 p = .14$). Post-hoc tests revealed that this was driven by an enhancement (lower score) in affective empathy in the ASMR-responder group on Emotional trials ($M = 11.02$, $SEM = 4.15$), compared to non-responders ($M = 31.10$, $SEM = 4.19$; $t(1,62.55) = 3.40$, $p = .0023$, $d = 1.12$). The Group contrast on Neutral trials was not significant, $p = .50$.

Affective Empathy Online

I found a significant main effect of Story Type ($F(1, 38) = 162.66$, $p < .0001$, $\eta^2 p = .81$), indicating better emotion identification on the Emotional than the Neutral trials. Neither the main effect of Group ($F(1, 38) = 2.85$, $p = .10$, $\eta^2 p = .07$) or the Story Type × Group interaction ($F(1, 38) = 1.96$, $p = .17$, $\eta^2 p = .05$) were significant.

Affect Sharing Offline

Figure 4.2 (right panel) shows the offline data for Affect Sharing. I found a significant main effect of Story Type ($F(1, 33) = 49.35$, $p < .001$, $\eta^2 p = .60$) indicating that participants undershare Emotional stores but overshare Neutral stories. There was no main effect of Group, $p = .38$, or a Story × Group interaction, $p = .75$.

Affect Sharing Online

I found a significant main effect of Story Type ($F(1, 38) = 11.44$, $p < .0017$, $\eta^2 p = .23$), indicating better emotion identification on the Emotional than the Neutral trials. Neither the main effect of

Group ($F(1, 38) = 0.44$, $p = .51$, $\eta^2 p = .01$) nor the Story Type × Group interaction ($F(1, 38) = .06$, $p = .81$, $\eta^2 p = .00$) were significant.

4.4 Discussion

The aim of the present study was to systematically investigate the links between ASMR responsiveness and empathy. Prior research has suggested that enhanced empathy may be a feature that distinguishes ASMR-responders from non-responders (McErlean & Banissy, 2017). However, this research has been restricted to self-reported empathy. The findings to date are neither replicated across different self-report measures (Poerio et al., 2018), nor consistent across cognitive and affective aspects of empathy (e.g., self-reported empathetic concern but not perspective taking is heightened in ASMR; McErlean and Banissy, 2017). One reason for these inconsistent findings may be that prior work has not measured the variety of sub-processes that can contribute to empathy: appropriately identifying the emotional state of a target; sharing what the target is actually feeling; sharing what I think the target is feeling (Coll et al., 2017). Here, I used both self-report and task-based measures to investigate, for the first time, how ASMR-responders differ from non-responders in each of these separable processes associated with empathic responding.

Studies 1 and 2 show that ASMR-responders consistently outperform non-responders on emotion identification across increasingly complex levels of emotional stimuli from vocal tone and facial expression (Study 1) to dynamic emotional displays from personal stories (Study 2). While Study 1 indicates that ASMR-responders are faster and more accurate at identifying different emotional expressions, Study 2 shows that they are also able to accurately decipher the emotional intensity of another's distress. Taken together, these results suggest that ASMR-responders are not only better at deciphering what other people are feeling but also how much they are feeling.

Whether or not these enhanced emotion identification skills have positive downstream consequences for interpersonal relationships is an open question. However, it seems plausible that being better calibrated to another's feelings facilitates more contextually appropriate use of interpersonal emotion regulation strategies (Niven et al., 2009), which, in turn, may impact relationship quality (Niven et al., 2012).

As well as displaying better offline emotion identification, Study 2 also suggests enhanced empathic accuracy in ASMR-responders compared to non-responders. Those with ASMR were more likely than non-responders to experience a similar emotional state to the target. Importantly, however, ASMR-responders and non-responders did not differ in how much they shared what they thought the target was feeling. Thus, although ASMR-responders display heightened empathic accuracy (a greater congruence of feeling states between self and other), this may simply be a consequence of better emotion identification rather than greater affect sharing of what they perceive the other person to be feeling.

The finding that ASMR-responders differ in offline emotion identification and empathic accuracy, but not affect sharing, may help to explain prior mixed evidence of the relationship between ASMR and empathy. Prior literature has solely used self-report questionnaires where the measurement of 'empathy' can sometimes conflate the emotion identification and affect sharing processes, both of which can independently modulate empathetic responding (Coll et al., 2017). Here, Studies 1 and 2 replicate the absence of higher self-reported trait empathy in ASMR-responders (Poerio et al., 2018). By measuring both emotion identification and affect sharing components separately, in a task-based manner, a clearer picture is revealed – ASMR-responders differ in emotion identification, but not affect sharing. This finding helps to tune our understanding of the relationship between ASMR and empathy because it suggests that empathy enhancements in ASMR-responders are likely to be driven by more precise identification of another's emotional state, which facilitates feeling what another person is feeling (affective empathy).

Our results also contribute to wider discussions of the importance of considering how empathy is conceptualised and measured in atypical groups (e.g., Coll et al., 2017; Santiesteban et al., 2021). Scientific understanding of empathy has been honed by studying atypical groups that display impairments in empathy (e.g., autism, alexithymia and psychopathy; Bird and Viding, 2014; T. F. Clark et al., 2008); I argue that theoretical frameworks would be similarly strengthened by considering atypical groups, like ASMR, with enhanced, rather than impaired, empathetic responding, similar to how examples of synaesthesia have been used to inform models of social cognition (J. Ward and Banissy, 2015; J. Ward et al., 2018). Indeed, comprehensive neuro-cognitive models of empathetic processes should be able to accommodate both extremes of the normal distribution.

Why do ASMR responders have superior emotion identification ability? The exact nature of the mechanisms underlying enhanced emotion identification in ASMR is an important avenue for future investigation. There are many subcomponents of emotion identification that might be responsible depending on the types of stimuli being processed under specific contextual circumstances (Bird & Viding, 2014). However, I suspect that candidate mechanisms include: (1) advanced perceptual categorisation for emotional stimuli across visual, auditory and tactile modalities and/or (2) heightened awareness and accuracy of one's own emotional state which is used to gain further insight into other's emotions through the process of affective empathy (e.g., Barrett, 2017; Christensen et al., 2021). I make these predictions based on emerging research showing that ASMR-responders show greater sensory processing sensitivity (Poerio et al., 2021; Roberts et al., 2020; Vardhan et al., 2020) and interoceptive awareness (Poerio et al., 2021), especially regarding how bodily sensation affects emotional states.

Whilst there were significant differences in performance using offline ratings, online ratings did not show the same effect (albeit often numerically similar in Emotion Identification and Affective Empathy comparisons). This disparity in online and offline ratings could shed light on the particular subcomponents of empathy that ASMR-responders perform better in. For example, it has been argued that offline measures rely more on explicit, verbally-mediated theory of mind relative to online measures (e.g., see Schilbach, 2014). Thus, it is possible that the inherent differences between online and offline ratings shown in Study 2 reflect the greater role played by reflective processing in ASMR-responders. It should be noted that the original authors of the CARER task showed a similar discrepancy between the two types of ratings in their study (Santiesteban et al., 2021).

While support for the authenticity of ASMR has been provided (e.g., via behavioural and biological measures; Poerio et al., 2018; Valtakari et al., 2019), it is less clear what drives individual differences in the intensity of ASMR. Recent work links ASMR to heightened sensitivity towards external cues that are salient as ASMR triggers (Poerio et al., 2021), with heightened sensory sensitivity also predicting the intensity of ASMR. Our findings of better emotion identification are consistent with the idea that ASMR-responders are more sensitive to emotional cues. However, several important questions remain: (1) is better emotion identification in ASMR influenced by individual differences in perceptual sensitivity to external cues or other cognitive abilities (e.g., the capacity to appraise a social situation and the ability to mentalise); (2) what is the relationship between the intensity and consequences of ASMR experiences and individual differences in emotion identification; and, (3) are the differences observed in this paper specific to emotion identification or are they also present other perceptual domains (e.g., identity or object identification)?

The studies examined differences between ASMR-responders and non-responders, but an equally valid approach would be to explore the extent to which individual differences in ASMR predict emotion identification abilities. Future research could examine whether individuals with stronger ASMR experiences have superior emotion identification abilities, and if any relationship may be extended to the perception of other social or non-social cues. Further, although ASMR is a complex emotional response, unlike similar experiences such as awe or frisson, it appears to be inherently social in nature. ASMR is not only predominantly triggered by social cues (e.g., affective touch, vocal sounds, and close personal attention; Liu and Zhou, 2019a; Poerio et al., 2018; Roberts et al., 2020; N. Smith and Snider, 2019) but also increases feelings of social connection (Poerio et al., 2018). This has led authors to speculate that ASMR may be a form of social grooming (e.g., Lochte et al., 2018), and suggest that the benefits of ASMR may derive from a unique ability to experience affective touch in the absence of actual touch (Poerio et al., 2021). The known links between emotion identification and social constructs such as social affiliation, integration and connectedness (e.g., prosocial behaviours, emotional competence, social affiliation and connectedness) suggest another important area for understanding empathetic responding in ASMR: the impact of trait and state ASMR on social relationships and behaviour (e.g., trust, relationship quality, prosociality). Doing so will not only contribute to understanding the mechanisms and consequences of ASMR, but it will also provide a unique experimental window whereby ASMR-responders to shed light on the relationships between complex social processes (e.g., emotion identification and social affiliation) that affect us all.

4.4.1 Conclusion

To summarise, here I provide evidence that AEQ-validated ASMR-responders exhibit greater emotion identification skills compared to non-responders. Now that I have identified behavioural differences in ASMR-responders, I now aim to identify electrophysiological differences in ASMR-responders.

Given the scarcity of electrophysiological investigation into ASMR discussed in Chapter 1, I aim to use the AEQ in conjunction with an EEG paradigm in the subsequent Chapter to build on prior work and describe the neural correlates of state ASMR.

Chapter 5

Oscillatory Correlates of ASMR in the sensor and source space

Abstract

Autonomous sensory meridian response (ASMR) describes an atypical multisensory experience of calming, tingling sensations in response to a specific subset of social audiovisual triggers. To date, the electrophysiological (EEG) correlates of ASMR remain largely unexplored. Here I sought to provide source-level signatures of oscillatory changes induced by this phenomenon and investigate potential decay effects—oscillatory changes in the absence of self-reported ASMR. I recorded brain activity using EEG as participants watched ASMR-inducing videos and self-reported changes in their state: no change (Baseline); enhanced relaxation (Relaxed); and ASMR sensations (ASMR). Statistical tests in the sensor-space were used to inform contrasts in the source-space, executed with beamformer reconstruction. ASMR modulated oscillatory power by decreasing high gamma (52-80 Hz) relative to Relaxed and by increasing alpha (8-13 Hz) and decreasing delta (1–4 Hz) relative to Baseline. At the source level, ASMR increased power in the low-mid frequency ranges (8-18 Hz) and decreased power in high frequency (21-80 Hz). ASMR decay effects

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[0] Note: this chapter has been published: Swart, T.R., Banissy, M.J., Hein, T.P., Bruña, R., Pereda E., Bhattacharya J. (2022). ASMR amplifies low frequency and reduces high frequency oscillations. *Cortex*.

reduced gamma (30-80 Hz) and in the source-space reduced high-beta/gamma power (21-80 Hz). The temporal profile of ASMR modulations in high-frequency power later shifts to lower frequencies (1-8 Hz), except for an enhanced alpha, which persists for up to 45 minutes post self-reported ASMR. Crucially, these results provide the first evidence that the cortical sources of ASMR tingling sensations may arise from decreases in higher frequency oscillations and that ASMR may induce a sustained relaxation state.

5.1 Introduction

People who experience ASMR report calming and pleasant tingling sensations that originate in the crown of the head when encountering specific audio-visual triggers (Barratt & Davis, 2015). Typically these tingling sensations originate at the back of the head and neck; they are then thought to radiate down the spine and into the limbs in periods of greater intensity (Barratt & Davis, 2015). ASMR induction is thought to be involuntary and heavily dependent on the environment and individual mood (Barratt & Davis, 2015; Poerio et al., 2018). Anecdotal evidence suggests individuals watch ASMR-eliciting stimuli to relieve symptoms of stress, anxiety, or even chronic pain (Barratt & Davis, 2015). However, the therapeutic benefits of ASMR and the prevalence of ASMR-responders (individuals capable of experiencing ASMR) in the general population are currently unknown.

Stimuli known to induce ASMR are idiosyncratic and thus can vary enormously. However, certain features are common (Barratt & Davis, 2015), including low volume voices (e.g., soft-spoken, whispering), repetitive movements or sounds (e.g., tapping, scratching, brushing), layered sounds, personal attention, close-up visuals, and expert manipulation of objects (Barratt & Davis, 2015; Barratt et al., 2017; Fredborg et al., 2018; Fredborg et al., 2017). In addition, there is further anecdotal evidence that touch is a strong trigger (Kovacevich & Huron, 2019; Poerio et al., 2018).

Some studies provide evidence of physiological correlates of ASMR. For instance, altered heart rate and skin conductance responses have been shown when viewing ASMR videos in ASMR-responders versus non-responders (Poerio et al., 2018). However, no data has yet to be published regarding heart rate variability. In addition, there are several task-based and resting-state fMRI studies in ASMR (S. D. Smith et al., 2019a; S. D. Smith et al., 2017, 2020). In these studies, reduced functional connectivity of resting states was found in ASMR-responders compared to non-responders (S. D. Smith et al., 2017). Specifically, ASMR-responders showed reduced functional connectivity in the right precuneus and posterior cingulate, the left medial frontal gyrus and thalamus, and bilateral superior temporal gyri. Conversely, increased functional connectivity was observed in the right occipital and left frontal cortical areas. The authors suggested that this could indicate a reduced ability to suppress multisensory experiences in these individuals.

In a task-based fMRI where 34 participants (17 ASMR-responders and 17 non-responders) watched ASMR stimuli and control stimuli, differential activation of regions was shown through group comparisons (S. D. Smith et al., 2019a). Specifically, episodes of ASMR were associated with increased activity in medial prefrontal regions, bilateral precentral gyri, the right superior prefrontal cortex, the left superior temporal cortex, and midline occipito-parietal structures (precuneus and cuneus). In contrast, control participants showed only a decrease in activity in the cuneus (S. D. Smith et al., 2019a).

Another fMRI study investigated ASMR-induced changes relative to an individual baseline within ASMR-responders (Lochte et al., 2018). Ten participants reported three states: no change (i.e., Baseline), Relaxation, or ASMR (e.g., the tingling sensations). When Relaxation was compared to Baseline, there was increased activity in the medial prefrontal cortex. When ASMR was compared to Baseline, there was increased activity in the media prefrontal cortex, bilateral nucleus accumbens, bilateral insula/inferior frontal gyrus, ventral premotor cortex, dorsal anterior cingulate cortex, left inferior parietal lobule, bilateral supplementary motor area and the left secondary somatosensory cortex. Reassuringly, the processes associated with these regions, such as reward responses (e.g., see review Schultz, 2000), interoception (e.g., see review Craig and Craig, 2009), and emotional arousal (e.g., Oliveri et al., 2003), were all implicated, thus supporting the reported phenomenology of ASMR (Barratt & Davis, 2015).

Another investigatory tool to study the neural correlates of ASMR spontaneous EEG, for example, the time-frequency oscillations derived from the electrophysiological data. Using such oscillatory neuroelectric activity, researchers can estimate the degree of involvement and synchrony that neurons exhibit when undergoing a specific cognitive function (e.g., Başar et al., 1999). These oscillations vary in frequency (rate of neuronal activity) and location, and can be associated with a context-specific process. For example, alpha waves (8-13 Hz) has been associated with relaxation (Niedermeyer, 1999) or the suppression of distractor stimuli (Foxe & Snyder, 2011; Jensen et al., 2002; Kelly et al., 2006).

Recently, researchers have published an EEG study investigating the oscillatory changes induced by ASMR in the sensor space (Fredborg et al., 2021). In this EEG ASMR study, 28 participants (14 ASMR-responders, 14 matched non-responders) indicated the presence of ASMR tingling sensations with a button press whilst presented with audio/audiovisual ASMR stimuli or audio/audiovisual control stimuli. Oscillatory power was estimated 500-1000ms after button press (ASMR onset) contrasted against 500 to 1000ms before button press (Baseline) in the alpha (8-12 Hz), sensorimotor rhythm (12.5-15 Hz), theta (4-7 Hz), and gamma (>30Hz) frequency bands. A between-group contrast revealed significantly enhanced alpha power at frontal, parietal, and precuneus electrodes for the audio ASMR trials. Only the enhanced alpha precuneus effect was replicated for the audiovisual contrast. Exploratory analysis for the audio trials also revealed significantly enhanced alpha power at occipital, parietal, and temporal regions in ASMR-responders compared to non-responders. Moreover, an enhancement of gamma power was seen at central electrodes for the audio trials only. An increase in sensorimotor rhythm power was seen at sensorimotor regions (C3, Cz, C4) for ASMR-responders during audio trials.

Within-subjects contrasts of ASMR-inducing stimuli against control stimuli in the audio trials revealed a similar significant enhancement of alpha power in frontal and cuneus electrodes.

Exploratory analysis for the audio trials also revealed enhanced alpha at P3 and P4 for ASMR-responders only. Baseline within-subjects contrasts of audio trials in ASMR-responders revealed enhancements of alpha power in frontal and medial frontal regions. Conversely, the same contrasts in non-responders (using the times from the matched ASMR-responders) reported decreases in alpha power in frontal, medial frontal, and precuneus regions. Exploratory analysis for ASMR-responders during ASMR audio trials revealed significant alpha power enhancement at frontal and frontocentral electrodes. Furthermore, sensorimotor rhythm power increased for ASMR-responders in audio trials only, whilst decreased for non-responders.

This study (Fredborg et al., 2021) has provided an excellent foundation for further EEG investigation into ASMR using time-frequency techniques. However, the authors acknowledge limitations, primarily the small sample size per group. Given the large effect sizes for alpha power enhancement seen in the previous EEG paper (e.g., $g = 1.79$; Fredborg et al., 2021), I expect to replicate this finding foremost. This prediction is further supported by the association of alpha power with distraction suppression (e.g., Jensen et al., 2002), where ASMR has previously been described as a trance-like state (Barratt & Davis, 2015).

I also aim to identify: 1) oscillatory neural correlates of ASMR during the tingling experience in both the sensor and source space; 2) decay effects of ASMR after the tingling sensations have ceased and estimate possible durations of such; and 3) identify the importance of temporal continuity of ASMR stimuli for ASMR induction through a novel control design.

5.2 Methods and Materials

5.2.1 Participants

Twenty-six healthy individuals (22 right-handed, 15 female, aged 18–45 years, mean ± SD: 27.0 ± 1.4 years) took part in this study. Participants were recruited via mailing lists at Goldsmiths University, social media platforms (e.g., reddit.com/r/ASMR), and word of mouth. All participants reported normal auditory, normal or corrected-to-normal visual acuity, and no neurological or psychiatric problems. All participants were classified as either weak or strong ASMR-responders using the data-driven tool ASMR-Experience Questionnaire (Swart et al., 2021). The study protocol was approved by the ethics committee of the Department of Psychology at Goldsmiths, University of London. All participants gave written informed consent before the study and were remunerated with either £ 20 or equivalent course credits. At the time of testing, no prior studies on ASMR using EEG had been conducted to help motivate our sample size. Accordingly, I followed an EEG study on similar phenomena (such as frisson) to inform our sample size (Trochidis & Bigand, 2012). Since completing our study, one EEG study investigating ASMR has been published, finding effects when testing fourteen participants (Fredborg et al., 2021).

5.2.2 Materials

To maximise the likelihood of ASMR, participants provided a 10 min long individualised ASMR video for the experiment. Since there is anecdotal evidence for a habituated ASMR response upon repeated exposure to the same ASMR video called ASMR tolerance, I requested that the individualised video be relatively new to the participant. To construct control videos, I randomly segmented each video in 120 5-s segments and re-ordered them using ffmpeg (an open-source multimedia editing tool https://ffmpeg.org/)—ensuring the low-level spatial and acoustic features were preserved between experimental and control videos.

5.2.3 Experimental design

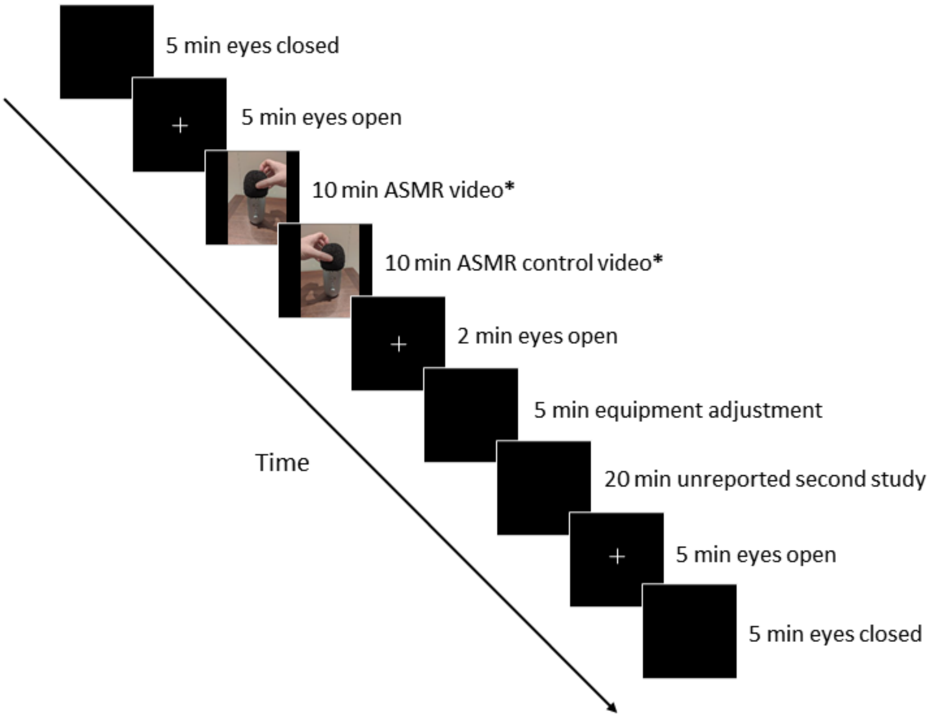
Each participant watched their chosen ASMR video, once scrambled (as control) and once in its original form (as experimental). Participants were seated approximately 50 cm in front of a computer screen in a dimly lit, sound-attenuated room whilst using in-ear earphones. First, five minutes of resting-state EEG with eyes closed was recorded, followed by five minutes of resting-state EEG with eyes open (fixating on a cross presented in the middle of the screen, see Figure 5.1). While watching the ASMR videos, the participant was instructed to keep their eyes open and press one of four buttons as frequently as they needed to indicate a change to their subjective state. The experimental design thus furnished four subjective self-reported states in each participant, formally defined as i) an unchanged normal state (Baseline), ii) a relaxed state with no tingling (Relaxed), iii) a state characterised by weak tingling sensation (WeakASMR), and iv) a state characterised by strong tingling sensations (StrongASMR). A button press was also mandatory at the beginning of each video.

The order of the control and the experimental ASMR videos were counterbalanced between participants, and each video was separated by two minutes of rest with a fixation cross presented on the screen (see Figure 5.1).

5.2.4 Electrophysiology acquisition

EEG signals were recorded with sixty-four Ag-AgCl electrodes (placed in accordance to the extended 10–20 system; Oostenveld and Praamstra, 2001) using the BioSemi ActiveTwo head cap and the ActiveTwo BioSemi system amplifier (BioSemi, Amsterdam, The Netherlands). The EEG signal was amplified by a BioSemi ActiveTwo amplifier and sampled at 512 Hz. Four external electrodes were placed above and below each eye and at the outer canthus of each eye—to record vertical (VEOG) and horizontal eye movements (HEOG), respectively. In addition, two external

Figure 5.1: *Schematic figure representing the timing of each recording block in the EEG experimental paradigm*



First, each subject had 5 minutes of resting-state EEG and ECG recorded with eyes closed, and then 5 minutes with eyes open. Subsequently, two ASMR videos were watched whilst reporting what state was currently being experienced, with a two-minutes presentation of a fixation cross between them. Then, a two-minute fixation cross, followed by another unreported study, were presented. Finally resting state was recorded again. *The order of the ASMR experimental video and ASMR control video was counterbalanced across the participant group. Thus, the control ASMR video originated from the same ASMR experimental video, except the temporal continuity was randomly shuffled every five seconds.

electrodes were placed on both ear lobes of each participant for re-referencing. Two additional electrodes were placed below the left clavicle and above the right hip bone to record ECG.

EEG data were preprocessed in MATLAB (MathWorks, Natick, MA) using the EEGLAB v2019.1 toolbox (Delorme & Makeig, 2004). Next, further data and statistical analysis were performed using the FieldTrip toolbox (Oostenveld et al., 2011). First, I re-referenced the data to the arithmetic average of the two earlobes. After, high-pass filtered was performed at 0.5 Hz (Hamming windowed finite impulse response (FIR) filter, 3380th order) and then notch filtered at 50

Hz (Hamming window FIR, 846th order) to remove power line noise. Artifact subspace reconstruction (ASR) was then used to detect noisy channels and then spherically interpolate them before running independent components analysis (ASR from the clean_ rawdata EEGLAB plugin, [Kothe and Makeig, 2013; Mullen et al., 2015]). Principal component analysis-weight adjusted ICA (runica) was then used per participant to remove VEOG, HEOG, and heartbeat-related components (mean 2.54 components removed, SEM 0.16).

After, the data were segmented into non-overlapping epochs of 2 seconds, labelled to reflect the subjective states indicated by the participant (Baseline; Relaxed; WeakASMR; StrongASMR). The first epoch of each state was excluded to avoid interference activity related to the button press. Next, an artefact rejection threshold of $\pm 80\mu$ V was applied, and any epoch exceeding this threshold were rejected (mean 17% epochs removed, SEM 2.45, where the mean total remaining epochs were 437, SEM 13.56). Finally, epochs containing visible artefacts such as muscle activity and eye-movements/saccades were rejected using visual inspection.

ECG data, calculated as the difference between the two ECG electrodes, were used to extract metrics of heart-rate (HR) and heart rate variability (HRV). Prior work has shown that ASMR reduces HR (Poerio et al., 2018). In addition, increases in resting HRV (vagally-mediated) have been linked to emotional processing by the prefrontal cortex (Mccraty & Shaffer, 2015). Since ASMR-responders report a calming effect from ASMR-inducing stimuli, I predict that HRV scores would be higher during and after experiencing ASMR. Epochs below a threshold of ten seconds were excluded. Inter beat intervals and HRV were calculated using the HRVTool MATLAB toolbox and its rrHRV method (Vollmer, 2015, 2019). Specifically, the HRV metrics extracted from the ECG signal were the root mean square of successive RR interval differences (RMSSD), high-frequency HRV (HF-HRV; Fast-Fourier-Transformation, bandwidth 0.15 to 0.4 Hz), and low-frequency HRV (LF-HRV; Fast-Fourier-Transformation, bandwidth 0.04 to 0.15 Hz, Malik et al., 1996).

5.2.5 Spectral analysis

The characteristic power spectral density was taken for each event state (Baseline, Relaxed, WeakASMR, StrongASMR) (in mV^2/Hz) from the EEG data using multitaper discrete prolate spheroidal sequences (DPSS). First, power was calculated from 1 to 80 Hz in steps of 1 Hz with spectral smoothing of 2 Hz—achieving high-frequency resolution (Oostenveld et al., 2011). Then, the mean power was calculated in each state for each participant by averaging of the segments of a given state, and then normalised by the total power across 1-80 Hz.

5.2.6 ASMR decay effect

Since an ASMR decay effect of unknown duration was hypothesised, the 'Baseline' and 'Relaxed' self-report states were subdivided by their relation in time to the ASMR states (WeakASMR, StrongASMR). Once either WeakASMR or StrongASMR was reported, any subsequent states of Baseline or Relaxed were labelled as PostASMR by adding the prefix 'Post' to the event labels, respectively (PostBaseline, PostRelaxed). Similarly, Baseline or Relaxed states reported before ASMR being achieved by the participant were labelled as PreASMR by adding the prefix 'Pre' (PreBaseline, PreRelaxed). These state-specific data epochs were collated if a participant left and re-entered a state multiple times throughout the video.

5.2.7 EEG source reconstruction

Collecting individual brain images of the participants was not feasible, and thus I relied on an average template on MNI space. A single template-based forward model was constructed based on the default average MNI brain coordinates. The head model consisted of a three-layer boundary element (BEM) model, generated using the whole-head tissue probability map provided with the NY Head (Huang et al., 2016). The three layers were defined as the inner skull (interface between the brain cavity and the skull), the outer skull (interface between the skull and the soft tissue of the scalp), and the scalp (outer layer of the skin). I used a homogeneous regular grid of dipoles defined in MNI space and with a separation of 10 mm, as source model. The final source model consisted of 2459 sources located inside the brain cavity (inner skull surface), and each dipole was labelled according to the Automated Anatomical Labeling (AAL) atlas (Tzourio-Mazoyer et al., 2002). The electrode positions were extracted from the standard definition for the 10-05 system provided by Robert Oostenveld in FieldTrip (Oostenveld et al., 2011). Finally, the forward model was built using a symmetric BEM approach as implemented in OpenMEEG (Gramfort et al., 2010). As the inverse method, I used a spatial filter based on dynamic imaging of coherent sources (DICS) beamformer (J. Gross et al., 2001). The spatial filters were calculated separately for each band using the frequency ranges obtained from sensor-space cluster-based permutation tests, using the average cross-spectral density matrix for all the frequency steps in the band, and using a regularisation factor of 5% of the average sensor power. Subsequently, each spatial filter was used to reconstruct each frequency step in the band for each source position. The input to the spatial filter is the Fourier transform of the time series of each channel for the frequencies in the band of interest, and the output is the Fourier transform of the time series of each source position. Subsequently, I obtained the per-frequency power by the averaged (for epochs) periodogram and normalized it by the broadband power (1 to 80 Hz). Finally, I calculated the relative power in the band of interest for each source position by adding all the frequency steps belonging to this band.

5.2.8 Statistical analysis

Due to the unreliable nature of ASMR induction and thus the variable number of epochs for each participant in each state, WeakASMR and StrongASMR were combined into one state (henceforth termed ASMR, unless otherwise specified).

Temporal scrambling (control videos)

Paired t-tests were used to compare the effect of temporal scrambling on ASMR stimuli for use as an effective control (whilst still keeping low-level features equivalent). Specifically, the duration of each state was contrasted between ASMR and control videos.

Sensor-level

FieldTrip power data structures were used for statistical analysis at the sensor level, using two-tailed cluster-based permutation tests (CBPTs) with a threshold correction tp control for the multiple comparisons problem at level 0.05 (5000 iterations; Maris and Oostenveld, 2007; Oostenveld et al., 2011). Each contrast was performed across all 64 electrodes at each of the following frequency bands: delta (1–4 Hz), theta (4–8 Hz), alpha (8–13 Hz), beta (13–30 Hz), gamma (30–80 Hz). For each statistical contrast plot (Figures 5.3, 5.4, 5.6 and 5.7), the above-normalised power of each frequency band was calculated as a percentage change from the contrast condition. Cohen's d effect sizes were subsequently calculated using the mean of all electrodes in the significant cluster using the FieldTrip toolbox.

The statistical contrasts used for both sensor and source space were divided into two categories. Firstly, the identification of the hypothesised steps for ASMR induction: i) Stage 1 was calculated from PreRelaxed vs PreBaseline, ii) Stage 2 was calculated from ASMR vs PreRelaxed, and iii) a summary contrast of ASMR vs PreBaseline was calculated in the event of a non-linear ASMR induction process. StrongASMR was also contrasted against WeakASMR to test the spectral differences between these distinct ASMR intensities.

The second category was the identification of potential decay effects of ASMR.These decay effects were defined as persisting oscillatory changes in the absence of self-reported ASMR (PreRelaxed vs PostRelaxed). For example, the video stimuli and self-report states between PreRelaxed and PostRelaxed are equivalent (and likewise with PreBaseline vs PostBaseline). Therefore, I define any difference between these two states as attributable to a decay effect of ASMR.

Approximate time windows for the decay effect of ASMR were estimated by comparing the Relaxed and Baseline contrasts. PostRelaxed vs PreRelaxed was estimated to be an immediate decay effect. PostBaseline vs PreBaseline was estimated to be on the scale of seconds to minutes. Finally, the eyes-open resting states recorded at the start and the end of the experiment were used to estimate a time window between 5 and 30 minutes. Assuming a participant experienced ASMR at the end of the second (unreported) EEG study, I estimate that five minutes would be the minimum possible duration. Similarly, assuming a participant only experienced ASMR within the first five minutes, an estimated maximum of 45 minutes is possible.

Source-level

Results from the sensor-space analysis were then used to inform the comparisons in the source-space. Specifically, the frequency sub-bands and the direction of the differences (tail) were applied in this exploratory source analysis. Finally, I implemented the false discovery rate (FDR) using an adaptive linear step-up procedure with a threshold set to a level of q = 0.05 (Benjamini et al., 2006, code freely available at https://uk.mathworks.com/matlabcentral/fileexchange/27423-two-stage-benjamini-krieger-yekutieli-fdr-procedure). This control provided an adapted threshold p-value (termed P_{FDR}).

Statistical tests were performed using one-tailed permutation tests with a cluster-based threshold correction to control for the multiple comparisons problem at level 0.05 (10,000 iterations; Maris and Oostenveld, 2007; Oostenveld et al., 2011). Effect sizes were subsequently calculated from the mean of all voxels in the significant cluster. Cortical regions are labelled following the

AAL atlas and are stated in the results given below if more than 50% of the region was significant. To further refine and improve the clarity of effects in each contrast, where possible, the cluster alpha level was reduced from 0.05 by increments of 0.01, then 0.001 and so on until the number of significant regions was lower than 10. These normalised powers were then calculated as a percentage change from the contrast condition in Figures 5.4 and 5.7.

When an effect was to be expected (for example, a specific band of interest found in related literature) but did not appear in sensor space, I also evaluated it using a two-tailed approach (as I did not know the direction of the effect), and the results were subsequently corrected for multiple comparisons. These results are labelled in the figure as “not matching sensor-space hypothesis” and marked with the sign $\diamondsuit$.

Heart-rate Variability

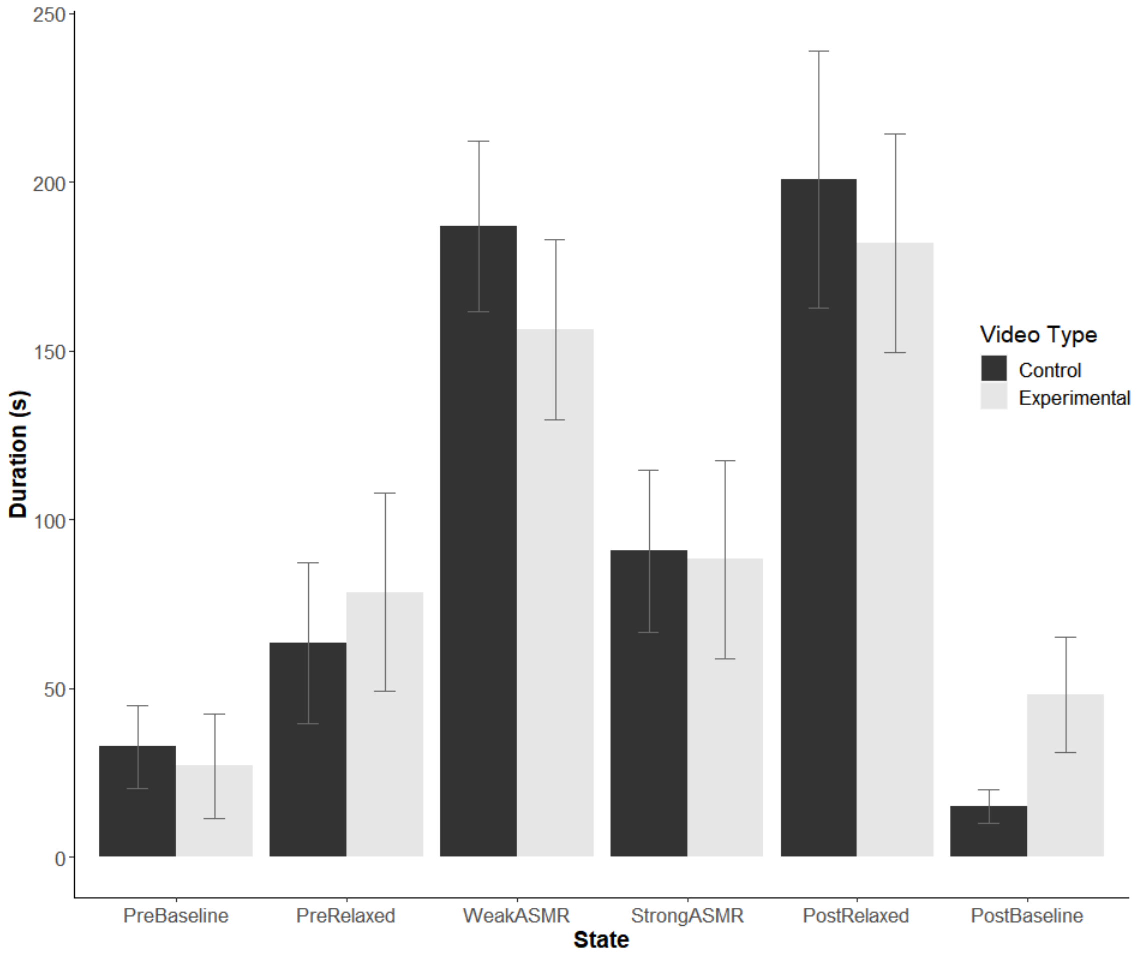
For HR, I performed a one-tailed t-test of ASMR compared to PreRelaxed and PreBaseline, where a reduction in HR in the ASMR group was expected (Poerio et al., 2018). Mean HRV values in each state were contrasted using paired t-tests. RMSSD scores were tested by contrasting ASMR vs PreRelaxed, ASMR vs PreBaseline and PreRelaxed vs PreBaseline. In addition, following the same format for the decay contrasts, the Relaxed, Baseline and resting-state contrasts were also performed (Post vs PreASMR). All HRV tests were FDR-controlled using the adaptive linear step-up procedure (q = 0.05; Benjamini et al., 2006).

5.3 Results

5.3.1 The effect of temporal scrambling on ASMR

Paired t-tests compared all six states between experimental and control videos, where temporal scrambling was the applied intervention. The PostBaseline contrast was the only contrast that

Figure 5.2: *Experimentally-induced changes to the duration of self-reported states throughout watching each ASMR video*



Experimentally-induced changes to the duration of self-reported states throughout watching each ASMR video. Experimental videos were personalised ten minute ASMR videos. Control videos contained the same content, except that the content was temporally shuffled every 5 seconds within the ten minutes. Error bars represent SEM. *$p < 0.05$.

showed a significant difference due to scrambling ($t(24) = -2.10$, $p = 0.046$, $d = -0.42$, Figure 5.2). The PreBaseline ($t(24) = 0.41$, $p = 0.69$), PreRelaxed ($t(24) = -0.56$, $p = 0.58$), WeakASMR ($t(24) = 1.16$, $p = 0.26$), StrongASMR ($t(24) = 0.18$, $p = 0.86$) and PostRelaxed ($t(24) = 0.50$, $p = 0.62$) contrasts revealed no significant differences. Since there were no significant differences shown for ASMR induction, state-specific epochs of both video types were collapsed together for the TF analysis below. Whilst there was a significant difference for the PostBaseline contrast, the effect size was small, and thus the decision was made to incorporate to boost the sample size.

5.3.2 Heart-rate Variability

When assessing the ASMR-induced changes to HR and HRV, three trends were revealed pre-correction. There was a trending decrease of HF power in the ASMR state compared to PreBaseline state ($t(14) = -2.05$, $p = 0.059$, $d = 0.53$). Secondly, there was a trending increase of LF power in the ASMR state compared to PreRelaxed state ($t(19) = 1.9$, $p = 0.072$, $d = 0.42$). Finally, there was a trending decrease of HR in the PreRelaxed state compared to the PreBaseline state ($t(15) = -1.43$, $p = 0.087$, $d = 0.36$).

Furthermore, the possibility of a delayed effect of HR and HRV changes was investigated. One effect was found, however it did not survive correction. Three trends were also revealed. A pre-correction significant increase in LF was found in the PostRelaxed state compared to the PreRelaxed state ($t(19) = 3.51$, $p = 0.0022$, $d = 0.79$). The first trend was a decrease in HR in the PostASMR state compared to the PreASMR state ($t(25) = -1.55$, $p = 0.067$, $d = 0.304$). Secondly, there was a trending decrease in HF power in the PostRelaxed state compared to the PreRelaxed state ($t(19) = -1.81$, $p = 0.086$, $d = 0.40$). Finally, there was a trending decrease in RMSSD in the PostASMR state compared to the PreASMR state ($t(25) = 1.51$, $p = 0.071$, $d = 0.297$).

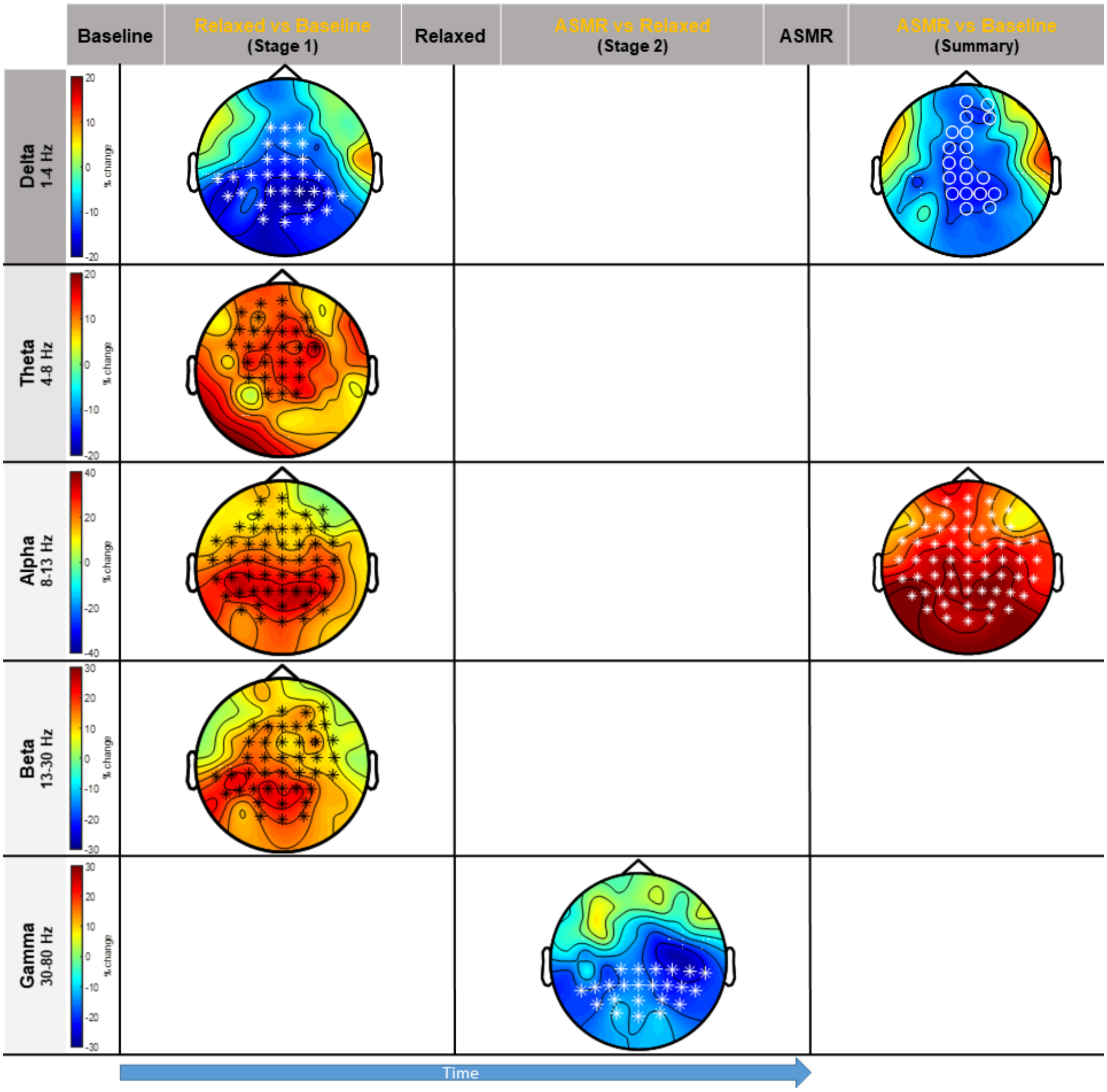
5.3.3 TF Responses

Oscillatory correlates of ASMR (sensor)

ASMR significantly modulated participants' oscillatory activity compared with a PreRelaxed and PreBaseline state (see Figure 5.3). When comparing the ASMR state relative to the PreRelaxed state (n = 23), I discovered a significant decrease in high gamma, primarily across posterior electrodes (50-72 Hz, one negative cluster, p = 0.0124, d = 0.55). Moreover, when comparing the difference between ASMR and PreBaseline states (n = 17), statistical testing revealed significantly lower delta power at central and frontocentral sites (1-2 Hz, one negative cluster, p = 0.0176, d = 0.63). In addition, a significant increase in alpha power was discovered in ASMR, increasing most strongly at posterior electrodes (9-13 Hz, one positive cluster, p = 0.0006, d = 0.73). Lastly, more beta power was present in ASMR relative to PreBaseline (13-14 Hz, trend-level positive cluster, p = 0.0284, d = 0.69).

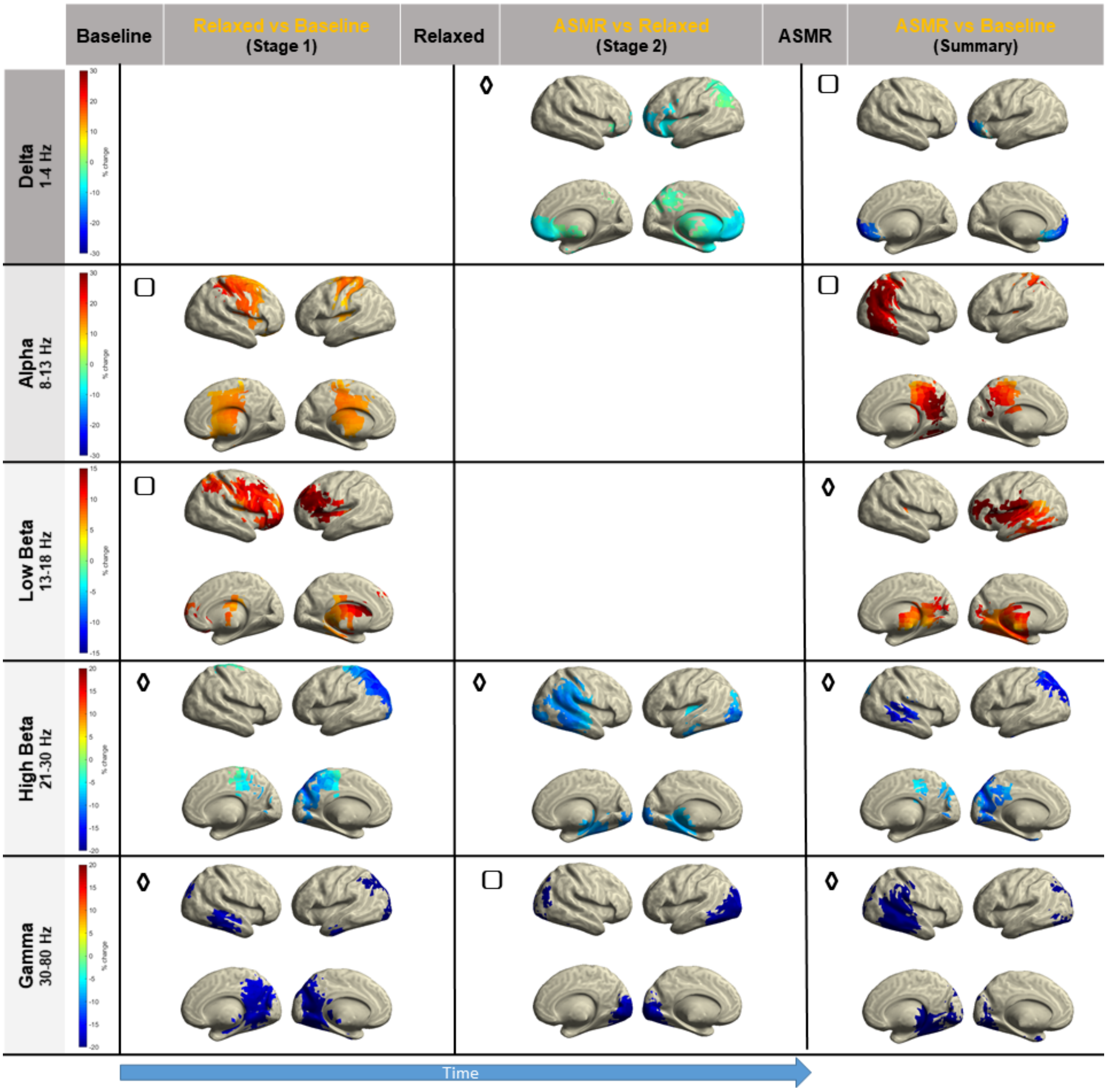
Significant differences in the spectral profile of the PreRelaxed state were discovered when compared with the PreBaseline state (n = 19, see Figure 5.3). PreRelaxed delta power decreased at central and bilateral parietal electrodes (1-2 Hz, one negative cluster, p = 0.0036, d = 0.65, Figure 5.3). Also, an increase in theta power was found in the PreRelaxed state, with theta power increasing across central and frontocentral electrodes (4-6 Hz, one positive cluster, p = 0.0066, d = 0.60, Figure 5.3). A higher change in alpha power was also discovered in the PreRelaxed relative to the PreBaseline comparison, in one positive cluster over central parietal regions and frontal central regions (10-13 Hz, p = 0.0016, d = 0.62). Lastly, an increase in beta power was shown in PreRelaxed across central and right central electrodes and central posterior and left parietal electrodes (13-18 Hz, one positive cluster, p = 0.0108, d = 0.63, see Figure 5.3).

Figure 5.3: *Sensor-space ASMR stage contrast*



Cluster-based random permutation tests were performed in the sensor-space comparing PreRelaxed vs PreBaseline; ASMR vs PreRelaxed; and ASMR vs PreBaseline (showed in columns) under the classical frequency bands (rows). Topographical plots are shown representing the proportional change from PreBaseline, PreRelaxed and PreBaseline, respectively. For Stage 1, PreRelaxed showed a significant decrease in delta at central and parietal sites ($p = 0.0036$); a significant increase in theta at central and frontocentral sites ($p = 0.0066$); an increase in alpha globally ($p = 0.0016$); and increase in beta power centrally ($p = 0.0108$). For Stage 2, ASMR showed a significant decrease in gamma power at posterior sites ($p = 0.0124$). For the summary contrast, ASMR decreased delta power centrally ($p = 0.0176$) and increased alpha globally ($p = 0.0006$). The progression in time has been represented by a change from PreBaseline to PreRelaxed to ASMR. The ASMR vs Baseline column represents the summary change. $^{o}p < 0.05$, $^{*}p < 0.01$. Colour of the topographical symbols have been modified where appropriate (from black to white) to improve contrast.

Figure 5.4: *Source-space ASMR stage contrast*



Cluster-based random permutation tests were performed in the source-space comparing PreRelaxed vs PreBaseline; ASMR vs PreRelaxed; and ASMR vs PreBaseline under sub-bands of the classical frequency bands based on the sensor-space analysis (see Figure 5.3). Surface plots are shown representing the proportional change from PreBaseline, PreRelaxed and PreBaseline respectively. The progression in time has been represented by a change from PreBaseline to PreRelaxed to ASMR. The ASMR vs Baseline column represents the summary change. For Stage 1, PreRelaxed showed a significant increase in alpha in parietal, frontal and temporal regions ($P_{FDR} < 0.05$), increase in low beta in frontal and temporal regions ($P_{FDR} < 0.05$), decrease in high beta in occipital and parietal regions ($P_{FDR} < 0.05$), and a decrease in gamma in occipital regions ($P_{FDR} < 0.05$). For Stage 2, ASMR showed a significant decrease in the delta in frontal regions ($P_{FDR} < 0.05$), a decrease in high beta in temporal regions ($P_{FDR} < 0.05$) and a decrease in gamma in occipital regions ($P_{FDR} < 0.05$). For the summary contrast, ASMR showed a significant decrease in the delta in frontal regions ($P_{FDR} < 0.05$), increase in alpha in parietal regions ($P_{FDR} < 0.05$), increase in low beta in occipital and temporal regions ($P_{FDR} < 0.05$), decrease in high beta in occipital and parietal regions ($P_{FDR} < 0.05$), and a decrease in gamma in temporal regions ($P_{FDR} < 0.05$). ☐ indicates a matching sensor-space hypothesis; ◇ indicates no matching sensor-space hypothesis.

Table 5.1: *Identified regions of interest included in the AAL-atlas*

Regions	Abbreviations	Regions	Abbreviations
Rolandic operculum	ROL	Inferior temporal gyrus	ITG
Cuneus	CUN	Middle frontal gyrus, orbital part	ORBmid
Lingual gyrus	LING	Inferior frontal gyrus, orbital part	ORBinf
Superior occipital gyrus	SOG	Inferior frontal gyrus, triangular part	ORBtriang
Middle occipital lobe	MOL	Inferior frontal gyrus, opercular	ORBoperc
Inferior occipital lobe	IOL	Superior frontal gyrus (medial orbital)	ORBsupmed
Fusiform gyrus	FFG	Superior frontal gyrus (orbital)	ORBsup
Superior parietal gyrus	SPG	Gyrus rectus	REC
Inferior parietal lobule	IPL	Anterior cingulate and paracingulate gyri	ACG
Supramarginal gyrus	SMG	Posterior cingulate gyrus	PCG
Angular gyrus	ANG	Precentral gyrus	PreCG
Precuneus	PCUN	Calcarine fissure and surrounding cortex	CALC
Paracentral lobule	PCL	Postcentral gyrus	PoCG
Superior temporal gyrus	STG	Heschl gyrus	HES
Middle temporal gyrus	MTG	Insula	INS

Oscillatory correlates of ASMR (source)

Sensor space tests revealed two prominent beta ranges used below: low beta (13-18 Hz) and high beta (21-30 Hz).

I discovered five source space effects that survived corrections when comparing the ASMR state to the PreBaseline state ($n = 17$). Firstly, a decrease in delta most prominent in frontal regions was revealed (1-2 Hz, one significant negative cluster, cluster alpha = 0.003, $P_{FDR} < 0.05$, $d = 0.78$). The associated regions were bilateral gyri recti (REC), left inferior frontal gyrus (orbital, ORBinf), left middle frontal gyrus (orbital, ORBmid), bilateral superior frontal gyri (medial orbital, ORBsupmed), and bilateral superior frontal gyri (orbital, ORBsup). Secondly, an increase in alpha most prominent in the cingulate and parietal gyri was revealed (9-13 Hz, one significant positive cluster, cluster alpha = 0.0005, $P_{FDR} < 0.05$, $d = 1.00$). More specifically, the following regions were shown to be significantly implicated (>50% regional association with the cluster): bilateral posterior cingulate gyri (PCG), right angular gyrus (ANG), right inferior parietal gyrus (IPG), and right precuneus (PCUN, see Figure 5.4). One other significant effect in the ASMR state was an increase in low beta, most prominently in occipital and temporal regions (13-18 Hz, one significant positive cluster, cluster alpha = 0.0004, $P_{FDR} < 0.05$, $d = 1.06$). The associated regions were left fusiform gyrus (FFG), left Heschl's gyrus (HES), left inferior temporal gyrus (ITG), left lingual gyrus (LING), left middle temporal gyrus (MTG), left rolandic operculum (ROL) and left superior temporal gyrus (STG, see Figure 5.4). A fourth effect was a decrease in high beta in ASMR, most prominent in occipital and parietal regions (21-30 Hz, one significant negative cluster, cluster alpha = 0.0001, $P_{FDR} < 0.05$, $d = 1.20$). The associated regions were left calcarine fissure and surrounding cortex (CALC), PCG-L, left cuneus (CUN), left superior occipital gyrus (SOG) and left superior parietal gyrus (SPG). The final result from the ASMR to PreBaseline state comparison was a decrease in higher gamma, most prominent in temporal regions (50-72 Hz, one significant negative cluster, cluster alpha = 0.00001, $P_{FDR} < 0.05$, $d = 1.06$). The associated regions were FFG-R, ITG-R, MTG-R, STG-R and the supramarginal gyrus (SMG).

Three significant differences in the ASMR state's spectral profile were discovered compared with the PreRelaxed state ($n = 23$, see Figure 5.4). Firstly, a decrease in delta power most prominent in frontal regions was seen (1-2 Hz, one significant negative cluster, cluster alpha = 0.02, $P_{FDR} < 0.05$, $d = 0.51$). The regions associated were ANG-L, bilateral anterior cingulate gyri (ACG), REC-LR, ORBinf-L, ORBmid-R, ORBsupmed-LR, ORBsup-LR, SPG-L and left temporal pole (middle temporal gyrus, MTG). Secondly, a decrease in high beta most prominent in temporal regions (21-30 Hz, one significant negative cluster, cluster alpha = 0.002, $P_{FDR} < 0.05$, $d = 0.72$). Specifically, the regions associated were MTG-R, STG-R and SMG-R. Finally, a decrease in gamma most prominent in occipital regions was revealed (50-72 Hz, one significant negative cluster, cluster alpha = 0.00005, $P_{FDR} < 0.05$, $d = 1.21$). The regions associated were CALC-L, bilateral inferior occipital lobe (IOL), left middle occipital lobe (MOL) and the LING-LR.

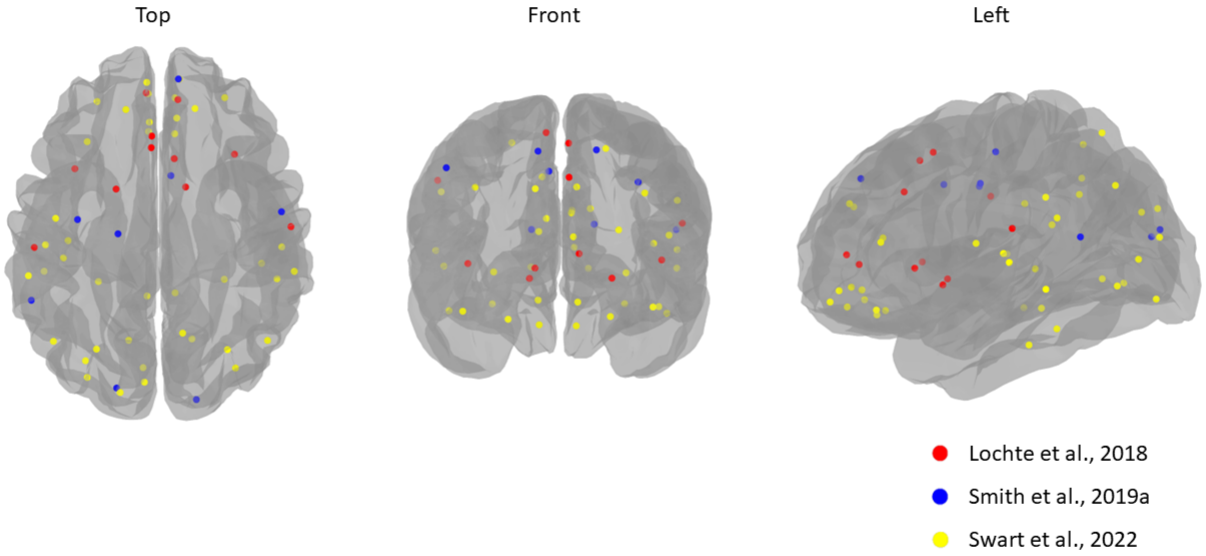
I discovered four effects that survived corrections when comparing the PreRelaxed state to the PreBaseline state (n = 19). An increase in alpha most prominent in parietal, frontal and temporal regions (10-13 Hz, one significant positive cluster, cluster alpha = 0.005, $P_{FDR} < 0.05$, d = 0.68). The regions associated were bilateral middle cingulate gyri (MCG), left paracentral lobule (PCL), bilateral postcentral gyri (PoCG), bilateral rolandic operculum (ROL), ORBmid-R, and right precentral gyrus (PreCG, see Figure 5.4). Secondly, a significant increase in low beta most prominent in frontal and temporal regions was revealed (13-18 Hz, one significant positive cluster, cluster alpha = 0.005, $P_{FDR} < 0.05$, d = 0.71). The associated regions were HES-L, bilateral inferior frontal gyri (opercular, ORBoperc), bilateral inferior frontal gyri (triangular, ORBtriang), left insula (INS), IPG-R, ORBmid-R, ROL-R, and ORBsup-R. Thirdly, a significant decrease in high beta, most prominent in occipital and parietal regions, was revealed (21-30 Hz, one significant negative cluster, cluster alpha = 0.002, $P_{FDR} < 0.05$, d = 0.82). The regions associated were ANG-L, CUN-L, IPG-L, MOL-L, PCUN-L, SOG-L, SPG-L, and PCL-R. Finally, a significant decrease in gamma was revealed most prominently in occipital regions (50-72 Hz, one significant negative cluster, cluster alpha = 0.00005, $P_{FDR} < 0.05$, d = 0.98). Specifically, the association regions were CUN-LR, LING-LR, SOG-L, and CALC-R (see Figure 5.4).

Decay effects of ASMR (sensor)

A significantly lower high gamma power was discovered when testing the decay effects of ASMR using the PostRelaxed and PreRelaxed states (n = 21). This cluster was most prominent across posterior electrodes (52-80 Hz, one significant negative cluster, p = 0.0092, d = 0.56, see Figure 5.6).

When testing the difference between PostBaseline and PreBaseline states (n = 10) I found significantly higher power in PostBaseline alpha, globally (10-13 Hz, one significant positive cluster, p = 0.0008, d = 0.80, see Figure 5.6). Also, I observed a significant decrease in gamma power at posterior electrodes (59-76 Hz, one significant negative cluster, p = 0.0156, d = 0.85) and higher

Figure 5.5: *3D Brain Plot of fMRI ASMR-associated regions with source-localised EEG regions*



Brain areas activated during ASMR. fMRI & source-localised EEG brain regions reported as significantly different during state ASMR have been combined in this plot from Figure 5.4 & two studies (Lochte et al., 2018; S. D. Smith et al., 2019a). Specifically, the regions depicted are the bilateral medial prefrontal cortex, bilateral nucleus accumbens, bilateral supplementary motor area, bilateral insula/inferior frontal gyrus, dorsal anterior cingulate cortex, left secondary somatosensory cortex, ventral premotor cortex (Lochte et al., 2018); left medial frontal gyrus, bilateral precentral gyrus, right superior frontal gyrus, left superior temporal gyrus, bilateral cuneus and right cingulate gyrus (S. D. Smith et al., 2019a). Regions implicated in yellow can be found in Table 5.1. Plots have been generated using nilearn.

beta power at frontal and central electrodes (13-14 Hz, one trend-level positive cluster, $p = 0.0274$, $d = 0.86$).

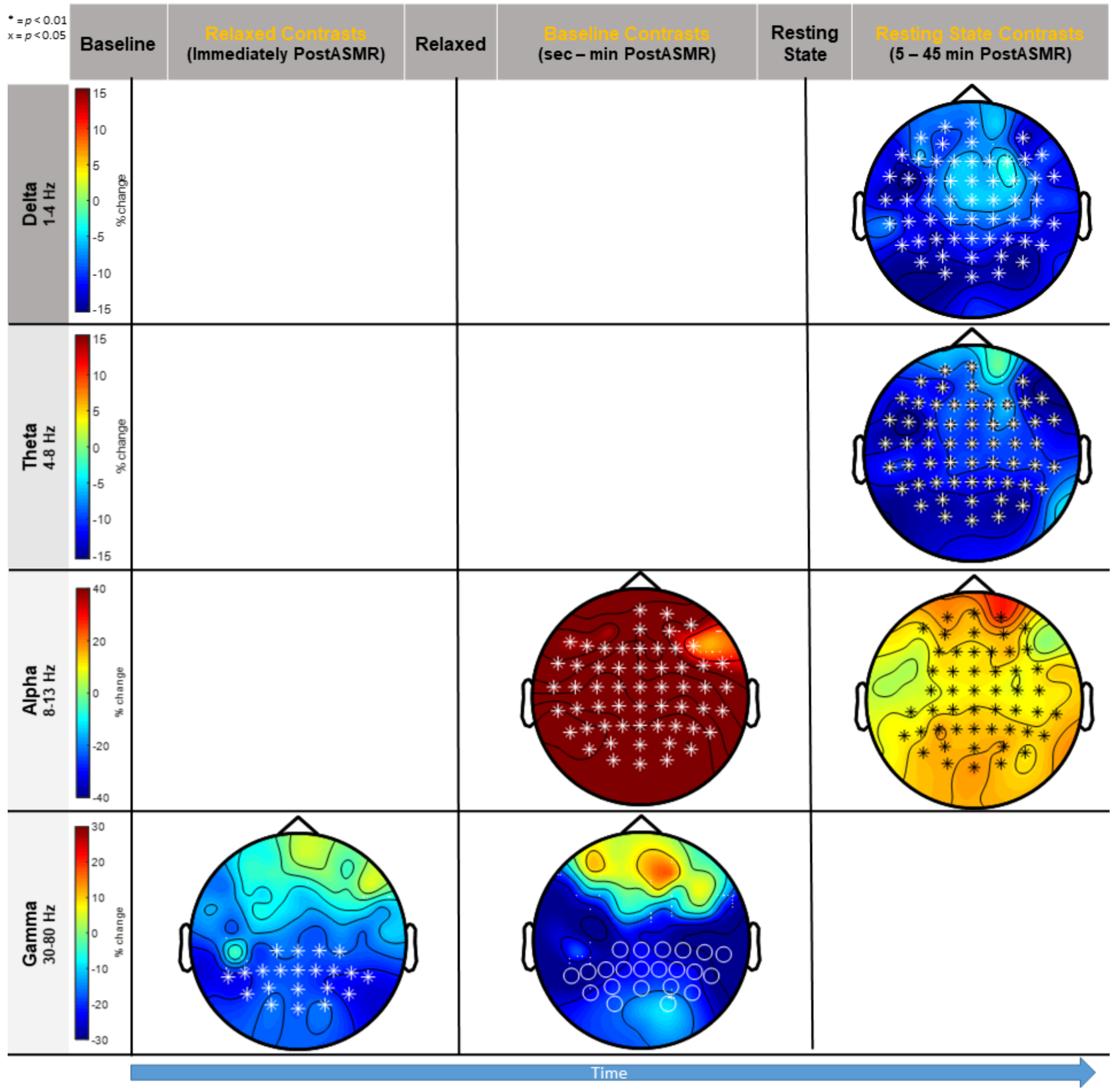
PostASMR eyes-open resting state was also found to exhibit significantly lower delta and theta power, in all electrodes, when compared to PreASMR eyes-open resting states ($n = 25$; 1-4 Hz, one significant negative cluster, $p = 0.0004$, $d = 0.75$; 4-5 Hz, one significant negative cluster, $p = 0.0006$, $d = 0.71$, see Figure 5.6). Finally, PostASMR eyes-open resting state was revealed to be characterised by higher alpha power (10-13 Hz, one significant positive alpha cluster, $p = 0.0008$, $d = 0.61$).

Decay effects of ASMR (source)

When comparing PostRelaxed with PreRelaxed ($n = 21$), two effects survived corrections. The first effect revealed was a decrease in high beta, most prominent at occipital and temporal regions (21-30 Hz, one significant negative cluster, cluster alpha = 0.001, $P_{FDR} < 0.05$, $d = 0.80$). Specifically, the association regions were FFG-R, IOL-R, ITG-R, LING-R, and MOL-R. The second effect was a significant decrease in gamma primarily in occipital regions (52-80 Hz, one significant negative cluster, cluster alpha = 0.00007, $P_{FDR} < 0.05$, $d = 0.80$). The associated regions were CALC-L, IOL-L, LING-LR, and MOL-L (see Figure 5.7).

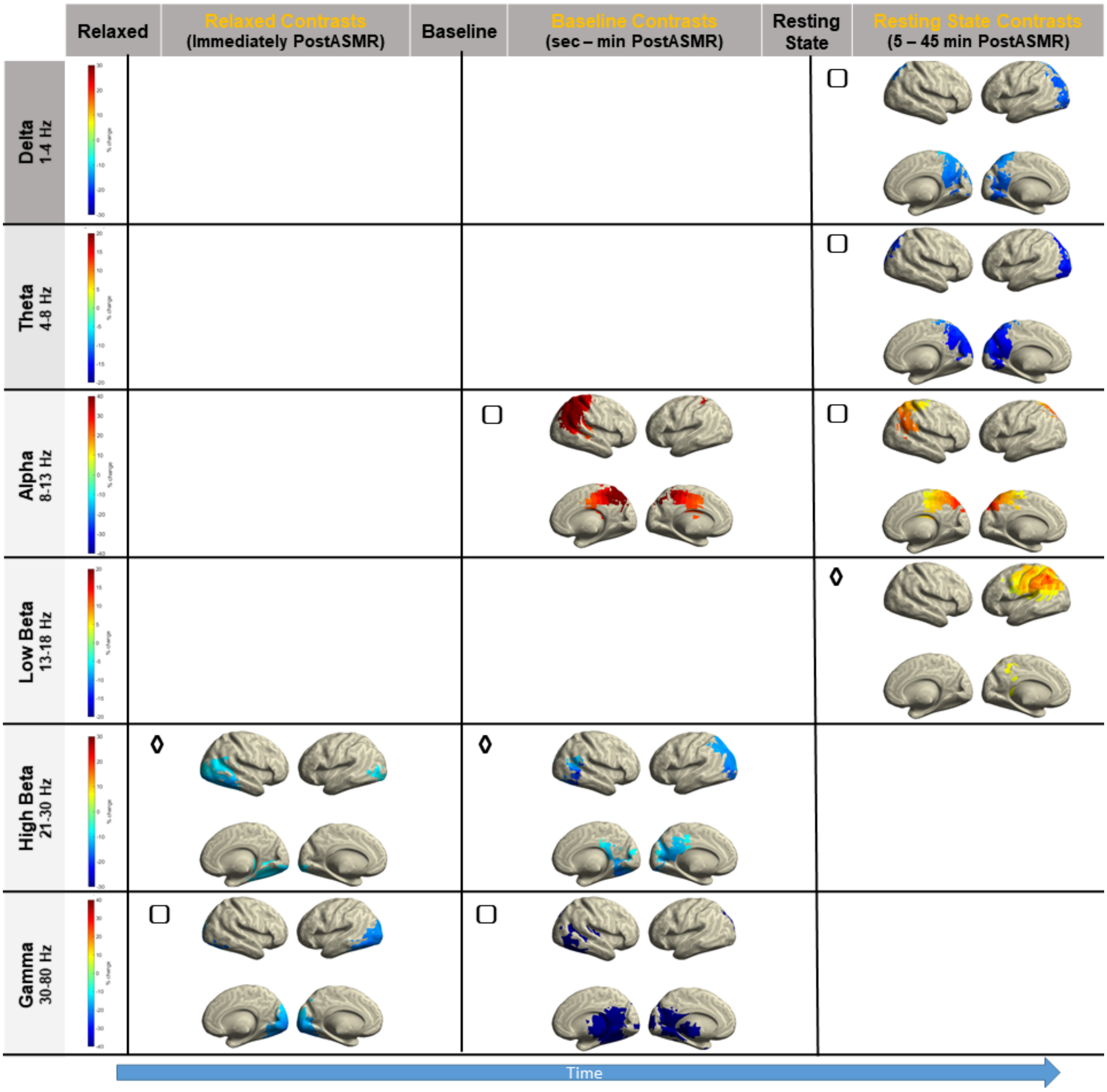
Testing the difference between PostBaseline and PreBaseline ($n = 10$), three effects were revealed. The first effect was a significant increase in alpha most prominent at parietal regions (10-13 Hz, one significant positive cluster, cluster alpha = 0.001, $P_{FDR} < 0.05$, $d = 1.27$). The associated regions were MCG-L, ANG-R, IPG-R, PCUN-R, and SPG-R (see Figure 5.7). Secondly, a significant decrease in high beta was revealed most prominently at occipital and parietal regions (21-30 Hz, one significant negative cluster, cluster alpha = 0.0003, $P_{FDR} < 0.05$, $d = 1.69$). The associated regions were ANG-L, CALC-L, PCG-LR, CUN-L, MOL-L, and SOG-L. Finally, a significant decrease in gamma was revealed most prominently at occipital and temporal regions (59-76 Hz,

Figure 5.6: *Source-space ASMR decay contrast*



Cluster-based random permutation tests were performed in the sensor-space comparing PostRelaxed vs PreRelaxed (representing Relaxed state data that immediately follow the end of a period of ASMR tingles); PostBaseline vs PreBaseline (representing Baseline data that typically occurred on a timescale between seconds and minutes after a period of ASMR tingles); and PostASMR Resting-state vs PreASMR resting state under the classical frequency bands. Topographical plots are shown representing the proportional change from PreRelaxed, PreBaseline and PreASMR resting-state, respectively. For the Relaxed contrasts, PostRelaxed showed a significant negative decrease in gamma power posteriorly ($p = 0.0092$). For the Baseline contrasts, PostBaseline showed a significant increase in alpha power globally ($p = 0.0008$); and a decrease in gamma power posteriorly ($p = 0.0156$). For the resting state contrasts, the PostASMR resting-state showed a significant decrease in delta power globally ($p = 0.0004$), a decrease in theta power globally ($p = 0.0006$), and an increase in alpha power globally (p = 0.0008). The progression in time has been represented by a change from PostRelaxed to PostBaseline to PostASMR resting state. The scale of the timeframe or the theoretical ranges is shown under the title of each column. $^{\circ}p < 0.05$, $^{*}p < 0.01$. Colour of the topographical symbols have been modified where appropriate (from black to white) to improve contrast.

Figure 5.7: *Source-space ASMR decay contrast*



Cluster-based random permutation tests were performed in the source-space comparing PostRelaxed vs PreRelaxed; PostBaseline vs PreBaseline; and PostASMR Resting-state vs PreASMR resting state under sub-bands of the classical frequency bands based on the sensor-space analysis (see Figure 5.6). Surface plots are shown representing the proportional change from PreRelaxed, PreBaseline and PreASMR resting-state, respectively. The progression in time has been represented by a change from PostRelaxed to PostBaseline to PostASMR resting state. The scale of the timeframe or the theoretical ranges is shown under the title of each column. For the Relaxed contrasts, PostRelaxed showed a significant decrease in high beta in occipital and temporal regions ($P_{FDR} < 0.05$) and a decrease in gamma in occipital regions ($P_{FDR} < 0.05$). For the Baseline contrasts, PostBaseline showed a significant increase in alpha power in parietal regions ($P_{FDR} < 0.05$), a decrease in high beta in occipital and parietal regions ($P_{FDR} < 0.05$), and a decrease in gamma in occipital and temporal regions ($P_{FDR} < 0.05$). For the resting state contrasts, PostASMR eyes-open showed a significant decrease in the delta in occipital and parietal regions ($P_{FDR} < 0.05$), decrease in theta power in occipital regions ($P_{FDR} < 0.05$), increase in alpha in parietal regions ($P_{FDR} < 0.05$), and an increase in low beta in frontoparietal regions ($P_{FDR} < 0.05$). □ indicates a matching sensor-space hypothesis; ◇ indicates no matching sensor-space hypothesis.

one significant negative cluster, cluster alpha = 0.00003, $P_{FDR} < 0.05$, $d = 2.16$). The associated regions were PCG-LR, LING-L, FFG-R (see Figure 5.7).

PostASMR eyes-open resting state was also compared with PreASMR eyes-open resting state ($n = 25$), where four significant differences were revealed. Firstly, delta power was significantly lower in PostASMR, most prominently in occipital and parietal regions (1-4 Hz, one significant negative cluster, cluster alpha = 0.00002, $P_{FDR} < 0.05$, $d = 0.82$, see Figure 5.7). Specifically, the regions associated were ANG-L, MOL-L, and PCUN-LR. Secondly, a significant decrease in theta power was revealed, most prominently in occipital regions (4-5 Hz, one significant negative cluster, cluster alpha = 0.0001, $P_{FDR} < 0.05$, $d = 0.81$). The regions associated were CALC-L, PCG-L, CUN-LR, MOL-L, PCUN-L, and SOG-LR. The third effect revealed was a significant increase in alpha most prominently over parietal regions (8-12 Hz, one significant positive cluster, cluster alpha = 0.001, $P_{FDR} < 0.05$, $d = 0.69$, see Figure 5.7). The regions associated were PCUN-L, SPG-LR, ANG-R, IPG-R, and PCL-R. Finally, a significant increase in low beta power most prominently over frontoparietal regions was revealed (13-18 Hz, one significant positive cluster, cluster alpha = 0.005, $P_{FDR} < 0.05$, $d = 0.69$). The associated regions were ANG-L, IPG-L, PoCG-L, SPG-L, and SMG-L.

5.4 Discussion

This study aimed to reveal the neural correlates of ASMR experiences by investigating large-scale brain oscillations. I further source localised the ASMR-induced oscillatory changes and their potential decay effects. First, I demonstrated that ASMR, compared to baseline, was associated with a robust change in five frequency bands over a multitude of brain regions. Specifically, I found decreases in delta power in prefrontal regions; increases in alpha power in parietal, frontal, and temporal regions; increases in low beta power in parietal and temporal regions, decreases in high beta power in parietal and occipital regions, and decreases in gamma power in occipital regions. Second, I observed a decay effect of ASMR in the absence of self-reported ASMR tingling sensations. Third, the temporal profile of the modulations by ASMR in high-frequency power later shifts to lower frequencies (1-8 Hz), except for enhanced alpha which persists for up to 45 minutes post self-reported ASMR. Finally, I showed that the temporal continuity of the ASMR-inducing video is not vital for ASMR induction.

Our findings support evidence provided by one prior study in which ASMR enhances alpha power during the experience (Fredborg et al., 2021). This positive effect was seen globally at the sensor level, with greater enhancement in occipital-parietal areas. According to the alpha inhibition-timing hypothesis, large alpha represents inhibitory processes that can be either attributed to relaxed mental inactivity (unspecific inhibition) or during active cognitive processes that require (process-specific) inhibition of distracting stimuli/less relevant brain regions (Klimesch et al., 2007). Moreover, it is hypothesised that when reference/baseline alpha power is small, the brain is primed for good perceptual performance. Thus, it is plausible that the alpha enhancement seen in the PreRelaxed vs PreBaseline and ASMR vs PreBaseline source contrasts represents a low reference alpha in the PreBaseline condition. Accordingly, I speculate this finding represents an initial high degree of multisensory processing whilst watching the ASMR stimuli. Subsequently, alpha power increases, thereby reflecting an enhanced state of relaxation (as indicated by the participant). There is no additional significant enhancement of alpha in the ASMR vs PreRelaxed source contrast, perhaps indicating no significantly enhanced relaxation, although the relative enhancement appears to be greater when comparing PreRelaxed and ASMR vs PreBaseline contrasts. Another interpretation (which is not mutually exclusive) of this enhanced alpha is that once this relaxed state has been achieved, stimuli from the external environment are suppressed in preference for internally-oriented attention (Cooper et al., 2006; Magosso et al., 2019;

Matsuoka et al., 2021). In this way, alpha synchronisation has been associated previously with internal mental processes such as self-referential thought and social cognition (Knyazev et al., 2011). Curiously, sensorimotor areas are implicated in the PreRelaxed vs PreBaseline source contrast, whilst regions associated with the default mode network (DMN) are implicated in the ASMR vs PreBaseline contrast. Alternatively, instead of inhibiting the processing of external stimuli altogether, this alpha activity could suggest a selective inhibition of stimuli through the inhibition of task-irrelevant brain regions (Jensen & Mazaheri, 2010; Klimesch et al., 2007; Symons et al., 2016). For example, Worden *et al.* have shown enhanced alpha oscillations in visual regions ipsilateral to attentionally-cued visual stimuli (2000). In the context of emotion perception, it has been suggested that alpha oscillations may facilitate the selection of emotionally salient social cues through this inhibitory role (Symons et al., 2016).

The Baseline and Resting-State decay source contrasts, but not the Relaxed contrasts, show an enhancement of alpha power in regions more similar to the ASMR vs PreBaseline source contrasts. This finding supports the notion that the enhanced alpha power is not restricted to an enhanced relaxed state, but could instead be related to ASMR-induced activity relating to DMN regions. I speculate this decay effect could then support the altered functional connectivity of DMN activity found in ASMR-responders by prior fMRI work (S. D. Smith et al., 2017).

Considering this alpha enhancement finding, the gamma power reduction in areas related to sensory processing (e.g., facial/visual/auditory processing in STG, FFG, CALC, LING) could be of interest. Previous work on auditory attention has shown a reduction in gamma power when attention was inwardly oriented, in contrast to attending to auditory stimuli (Villena-González et al., 2018). Therefore, this could reflect a change in internally-oriented thinking in contrast to attending the ASMR stimuli. This pattern of alpha enhancement and gamma decrease has also been suggested to be a top-down control for more internally driven attention in another study (Mu & Han, 2010). However, it should be noted that, in that study, the time-frequency analysis was limited to 40 Hz, whilst the gamma effects reported here range between 50-80 Hz. Typically, gamma-band activity is enhanced when processing multisensory stimuli, especially visual stimuli (Chandrasekaran & Ghazanfar, 2009; Chen et al., 2010). For example, a significant gamma enhancement in the FFG was previously shown during visual stimulus encoding (Tallon-Baudry et al., 2005). This gamma prediction is more aligned with the results of the Fredborg *et al.* study, where they found an enhancement in gamma for the audio trials only (Fredborg et al., 2021). Due to the individualised ASMR content, faces were not consistent enough to drive this enhancement. Conversely, it could be argued that the non-ASMR conditions (PreBaseline/PreRelaxed) involved greater visual processing, which then was inhibited during the ASMR experience in preference to internal processing.

A novel finding, distinct from previous research, was the modulation of beta power by ASMR. Beta modulation has been found in tasks involving sensorimotor processing (Cheyne et al., 2003; Senkowski, 2005), auditory processing (Eulitz & Obleser, 2007), action observation (Cheyne et al., 2003), emotional recognition (Chen et al., 2010), or even the predictive coding of audiovisual stimuli (e.g., see Arnal and Giraud, 2012). These processes are all particularly relevant for processing ASMR stimuli and the perception of the ASMR tingling sensations. For example, when assessing auditory processing, one study has found prolonged event-related desynchronisation of upper beta (15-30 Hz, strongest at 24Hz) in a task designed to extract phonological features from speech (Eulitz & Obleser, 2007). A similar phenomenon might be occurring in the present study. Our high beta decrease in power shown could also be explained by the extraction of acoustically complex features from whispered or softly spoken speech in ASMR stimuli. Whispered speech is a common property present in ASMR stimuli (Barratt et al., 2017; Kovacevich & Huron, 2019), and whispering is also known to impoverish the quality of communication in terms of spectral acoustic information (Frühholz et al., 2016). Considering this reasoning with the inhibitory effect of the alpha seen during ASMR, the enhanced alpha may represent the suppression of distractors irrelevant to this goal of vocal processing. If ASMR stimuli do indeed prime the individual to be more capable of filtering distractors, this could explain the reported use of ASMR as a study aid (Kovacevich & Huron, 2019). An alternative explanation for the modulation in low beta-band power is the proposed maintenance of the current sensorimotor or cognitive state (Engel & Fries, 2010). Whilst speculative, it is possible that the beta band activity relates to the maintenance and monitoring of the induced state (Spitzer & Haegens, 2017).

Another novel finding was the decrease in delta power seen in both sensor and source space contrasts. Medial prefrontal regions are implicated, supporting prior neuroimaging findings (Fredborg et al., 2021; S. D. Smith et al., 2019a). It has been hypothesised that delta activity could be correlated with anticipation of a reward (e.g., see Knyazev, 2007. This could explain the decreases in delta power seen in the ASMR vs PreRelaxed and PreBaseline contrasts, where reference states have higher (anticipatory) delta powers. Alternatively, a decrease in reward-related delta power has been seen through the administration of legal psychoactive drugs such as caffeine (Hammond, 2003), tobacco (Knott et al., 2008), and alcohol (Sanz-Martin et al., 2011). Thus, the decrease in frontal delta here may represent reward-related processing. Moreover, it has been suggested that relative delta and alpha oscillatory powers are more strongly negatively correlated in adults but less so in childhood (Knyazev, 2007). It has also been proposed that the relative strength of inhibitory control increases during childhood (see J. M. Clark, 1996), where there is a concomitant shift of relatively low-frequency dominance (e.g., delta) to relative alpha dominance throughout development (Knyazev, 2007). I speculate this developmental enhancement in inhibitory control could be related to the onset of ASMR capability (or at least the self-reported recollection of onset), which is thought to be between late childhood (mean age of 8; Barratt and Davis, 2015) and preadolescence (mean age of 15; Poerio et al., 2018) for many ASMR-responders.

To our knowledge, this is the first study to provide neurophysiological evidence of the persistent decay effects of ASMR. Our results show that in periods reported as identical by the participant (e.g., PostRelaxed vs PreRelaxed) and under comparable experimental conditions (e.g., same ASMR video), there are electrophysiological differences that can be seen up to 45 minutes. Notably, the enhanced alpha effect persists even after the ASMR experience has been reported to have ended. Therefore, there is electrophysiological evidence for prolonged ASMR-induced relaxation, which corroborates self-reported data. This finding supports the idea for ASMR to be used therapeutically. However, further investigation is required to determine how long these effects last and if there are adverse side effects to this end. Moreover, when comparing resting-state contrasts, a general trend of low frequency decreases in power with concomitant higher frequency enhancements can be seen. One fMRI-EEG resting-state study has provided evidence that this pattern of activation and deactivation represents cognitive functions such as self-reflection, working memory and language (Jann et al., 2010). Therefore, this ASMR-modulated resting state may reflect a greater degree of self-reflection.

The novel control design in this study has been shown not to elicit significant differences in ASMR state duration for ASMR-responders. I hypothesised that by disrupting the temporal continuity of the ASMR videos, higher-order properties of the stimuli (like narrative) would be disrupted whilst maintaining lower-level properties (like lighting) across the video as a whole. Therefore, the core properties of the auditory and visual stimuli may be inherently sufficient for ASMR induction. Alternatively, individual differences within this result are likely being averaged out. Participants verbally reported either an enhancement of ASMR intensity (perhaps due to expectancy effects of their individualised videos) or a disruption of ASMR induction due to temporal scrambling. Therefore, these individual differences might portray different outcomes for different ASMR subtypes. For example, an ASMR-Responder who prefers repetitive sounds like tapping for ASMR induction might be unaffected/enhanced by this experimental manipulation. On the other hand, an ASMR-Responder who prefers personal attention and simulation-like videos would be negatively affected. Whilst only ASMR-responders as identified using the AEQ were tested in this study, an interesting addition would be to investigate the individual differences of the ASMR response using a AEQ-clustered cohort with greater stratification (i.e., Control+, Control-, ASMR-Strong, ASMR-Weak). For example, it would be interesting to see whether the Control+ cohort, who find ASMR stimuli relaxing with no tingling sensations, exhibit a similar Relaxed profile to ASMR-responders given the same self-reported state.

This study builds and expands on prior work by Fredborg and colleagues in several ways (2021). Firstly, data from a larger sample size of ASMR-responders have been collected. Secondly, a novel control stimuli design has been tested, whereby the temporal continuity of the ASMR video has been scrambled to form the control video. I aimed to maintain all low-level features of the ASMR video, but violate the expectancy of the familiarity of the video. Thirdly, research into idiosyncratic sensory experiences such as chills often uses individualised stimuli to maximise the likelihood of a (strong) experience in experimental settings (e.g., Mori and Iwanaga, 2017). Given the control video stimuli design mentioned above, I aimed to use personalised ASMR videos to maximise ASMR intensity and likelihood with corresponding personalised control videos. In addition, our study was entirely exploratory, and thus relied on nonparametric data-driven clustering in the sensor-space order to extract meaningful results. In this way, experimenter-introduced bias can be eliminated, where no prior data in the EEG field could otherwise inform the analysis. These results from the sensor space then informed further cluster tests in the source space, thereby estimating the origin of particular oscillatory signals identified in the previous step. Moreover, our methodological design allows for inferences to be made regarding a potential decay effect of

ASMR anecdotally reported previously (Barratt & Davis, 2015). Finally, our study takes ASMR-Responder identification one step further by using a new data-driven tool relying on an unsupervised machine learning algorithm, the ASMR-Experience Questionnaire (Swart et al., 2021).

There are some limitations to this study. Firstly, individualised ASMR stimuli were used to maximise the likelihood of ASMR induction. The relative drawback of this approach is the non-standardised stimuli which may have affected the results and interpretations. For example, some individualised ASMR stimuli contained whispering sounds, whilst others did not. Consequently, some neural differences seen may be a result of the different processing required for such stimuli. Secondly, as indicated in the prior EEG study, several participants indicated that the EEG equipment setup (and the required personal attention) induced ASMR itself. Since I have shown there are indeed decay effects, these confounds might be present in our data. Thirdly, a template head-model was applied to all datasets, and thus the source localisations could bear minor inaccuracies. For example, one assumption of using a template brain is that the participants' brain anatomy are "normal". This assumption may, thus, bias the differences identified between certain brain regions. The error (e.g., spectral leakage) present in this identification can be minimised using individualised anatomical images. However, consistent electrode cap placements should minimise these inaccuracies. Future work could include a follow-up MRI study capturing the anatomical images of the participant cohort reported here. In addition, future work using simultaneous EEG and novel near-silent fMRI adaptations such as Looping Star fMRI would help confirm identified regions whilst minimising the loud environment typically associated with an MRI scanner (Dionisio-Parra et al., 2020; Lochte et al., 2018). This technique would be well suited to capture with high accuracy and precision both temporal and spatial features of the ASMR experience in real-time. A clearer picture will be seen if a study design incorporates effective control stimuli and a control participant group. Finally, whilst no differences were found in tingle duration between experimental and control videos, the scrambling effect may have influenced the results from the combined dataset.

5.4.1 Conclusion

Altogether, I showed the robust changes in the patterns of dynamical brain oscillations associated with an ASMR tingling experience and identified its underlying cortical network. Further, I demonstrated the long-lasting effects of ASMR across a wide range of brain regions and oscillatory powers, including evidence for prolonged relaxation, offering potential neurophysiological support for the speculative therapeutic claim of ASMR.

In the subsequent Chapter I aim to bring the findings of all the current and previous Chapters together in light of other recent findings to formulate a testable model with specific predictions.

Chapter 6

Discussion

6.1 Aims Revisited

This thesis aimed to further characterise both state and trait ASMR in terms of classification, empathic abilities and electrophysiological neural correlates. Specifically, as outlined in Chapter 1, the questions addressed were:

- **Chapter 3:** Can participants be characterised using data-driven methods through their responses to a series of sensory-affective questions presented following a variety of ASMR stimuli?

ASMR-responders have been successfully characterised and classified using a data-driven clustering approach therefore eliminating experimental bias. A five cluster solution was found to be the most effective and useful at delineating cluster groups. The groups were as follows: ASMR-StrongResponders (ASMR-S); ASMR-WeakResponders (ASMR-W); non-responders with positive affective responses to ASMR (Control+); non-responders with negative affective responses to ASMR (Control-); Responders reporting negative non-head dominant tactile sensations (False-Positive). I predict as the reference clustering dataset grows that the inherent differences in responses to the sensory-affective questions will draw out even more groupings in respondents. It may be likely that whilst the data are best characterised by a greater number of groupings, for the purpose of most analyses these groupings can then be condensed into the 5 aforementioned participant groups. Depending on the analysis in question and the use of the AEQ (e.g., for False-Positive identification) the value of k can be adjusted to account for the aims.

- **Chapter 4:** Is trait ASMR associated with enhanced empathy and, if so, is there a particular subcomponent that is driving these effects?

Trait ASMR is associated with enhanced components of empathy. Specifically, the CARER and GERT-S tasks revealed greater emotion identification scores in ASMR-responders compared to non-responders. In contrast, there was no significant difference in affect sharing scores - the capacity for the Empathiser to share the emotion identified in the Target. This result may explain why self-report differences have been inconclusive in previous studies, where some self-report measures conflate these two processes. The known links between emotion identification and social constructs such as social affiliation, integration and connectedness (e.g., prosocial behaviours, emotional competence, social affiliation and connectedness) suggest another important area for understanding empathetic responding in ASMR: the impact of trait and state ASMR on social relationships and behaviour (e.g., trust, relationship quality, prosociality). Doing so will not only contribute to understanding the mechanisms and consequences of ASMR, but it will also provide a unique experimental window whereby ASMR-responders can shed light on the relationships between complex social processes (e.g., emotion identification and social affiliation) that affect us all.

- **Chapter 5:** What oscillatory correlates of state ASMR can be detected using EEG methodologies, and can, with the aid of source-localisation, speculations be made about possible reason certain brain regions are implicated?

First, I demonstrated that ASMR, compared to baseline, was associated with a robust change in five frequency bands over a multitude of brain regions. Specifically, I found decreases in delta power in prefrontal regions; increases in alpha power in parietal, frontal, and temporal regions; increases in low beta power in parietal and temporal regions, decreases in high beta power in parietal and occipital regions, and decreases in gamma power in occipital regions. Second, I observed a decay effect of ASMR in the absence of self-reported ASMR tingling sensations. Third, the temporal profile of the modulations by ASMR in high-frequency power later shifts to lower frequencies (1-8 Hz), except for enhanced alpha which persists for up to 45 minutes post self-reported ASMR. Finally, I showed that the temporal continuity of the ASMR-inducing video is not vital for ASMR induction. I speculate that the enhancement of alpha and reduction of gamma may indicate a suppression of exteroceptive cues during ASMR, with an inward shift of attention to interoceptive cues instead. Furthermore, I speculate that the high frontal delta in baseline states reflects the anticipation of reward which is sustained in relaxed states, only to reduce in the ASMR states.

- **Chapter 6:** Can both state and trait ASMR be explained using existing models that incorporates the findings outlined in Chapters 1 and 3 to 5?

6.2 Cross-Activation Model of ASMR

In this section I will discuss the findings of Chapters 3 to 5 in the context of existing theoretical models of ASMR (e.g., McGeoch and Rouw, 2020).

6.2.1 Background and Overview

Since the first peer-reviewed publication on ASMR a putative link between synaesthesia and ASMR has been suggested (Barratt & Davis, 2015). Whilst the increased co-prevalence of ASMR and synaesthesia proposed was insignificant, the trending effect and the similarities of cross-modal sensory activations between the two warrants further investigation (e.g., see Section 1.3.3).

Both multisensory experiences can be driven by cross-modal sensory activations and thus it is logical for the ASMR field to draw insights from the synaesthesia field in terms of theoretical models explaining the experience. There are a number of theoretical models in synaesthesia that have been proposed throughout the years, from cross-activation (Ramachandran & Hubbard, 2001), disinhibited feedback (Grossenbacher & Lovelace, 2001) to stochastic resonance (Lalwani & Brang, 2019).

McGeoch & Rouw (2020) have proposed a model that relies on the principles of cross-activation for ASMR. Moreover, they suggest that the insula is synaesthetically cross-activated from the neighbouring primary auditory cortex in Heschls' gyri to generate the experiences reported in ASMR. Specifically, they suggest that the tingling sensations are cross activated between the primary auditory cortex and the dorsal posterior insula (dplns). The dlpns has been proposed to contain bodily physiological representations (that are constantly re-represented in real-time that are integrated with other inputs to construct a dynamic representation of an individual's emotional wellbeing - termed the "global emotional moment"; Craig, 2014; Craig and Craig, 2009). Moreover, the dplns is suggested to contain the interoceptive map for affective touch, driven by unmyelinated c-tactile afferents (CT-afferents). Specifically, CT-afferents have been shown to be induced by slow stroking, brushing and confers pleasant touch with emotional bonding in close relationships (e.g., see the following review Olausson et al., 2010). Subsequently, it has been proposed that the "auditory input into the interoceptive representation is then re-represented into the global emotional moment in the AIC [anterior insular cortex] to generate the sense of wellbeing and euphoria described in ASMR" (McGeoch & Rouw, 2020). This is in contrast to previous suggestions that ASMR may be a form of auditory-somatosensory synaesthesia, where the cross-activation from the primary auditory cortex to the postcentral gyrus is anatomically more distant (Barratt & Davis, 2015; S. D. Smith et al., 2017).

The suggested mechanism of wellbeing modulation for the 'global emotional moment' is the regulation of sympathovagal balance - i.e., the balance of the sympathetic (fight or flight response) and parasympathetic nervous system (rest and digest response) (Craig, 2014; Strigo & Craig, 2016). This homoeostatic and autonomic control has been proposed to involve the insula as well as the aforementioned dynamic representation of emotional states (Strigo & Craig, 2016). McGeoch & Rouw (2020) also postulate that the anterior cingulate cortex can be viewed as a "homeostatic motor cortex", augmenting the insula as a homeostatic sensory cortex.

6.2.2 Evaluating the Cross-Activation Model Predictions

Predictions from the cross-activation model will be discussed in the context of the findings of this thesis primarily, and from the literature as well.

Neurobiologically, the model predicts that the primary auditory cortex would first be activated, spreading to the dlpns and then to the anterior insular cortex and finally the ACC (McGeoch & Rouw, 2020). This prediction is best tested using connectivity analyses on EEG or MEG data with high temporal resolution (and/or spatial resolution). However, fundamentally any cross-activation model relies on activation of proximal regions from a primary sensory processing region (e.g., the primary auditory cortex). Therefore, this activation spread should be observed reliably, even if secondary or tertiary downstream activations vary between experiences.

Indeed, Locthe *et al.*, (2018) found bilateral insulae activation and dorsal ACC activation when comparing tingle moments to baseline moments. However, these regions were not activated in a task-based fMRI by another research group as discussed in Section 1.2.5 (S. D. Smith et al., 2019a). Instead, ASMR-experiencers showed greater activation in the left superior temporal gyrus, which could implicate the primary auditory cortex. Therefore, in the literature there is mixed reliable evidence of ASMR-specific activation of the ACC, primary auditory cortex, and insulae. In Chapter 5 I found ASMR-specific activations in primary auditory cortex, when comparing ASMR to baseline. Furthermore, I found bilateral anterior cingulate gyri activations when comparing

ASMR and relaxed states preceding the ASMR experience. Interestingly, I only found left insula activation when comparing PreRelaxed and PreBaseline states, and not during ASMR activation. Moreover, a wide number of regions appear to be implicated in the ASMR experience that are unlikely to stem from simple cross-activation from the primary auditory cortex to the insula/ACC (e.g., see Figure 5.5). Therefore, the current literature provides mixed support of this prediction - i.e., that the primary auditory cortex would first be activated, spreading to the dlpns and then to the anterior insular cortex and finally the ACC - and perhaps indicates a more complex and flexible mechanism at play.

Behaviourally, the cross-activation model of ASMR predicts that the sympathovagal balance would shift towards parasympathetic during ASMR, which could be measured using HRV (McGeoch & Rouw, 2020). Specifically, parasympathetic activation would typically be shown by an increase in global RMSSD HRV and changes to frequency-domain measurements that are condition and measurement specific (for a comprehensive review see Shaffer and Ginsberg, 2017). In Chapter 5 non-significant trending effects of HR, and HRV measures were found but they did not survive corrections. However, the trends found could indicate an underpowered increase in parasympathetic activity through a trending reduction in HR Post vs Pre ASMR. Moreover, a conflicting trend in decreasing activity in the HF band would indicate a shift towards sympathetic activation, which does not support the above prediction. Similarly, Poerio and colleagues (2018) also found concomitant measures of both para- and sympathetic activation. They found a reduction in HR induced by ASMR, which suggests an increase in parasympathetic activity, whilst they also found an increase in skin conductance, which simultaneously suggests an increase in sympathetic activity. Overall, the evidence for this prediction is again mixed, but further investigation is warranted to fully unpack the driving mechanisms behind this complex emotion.

Outside of the scope of the data presented in this thesis, data have been published since the cross-activation model of ASMR was proposed that can also be used to evaluate predictions of this model that have been discussed in Chapter 1. Since the insula is thought to be responsible for aspects of interoception, it has been hypothesised that ASMR-responders should show heightened scores compared to non-responders in measures of interoceptive awareness (McGeoch & Rouw, 2020). Indeed, as outlined in Section 1.3.3 interoceptive sensibility has positively predicted the intensity of ASMR trigger responses in one study (Poerio et al., 2021), whilst no relationship was found using the measure suggested by McGeoch & Rouw (2020) in a different study (Roberts et al., 2021b). Mixed evidence supports this prediction, however further investigation is required to replicate previous findings.

6.2.3 Limitations of the Cross-Activation Model

Above I have discussed the extent to which my findings match the predictions presented by the cross-activation model. Overall, the data presented here do not reliably match with these predictions. There are other limitations noticeable in this model which need to be discussed. Primarily, the cross-activation model does not adequately explain the presence and role of non-auditory ASMR triggers. Touch is an important under-measured modality for inducing ASMR (Poerio et al., 2021), due to its reduced ease of measurement in comparison to online studies relying on ASMR videos. Furthermore, visual cues alone are also sufficient in some ASMR-responders to induce state ASMR, albeit being generally less effective than auditory triggers (Barratt et al., 2017).

In theory, it is clear how auditory triggers may drive both the somatosensory and affective experiences associated with state ASMR. The model explains non-auditory triggers by them typically possessing "similar properties to the auditory triggers". The authors suggest that high-level, global networks may be involved in explaining the effectiveness of these non-auditory triggers (McGeoch & Rouw, 2020). However, in the context of ASMR induced by affective touch (e.g., tracing on the back, or combing for lice), another possibility is that the insula and/or somatosensory cortices are activated through the somatosensory pathways, instead of through the primary auditory cortex. I suggest that this activation pathway is more logical and more prone to form during brain development.

Crucially, the broader perceptual changes of trait ASMR haven't been explained by the cross-activation model of ASMR. For example, how does hyperconnectivity between insula and auditory cortices explain why trait ASMR has been associated with visual symptoms of AIWS (Bedwell & Butcher, 2020), or a reported higher co-occurrence of ASMR and synaesthesia (Section 1.3.3)? Why are there personality differences between responders and non-responders (as discussed in Section 1.3.1). Whilst the majority of state ASMR may be explained by cross-activation, the more general traits associated with ASMR are left largely unexplained.

6.2.4 Can ASMR Research Learn from Synaesthesia Research?

I have explored how the current data integrate into the cross-activation model of ASMR - a model that has been explored extensively in synaesthesia research and has been adopted into ASMR research. There are also other models from synaesthesia research that could be applied to ASMR as an initial framework. For example, recent advancements that might have relevance to ASMR are the stochastic resonance (Lalwani & Brang, 2019) and predictive processing (Seth, 2014) frameworks. Due to the limited scope of this thesis I have selected the stochastic resonance model to attempt explain the findings in the thesis and the in the greater literature. Similar claims have been pitched by Lalwani & Brang (2019), but due to the similarities of ASMR and synaesthesia discussed in Section 6.2.1, I believe the ASMR field can benefit greatly from the frameworks suggested here. Below I will attempt to adopt the framework in the context of state and trait ASMR.

6.3 Stochastic Resonance Model of ASMR

6.3.1 Background

To overcome the shortfalls from the cross-activation model of ASMR mentioned in Section 6.2.2, a new model of ASMR should be able to explain how the ASMR affective and somatosensory experiences arise from all implicated senses (touch, sound, vision). Furthermore, as ASMR-responders demonstrate numerous other trait-like differences, the comprehensive model should be able to explain these broader phenotypical differences. Considering the evidence reviewed above, I propose a new model of ASMR - using the stochastic resonance model of synaesthesia as a framework (Lalwani & Brang, 2019) - suggesting that a simple change in neural noise can lead to both the ASMR experience, as well as the broader phenotype of functional and perceptual changes seen in ASMR-responders.

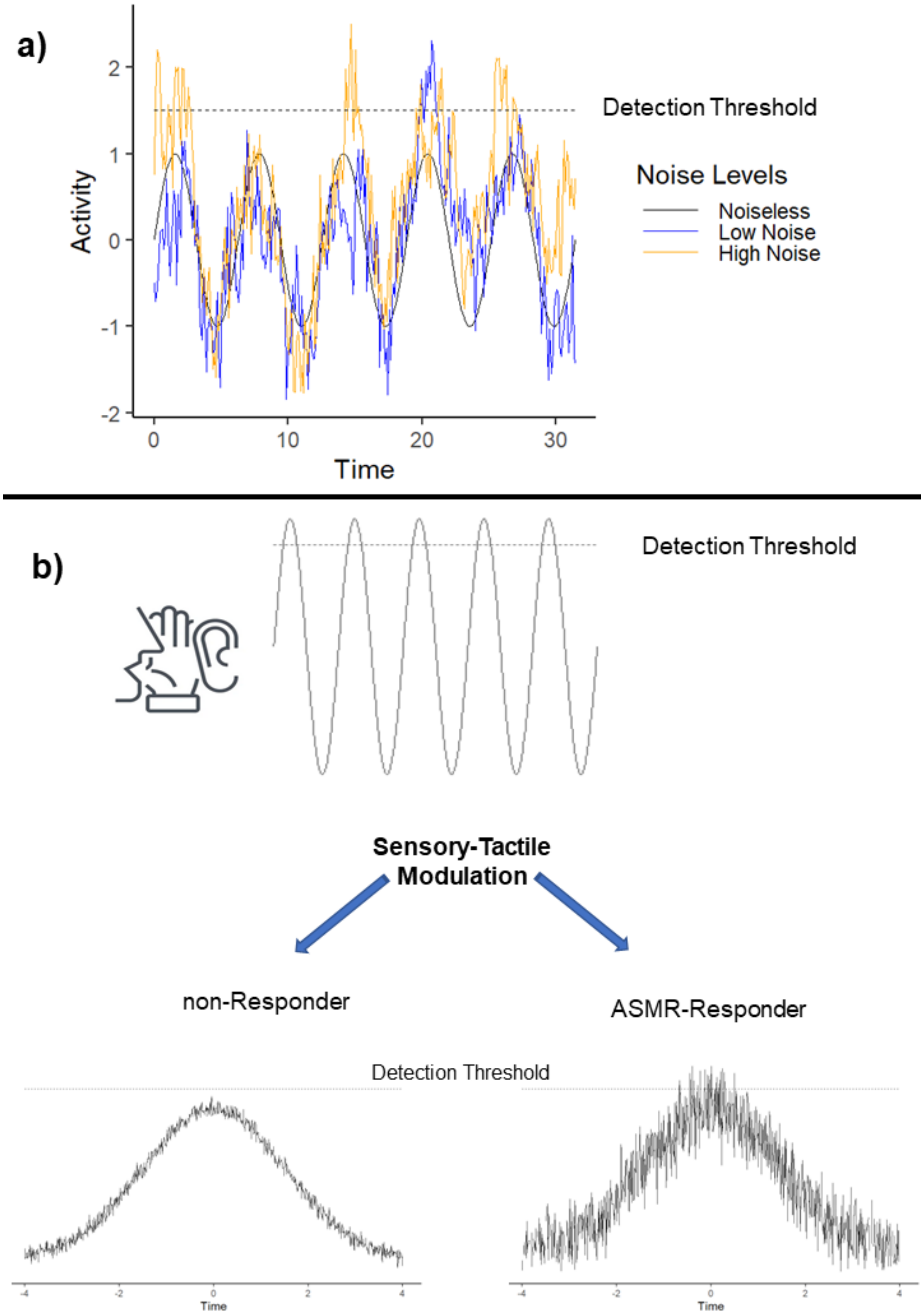
6.3.2 Definition of Stochastic Resonance

Whilst electronic systems are often optimised by filtering and removing noise from the signal, (neuro)biological systems can often benefit from the presence of noise (Faisal et al., 2008; McDonnell & Ward, 2011; Söderlund et al., 2007). Counterintuitively, noise in a neural system is able to improve signal transmission/detection (see Figure 6.1a) – a phenomenon resulting from the principles of stochastic resonance (see the biologically relevant review McDonnell and Abbott, 2009). Stochastic resonance is where an increase in input noise results in an improved signal-to-noise ratio (McNamara & Wiesenfeld, 1989), thereby conferring signal-processing 'noise benefits' (McDonnell & Abbott, 2009). Consequently, noise makes a system more excitable through stochastic resonance (Kurrer & Schulten, 1995). This enhanced excitability can be beneficial in neural systems. For example, in the case of stochastic synchronisation, adding noise facilitates synchronisation among coupled excitable systems (Kurrer & Schulten, 1995; Lindner et al., 2004; Neiman et al., 1999; Zhou et al., 2001). Signal detection is only one of many signal processing problems that stochastic resonance can influence. More complicated information transmission processes include signal estimation, compression, error-rate and classification (McDonnell et al., 2008). Whilst some neurons are responsible for simple binary state changes (i.e., signal detection), other neurons, and more specifically networks of neurons, will be responsible for transmitting qualitative information such as intensity. A form of stochastic resonance called suprathreshold stochastic resonance (SSR) exists, which refers to the "instantaneous averaging of the outputs from an array of independently noisy threshold devices that all receive the same signal" (McDonnell et al., 2008). McDonnell and colleagues have proposed the stochastic quantisation of SSR which considers the output of a network where varying random noise has been applied to the thresholds of an ensemble of neurons. The result of this process is that a signal can be 'sampled' at a given number of points across the signal space (i.e., quantisation), thereby allowing neurons that simply fire or not fire to convey information belonging to more than 2 states more effectively (McDonnell et al., 2008). For example, if the neural noise within the somatosensory cortex was not only enhanced, but also exhibiting intra-regional variation of this enhanced neural noise, then the neuronal ensemble averages would output a more accurate signal (see Figure 6.2). Whilst stochastic resonance is the simplest example to apply to ASMR, it should be noted that SSR exists as well.

6.3.3 Applying Stochastic Resonance to ASMR

Here, I propose a neural model of ASMR based on the principles of stochastic resonance and synchronisation. Previous models of ASMR suggest hyperconnectivity between auditory regions and the insula as an explanation for the ASMR experience (as discussed in Section 6.2.2), while largely ignoring the broader perceptual changes (McGeoch & Rouw, 2020). For example, hyperconnectivity between auditory regions and the insula cannot explain why trait ASMR has been

Figure 6.1: *Graphical representation of stochastic resonance, and a putative mechanism for state ASMR*



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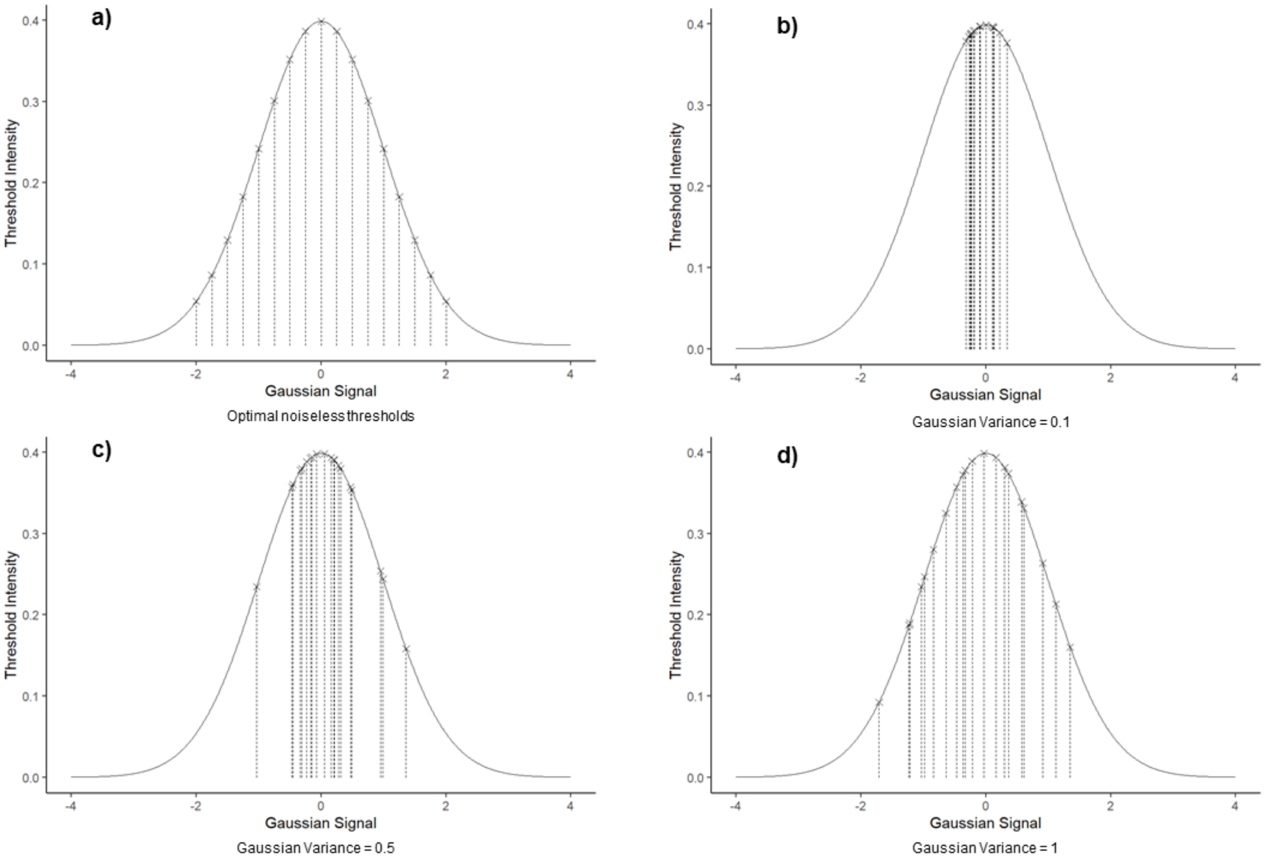
a) This model reflects signal detection. The black dashed lined indicates the required intensity for detection. The red line shows a signal in the absence of noise; the blue line shows a signal with low levels of noise (or example ASMR-Weak from Chapter 3); the yellow line shows a signal with high levels of noise (for example ASMR-Strong from Chapter 3). Only high levels of noise consistently allows the signal to surpass the detection threshold, whereas low levels of noise occasionally allows signal detection. **b**) The black dotted line represents the detection threshold. The blue arrows represent the cross-modal modulatory activity from the inducer (e.g., sound) to the corticolimbic pathway (e.g., somatosensory cortex or insula). For non-responders the insufficient neural noise present does not allow the modulatory activity to be detected. Conversely, for ASMR-Responders the functional modulatory activity reaches the threshold detection. Adapted from (Lalwani & Brang, 2019).

Figure 6.2: *Graphical representation of suprathreshold stochastic resonance*



This model reflects signal decoding. The vertical dotted lines reflect the threshold of an individual neuron in an ensemble. Together, through the variation of neuronal thresholds, the underlying signal can be decoded more accurately with more noise. **a)** represents the ideal distribution of neuronal thresholds in a noiseless system where the thresholds can are predetermined perfectly for decoding; **b)** represents low amount of noise added to the neuronal thresholds (Gaussian variance = 0.1); **c)** represents medium amount of noise added to the neuronal thresholds (Gaussian variance = 0.5); **d)** represents a large amount of noise added to the neuronal thresholds (Gaussian variance = 1). This model most similarly reflects the optimal predetermined thresholds viewed in a). It is important to note that if the noise increased maximally then the decoding accuracy would decrease again, with thresholds existing towards to the extremes of the bell curve and thus reducing their usefulness. Adapted from (McDonnell et al., 2008).

associated with visual symptoms of AIWS (Bedwell & Butcher, 2020), or a reported higher co-occurrence of ASMR and synaesthesia (Section 1.3.3). By contrast, the stochastic resonance model is able to explain both state and trait ASMR driven primarily due to higher levels of noise in the concurrent modality. In this way normal activity sent along pre-existing multisensory connections by the inducer hyperactivates the concurrent modality (e.g., tactile processing) through stochastic resonance, leading to the additional sensory-affective experience (as depicted in Figure 6.1b).

Adopting the 'concurrent' terminology from synaesthesia literature (Lalwani & Brang, 2019), the proposed concurrent modality are regions involved in the cortico-limbic pathway. This pathway links the primary and secondary somatosensory cortices to posterior parietal cortical areas and to the insular cortex. From the insular cortex the amygdala, perirhinal cortex and hippocampus are also associated (Friedman et al., 1986). The cortico-limbic pathway is responsible for not only somatosensory processing but also with integrating somatosensory input with other sensory modalities (e.g., audition and vision) and with reward, learning and memory (Friedman et al., 1986). Consequently, if the cortico-limbic pathway exhibits altered functional connectivity and is more readily excitable in ASMR-responders due to stochastic resonance, it is plausible that both state and trait ASMR can be explained.

Cross-modal Sensory-Tactile Modulation

This model proposes that one of the main distinguishing differences between ASMR-responders and non-responders is the level of neural noise present in the cortico-limbic pathway and not the neuroanatomical connections between the inducer and insular cortex. Crucially, the sensory systems are linked anatomically, where stimuli presented in one modality can modulate activity in touch processing (Cardini et al., 2011; J.-H. Lee & Spence, 2009; Söderlund et al., 2007). However, typically these cross-modal modulations are limited only to modulatory activity through sensory threshold modulation, limited to the extent that a sound will not be able to induce a tactile neuron to generate an action potential. Therefore, these cross-modal modulations typically do not reach the perceptual awareness of non-responders. However, the presence of increased neural noise in tactile processing areas could augment these cross-sensory signals sufficiently to generate suprathreshold activity through stochastic resonance.

Several studies have shown that auditory or visual stimuli can modulate tactile processing (Cardini et al., 2011; J.-H. Lee & Spence, 2009; Spence et al., 2004; Tajadura-Jiménez et al., 2012). For example, task-irrelevant sounds have been shown to modulate the number of perceived vibrotactile targets, especially under high attention loads (J.-H. Lee & Spence, 2009). Similarly, viewing touch on oneself modulated hemispheric perception of the touch and was associated with reduced activity in the ventral premotor cortex and somatosensory cortex in another study (Cardini et al., 2011). Another example of visual-tactile modulation was demonstrated when a participant was viewing a laser pointer directed at a false rubber hand. Two thirds of participants reported experiencing tactile and thermal sensations when the hand appeared to be their own (Durgin et al., 2007). A different lab reported a similar finding where participants were given the visual impression that an artificial limb belonged to them (Schaefer et al., 2009). Not only did participants report feeling that they possessed a supernumerary third arm but a concomitant increase in activity in the primary somatosensory cortex was also shown. Interestingly, this cross-modal modulation was found to be predictive of the reported effectiveness of the visuo-tactile illusion (Schaefer et al., 2009). Therefore, if state ASMR, driven by stochastic resonance, is the result of these modulations reaching perceptual awareness, the resting state activity of the somatosensory cortex should be enhanced following ASMR induction. Indeed, this was precisely shown in Chapter 5, where increased resting state low beta activity in the postcentral gyrus was present following ASMR induction in contrast to resting state preceding ASMR induction.

The stochastic resonance model of ASMR is based on four main assumptions: (1) ASMR occurs through common pathways that are functionally ubiquitous in us all; (2) ASMR triggers are unpredictable at onset but will broadly stabilise over time through repeated exposure; (3) there is a greater degree of neural noise present in at least one region in the cortico-limbic pathway in ASMR-responders; (4) trait ASMR and the associated cognitive, perceptual and functional differences is, at least in part, a consequence of this increased neural noise and the subsequent exposure of state ASMR. Below, I review evidence based on the current literature supporting this model and propose candidate regions that can be systematically investigated.

6.3.4 Evidence in this Thesis and the Literature Supporting the Stochastic Resonance Model

The SR model assumes that the pathways responsible for ASMR exist and are functionally relevant in both ASMR-responders and non-responders. Akin to the proposals made by Lalwani & Brang (2019), I speculate that without the enhanced neural noise in the cortico-limbic pathway, the bottom-up sensory input into the tactile processing system simply masks detection of cross-modal modulation. Therefore, under typical scenarios the strength of cross-modal modulations from the inducer never reaches detection, thereby precluding the possibility of experiencing ASMR.

Neurobiological Evidence for Stochastic Resonance in ASMR

One of the most important assumptions of the SR model of ASMR is the presence of neural noise in the cortico-limbic pathway of ASMR-responders. This keystone assumption of the model is indirectly supported by research showing that ASMR-responders show altered neural connectivity in the somatosensory cortex and insula cortex at rest (S. D. Smith et al., 2019a; Chapter 5) and both of these regions are implicated in state ASMR (Fredborg et al., 2021; Lochte et al., 2018; Chapter 5). Moreover, both regions are heavily involved in tactile processing (e.g., Burton et al., 1999;

Craig et al., 2000), sensorimotor processing (e.g., S. Lee et al., 2013; Stephani et al., 2011), emotion identification (e.g., Adolphs et al., 2000; Pugnaghi et al., 2011) and feeling emotions (e.g., Damasio et al., 2000; Lamm and Singer, 2010). Emotion regulation has also been attributed to both of these regions, particularly through their connections to the amygdala and the well-established role of the amygdala in emotion regulation (Augustine, 1996; Höistad & Barbas, 2008). Consequently, once activated, given the appropriate cues, the insula and somatosensory cortex are both strong candidates (not mutually exclusively) to facilitate the euphoria and calming tingling sensations associated with state ASMR.

I agree with the predictions presented in the cross-activation model of ASMR (McGeoch & Rouw, 2020) and the stochastic resonance model of synaesthesia (Lalwani & Brang, 2019). Specifically, I predict the emotional valence attached to the experience is heavily driven by environmental context which encompasses the inducing triggers. In this way, the SR model of ASMR can explain the small proportion of individuals who experience tingling sensations to ASMR triggers, which they report as unpleasant and reducing feelings of calmness (Swart et al., 2021). For example, whilst for most ASMR-responders the sound of pencil on paper may be associated as relaxing from times they were reading in the library, others may have associated these sounds as stressful from silent examinations. There are several putative candidates within the cortico-limbic system that could mediate affective responses once the pathway has been cross-modally activated (for example in the somatosensory cortex by stochastic resonance). These regions could be activated downstream in the cortico-limbic pathway and reside in the cortex such as the insular cortex (Uddin et al., 2017), or even in subcortical areas such as the thalamus or brainstem (Venkatraman et al., 2017). Below, evidence and predictions will be discussed for the somatosensory cortex and the insula in the context of the induced sensory-emotional response and the broader trait of ASMR.

If state ASMR is indeed related to enhanced neural noise in the cortico-limbic pathway then I would predict to see differential activity within these regions. Indeed, in Chapter 5 I have shown that ASMR-responders show decreased delta power in the ACG, MTG, mPFC and regions surrounding the operculum compared to a relaxed state. It should be noted that whilst there was a decrease in activity induced by state ASMR, it cannot be determined without additional tools, such as magnetic resonance spectroscopy, whether this is due to an increase in inhibitory GABAergic activity or a decrease of excitatory activity. Therefore, the decrease in activity does not exclude the role of SR in these areas.

Stochastic Resonance and ASMR Decay Effects

Another striking finding revealed in Chapter 5 is the existence of a decay effect of ASMR. Two states that were reported to be identical by the participant showed neural differences, where the stimuli presented were not identical but shared low level acoustic and visual features. The proposed difference stems from the state ASMR experienced temporally between the two reported states and thus was termed the decay effect. Of particular interest to the stochastic resonance model of ASMR is the enhanced activity in the somatosensory cortex, precuneus and supramarginal gyrus in the resting state following ASMR induction compared to PreASMR resting state. If ASMR is a consequence of enhanced neural noise in the somatosensory and somatosensory association regions, then I would expect this area to remain overactivated following ASMR induction. Furthermore, the precuneus has been implicated in empathy and self-awareness (e.g., Cavanna and Trimble, 2006), perhaps reflecting a form of ASMR-induced emotional reappraisal during the PostASMR resting state condition.

Relaxation-Induced Neural Noise as a Priming State for ASMR?

Neural noise has been shown to increase compared to baseline after listening to relaxing music in parietal, temporal and occipital regions (as measured by sample and approximate entropy; Nawaz et al., 2018). Therefore, I speculate that it is possible that this enhancement of neural noise is related to auditory processing steps that are present when listening to whispering sounds or tapping and scratching sounds. To my knowledge, no investigation has been pursued to identify the effects of whispering or unpredictable tapping on the brain. However, it is known that the spectral acoustic properties of whisperings exhibit greater entropy levels (Frühholz et al., 2016), therefore it is possible that this state can be transferred during auditory processing. If true, then depending on the cortical origin of the enhanced neural noise, the processing of these ASMR triggers may be able to enhance neural noise in the cortico-limbic pathway, such as the somatosensory cortex or the insula. The close anatomical proximity and structural connectivity between the primary auditory cortex and the insula may support this notion (Mesulam & Mufson, 1985), akin to the proposals made by McGeoch & Rouw (2020). Whilst indirect, in Chapter 5 both the left Heschl's gyrus and left insula showed significantly greater low beta power in the PreRelaxed state compared to the PreBaseline state. Furthermore, the same contrast revealed greater alpha power in premotor, and somatosensory regions.

Speculatively, this may represent a priming step for ASMR by inducing neural noise. Consequently, once this priming state has been achieved, tactile sensations would be able to be induced by cross-modal modulations reaching detection threshold through stochastic resonance.

Can Stochastic Resonance Explain the Early Onset of Trait ASMR Typically Reported?

One the main strengths of the stochastic resonance model of ASMR is that it can explain both developmental (the most common) form of ASMR as well as acquired forms that have been sporadically reported later in adulthood (Barratt & Davis, 2015). This model predicts that idiosyncratic ASMR triggers in ASMR initially change each time ASMR is evoked, based on the current state of the tactile system. However, through repeated exposure of the same ASMR trigger eliciting suprathreshold ASMR experiences, these associations would be predicted to broadly stabilise over time. For example, a pre-adolescent naive ASMR-responder (the most commonly reported age of ASMR onset) may first experience ASMR through a variety of different scenarios (and sensory modalities) such as whilst roleplaying with their friends or when an adult combs their scalp for lice. Then, over time scenarios with the greatest successful repeated exposure (e.g., the sound of hushed whispers and pencils on paper in a silent classroom) would become the most consistent trigger.

Indirect evidence for these predictions exists in the literature. For example, developmental neural noise increases as a function of age during maturation (Angulo-Ruiz et al., 2021; McIntosh et al., 2010; Miskovic et al., 2016), which correlates, when properly tuned (Golos et al., 2016), with stable behaviour and accuracy (McIntosh et al., 2010). Notably, in a large cross-sectional study which evaluated the change of sample entropy/brain signal variability (as a measure of neural noise) between the age of 7 and 11, neural noise increased most dramatically between the age of 7 and 8 years old (Miskovic et al., 2016). Therefore, according to the SR model of ASMR, I would predict that the most common age of ASMR onset would occur within this timeframe. Indeed, according to the average median ages across three different datasets, the age of initial ASMR onset is 7 years old (8 - Scofield, 2019; 6 - Barratt and Davis, 2015, 2015; 7 - Swart et al., unpublished). I hypothesise that due to the dramatic increase in neural noise in the cortico-limbic pathway at this age, the likelihood of cross-modal activation (for example in the somatosensory cortex) is much higher when provided with the required environmental and contextual cues.

Stochastic Resonance and ASMR Trigger Associations

This model does not explicitly predict which triggers will form an association with the ASMR experience, or how these associations will stabilise over time. However, I hypothesise that repeated exposure and the strength of the concomitant rewarding and calming pleasant sensations experienced with state ASMR will be determining factors in solidifying these associations. Whilst variations of ASMR trigger preference are suspected to occur over time in adulthood, for example in terms of ASMR immunity (where watching the same ASMR video will result in diminishing returns and can eventually fail to elicit ASMR), I predict that the broader preference of trigger types persist. For instance, triggers that exhibit similar low-level acoustic features such as tapping, or scratching may vary once associations have broadly stabilised. However, a developing ASMR-responder repeatedly exposed to suprathreshold activation by whispering through stochastic resonance will form a preference for whispering as a trigger later in life. Indeed, these inducer-concurrent learnt associations are akin to the mechanisms proposed in synaesthesia literature (Lalwani & Brang, 2019; Root et al., 2018; Simner & Bain, 2013).

Stochastic Resonance and ASMR Empathic Accuracy

ASMR-responders have been shown in Chapter 4 to display significantly enhanced empathic accuracy compared to non-responders, driven by more accurate emotional identification in others. The stochastic resonance model of ASMR could explain this finding by increased levels of neural noise present in either the somatosensory or insula cortices. For example, previous findings have shown that lesions in SII have resulted in an impaired ability to recognise emotions (Adolphs et al., 2000). Therefore, if there is greater neural noise in SII in ASMR-responders, then a weaker signal (i.e., less apparent emotional cues) would be sufficient (amplified through stochastic resonance) to detect the emotional cues in others. Similarly, in the context of SSR, if ASMR-responders showed a greater variation of neural noise in SII then a more accurate detection of emotional cues is also possible (i.e., more accurate stochastic quantisation of the input signals). Enhancements in neural noise in the anterior insula could also explain the enhanced empathic accuracy seen, where the anterior insular cortex has been implicated in processing of social emotions (e.g., Lamm and Singer, 2010). In particular, I speculate that noise-modulated insular-occipital connections (e.g., cuneus and lingual gyrus) may play a role in the enhanced emotional expression recognition seen in the CARER and GERT-S tasks (Dal Monte et al., 2013; Ghaziri et al., 2017). This speculation is indirectly supported in Chapter 5 by two state ASMR modulation of these regions: the PreRelaxed vs PreBaseline contrast revealed significant changes in activity in the cuneus, lingual gyrus and the insula; the ASMR vs PreBaseline contrast revealed changes in activity in the lingual gyrus and cuneus. The valence and the specific emotion being processed results in various hemispheric or regional activation differences when comparing SII and insula involvement (e.g., as reviewed in Kropf et al., 2019; Uddin et al., 2017). This is particularly relevant since the valence range tested in the CARER task used for study in Chapter 4 was between neutral stimuli to distressing stimuli. Therefore, it may be possible to investigate which region(s) could be implicated by enhanced neural noise by using paradigms where the insula and SII differentially activate, such as when viewing images depicting pain as used by Orenius and colleagues (2017). For example, I would predict that ASMR-responders would show greater activation of the left SII when negative emotion and laser stimuli were presented together. Similarly, it is thought that SII activity in pain processing rapidly increases for high intensity stimuli (Timmermann et al., 2001). If neural noise levels in SII were greater in ASMR-responders, I would predict lower pain thresholds to cause activation of SII than in non-responders (Straube & Miltner, 2011). Since pain processing is highly dependent on both the somatosensory and the insula cortices, I would also predict atypical pain processing with ASMR-responders exhibiting lower pain thresholds.

Stochastic Resonance and Altered Sensory Processing

As described in Section 1.3.3, trait ASMR has been reported to significantly co-occur with visual symptoms of Alice in Wonderland Syndrome (AIWS; Bedwell and Butcher, 2020). Examples of visual symptoms are the inability to appreciate the size of objects or the exaggeration of depth and detail of objects. The superior parietal and inferior parietal cortices been implicated in playing a role for these visual symptoms for AIWS in one fMRI study (Brumm et al., 2010). Interestingly, both of these regions were also implicated in Chapter 5, specifically in the ASMR vs PreBaseline contrast. Furthermore, the number of visual symptoms of AIWS was found to be a significant predictor of the age of onset of ASMR. Therefore, it is possible the greater degree of visual AIWS symptoms and younger age of ASMR onset reflect a greater degree of neural noise, possibly in the corticolimbic pathway. There is some evidence that atypical activity in the somatosensory cortex is responsible for certain forms of visual distortions (Chouinard et al., 2012). Similarly, in an imaging case study of Robin Hood syndrome causing AIWS visual symptoms (e.g., problems assessing distance), abnormal blood flow was seen to the frontoparietal operculum, perhaps indicating a role of the insula for these visual distortions (Morland et al., 2013).

Section 1.3.3 reports that trait ASMR appears to be significantly associated with misophonia. Moreover, misophonia has been reported to be associated with significant activation of the anterior insular cortex (Kumar et al., 2017; Schröder et al., 2019). Increased neural noise in the insula could result in over-activation by stochastic resonance in response to specific auditory stimuli processed by the adjacent auditory cortex. Consequently, the visceral aversion and negative emotional reaction to these auditory cues would be plausible through this mechanism. Therefore, the stochastic resonance model of ASMR can not only explain state and trait ASMR but also the higher coincidence rate of misophonia in ASMR-responders.

Similarly, there is evidence that ASMR-responders exhibit heightened sensory processing sensitivity and sensory suggestibility (see Section 1.3.3). However, it is still not clear whether this heightened sensitivity is specific to one modality or more general. In one experimental exercise in the sensory suggestibility scale, ASMR-responders reported greater scores when challenged about whether they felt any heat sensations from an LED flashlight (Keizer et al., 2020). It is known that both the secondary somatosensory cortex and the insula respond differentially to thermal intensities (Frot et al., 2007) and are differentially involved in imagined and hypnotically induced thermal pain (Derbyshire et al., 2004). Therefore, it is feasible that a more readily excitable somatosensory and/or insula cortices may lead to more vivid sensory imagery to such a challenge. Furthermore, higher emotional awareness and appreciation for sensory aesthetic experiences predicts more intense ASMR trigger responses. Greater neural noise in the insula may be driving this effect. It is well documented that the insula is readily activated in aesthetic perception (S. Brown et al., 2011; Cupchik et al., 2009), where the insula is thought to be responsible for appraising the valence of the perceived objects (S. Brown et al., 2011). Thus, a more readily activated insula may be responsible for greater emotional reactivity to perceived sensory stimuli.

Insular Noise and Interoception

A distortion of time has also been associated with ASMR (as described in Section 1.3.1), first proposed by the relationship of ASMR with flow in the seminal paper by Barratt and Davis (2015). This phenomenon has been subsequently noted in the AIWS paper, although no significant correlations between non-visual AIWS symptoms and ASMR age of onset were found (Bedwell & Butcher, 2020). However, it is hypothesised that the insula plays an important role in time perception (Cauda et al., 2013; Craig & Craig, 2009), along with the inferior frontal gyrus (Livesey et al., 2007) and the anterior cingulate cortex (Coull, 2004). Of note, Chapter 5 reports involvement of the anterior cingulate gyrus, inferior frontal gyrus and the insula either in the priming PreRelaxed vs PreBaseline or ASMR vs PreBaseline contrasts. Therefore, if increased neural noise in the insula is responsible for state ASMR, and particularly the loss of time perception quality of ASMR, then I would predict ASMR-responders to be more prone to time-related distortions during high attention tasks. Equally, if a more efficient and accurate functioning of the insula is a result of SSR then I would also predict ASMR-responders to exhibit more accurate temporal perception in general, for example as measured by a simple time estimation task. Moreover, if the insula is implicated, I would expect ASMR-responders to show greater interoceptive abilities compared to controls. Indeed, interoceptive sensibility, the self-evaluated assessment of subjective interoception (Garfinkel et al., 2015), has been shown to positively predict the intensity of ASMR trigger responses (Poerio et al., 2021). Interestingly, this effect was driven primarily by the emotional awareness subscale (measuring awareness of the connection between body sensations and emotional states), which may be related to the enhanced emotion identification capabilities reported in Chapter 4.

Is the Circadian Skew for ASMR Induction Related to Stochastic Resonance?

To my knowledge, no study has investigated how the propensity to experience ASMR relates to the circadian rhythm. Some data suggest that ASMR is most commonly experienced in the evening or before going to sleep (Barratt & Davis, 2015). However, it is impossible to determine whether this trend is due to either an enhanced propensity for ASMR induction towards the end of the day, or simply because the motivation to experience relaxing sensations is more favourable right before going to bed, or both. The stochastic resonance model of ASMR would predict the involvement of the former. It has been shown that cortical excitability increases at night, which coincides with a decrease in cognitive performance and wellbeing (Ly et al., 2016). If the overall cortical excitability increases at night, then it would be even more likely for cross-modal modulatory activity to activate the corticolimbic pathway through stochastic resonance.

Pharmacological evidence

Whilst there have been no investigations into artificially inducing ASMR through behaviour or drugs, there have been reports of transient drug-induced tingling sensations in the head from cocaine (Green et al., 2009) or more generally on opioids (Walsh et al., 2001) and MDMA (Dolder et al., 2018). Similarly, related phenomena such as aesthetic chills can be induced by a wide variety of stimuli in nuanced variations (Bannister, 2019), where population estimates range from roughly half (Huron & Margulis, 2010) to 90% (Bannister, 2020). Furthermore, tingling can arise in us all from a plethora of conditions and processes from mechanical stimulations or even in the absence of stimulation (for a more detailed review see Tihanyi et al., 2018).

6.3.5 Limitations & Future Directions of the Stochastic Resonance Model

There are a number of limitations and shortcomings inherent to the proposed SR model of ASMR. The affected regions proposed here are quite broad as an entire pathway has been proposed. Target regions in the corticolimbic pathway have been specifically mentioned such as the insula, somatosensory cortex and subcortical regions such as the thalamus or brainstem. However, this model aims to provide a framework to direct future investigation into brain regions responsible for generating ASMR. One limitation is the potential difficulty in measuring and/or modulating *endogenous* neural noise. For example, it may not be sufficient to modulate noise added to external stimuli in order to prove brain function depends on internal sources of random noise (McDonnell & Abbott, 2009). Instead, the researcher must identify a way of modulating endogenous variability in noise to determine how this noise affects performance on a task. However, there is some research to suggest that endogenous noise levels for SR can be enhanced by external noise levels, only when endogenous noise levels are lower than the optimal level (Aihara et al., 2008, 2010).

Internal noise levels is also thought to vary widely across subjects as well as within subjects (Aihara et al., 2010). Therefore, effects for analyses averaged across subjects may be underrepresented or subject to high degrees of variability (Kitajo et al., 2003). It is possible that modulating levels of arousal could affect internal noise (WARD, 2004). If this is the case ASMR-experiencers may present an ideal population to more reliably study the effects of stochastic resonance in the brain, by using state ASMR as a tool to indirectly modulate endogenous neural noise levels.

Another limitation is that if and when "noise benefits" are shown in a neural system, it may always be possible for a superior non-noisy system to be more effective, but not efficiently feasible at the network level (for example see Figure 6.2a), or for the degree of redundancies the brain shows in function (McDonnell & Abbott, 2009).

Whilst the SR model of ASMR has been proposed here to explain the shortfalls of the cross-activation model, it should also be noted that these models are not necessarily mutually exclusive. In fact, the "global emotional moment" described in Section 6.2.1 could augment the SR model of ASMR through neural noised induced activation and re-representation.

Testable Predictions

Following the limitations mentioned above and the recommendations of McDonnell & Abbott (2009), the stochastic resonance model of ASMR can be used to make several predictions that can be readily tested.

Firstly, I predict that ASMR-responders will show altered processing and excitability in the touch modality, where the inducing modalities appear anatomically normal, and where altering noise levels in specific regions in the corticolimbic pathway (e.g., the somatosensory/insula cortex) can induce or modulate ASMR. In addition, endogenous neural noise levels in these regions will be statistically different preceding and following state ASMR. These neural noise levels can be measured in a number of ways. For example, using EEG entropy measures that quantify the meaningful structural richness inherent in the brain signals. Multiscale entropy measures have been used for just this purpose in biomedical signals (e.g., refined composite multiscale fuzzy entropy; Azami et al., 2017). Similarly, enhanced neural noise should also be detectable by enhanced brain excitability in the effected regions. For example, if the somatosensory cortex exhibits greater neural noise it should be easier to show a motor response using TMS. Next, the touch modality will be the most sensitive in ASMR-responders. Other sensory modalities will appear anatomically normal and will only show heightened sensitivity in the context of the associated emotional cues. For example, ASMR-responders should exhibit normal auditory sensitivity, however when the cues are associated with a particular valence, (e.g., negative cues in misophonia or positive cues in musical chills) then there will be a greater co-occurrence of these emotional sensory sensitivities in ASMR-responders compared to the general population. This is, in part, supported by higher self-reported co-occurrences of trait ASMR and musical chills/misophonia (see Section 1.3). As proposed by Lalwani & Brang (2019) for synaesthesia, trait ASMR can be acquired at any time. However, as neural noise levels are greater during development (particularly preadolescence), there will be a peak of reports in trait ASMR onset between the ages of 7-11. Similarly, in developmental ASMR-responders, cortical excitability/EEG entropy/excitatory and inhibitory neurotransmitter levels should be able to predict trait ASMR, even before onset of the first ASMR response. Finally, SR in the insula should facilitate lower pain and pleasant touch processing thresholds in ASMR-responders due to the enhanced SR-induced excitability. Similarly, this enhanced excitability in ASMR-responders should also show greater interoceptive capabilities compared to non-responders, e.g., using the heartbeat detection task.

6.3.6 Conclusion

Using the predictions stated in the previous section the stochastic resonance model of ASMR can be extensively validated. This model suggests that both state and trait ASMR are linked in developmental forms of ASMR, and not simply a cross-activation of inducer to touch modalities. The stochastic resonance model of ASMR incorporates recent findings from research on perceptual systems and neuroimaging studies of ASMR-responders to provide a theoretical framework to drive ASMR research forward. Using testable hypotheses, I hope this model builds on prior work and progresses our understanding of the neurological basis of ASMR and the role neural noise in sensory processing in general.

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Appendix

Chapter 3

Table A.1: *Characteristics of ASMR stimuli present in the AEQ*

Main trigger type	Block	Trigger	Author	YouTube URL Suffix youtube.com/watch?v=
Visual	Voiceless	Face touching	ASMRDarling	At4JDrtw8_8
		Drawing	WhispersRed ASMR	VJOD28o5Xac
		Hair brushing	ASMR PPOMO	fpxUn3LH3Io
	Whispered	Folding towels	Gentle Whispering ASMR	RYL9IUEobME
		Face touching	Gentle Whispering ASMR	8IPdgr8MRcI
		Letter tracing	LauraLemurex ASMR	W_G3uF-v1PE&
Auditory	Whispered	Whispering only	ASMRMagic	Z9Wj3a3w8Yk
		Mic brushing	Gibi ASMR	CTH_cEmp6Kw
		Tapping	Gibi ASMR	FidhD-izZnk
		Fabric scratching	LauraLemurex ASMR	LieEUj9penI
	Voiceless	Fabric scratching	LauraLemurex ASMR	BLo8Fs_PidA
		Tapping fast only	ASMR PPOMO	Os6R2nSMic0
		Crinkly paper	Made In France ASMR	LDzu4amxsDo
		Mic brushing	LauraLemurex ASMR	DQgDQ8MFjsk
Simulation	Softly Spoken	Haircut	Gentle Whispering ASMR	gf_MqDBBMPI

Note. Main trigger type specifies the predominant trigger present in the video, and block specifies the presence of whispering layered on top of the ASMR triggers. All URLs were accessed and working 12/12/2018.

Table A.2: *Tingles - Games-Howell Post-Hoc Test*

				Head		
		ASMR-W	**ASMR-S**	**Controls-**	**Controls+**	**False-Positive**
ASMR-W	Mean difference	—	-0.360 ***	0.485 ***	0.383 ***	0.180
	p-value	—	< .001	< .001	< .001	0.162
ASMR-S	Mean difference		—	0.845 ***	0.743 ***	0.540 ***
	p-value		—	< .001	< .001	< .001
Controls-	Mean difference			—	-0.102 **	-0.305 **
	p-value			—	0.002	0.002
Controls+	Mean difference				—	-0.203
	p-value				—	0.061
				Body		
ASMR-W	Mean difference	—	-0.369 ***	0.458 ***	0.4039 ***	-0.138
	p-value	—	< .001	< .001	< .001	0.315
ASMR-S	Mean difference		—	0.827 ***	0.7732 ***	0.231 *
	p-value		—	< .001	< .001	0.017
Controls-	Mean difference			—	-0.0541	-0.596 ***
	p-value			—	0.184	< .001
Controls+	Mean difference				—	-0.542 ***
	p-value				—	< .001
				Intensity		
ASMR-W	Mean difference	—	-0.319 ***	0.344 ***	0.2837 ***	-0.0299
	p-value	—	< .001	< .001	< .001	0.959
ASMR-S	Mean difference		—	0.663 ***	0.6027 ***	0.2890 ***
	p-value		—	< .001	< .001	< .001
Controls-	Mean difference			—	-0.0600 **	-0.3737 ***
	p-value			—	0.002	< .001
Controls+	Mean difference				—	-0.3136 ***
	p-value				—	< .001

Note. * p < .05, ** p < .01, *** p < .001

Table A.3: *Affect - Games-Howell Post-Hoc Test*

		ASMR-W	ASMR-S	Controls-	Controls+	False-Positive
Pleasant						
ASMR-W	Mean difference	—	-0.141 *	0.886 ***	0.180 **	0.513 **
	p-value	—	0.014	< .001	0.001	0.001
ASMR-S	Mean difference		—	1.027 ***	0.321 ***	0.653 ***
	p-value		—	< .001	< .001	< .001
Controls-	Mean difference			—	-0.706 ***	-0.373 *
	p-value			—	< .001	0.021
Controls+	Mean difference				—	0.333 *
	p-value				—	0.045
Calm						
ASMR-W	Mean difference	—	-0.0179	0.126 ***	0.00740	0.289 ***
	p-value	—	0.786	< .001	0.982	< .001
ASMR-S	Mean difference		—	0.144 ***	0.02527	0.307 ***
	p-value		—	< .001	0.388	< .001
Controls-	Mean difference			—	-0.11892 ***	0.163 ***
	p-value			—	< .001	< .001
Controls+	Mean difference				—	0.282 ***
	p-value				—	< .001

Note. * p < .05, ** p < .01, *** p < .001

Table A.4: *Trait - Games-Howell Post-Hoc Test*

		ASMR-W	ASMR-S	Controls-	Controls+	False-Positive
Frisson						
ASMR-W	Mean difference	—	-0.0327	0.103	0.0635	-0.0530
	p-value	—	0.954	0.174	0.579	0.898
ASMR-S	Mean difference		—	0.135 *	0.0962	-0.0203
	p-value		—	0.032	0.177	0.997
Controls-	Mean difference			—	-0.0393	-0.1557
	p-value			—	0.891	0.090
Controls+	Mean difference				—	-0.1165
	p-value				—	0.275
Empathetic						
ASMR-W	Mean difference	—	-0.0639	0.0349	0.0244	0.01706
	p-value	—	0.409	0.883	0.961	0.998
ASMR-S	Mean difference		—	0.0988 *	0.0883 *	0.08097
	p-value		—	0.030	0.048	0.575
Controls-	Mean difference			—	-0.0105	-0.01781
	p-value			—	0.998	0.997
Controls+	Mean difference				—	-0.00729
	p-value				—	1.000

Note. * p < .05

Table A.5: *Trigger - Games-Howell Post-Hoc Test*

				Calming Voices		
		ASMR-W	**ASMR-S**	**Controls-**	**Controls+**	**False-Positive**
ASMR-W	Mean difference	—	-0.0405	0.255 ***	0.114 *	0.0282
	p-value	—	0.897	< .001	0.048	0.983
ASMR-S	Mean difference		—	0.295 ***	0.154 **	0.0687
	p-value		—	< .001	0.003	0.694
Controls-	Mean difference			—	-0.141 **	-0.2268 ***
	p-value			—	0.006	< .001
Controls+	Mean difference				—	-0.0858
	p-value				—	0.427
				Calming Drawing		
ASMR-W	Mean difference	—	0.0195	0.181 ***	0.1000 *	0.00397
	p-value	—	0.976	< .001	0.031	1.000
ASMR-S	Mean difference		—	0.162 ***	0.0805	-0.01548
	p-value		—	< .001	0.098	0.998
Controls-	Mean difference			—	-0.0811	-0.17712 *
	p-value			—	0.135	0.018
Controls+	Mean difference				—	-0.09603
	p-value				—	0.373

Note. * p < .05, ** p < .01, *** p < .001

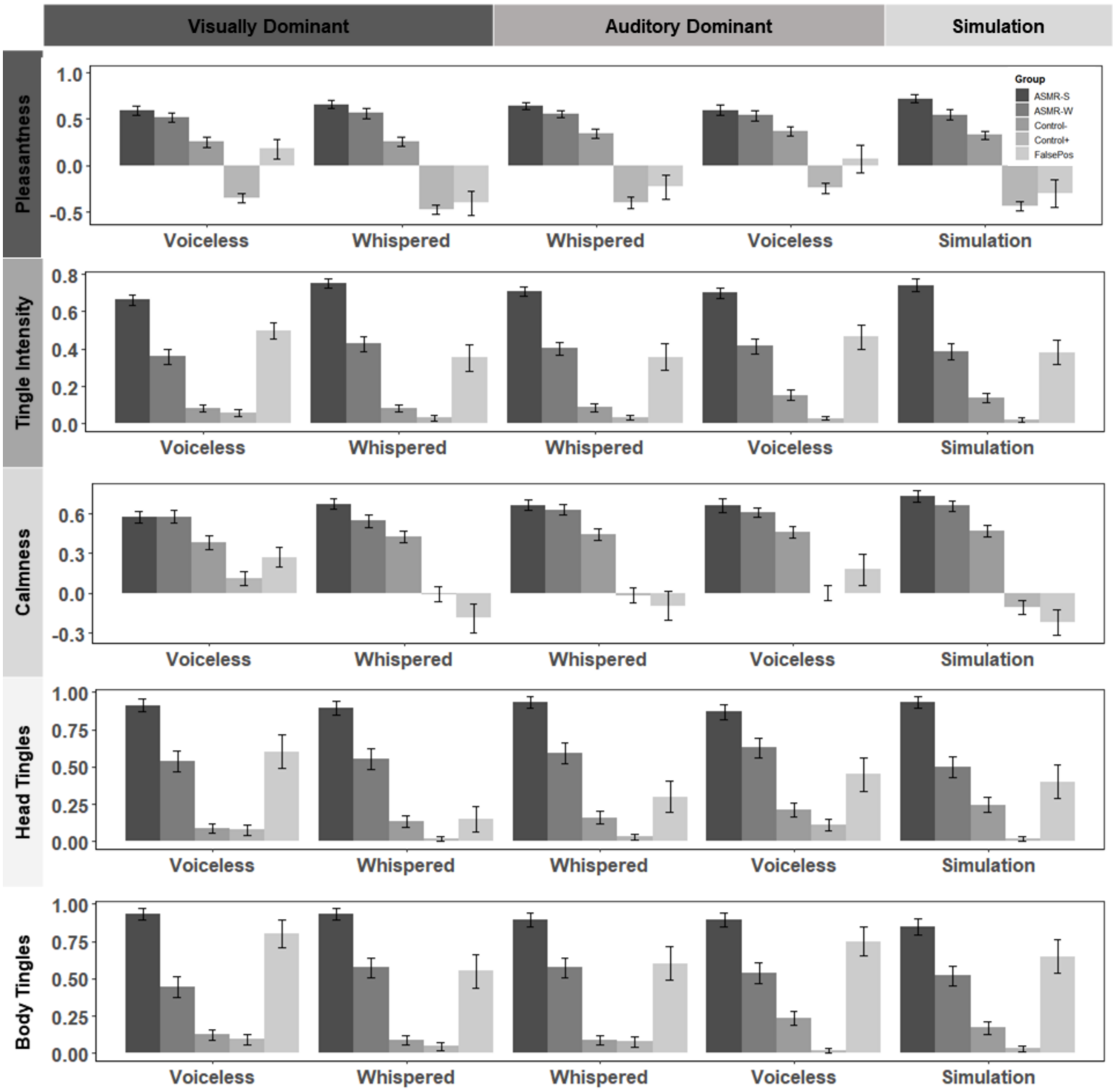
Table A.6: *Body Tingle Location - Games-Howell Post-Hoc Test*

		ASMR-W	ASMR-S		Controls-		Controls+		False-Positive
Neck									
ASMR-W	Mean difference	—	-0.329	***	0.251	***	0.2117	***	-0.0619
	p-value	—	< .001		< .001		< .001		0.938
ASMR-S	Mean difference		—		0.579	***	0.5403	***	0.2667
	p-value		—		< .001		< .001		0.046
Controls-	Mean difference				—		-0.0392		-0.3127
	p-value				—		0.134		0.004
Controls+	Mean difference						—		-0.2736
	p-value						—		0.012
Shoulders									
ASMR-W	Mean difference	—	-0.326	***	0.271	***	0.2455	***	-0.0667
	p-value	—	< .001		< .001		< .001		0.946
ASMR-S	Mean difference		—		0.596	***	0.5710	***	0.2589
	p-value		—		< .001		< .001		0.080
Controls-	Mean difference				—		-0.0251		-0.3373
	p-value				—		0.543		0.006
Controls+	Mean difference						—		-0.3121
	p-value						—		0.012
Upper Back									
ASMR-W	Mean difference	—	-0.166	*	0.158	***	0.1422	***	-0.0214
	p-value	—	0.047		< .001		< .001		0.999
ASMR-S	Mean difference		—		0.324	***	0.3083	***	0.1447
	p-value		—		< .001		< .001		0.482
Controls-	Mean difference				—		-0.0158		-0.1794
	p-value				—		0.734		0.145
Controls+	Mean difference						—		-0.1636
	p-value						—		0.210
Left Arm									
ASMR-W	Mean difference	—	-0.0997		0.137	***	0.12727	**	-0.00159
	p-value	—	0.422		< .001		0.002		1.000
ASMR-S	Mean difference		—		0.237	***	0.22697	***	0.09811
	p-value		—		< .001		< .001		0.649
Controls-	Mean difference				—		-0.00970		-0.13856
	p-value				—		0.686		0.114
Controls+	Mean difference						—		-0.12886
	p-value						—		0.159
Right Arm									
ASMR-W	Mean difference	—	-0.121		0.113	**	0.10584	**	-0.0230
	p-value	—	0.177		0.004		0.009		0.995
ASMR-S	Mean difference		—		0.234	***	0.22697	***	0.0981
	p-value		—		< .001		< .001		0.626
Controls-	Mean difference				—		-0.00676		-0.1356
	p-value				—		0.914		0.127
Controls+	Mean difference						—		-0.1289
	p-value						—		0.159

				Neck				
		ASMR-W	**ASMR-S**	**Controls-**		**Controls+**		**False-Positive**
ASMR-W	Mean difference	—	-0.111	0.0775	**	0.0503		0.0115
	p-value	—	0.140	0.003		0.201		0.999
ASMR-S	Mean difference		—	0.1882	***	0.1610	**	0.1222
	p-value		—	< .001		0.005		0.204
Controls-	Mean difference			—		-0.0272		-0.0660
	p-value			—		0.271		0.415
Controls+	Mean difference					—		-0.0388
	p-value					—		0.851
				Lower Body				
ASMR-W	Mean difference	—	-0.0584	0.0548	*	0.0347		0.04960
	p-value	—	0.437	0.038		0.462		0.152
ASMR-S	Mean difference		—	0.1133	**	0.0932	*	0.10804
	p-value		—	0.003		0.028		0.008
Controls-	Mean difference			—		-0.0201		-0.00523
	p-value			—		0.349		0.992
Controls+	Mean difference					—		0.01486
	p-value					—		0.857
				Lower Back				
ASMR-W	Mean difference	—	-0.111	0.0775	**	0.0503		0.0115
	p-value	—	0.140	0.003		0.201		0.999
ASMR-S	Mean difference		—	0.1882	***	0.1610	**	0.1222
	p-value		—	< .001		0.005		0.204
Controls-	Mean difference			—		-0.0272		-0.0660
	p-value			—		0.271		0.415
Controls+	Mean difference					—		-0.0388
	p-value					—		0.851

Note. * p < .05, ** p < .01, *** p < .001

Figure A.1: *5-cluster grouping scores of individual videos labelled by stimuli type*



Mean scores of the cluster variables Head (presence of tingles in the head), Body (presence of tingles anywhere in the body except the head) and absolute Calm, Pleasantness and Intensity (mean score of Peak and average intensity scores) are presented. Each column represents one of the five video blocks displayed in Supplementary Table 1. Error bars represent SEM. 2-Cluster groupings are ASMR-Responders (ASMR-S, ASMR-W) and non-Responder (Control+, Control-, False-Positive). ASMR-R represents ASMR-Responders; ASMR-S represents ASMR-Strong; ASMR-W represents ASMR-Weak.