Altered states of Ganzfeld: A systematic review

Abstract

The Ganzfeld experiment appears as a uniform and unstructured field that may measure altered states of consciousness. The experiment uses a dim light frequency projected on translucent eye covers combined with a static audio frequency emitted through a pair of headphones. Since altered states and alpha interactions appear in Ganzfeld studies, the hypothesis here states that they may be internally related. Therefore, the extraction filtered EEG data from combined stimulations of light and static sound for their implications on consciousness. The systematic search included PubMed, Scopus, Medline (OVID), and the Web of Science databases to gather data. Between January 2000 and January 2022, only four controlled trials studied the Ganzfeld-EEG stimulation. The results verify the role of alpha interactions during hallucination-like imagery. Furthermore, this review highlights a significant gap in Ganzfeld-induced altered states of consciousness research.

Keywords – Altered, Consciousness, EEG, Ganzfeld, Hallucination, Systematic Review

1. Introduction

Prolonged exposure to the Ganzfeld experiment induces altered states of consciousness resulting from sensory deprivation (Ben-Soussan et al., 2019; Glicksohn et al., 2019; Kübel et al., 2020; Pütz et al., 2006; Schmidt & Prein, 2019; Schmidt et al., 2020; Wackermann et al., 2008). Research shows that dissociative imagery (Ben-Soussan et al., 2019; Miskovic et al., 2019), hallucination-like symptoms (Rogers et al., 2020; Voges et al., 2015; Wackermann et al., 2008), and thalamocortical decoupling that provokes alpha band brainwaves (Schmidt et al., 2020; Sumich et al., 2018) are common characteristics of Ganzfeld. However, the relationship between mental imagery and the frequency of hallucinations remains unclear (Sumich et al., 2018). Thus, a systematic review that consolidates the scientific literature of imagery formation during alpha activity may provide insights into the frequency of hallucinations.

This review further explores Ganzfeld because the development of visual imagery can be a powerful tool for exposing underlying mechanisms within the visual environment (Yu et al., 2015). In the apparatus, red light is reportedly emitted on the cavities of Ping-Pong balls over the eyes to facilitate immersion (Kübel et al., 2020; Miskovic et al., 2019; Pütz et al., 2006; Schmidt & Prein, 2019; Schmidt et al., 2020; Wackermann et al., 2002). The static sound of a waterfall (Pütz et al., 2006; Wackermann et al., 2002), pink noise (Miskovic et al., 2019), or a related frequency (white/violet/brown noise; Schmidt & Prein, 2019) played through headphones may be used in combination to achieve sensory deprivation. Although there is no consensus about the most effective light and sound modality for altering consciousness (e.g., Bartossek et al., 2021; Kübel et al., 2020).

1.1. Altered States of Consciousness Framework

In 2019, Miskovic et al. noted mild dissociation in a Ganzfeld pilot study caused by spatial disorientation. Erdelyi (2004) defined state-dissociation as a subliminal perception that can “wax and wane and, even, reverse over time”. Subsequently, spatial disorientation manifests as "a misinterpretation of an experience of sensory perception, especially a visual one… the mistaken perception is due to physical rather than psychological causes” (Sánchez-Tena et al., 2018). During sensory deprivation, these kinds of altered states may appear as dreamlike imagery (Pütz et al., 2006; Wackermann et al., 2002) or distortions of experience (Ben-Soussan et al., 2019; Glicksohn et al., 2019; Schmidt & Prein, 2019). In people more susceptible to psychotic-like experiences, Daniel & Mason (2015) observed a higher frequency of hallucinations during sensory deprivation.

Blocking sensory input may stimulate alpha band interactions (Schwenk et al., 2020; Glicksohn et al., 2019; Samaha & Postle, 2015; Wackermann et al., 2002) and impact visual cortex excitability (Berezovsky et al., 2021; Rangaswamy et al., 2007; Samuel et al., 2018; Zazio et al., 2019). In light of such specific neurophysiological developments, Ganzfeld’s homogeneous perceptual stimulation (Kübel et al., 2020; Schmidt & Prein, 2019; Sumich et al., 2018; Wackermann et al., 2008) requires a systematic investigation. Computational models and functional magnetic resonance imaging (fMRI) data suggest that orientation biases in the visual cortex may be present during predictive processing (Roth et al., 2018). The resulting "sensitivity to second-order changes" affects neuronal responses and creates a vignetting phenomenon in the presence of light as a stimulus. This particular altered state may exhibit pseudo-orientation tuning.

Conversely, there is a significant amount of evidence supporting the effects of light for cortical orientation tuning (Shinhmar et al., 2021; Roth et al., 2018; Carlson, 2014). In an imagery adaptation paradigm, Voges et al. (2015) found improved spatial adaptations and implicit consolidated motor memory after repeated light-induced Ganzfeld trials compared to free viewing of the surroundings. These changes may attribute to retinal mechanisms of spatial orientation or a stable visual stimulus. Lacquaniti et al. (2015) further confirmed that the brain could take advantage of a structured environment and improve spatial and temporal estimates of current events. They demonstrated that predictive behaviour might improve perception through probable stimuli.

If perceptual interactions manifest as spatial disorientation or improve spatial adaptations over time is purely speculative. Although, it is noteworthy that the resulting effect creates hallucination-like symptoms in Ganzfeld (Rogers et al., 2020; Voges et al., 2015; Wackermann et al., 2008). Hence, this literature is vital for understanding the frequency of predictive hallucinations. In order to fully utilise the framework, predictive hallucinatory interactions must be clarified first. Thenceforth, we can correlate Ganzfeld-induced mental activity with the resulting neural activity.

1.2. Multimodal Ganzfeld Experiments (MMGF) Until Now

Stimulating the brain with different light and sound frequencies is known as multimodal Ganzfeld experiment (MMGF; Schmidt & Prein, 2019; Pütz et al., 2006). Ganzfeld regained attention in the scientific studies of consciousness in the 21st century after its initial inception in 1930 by Wolfgang Metzger (Schmidt & Prein, 2019). These experiments examine predictive hallucinatory interactions in sleep laboratories primarily (Kübel et al., 2020; Pütz et al., 2006; Wackermann et al., 2008; Wackermann et al., 2002). Participants are prepared in advance to expect dreamlike imagery through alterations in colours, shapes, scenes, figures and forms. In a controlled setup, the underlying hallucinatory illusions may be closely related to fantasy proneness instead of hallucinatory predispositions (Daniel & Mason, 2015).

Moreover, Miskovic et al. (2019) recorded that the brain may create alterations in the absence of meaningful perceptual inputs due to diminished alpha-blocking. From Roth et al. (2018) and Lacquaniti et al. (2015), we know that light-driven predictive processing during spatial orientation plays a role in perception. At the same time, static sound may stimulate dopaminergic mid-brain regions and the right superior temporal sulcus to facilitate learning and functional connectivity (Angwin et al., 2017; Herweg & Bunzeck, 2015; Rausch et al., 2014). In addition to dopamine release, Baijot et al. (2016) suggested that white noise may be specific for improving vigilance.

Tsuji et al. (2004) and Kübel et al. (2020) recorded significant levels of increased or decreased self-awareness when red light was used. Additionally, red flashes on a blue background may be most effective when isolating photopic negative responses from the inner retina (Berezovsky et al., 2021; Rangaswamy et al., 2007). Other interactions of red light induced altered states could decrease cortical arousal (Ben-Soussan et al., 2019; Le & Silverman, 2011) or improve mitochondrial function when exposed for three minutes in the morning for one week (Shinhmar et al., 2021).

On the other hand, Bartossek et al. (2021) observed relaxation using white light, whereas, Kübel et al. (2020) observed green light and brown noise modality to induce relaxation. Schmidt & Prein (2019) found that the overall level of absorption induced by white noise is higher than other noise frequencies (violet and brown) in MMGF. More particularly, white noise can independently evoke auditory hallucinations (Schepers et al., 2019; Schmidt & Prein, 2019). 47.2% of patients with a psychotic disorder reported two or more white noise speech illusions, followed by 37.1% of their siblings and 41% of the general population (n=4068; Schepers et al., 2019). Secondly, they may not signal an increased risk in a non-clinical sample. In Akiyama et al. (2020) neonates' study, white noise interactions at alpha-theta bands were significantly pronounced compared to music interactions and no intervention controls.

Based on these findings, MMGF-driven functional connectivity may interact with self-awareness, thalamocortical and mitochondrial function, relaxation and absorption. Seemingly, the subsequent dopaminergic responses and hallucinations appear enhanced during rest-state. It is worth mentioning that subjective reports of Ganzfeld imagery appear similar to hypnagogic hallucinations, but their neurophysiological markers are distinct (Sumich et al., 2018). They are observable through EEG-recorded brainwaves, namely delta (1.5–6 Hz δ), theta (6–8 Hz θ), alpha (8–10 Hz α1 & 10–12 Hz α2), beta (12–18 Hz β1, 18–21 Hz β2, & 21–30 Hz β3), and gamma (> 30 γ) (Akiyama et al., 2020; Ben-Soussan et al., 2019; Pütz et al., 2006; Koudelková & Strmiska, 2018).

1.3. Alpha Band and Thalamic Interactions

Amongst the five distinct bands of brainwaves, alpha interactions may play an extensive role in cognitive and sensory information processing (Samuel et al., 2018). Alpha-induced imagery may inversely relate to cortical activation in the brain's frontal asymmetry, which marks threat avoidance tendencies (Heffer & Willoughby, 2020). The context within which a stimulus appears tends to modulate the associated perception (Yu et al., 2015). Here, memory content retrieval, activation and embedding can be traced back to the thalamocortical feedback loops of alpha activity (10-12 Hz) through Ganzfeld imagery (Le & Silverman, 2011).

In 2020, Schwenk suggested that local inhibitory feedback loops may generate alpha oscillations in the visual cortex. Additionally, Vijayan & Kopell (2012) highlighted alpha oscillations as a product of the thalamus or a combination of the thalamus and the neocortex. Furthermore, simultaneous examination of alpha oscillations from in vivo studies indicated that a small fraction (10-30%) of thalamocortical cells show high threshold bursts at the alpha frequency when exposed to specific agonists (Heffer & Willoughby, 2020).

Moreover, beta rhythms may accompany neocortical alpha rhythms and not occipital alpha rhythms as per the mu rhythm model (Vijayan & Kopell, 2012). According to the model, Vijayan & Kopell (2012) suggested that the mu rhythm, which is a mixture of alpha and beta neocortical rhythms over the somatosensory cortex, fundamentally differs from the occipital rhythm, as a beta rhythm does not accompany occipital rhythms. After consolidating these findings, it is evident that interactions in the altered states' framework are speculative but tend to exist in some form.

1.4. The Present Study

To summarise, the literature observes a significant gap in the research. A limited number of experiments examined the associated functional connectivity through EEG in MMGF (e.g., Ben-Soussan et al., 2019; Gerding et al., 2012; Glicksohn et al., 2019; Le & Silverman, 2011; Miskovic et al., 2019; Sumich et al., 2018; Pütz et al., 2006; Voges et al., 2015; Wackermann et al., 2002). In consequence, scientific studies of light and sound are inexhaustive independently, but their combined effects have not been rigorously researched. Our investigation found that MMGF may induce altered states of consciousness (hereafter, ASC). It could additionally aid as a model to study audio-visual hallucinations, dissociation and psychotic experiences (Pütz et al., 2006; Schmidt & Prein, 2019; Schmidt et al., 2020; Wackermann et al., 2008).

Therefore, the aim is to review Ganzfeld-EEG as a tool to measure the presence of conscious interactions. Based on previous studies, the hypothesis states that ASC may internally correlate with alpha activity during sensory deprivation. In addition, the light and sound modalities found during synthesis would be an important factor for gaining insights about hallucinations.

Also, sensory deprivation and perceptual deprivation have been used interchangeably due to their similarities in producing mental imagery, which appear in the literature as (pseudo)hallucinations or audio/visual percepts (Schmidt & Prein, 2019; Wackermann et al., 2002). Apart from extracting and synthesising the evidence from previously conducted Ganzfeld-EEG studies, the review discusses the implications of the probable stimuli. Reportedly, this is the first systematic review conducted to observe the effects of Ganzfeld on consciousness.

2. Materials and Methods

This review adheres to the guidelines of the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA; Moher et al., 2009). In addition, the review was prepared and revised according to the PRISMA checklist (Moher et al., 2009). Furthermore, Cochrane Collaboration’s Tool (Higgins et al., 2011) assesses the risk of biases of the controlled trials.

2.1. Search Strategy

In February 2022, the systematic search included PubMed, Scopus, Medline (OVID) and the Web of Science databases. The timeline included studies conducted between January 2000 to January 2022. Systematically, the search strategy looked for controlled trials in English that examined brainwaves and the associated mental imagery in the Ganzfeld experiment. Keywords searched to identify the inclusion of EEG were “Electroencephalogram", "Electroencephalography", or "EEG”. As the next step, these words intersected with “Ganzfeld” in the title and abstract. The search was limited to controlled trials that were full-text and peer-reviewed.

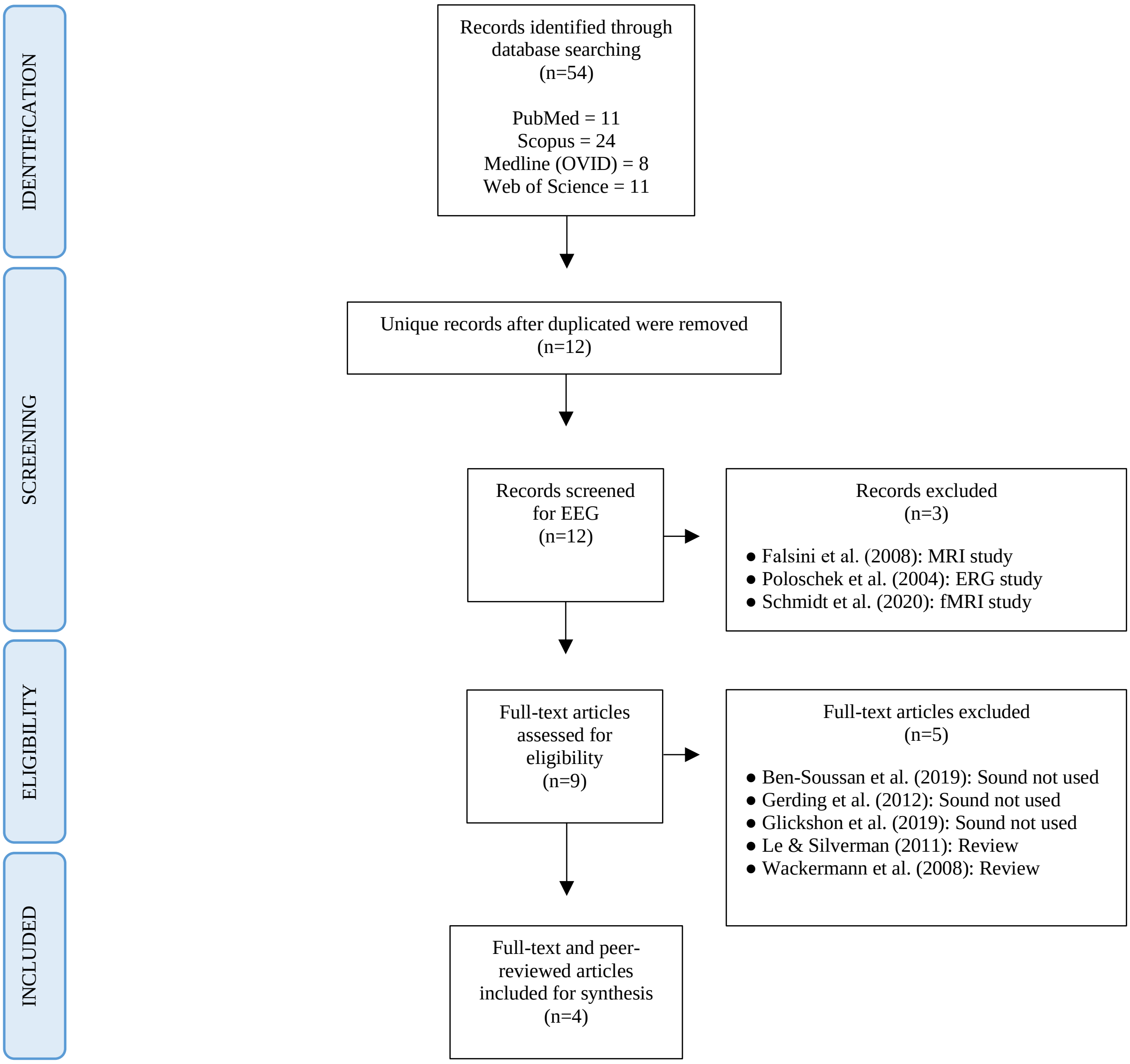
2.2. Inclusion and Exclusion Criteria

Only studies that selected human participants are included. The inclusion criteria checked for controlled trials that examined electroencephalogram (EEG) data. Additionally, the criteria included only the controlled trials that used light and static sound frequencies for immersion into MMGF. The selected studies were required to incorporate an experimental design.

All the controlled trials are examined for relevance, eligibility and quantifiable data. Physiological measures, except EEG, are excluded since the criteria filtered the controlled trials specifically to study neural activities. The ineligible studies were either reviews or did not study a combined light and sound modality. Moreover, this systematic review does not refer to any article published before 2002 to maintain relevance. Reasons for exclusion and an overview of the selection process can be found in figure 1.

Figure 1

Flowchart of the Selection Process



3. Results

The controlled trials found replicated the Ganzfeld-EEG experiment under the red light condition in combination with a static sound frequency of a waterfall or pink noise. The impact of the halved Ping-Pong balls and the light diffusing goggles were not discussed in detail. All the controlled trials studied the subjective experiences of hallucinatory imagery along with the behaviour of alpha band brainwaves.

3.1. Descriptives of the Experimental Designs

Four articles passed the final screening. One hundred and eighty-seven MMGF-EEG sessions were conducted in total. Phase 2 participants from Pütz et al. (2006) were excluded from the total since the participants were selected from phase 1. Combined, Miskovic et al. (2019) and Wackermann et al. (2002) had ninety-eight independent control conditions. Sumich et al. (2018) studied fear and serenity soundtracks during flicker-Ganzfeld and used the pink noise modality as a control instead. The descriptives of the extraction are recorded in table 1.

Table 1

Descriptives of the Extraction

Study	**Sample Size (n)**	**Selected Sample of n**	**Removed Sample of n**	**Mean Age**	**MMGF**	**Control Conditions**	**Total Ganzfeld Sessions**	**Total Control Sessions**	**Total MMGF-EEG Sessions**
Miskovic et al. (2019)	22	8F+11M =19	Hardware error - 3	23.18	1	2	19	38	19
Pütz et al. (2006)	40	Phase 1: 28F+11 M=39; Phase 2: 7F**	Phase 1: Anti-depressant - 1 Phase 2: Low mentation responses - 32**	Phase 1: 39; Phase 2: 49.2	Phase 1: 2; Phase 2: 3	Phase 1: No EEG	Phase 1: (39x2) + Phase 2: (7x3) =99	78	21
Sumich et al. (2018)	46	29F+16 M=45	Outlier with 500+ reported imagery - 1	24.15	3	Flicker-Ganzfeld + Pink noise	135	45	135
Wackermann et al. (2002)	17	12F	Low alpha activity - 5	33.3	1	5	12	60	12
Total	125	115	10	32.45	10	7	265	221*	187

F – female, M – male, MMGF – multimodal Ganzfeld experiments

****Phase 2 is not included in the total**

***Total Non-MMGF + non-EEG = 98 control sessions**

3.2. Experimental Conditions

All four studies probed predicted imagery during Ganzfeld conditions to some extent. Miskovic et al. (2019) suggested colour and perception induced imagery. Pütz et al. (2006) familiarised the participants with Ganzfeld and observed any onset of imagery during phase 1. Vivid imagery and inner perceptions were ascribed to the experiment, but participants who did not experience them were told to expect them at later stages. Sumich et al. (2018) described simple and complex images, humanoid figures and scenery. To reduce priming effects, they also asked the participants to expect other types of imagery. On the other hand, Wackermann et al. (2002) inquired about mental activity and guided imagery during the experiment through on-demand mentation reports via intercom channels. The experimental conditions are elaborated in table 2.

Table 2

Summary of Experimental Conditions

Study	Control Conditions	MMGF Duration	MMGF Conditions	Physiological Measurements	Self-Reports
Miskovic et al. (2019)	Eyes closed in a dark room, changing shapes on a dark screen	10 m	Uniform red light, pink noise via headphones, halved Ping-Pong balls as eye covers	EEG & a button press	Qualitative self-reports (encoded form, movement, colour & boundary fusion), written mentation transcribed to a digital format
Pütz et al. (2006)	Phase 1: MMGF Screening 1 – 20 m (no EEG), screening 2 – 30 m (button press); Phase 2: MMGF 45 m (EEG)	45 m (60-75 net)	Uniform red light, waterfall sound via headphones, translucent anatomical goggles as eye covers,	EEG, vertical electrooculogram (right eye), electromyogram, electrocardiogram, respiration & a button press	Qualitative structured reports (pre-experiment mental and somatic status & MMGF inquiry), mentation tape recorded
Sumich et al. (2018)	Pink noise	20 m 30 s	Flickering red light, fear and serenity soundtracks via earphones, cardboard panel eye frames, light diffusing goggles	EEG & a button press	Qualitative self-reports, 32-item Cardiff Anomalous Perception Scale, 35-item Betts' questionnaire on mental imagery, 60-item Positive and Negative Affect Schedule-Expanded Form, mentation audio recorded
Wackermann et al. (2002)	Wakefulness before sleep onset, sleep onset, sleep stage 1, sleep stage 2, relaxed waking, daytime waking	30-40 m (90-120 net)	Uniform red light, waterfall sound via headphones, halved Ping-Pong balls as eye covers	EEG & a button press	Qualitative on-demand inquiry, 46-items mentation reports, mentation tape recorded

MMGF – multimodal Ganzfeld, EEG – electroencephalogram, s – seconds, m – minutes, h – hours
Note - Net time includes interruptions for reporting and inquiry.

3.3. Ganzfeld-EEG Records

Trait alpha was a significant predictor for audio-visual imagery (Pütz et al., 2006; Wackermann et al., 2002). However, only Sumich et al. (2018) used standardised self-reporting questionnaires to investigate the subjective experiences of accelerated alpha activity. On the whole, protocols were set to remove excessive artefacts and EEG data correlated with the altered states of the participants (Miskovic et al., 2019; Pütz et al., 2006; Sumich et al.; Wackermann et al., 2002). Furthermore, alpha activity was sensitive to the presence or absence of mental imagery (Miskovic et al., 2019). There was a significant acceleration of 10-12 Hz alpha activity in the absence of imagery. A decrease of 8-10 Hz alpha activity with a subsequent increase of 6-10 Hz beta activity marked the presence of mental imagery (Pütz et al., 2006). The detailed qualitative and quantitative reports of the studies are recorded in table 3.

Table 3

Summary of MMGF Reports

Study	MMGF Self-Reports	MMGF-EEG Reports
Miskovic et al. (2019)	Boundary fusion was achieved. Geometric and amorphous visual forms were reported. State-dependent sporadic imagery was achieved.	Upper parieto-occipital alpha accelerations (10-12 Hz). Opening the eyes blocked theta activity (6-10 Hz) - no decrease in brain arousal. Faster alpha oscillations correlated with higher perceptual fading episodes. No difference between MMGF and eyes closed conditions. (all $p_{perm} < 0.05$)
Pütz et al. (2006)	Phase 1: Gradually evolving perceived imagery (65.9%) associated with longer pre-response interval ($r = -0.17$), 'sudden' imagery (34.1%), distinctness of imagery ≥ '4' –clear (80.5%) and reality character of imagery ≥ '4': - real (64.6%) correlated ($r = +0.602$). Sleepiness ≤ '2' – awake (67.1%). Relaxation ≥ '4' – relaxed (61.0%). Several reports correlated with self-reported alertness ($p < 0.04$). Clearness or imagery correlated with relaxation before experimentation ($p < 0.004$). The vividness of imagery correlated with life events ($p < 0.002$). Negative mood reported before experimentation correlated with sleepiness during imagery ($p < 0.005$).; Phase 2:	The decline in alpha power (8-10 Hz) in parietal regions during image formation correlated with an increase in the beta frequency band. There were accelerations in alpha (10-12 Hz) when no imagery occurred. Overall beta accelerations (18-30 Hz) and centro-parietal delta (1.5-6 Hz) were observed 10 seconds before presenting mentation reports.

	Post hoc review confirmed well-structured audio-visual percepts.	
Sumich et al. (2018)	Men reported higher number of imagery than women. Positive schizotypy correlated with imagery in flicker Ganzfeld. Positive and Negative Affect Schedule-Expanded Form recorded significant levels of mood induction across all 3 MMGF (repeated measures analysis of variance; p<0.001)	Lower alpha (13.1-16 Hz) inversely related to perceptual anomalies and flicker-Ganzfeld-induced imagery. Simple and complex imagery strongly correlated with occipital alpha compared to frontal alpha. Flicker frequency was significant during alpha activity (p<0.001).
Wackermann et al. (2002)	Visual percepts present (91.9 sleep stage 1, 90.4 % - MMGF). Auditory percepts present (48.6 – sleep stage 1, 28.8 % - MMGF). No decrease in vigilance (46-item mentation report - MMGF).	Overall alpha (8-12 Hz) accelerated compared to other waking states. No signs of decreased vigilance of alpha acceleration in MMGF.

MMGF – multimodal Ganzfeld experiments

3.4. Qualitative Analysis

The experimenters maintained significant control over the recorded mentation reports in all the trials. Mental activity reports collected through interviews and on-demand mentation might not be adequate since ASC could be over-reported or under-reported. However, the extraction recorded more visual imagery than auditory imagery during alpha activity. In comparison, there were contrasting effects of uniform red light and flickering red light. The low alpha activity was equated with imagery formation in all the trials. However, Pütz et al. (2006) observed uniform-Ganzfeld imagery at 8-10 Hz, while Sumich et al. (2018) ascribed flicker-Ganzfeld imagery at 13-16 Hz.

3.5. Risk Analysis

In retrospect, the sample size was relatively small to generate generalisable data. Some of the participants in Pütz et al. (2006) and Wackermann et al. (2002) were the same, which may cause desirability biases since participants were familiar with the researchers and MMGF. Miskovic et al. (2019) recruited twenty-two participants but did not mention the final count of male and female participants after excluding three participants. We may assume the study consisted of eight females till the end, as no updated records were mentioned. Since the extracted data either recruited volunteers internally or provided paid participation, sampling methods may have influenced segregation biases. Furthermore, the studies did not consider cultural differences.

Intentional interruptions with on-demand reports and task performance might have resulted in false positives. Alternatively, participants' expectations could increase the chances of misrepresentations. In contrast, pressing a button when a perceptual alteration occurs may prevent participants from reaching deeper states of ASC since staying alert was required. Furthermore, the response criterion, i.e., the tendency to lean towards the extremes, is a subsequent limitation in sensory deprivation studies (Zazio et al., 2019).

While Pütz et al. (2006) noted that using the mentation reports failed to provide optimal results, Miskovic et al. (2019) used an outdated assessment scheme from 1975 by Siegel et al. to code the qualitative data. Pütz et al. (2006) and Wackermann et al. (2002) used original assessments, where decoding the lexicon may be difficult. For example, the difference between the meaning of "thoughts" and "perceptions" may be confounded in the mentation reports by Wackermann et al. (2002). Table 4 further assesses the risk of biases through Cochrane Collaboration's Tool (Higgins et al., 2011).

Table 4

Cochrane Collaboration's Tool for Risk of Bias Assessment

Bias Domain	**Source of Bias**	**Support for Judgement**	**Review Author's Judgement (assess as low, unclear or high risk of bias)**
Selection Bias	Random sequence generation	**Miskovic et al. (2019) -** Quota sampling was used. Volunteers were recruited from the university at which the experiment was conducted.	Unclear
		Pütz et al. (2006) - Simple random sampling was used. Volunteers were recruited from local newspaper ads and Wackermann et al. (2002).	Low
		Sumich et al. (2018) – Detailed selection procedure is not available.	High
		Wackermann et al. (2002) - Simple random sampling was used. Volunteers were recruited from local newspaper ads.	Low
	Allocation concealment	**Miskovic et al. (2019) -** The same participants also participated in the control settings.	High
		Pütz et al. (2006) – Seven participants were hand-selected based on the mentation reports for phase 2.	High
		Sumich et al. (2018) – The same participants also participated in the control settings.	High
		Wackermann et al. (2002) - The same participants also participated in the control settings.	High
Performance Bias	Blinding of participants and personnel*	**Miskovic et al. (2019) -** Experimenters were significantly involved and constantly communicated with the participants. Participants were wearing eye covers during most of the experimentation.	Low
		Pütz et al. (2006) - Experimenters collected mention reports through recording devices. Participants were wearing eye covers.	Low

		Sumich et al. (2018) – Experimenters collected mention reports through recording devices. Participants were wearing eye covers.	Low
		Wackermann et al. (2002) – Experimenters were significantly involved and constantly communicated with the participants. Participants were blinded, and the experimenters spoke via intercom.	Low
Detection Bias	Blinding of outcome assessment*	**Miskovic et al. (2019) –** No precise detection of imagery and interacting alpha sub-band.	Unclear
		Pütz et al. (2006) - The blinding was adequate as the electrograms recorded minute changes over a brief period.	Low
		Sumich et al. (2018) - The blinding was adequate as the electrograms recorded minute changes over a brief period.	Low
		Wackermann et al. (2002) - No precise detection of imagery and interacting alpha sub-band.	Unclear
Attrition Bias	Incomplete outcome data*	**Miskovic et al. (2019) -** Twenty-two participants were recruited, but the final segregation between male and female participants was not reported after three participants were removed. EEG contamination due to artefacts was found. Initial screening criteria were established to remove participants with photopic epilepsy and motion sickness.	High
		Pütz et al. (2006) - Forty participants were recruited. One participant using anti-depressants was removed. EEG data retrieved from seven "high responders" was selected during the initial screening for phase 2. Effects may be observed due to the participants who provided a relatively high number of mental activity reports, i.e., "high responders".	Unclear
		Sumich et al. (2018) – An outlier was identified. Artefacts were structurally removed. Failures to generate significant data were systematically noted.	Low
		Wackermann et al. (2002) - Seventeen participants were recruited. Five participants were removed because of low alpha activity. The inclusion criteria were reported, and only participants with good health, no medication, no reported sleep disorders, no neuropsychiatric pre-history and a well pronounced alpha rhythm were included.	Low
Reporting Bias	Selective Reporting	**Miskovic et al. (2019) -** Brief experiment. Speculative reporting.	High
		Pütz et al. (2006) – Participants were classified as "high responders" based on subjective mental activity reports.	High
		Sumich et al. (2018) – Four electrode channels were studied to minimise data inflation. Quantifiable reporting was adequate.	Low
		Wackermann et al. (2002) – Multiple controls assessed simultaneously. Quantifiable reporting was adequate.	Low
Other Biases	Anything else, ideally prespecified	**Miskovic et al. (2019) -** Small sample size. Brief experiment. Evaluation and experience of the EEG technicians. Guided inquiry.	High
		Pütz et al. (2006) – Small sample size. Evaluation and experience of the EEG technicians. Unstandardised self-reports.	High

		Sumich et al. (2018) - Small sample size. Evaluation and experience of the EEG technicians.	High
		Wackermann et al. (2002) – Small sample size. Overnight experimentation. Evaluation and experience of the EEG technicians. Guided inquiry. Unstandardised self-reports.	High

***Assessments made for each main outcome.**

4. Discussion

Based on the literature, we can distinguish alpha-induced ASC in Ganzfeld via EEG channels. In comparison, all the extracted studies recorded alpha band activity and subjective reports of audio-visual alterations across various time frames. The self-reports suggested that ASC may be relaxing. MMGF’s immersive relaxation (Miskovic et al., 2019; Pütz et al., 2006; Wackermann et al., 2002) and serenity-induction (Sumich et al., 2018) correlated with overall alpha interactions. Conversely, variables independent of MMGF-EEG may create alterations (Schmidt & Prein, 2020) which predisposes the studies to several limitations.

4.1. Limitations of the Experimental Design

The extraction was limited to English. There were no randomised controlled trials on MMGF-EEG identified during screening. Indeed, overlooked limitations of the extraction might impair the overall quality of the systematic review to a certain extent. Although this review identified a significant gap in the literature for large sample studies, the filter removed physiological measures except EEG to emphasise neural interactions. The evidence may not be strong to formulate generalisable data yet. Nonetheless, it can pave the way for further research.

Alongside, this review is limited to the internal consistency of the controlled trials for qualitative synthesis. However, to reduce the number of limitations, the systematic process followed the guidelines provided by the PRISMA statement (Moher et al., 2009). Additionally, risk of biases segregated as “low, unclear or high” report the overall findings. The inability to identify medium-risk biases is a limitation of Cochrane Collaboration’s Tool (Higgings et al., 2011), which makes this systematic review vulnerable to ambiguity.

4.2. Implications

Our brains may create meaning during neutral sensory inputs (Schepers et al., 2019), which might have significant implications for consciousness research. MMGF’s uniform and unstructured field may be used as an additional tool to accelerate alpha activity for individuals with disorders of consciousness recovering from memory impairments. Improved predictive processing during orientation tuning tasks implicates the interaction of light as a probable stimulus (Lacquaniti et al., 2015; Roth et al., 2018). Parallel to light, sound may stimulate dopaminergic brain regions and aid memory (Angwin et al., 2017; Herweg & Bunzeck, 2015; Rausch et al., 2014). Although light and static sound have been individually observed for their advances with clinical samples, MMGF has been implemented only with healthy participants. More research is required to establish decisive implications for combined external inputs through zero and intentional interruptions.

Alpha firings in the peak or the trough are conditional (Vijayan & Kopell, 2012) and relative to individual differences (Samaha & Postle, 2015). MMGF did not dampen alertness but trait alpha peaking frequencies correlated with the frequencies of perceptual alterations (Miskovic et al., 2019). Hence, combined red light and static sound frequencies may help specific individuals regulate visual cortex excitability and facilitate learning by training alpha interactions. However, the high and unclear risk of biases implicates the need for higher powered and quality experimental procedures.

4.3. Recommendations for Further Research

Recognising the physiological mechanisms of central and peripheral vision is influential for managing and rehabilitating different kinds of patients, such as those suffering from age-related macular degeneration or glaucoma (Yu et al., 2015). MMGF produced more visual percepts than auditory percepts during alpha accelerations (Wackermann et al., 2002) which may have scope for future explorations in cognitive neuroscience. Additionally, more research is required to identify if Ganzfeld stimulation would benefit sensory, short-term, long-term and/or working memory. Exposure to perceptual deprivation for people experiencing hallucinations could help understand the interactions between the frequency of hallucinations and the nature of disorders such as psychotic disorders and schizophrenia through self-reports (Schepers et al., 2019; Schmidt & Prein, 2019).

Erdelyi (2004) notes that data may be available but not readily accessible in the dissociation paradigm, causing gaps in construct validity. This systematic review recommends that researchers conduct structured randomised control trials of MMGF to bridge the gap, and increase validity and ethical certainties. MMGF may be a safe and stable apparatus to measure the long-term effects of altered states and alpha accelerations, but the limited number of studies raises ethical concerns. Ultimately, holistically assessed subjective interactions and responses to stimuli can help detect and measure higher states of consciousness.

5. Conclusion

Through the Ganzfeld-EEG stimulation, researchers, practitioners and individuals can measure consciousness' responses to light and sound stimuli. Data from four MMGF-EEG controlled trials show audio-visual hallucination-like imagery and alpha accelerations in the cerebral cortex (Miskovic et al., 2019; Pütz et al., 2006; Sumich et al., 2018; Wackermann et al., 2002). So far, uniform MMGF may produce relaxing effects (Pütz et al., 2006; Wackermann et al., 2002), and flickering MMGF may induce fearful and serene imagery based on the associated sound frequency (Sumich et al., 2018). Both modalities significantly alter consciousness. Even though, the systematic review verifies the hypothesis, the internal relation of ASC and alpha activity is limited. Ideally, more research is required since the extraction is exposed to several risks of biases. The results provide the foundation for novel research in consciousness and if an apparatus can measure ASC, it may simultaneously measure conscious interactions.

Conflict of Interest

None to declare.

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