



A Review on the Role of Affective Stimuli in Event-Related Frontal Alpha Asymmetry

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Specialty section:

This article was submitted to
Human-Media Interaction,
a section of the journal
Frontiers in Computer Science

Received: 03 February 2022

Accepted: 30 May 2022

Published: 01 July 2022

Citation:

Sabu P, Stuldreher IV, Kaneko D and
Brouwer A-M (2022) A Review on the
Role of Affective Stimuli in
Event-Related Frontal Alpha
Asymmetry.
Front. Comput. Sci. 4:869123.
doi: 10.3389/fcomp.2022.869123

Frontal alpha asymmetry refers to the difference between the right and left alpha activity over the frontal brain region. Increased activity in the left hemisphere has been linked to approach motivation and increased activity in the right hemisphere has been linked to avoidance or withdrawal. However, research on alpha asymmetry is diverse and has shown mixed results, which may partly be explained by the potency of the used stimuli to emotionally and motivationally engage participants. This review gives an overview of the types of affective stimuli utilized with the aim to identify which stimuli elicit a strong approach-avoidance effect in an affective context. We hope this contributes to better understanding of what is reflected by alpha asymmetry, and in what circumstances it may be an informative marker of emotional state. We systematically searched the literature for studies exploring event-related frontal alpha asymmetry in affective contexts. The search resulted in 61 papers, which were categorized in five stimulus categories that were expected to differ in their potency to engage participants: images & sounds, videos, real cues, games and other tasks. Studies were viewed with respect to the potency of the stimuli to evoke significant approach-avoidance effects on their own and in interaction with participant characteristics or condition. As expected, passively perceived stimuli that are multimodal or realistic, seem more potent to elicit alpha asymmetry than unimodal stimuli. Games, and other stimuli with a strong task-based component were expected to be relatively engaging but approach-avoidance effects did not seem to be much clearer than the studies using perception of videos and real cues. While multiple factors besides stimulus characteristics determine alpha asymmetry, and we did not identify a type of affective stimulus that induces alpha asymmetry highly consistently, our results indicate that strongly engaging, salient and/or personally relevant stimuli are important to induce an approach-avoidance effect.

Keywords: alpha asymmetry, EEG, approach-avoidance, emotion, motivation, computational psychophysiology, affective computing, mental state monitoring

INTRODUCTION

When examining the emotional experience of individuals with a certain product, task or situation, they are commonly asked about it. For instance, in food research, usage of explicit, verbal questionnaires is by far the most common way to assess consumers' emotional experience (Lagast et al., 2017; Kaneko et al., 2018). However, explicit, verbal measures have their shortcomings.

Firstly, social desirability and self-presentational concerns can influence self-reported measures (Gawronski and de Houwer, 2014). Dell et al. (2012) found that respondents were about 2.5 times more likely to favor a technology believed to be developed by the interviewer than an exactly identical alternative. Furthermore, questionnaires usually reflect summative emotions post-interaction (Lottridge et al., 2012). Explicit measures are not well-suited for continuous monitoring to understand how emotional experience changes over time, such as during the interaction with a product. Continuous self-reporting is demanding and adds another task, and affects the emotional experience itself. To overcome such limitations, researchers have been arguing for the use of implicit measures (Gawronski and de Houwer, 2014), such as those inferred from spontaneous behavior or physiological signals. These allow for more objective measures that are not affected by response biases and continuous observation of the individual's emotional or affective state (Reuderink et al., 2013).

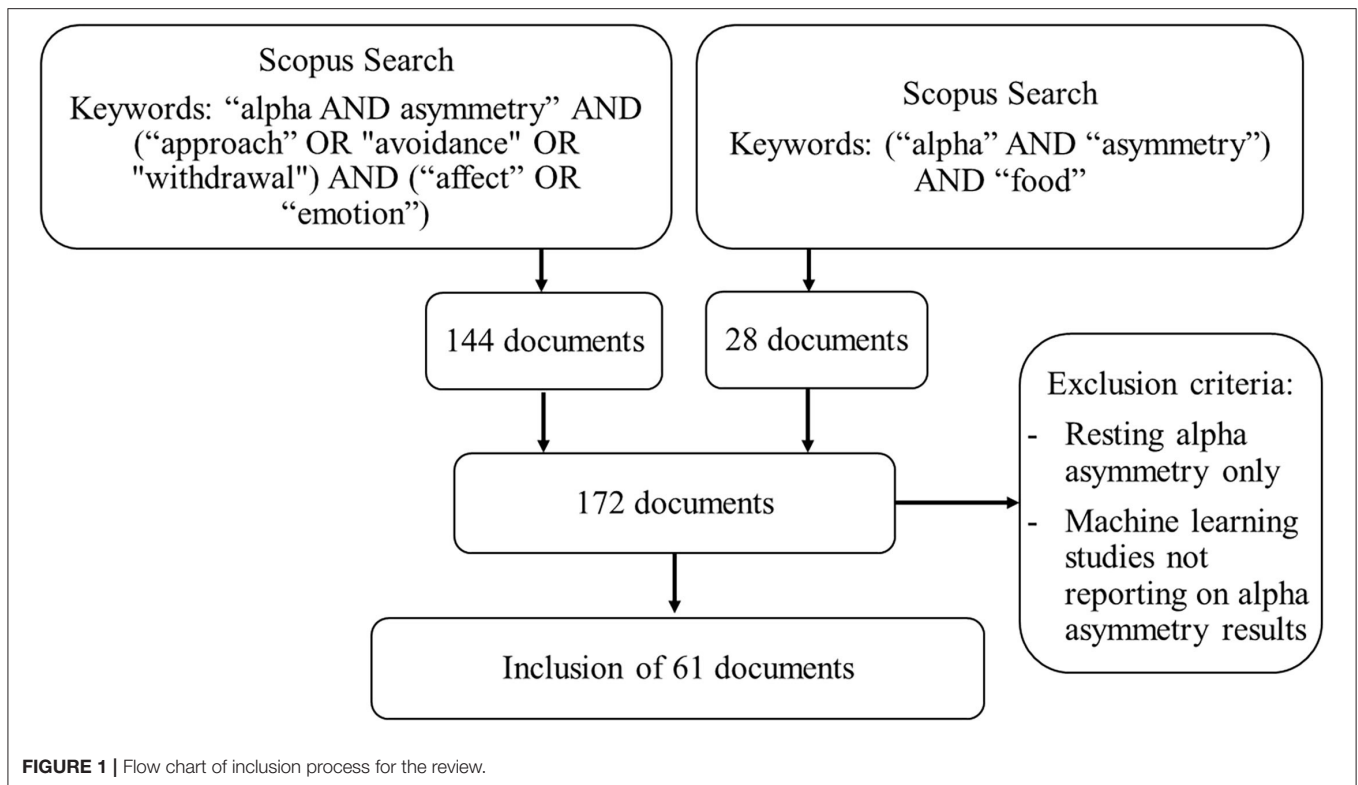
The circumplex model of affect characterizes emotions by valence and arousal (Russell, 1980). Valence refers to pleasantness, i.e., the degree of positive or negative affect, whereas arousal refers to the energetic component of the emotion (alertness). Research has consistently linked skin conductance to arousal (Christopoulos et al., 2019; Bartolomé-Tomás et al., 2020). Also, other types of physiological responses have been found to generally map better on arousal rather than valence (Mauss and Robinson, 2009). Valence has been found to be more difficult to assess using physiological measures. In this regard, asymmetric frontal cortical activation is of particular interest for implicitly measuring emotional processes (Coan and Allen, 2004; Harmon-Jones et al., 2010; Diaz and Bell, 2012). Early research has reported high incidence of negative affect in individuals with unilateral left hemispheric brain damage (Alford, 1933; Goldstein, 2004). These patients showed increased negative responses, fear and pessimism about the future. On the other hand, patients with unilateral right hemisphere damage displayed euphoric reactions (Denny-brown et al., 1952), such as inappropriate presentation of positive affect and laughing (Scherer and Ekman, 1984). In the late 70s, patterns of emotion processing have been associated with differences in the EEG alpha band (8–12 Hz) between the left and right frontal cortex, and was termed frontal alpha asymmetry (Tucker et al., 1981; Ahern and Schwartz, 1985; Davidson et al., 1985). Note that alpha power is inversely related to brain activity, such that low alpha activity is taken as an indication of high regional brain activation (Cook et al., 1998; Allen et al., 2004a).

Initial research focused on an affective explanation of frontal alpha asymmetry responses to stimuli. Larger relative left hemispheric activation was argued to be associated with positively valenced stimuli and increased right hemispheric activation with negatively valenced stimuli (Briesemeister et al., 2013). Next to this valence model, the approach-avoidance, or approach-withdrawal, model was explored. In this model, activity in the right frontal cortex has been related to avoidance motivation, a tendency to withdraw from a certain stimulus, and activity in the left frontal cortex with approach motivation toward a stimulus (Davidson et al., 1990; Davidson and Irwin,

1999; Coan and Allen, 2003; Davidson, 2004; Alves et al., 2008; Harmon-Jones et al., 2010; Diaz and Bell, 2012). Since approach motivation is often associated with positive valence and avoidance with negative valence, the expected cortical activity patterns of these two theories overlap in many cases (Reuderink et al., 2013). Studies that specifically disentangled valence and approach-avoidance motivation were in line with the approach-avoidance model (Carver and Harmon-Jones, 2009; Berkman and Lieberman, 2010). The defining difference was found in the hemispheric activation pattern in response to anger (Reuderink et al., 2013). Anger as a negatively valenced emotion was found to be lateralized in the left hemisphere just like happiness instead of the right hemisphere as would be expected based on valence motivation (Davidson, 1984). Further support for the approach-avoidance model was found in transcranial magnetic stimulation experiments (Rutherford and Lindell, 2011).

Frontal alpha asymmetry as a tool to monitor motivational processes related to emotion would be desirable in a variety of application fields, such as marketing (including evaluating public service announcements, e.g., Inguscio et al., 2021), product design (e.g., cosmetics—Gabriel et al., 2021), human-computer interfaces, gaming and the diagnosis of affective disorders (Briesemeister et al., 2013). Another upcoming application and research area where frontal alpha asymmetry is highly relevant, is neuroesthetics (Babiloni et al., 2015; Cartocci et al., 2018, 2021; Daly et al., 2019). However, it is important to realize that frontal alpha asymmetry is not specific for motivational processes, but is also moderated by e.g., unilateral hand contractions (Harmon-Jones et al., 2010) and seating position (Baldwin and Penaranda, 2012). Variations in such factors between studies may underlie diverse results in recent literature, together with differences in data recording (e.g., noise, number of participants, recording length), processing and analysis methods (Smith et al., 2017). Additionally, researchers have used a wide variety of stimuli that were hypothesized to induce frontal alpha asymmetry and found mixed results. This review focuses on the factor of affective stimuli potentially affecting the approach-avoidance effect as measured by alpha asymmetry in the context of emotion. We expect that stimuli may crucially affect frontal alpha asymmetry through their potential to emotionally and motivationally engage the recorded individuals. Since frontal alpha asymmetry describes an approach-avoidance effect, affective stimuli that are strongly motivating in either of the directions are expected to produce clear results. Although it is extremely difficult to quantify this a priori (Brouwer et al., 2015b), we think some general expectations can be formulated for stimulus categories that are prevalent in alpha asymmetry emotional research.

We expect affective stimuli to induce strong approach-avoidance effects when they are engaging and realistic. In that sense, real stimuli that are part of an engaging task would be most effective. We expect that stimuli that are only perceived are less potent than active tasks. Within the “perception” category, we expect images and sounds (i.e., sensory unimodal stimuli that represent a certain object or situation) to be less potent than videos (bi-modal), followed by real cues (multimodal and realistic; the actual object or situation itself). Within the “action” category, we expect that games may be particularly engaging



tasks and therefore elicit strong approach-avoidance effects. Finally, clearer effects of affective stimuli on alpha asymmetry are expected if the stimuli are particularly relevant for the participants under study (e.g., food is likely to produce stronger approach motivation for individuals who have not eaten for a long time compared to individuals who have).

To date there is no review focused on the stimuli that can evoke an approach-avoidance effect measured by frontal alpha asymmetry. Hence, as of yet it is unclear which types of affective stimuli elicit a strong approach or avoidance effect. Exploring this will help to understand better what is reflected by frontal alpha asymmetry, under which circumstances frontal alpha asymmetry can be expected to be an informative marker of emotion and what causes the diversity in literature in order to unify conflicting results.

METHODS

Literature was searched on Scopus using the keywords “alpha AND asymmetry” AND (“approach” OR “avoidance” OR “withdrawal”) AND (“affect” OR “emotion”) and yielded 144 documents. Additionally, given our special interest in this measure from the perspective of studying food related emotion (Kaneko et al., 2018; Modica et al., 2018; Songsamoe et al., 2019), a search on Scopus using the terms (“alpha” AND “asymmetry”) AND “food” was conducted as well, resulting in 28 more papers. Out of the resulting 172 documents only those that had measured frontal alpha asymmetry related to an event or a stimulus (i.e., not resting alpha asymmetry only) were included. Furthermore,

studies using a machine learning approach without separately reporting on the exact alpha asymmetry results were excluded. This resulted in the inclusion of 61 papers. **Figure 1** visualizes the search and selection procedure.

The 61 selected studies were divided into five stimulus categories that were expected to systematically differ in their effectiveness to engage the subjects: 1. Images & sounds, 2. Videos, 3. Real cues, 4. Games, 5. Other tasks (Imagery; Modifying facial expression; Speech, reading and writing). While most studies involve some task, studies in the category “Games” and “Other tasks” specifically designed tasks to elicit a certain emotional state: performing the task serves as the main stimulus, and in case of games, the resulting or expected outcome in addition to performing the task.

Papers are summarized and evaluated per stimulus type. A summarized description of all 61 studies can be found in **Table 1**. Studies were rated based on whether the stimulus alone induced an alpha asymmetry approach-avoidance effect (one before last column in **Table 1**) and if applicable, whether alpha asymmetry approach-avoidance effects were found for, or in interaction with certain conditions or participant subgroups (last column in **Table 1**). Effects are indicated by “++” for a significant effect, “+” in case of a trend and “0” for no effect. **Supplementary Table 1** contains information on the context or goal of the 61 studies and more details about the stimuli and results. Furthermore, since cortical hemispheric specialization of emotion may differ between left- and right-handed individuals (Harmon-Jones et al., 2008; Walsh et al., 2017), handedness is indicated in the “Participants” column of **Supplementary Table 1**

TABLE 1 | Overview of studies arranged by stimulus types with (the hypothesized) approach-avoidance effect indicated by ++ (significant), + (trend) and 0 (none) of the stimulus alone, and/or other effects involving the stimulus. Note that many studies were set up for studying the 'other' effect (e.g. interaction with person characteristics or interaction between stimuli and other condition).

Study	Stimuli	Participants	Stimulus effect	Other effect
Images & sounds (n = 18): images (n = 16), sounds (n = 2)				
Deng et al. (2021)	Viewing pictures (neutral, positive, negative and drug-related contents) before and after drug abstaining training.	40 male drug abstainers: training group (n=20) and control group (n = 20)	0	++
Grassini et al. (2020)	Images depicting snakes, spiders, butterflies, and birds.	34 students (28 female)	0	
Gayathiri et al. (2020)	Neutral and high valence - high arousal pictures from the International Affective Picture System (IAPS).	15 adults suffering from major depressive disorder (7 male)	0	+
Adolph et al. (2017)	Negative, neutral, and positive emotional pictures.	43 students (28 female)	0	+
Schöne et al. (2016)	Erotic pictures, pictures of dressed attractive women and control pictures (and pictures of extreme sport and daily activities).	17 male students	++	
Gable and Poole (2014)	Anger pictures and neutral pictures.	32 students (15 female)	0	+
Uusberg et al. (2014)	Affective pictures ranging from very pleasant to unpleasant.	70 students (28 male)	0	
Ischebeck et al. (2014)	Neutral, aversive, and pictures related to OCD (obsessive-compulsive disorder).	20 patients (9 male) with (OCD) and 20 matched healthy controls (8 male)	0	+
Poole and Gable (2014)	Approach-positive, approach-negative, and withdrawal-negative pictures from the internet and IAPS.	48 students (36 female)	0	
Huster et al. (2009)	36 pictures from the IAPS in restricted randomized order- three pictures of the same affective category presented successively.	28 students (13 female)	++	
Rabe et al. (2008)	Four pictures (from IAPS) for 1 min each of category neutral, positive, negative, and trauma-related.	Participants with (subsyndromal) posttraumatic stress disorder receiving cognitive behavioral therapy (n = 17, 15 females) before and after therapy, wait-list controls (n = 18, 10 females)	0	++
Wiedemann et al. (1999)	Neutral, panic-relevant, anxiety-relevant but panic-irrelevant, or anxiety-irrelevant but emotionally relevant pictures, and performance of a motor task.	Patients with panic disorder (n = 23, 3 male) and controls (n = 25, 6 male)	0	++
Gable and Harmon-Jones (2008)	Pictures of dessert or neutral pictures of objects.	26 female students	0	++
Winter et al. (2016)	Food images.	58 female participants recorded twice: once fed, once fasted	0	+
Crabbe et al. (2007)	Unpleasant, neutral and pleasant IAPS pictures, before and after rest and exercise conditions.	34 young, fit and active volunteers (13 female)	0	0
Cartocci et al. (2018)	Six neutral images from IAPS, followed by ten ineffective, effective, and awarded anti-smoking Public Service Announcements.	3 heavy smokers, 11 light smokers, 15 non-smokers	0	++
Chen et al. (2015)	Scary and soothing sound stimuli.	18 students (16 male)	0	++
Papousek et al. (2018)	Three sound recordings: anger/aggression, sadness/desperation, neutral.	62 students (30 male)	0	++
Videos (n = 15)				
Olszewska-Guizzo et al. (2021)	Nine fixed-frame videos, filmed before the pandemic: busy downtown and residential green.	25 adult Singaporeans (14 female)	0	+
Joaquim et al. (2020)	Emotion-eliciting commercials: neutral, tenderness, amusement, sadness, disgust, anger and fear.	25 male and female subjects	+	
Zhao et al. (2018)	Emotion-eliciting film excerpts: tenderness, anger, and neutral.	37 students (17 males)	++	
Cartocci et al. (2017)	Spots and images of awarded, effective and ineffective antismoking public service announcements.	7 non-smokers, 9 light-smokers, 6 heavy-smokers	++	
Papousek et al. (2014)	Film comprising scenes of real injury and death.	148 female university students	++	
Prause et al. (2014)	Neutral and a sexually motivating film.	65 participants (22 females)	++	
Vecchiato et al. (2014)	TV commercials.	24 subjects (12 female) who liked or disliked the commercials	0	++

(Continued)

TABLE 1 | Continued

Study	Stimuli	Participants	Stimulus effect	Other effect
Hosseini et al. (2007)	Movie clips to induce relaxation, happiness, anxiety and sadness.	40 female students (extroverts, introverts, neurotics and emotionally stables)	0	++
Aftanas and Varlamov (2004)	Emotional film clips (neutral, relaxation, joy, anger, sexual arousal, disgust, fear, sadness, stress stimulation).	Non-alexithymic ($n = 27$, 7 male) and alexithymic ($n = 17$, 14 male) participants	0	++
Hakim et al. (2021)	Video commercials of six food products.	33 (13 male) subjects	0	
Walsh et al. (2017)	Videos of food concerns (safety, hygiene and spoilage) and matched control videos.	40 students (31 female)	++	
Hajal et al. (2017)	Videos of own infants expressing distress.	26 mothers of 5- to 8-month-olds	++	+
McGeown and Davis (2018)	Chips to eat and video of confederate eating.	93 female students		++
Missana and Grossmann (2015)	Dynamic happy and fearful body expressions in two second clips.	20 4-month-old (10 female) and 20 8-month-old (10 female) infants	0	++
Lee et al. (2017)	Visual music as an emotional stimulus.	16 participants	++	
Real cues ($n = 11$)				
Kline et al. (2000)	Pleasant (vanilla), unpleasant (valerian), and neutral (water) odors.	58 women, aged between 58 and 70	++	
Kaneko et al. (2019)	Tasting different types of normal drinks, and diluted vinegar.	70 healthy participants (19 men)	0	
Lagast et al. (2020)	Tasting universally accepted (sucrose) and non-accepted (caffeine) solution, a personally selected accepted and non- accepted drink, and water.	32 participants	0	
Sargent et al. (2020)	Two machines to prepare hot beverage.	26 participants (14 females)	++	
Brouwer et al. (2017)	Cooking and tasting chicken or mealworms stir-fry dishes.	41 participants (19 female)	++	+
Olszewska-Guizzo et al. (2020)	Six landscape scenes (urban green and urban downtown).	22 adults (13 female)	+	
Knott et al. (2008)	Induction of neutral mood (holding a pen) or depressive mood (holding lighted cigarette over an ashtray without bringing to mouth).	11 (5 male) regular and 11 (6 male) light smokers	++	+
Modica et al. (2018)	Visual, visuo-tactile and exploration of food (daily food and comfort food; major and private label; foreign and local product).	Experiment 1: $n = 19$; experiment 2: $n = 13$ (5 males)	++	
Bolinger et al. (2020)	Positive prompts: express love, play peek-a-boo, sing; negative prompts: pretend infant has a rash, crawled to an electrical outlet.	25 infant (-parent dyads), 12 females	+	
Uusberg et al. (2015)	Degrees of social contact, varied by different gaze directions of a "live" model.	40 students (13 male)	0	++
Pönkänen and Hietanen (2012)	Neutral and smiling young females with a direct and an averted gaze, presented "live" through a liquid crystal shutter.	22 female undergraduates	0	0
Games ($n = 5$)				
Rodrigues et al. (2018)	Move around in a virtual T maze via joystick, with monster trial (negative event) and sheep trial (positive event).	30 participants (12 male)	++	++
Shankman et al. (2007)	Bogus computerized slot machine paradigm with three reels of numbers and fruit and two different payoff situations: reward and no incentive.	70 individuals with current MDD (29% male), 37 control participants (34% male)	0	+
Harmon-Jones et al. (2008)	Cues indicating that an easy, medium, or hard anagram would be presented and whether correct solution would result in receiving money or avoiding losing money.	Individuals with bipolar spectrum diagnosis ($n = 41$, 61% female) and individuals with no major affective psychopathology ($n = 53$, 49% female)	0	++
Miller and Tomarken (2001)	Delayed reaction time task including manipulations of incentive, expectancy, and response.	60 students (30 male)	++	
Sobotka et al. (1992)	Reward and punishment to responses to up or downward pointing arrows using finger press or finger lift response.	15 students (7 male)	++	

(Continued)

TABLE 1 | Continued

Study	Stimuli	Participants	Stimulus effect	Other effect
Other tasks (n = 12): Imagery (n = 4), modifying facial expression (n = 2), speech, reading and writing (n = 6)				
Mennella et al. (2015)	Imagery task including pleasant, neutral, and unpleasant narratives.	Dysphoric (n = 23) and non-dysphoric (n = 24) individuals	0	++
Wacker et al. (2008)	Emotional imagery of three scenarios of approach-avoidance conflict.	93 young men either high or low in trait behavioral inhibition system (BIS)	0	++
Wacker et al. (2003)	Emotional imagery.	109 male soccer players	++	
Papousek et al. (2017)	Reappraisal Inventiveness Test with anger-eliciting vignettes.	78 female university students	0	++
Stewart et al. (2014)	Producing approach (angry and happy) and withdrawal (afraid and sad) facial expressions.	Individuals with (n = 143) and without (n = 163) lifetime major depressive disorder	0	++
Coan et al. (2001)	Producing facial configurations denoting anger, disgust, fear, joy, and sadness.	36 students (10 male)	0	++
Pérez-Edgar et al. (2013)	Dot-probe paradigm with face pairs depicting angry, happy and neutral expressions, and stressful speech condition.	45 students (23 male)	0	++
Wang et al. (2015)	Public speech combined with reappraisal writing, irrelevant writing, or non-writing.	92 students	0	++
Li et al. (2016)	Writing task describing an anger-eliciting event, where participants were irritated by people with higher or lower social power.	29 students (13 male)	++	
Rejer and Jankowski (2017)	Internet advertisements during a text-reading task.	6 subjects (5 male)	+	
Brouwer et al. (2015a)	Reading a novel with emotional and non-emotional sections.	71 participants (35 female)	++	
Brooker et al. (2016)	Three emotion-eliciting episodes (conversation with experimenter, with stranger, stranger reading a script).	89 longitudinal twin sample (54% male)	++	

for all studies that report it. Most studies use right-handed participants and those that reported to have included left-handed persons stated that the results did not change by doing so.

RESULTS

Figure 2 presents the percentage of studies showing a significant effect of stimuli alone and in interaction with other conditions or participant subgroups, separately for each of the five stimulus categories. In the next sections, studies are discussed per stimulus category.

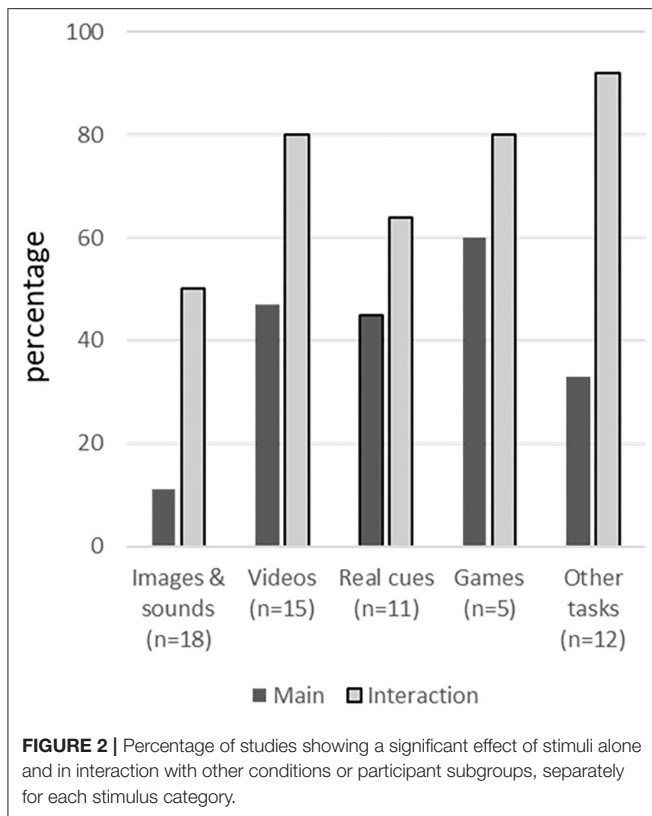
Images and Sounds (n = 18)

Most studies using sensory unimodal stimuli used visual (n = 16) rather than auditory (n = 2) stimuli. Studies utilizing unimodal stimuli appeared to show a significant effect only when the stimulus was particularly relevant for the participant group. This pattern can be seen in several clinical and substance-related studies.

Rabe et al. (2008) described that patients with posttraumatic stress disorder from motor vehicle accidents had increased right-sided activation during exposure to trauma-related pictures compared to neutral pictures. Cognitive behavioral therapy led to a significant reduction of right anterior activation for the group receiving therapy (n = 17) compared to wait-list controls (n = 18) in response to the trauma stimulus.

Likewise, Wiedemann et al. (1999) conducted a study where patients with panic disorder (n = 23) compared to healthy controls (n = 25) were confronted with neutral (mushroom), panic-relevant (emergency situation), anxiety-relevant but panic-irrelevant (spider), or anxiety-irrelevant but emotionally relevant pictures (erotic image). They found a significant decrease of right compared to left frontal alpha power in response to the emergency picture category for the group with panic disorder but not for the healthy control group. Gayathiri et al. (2020) reported elevated right hemispheric activity, indicating avoidance, when individuals with major depressive disorder (n = 15) viewed images of high valence and arousal relative to neutral ones. Contrary to these studies, Ischebeck et al. (2014) did not find differences between twenty patients with obsessive compulsive disorder and twenty matched controls during viewing neutral, aversive and OCD-related images.

In Deng et al. (2021), drug abstainers' (n = 40) responses to drug-related images were compared to positive, negative, and neutral pictures in the context of evaluating the effect of a training on emotion regulation. While there was no main effect of picture type, improved alpha asymmetry scores for negative and drug-related pictures were found for the training group pre- and post-training. Cartocci et al. (2018) found higher frontal alpha asymmetry for heavy smokers compared to light smokers and non-smokers when viewing effective public service announcement (PSA) pictures. In their earlier study frontal alpha



asymmetry for different PSA images did not differ (Cartocci et al., 2017), which might be attributed to several differences between the studies, such as a lower number of participants in the earlier study ($n = 22$ vs. $n = 39$).

The previously described pattern of responses only in groups for whom the stimuli are relevant is likely also important for non-clinical samples. Schöne et al. (2016) asked seventeen male students to view erotic pictures of high salience as well as depictions of dressed attractive women and found significant results of picture category. Winter et al. (2016) used food images to assess the effect of hedonic hunger and restrained eating on frontal alpha asymmetry with 58 female participants. They found that higher restraint scores were associated with increased right frontal asymmetry and higher hedonic hunger was associated with increased left frontal asymmetry. Additionally, they found that overweight compared to normal weight individuals displayed greater left asymmetry. However, for the condition of fasted and fed state no differences emerged. Gable and Harmon-Jones (2008) did report for 26 female students that while dessert pictures alone did not evoke significant asymmetric activation, more time since eaten and dessert liking related to increased left frontal asymmetry for dessert pictures.

Our search resulted in two studies using auditory stimuli only. Papousek et al. (2018) ($n = 62$ students) explored inter-individual differences in frontal alpha asymmetry to other people's affect using sound recordings of three categories: anger (shouting),

sadness (crying) and neutral (trivial everyday sounds) as a reference condition. Results show that individuals with higher compared to lower level of antagonism (assessed by a Personality Inventory) had less relative right frontal activation (approach) in response to the anger stimulus, whereas subjects with higher levels of detachment displayed greater relative right hemisphere activation (withdrawal) to the crying stimulus. Similarly, in Chen et al. (2015) a sample of 18 students listened to scary and soothing sounds. Subjects who showed a greater withdrawal response to scary sounds displayed a decreased pleasant state, and participants with higher approach motivation showed an increased pleasant state.

Videos ($n = 14$)

As expected, studies using video stimuli showed more often strong approach-avoidance effects than studies using unimodal stimuli (images & sounds), both as effect of the stimuli alone and in interaction with participant characteristics and conditions.

Unlike the anti-smoking image stimuli as described above in section Images and Sounds (Cartocci et al., 2017), anti-smoking video announcements induced effects in alpha asymmetry. Video announcements that had independently been classified as “awarded” induced an increased approach-avoidance effect compared to independently classified “ineffective” and “effective” ones. Another study on this topic (Cartocci et al., 2019) found that smokers showed stronger alpha-asymmetry avoidance than non-smokers in response to anti-smoking videos, highlighting again the importance of the interaction between stimuli and participant characteristics in approach-avoidance effects.

Not all studies using advertising videos have shown positive results. Joaquim et al. (2020) have reported only a trend in correlation between the asymmetry index for low alpha frequency band and negative emotions elicited by commercials viewed by 25 subjects. In a study by Hakim et al. (2021) 33 subjects watched skits from a comedy series followed by commercials of food products and later completed a choice task consisting of six products altogether. Results show that frontal alpha asymmetry as recorded during commercial viewing did not significantly differ for neither closely nor distantly ranked products. Vecchiato et al. (2014) showed six TV commercials (duration around 30 s) to 15 volunteers. Participants were divided into “LIKE” and “DISLIKE” group according to their pleasantness response rating. As expected, the “LIKE” group displayed increased left hemisphere activity compared to the “DISLIKE” group.

Walsh et al. (2017) recruited 40 students and showed them breakfast meal videos of 40 s in duration. The clips contained emotion-eliciting events with hygiene, safety, and spoilage concerns and almost identical controls without such concerns. For the spoilage videos they found greater right hemisphere activation indicating avoidance response when compared to its matched control. For the hygiene and safety videos they did not find significant differences. In another food related study, McGeown and Davis (2018) recorded the brain activity of 93 female students while watching a confederate consuming potato chips, followed by conducting a visual-probe task with non-food and food items of high craving ratings. Overweight participants (based on BMI) compared to leaner counterparts showed

increased left frontal alpha asymmetry during the confederate video and greater attentional bias toward food pictures.

Most video studies used videos to induce basic types of emotion. Zhao et al. (2018) presented three film clips (duration of around 80 s each) to 37 students to elicit tenderness, anger and neutrality. They found greater left frontal activation during the tenderness film clip. The anger eliciting film clip led to expected greater right frontal activation. Papousek et al. (2014) displayed a film with a duration of ~10 min consisting of scenes of severely injured, mourning and dying people, to 148 female students. The expected effect of a right-sided shift of dorsolateral prefrontal asymmetry was found. In Prause et al. (2014) 65 students viewed a neutral film (10 min duration) followed by a sexual film (3 min duration). Increased alpha power was found in the left hemisphere (i.e., approach) during sexual compared to neutral films. Furthermore, self-reported mental sexual arousal and alpha asymmetry were positively correlated. In a study by Hajal et al. (2017) 26 mothers of 5- to 8-month-olds watched a 15-min video composed of 10 s clips of their own infants expressing distress. They found an association between greater right frontal asymmetry shift (from baseline to infant distress video) and higher self-reported sadness.

A large proportion of studies specifically examined the interaction between stimulus and groups of participants with certain characteristics. Hosseini et al. (2007) showed four video clips (duration of 3 min each) to induce relaxation, happiness, anxiety and sadness. Their sample consisted of 40 female students equally divided into four groups: extroverted, introverted, neurotic and emotionally stable. They found that right frontal asymmetry was associated with negative affect for the introvert and emotionally stable groups. Aftanas and Varlamov (2004) showed 10 film neutral and emotional clips each of 1.5–4.5 min duration to individuals with alexithymia ($n = 17$), a personality trait characterized by difficulties in emotional self-regulation, and non-alexithymic ($n = 27$) participants. In all cases subjects with alexithymia showed greater reactivity of the right hemisphere to the emotional clips relative to neutral, suggestive of increased avoidance motivation. Olszewska-Guizzo et al. (2021) found no significant effect for frontal alpha asymmetry for video type (nature exposure and busy public spaces), but a significant decrease of frontal alpha asymmetry as recorded following a national lockdown with a Stay-at-Home order compared to before the pandemic ($n = 22$). Missana and Grossmann (2015) studied a sample of 20 4-month-old and 20 8-month-old infants, and found that only the older infant group showed increased left-sided frontal alpha asymmetry in response to point-light display of happy body expressions and higher right-sided activation in response to fearful body expressions.

Real Cues ($n = 11$)

We expected that in general, real cues should produce stronger approach-avoidance effects than videos. However, the proportion of studies finding significant effects is similar.

Kaneko et al. (2019) and Lagast et al. (2020), who explored the effect of different types of drinks on frontal alpha asymmetry in, respectively, 70 and 32 participants, observed no significant effects. However, odors as researched by Kline et al. (2000)

recording EEG in 58 women have led to increased relative left frontal activation for the pleasant stimulus (vanilla) when compared to unpleasant (valerian) and neutral (water).

Two neuromarketing studies utilizing real cues reported significant results for frontal alpha asymmetry. Modica et al. (2018) compared different categories of food items: daily and comfort food, major and private brands, and foreign and local products in two experiments ($n = 19$ and $n = 13$). They found increased tendency for approaching comfort compared to daily food, and foreign compared to local products during visual exploration and visual and tactile exploration phases. In addition, the private label compared to major brand also showed higher approach in the visual and tactile exploration phases. Similarly, Sargent et al. (2020) compared two machines to prepare hot beverages, one from a market leader and the other from a follower machine in an office setting ($n = 26$). It was shown that the market leader machine's user interface was preferred, indicated by self-reports and supported by significant valence measured by frontal alpha asymmetry and arousal extracted from electrodermal activity measures. Another study using a real food-related stimulus, was conducted by Brouwer et al. (2017), where 41 participants cooked and tasted two stir fry dishes. For one the main ingredient was chicken (hypothesized to induce approach) and for the other mealworms (hypothesized to evoke avoidance). The expected effect of food condition was found in frontal alpha asymmetry throughout the entire cooking and tasting session, significantly during the frying interval.

In a substance study, Knott et al. (2008), exposed 11 regular and 11 light smokers to a neutral and a cigarette-cue (holding a pen and holding a lighted cigarette above an ashtray respectively), while EEG was recorded. Results show that particularly regular female smokers exhibited withdrawal-related negative affect to holding the cigarette compared to holding the pen.

Three studies in our selection used real social interaction cues. In a study with 25 infant-parent dyads, Bolinger et al. (2020) used positive (e.g., parent played peek-a-boo with the infant) and negative prompts (e.g., parent pretended that the infant has rash on his/her face) and found significantly increased right-sided frontal alpha asymmetry (reflecting avoidance or withdrawal) for the negative prompts. No effects were observed for positive and neutral stimuli. Uusberg et al. (2015) and Pönkänen and Hietanen (2012) explored how eye-contact is related to frontal alpha asymmetry. In Uusberg et al. (2015) ($n = 40$) the degree of social contact was varied by gaze direction and as expected, neuroticism was related to stronger right-sided activation in response to direct gaze. In Pönkänen and Hietanen (2012) ($n = 22$) the expected left-sided asymmetry in response to direct gaze was not observed.

Finally, Olszewska-Guizzo et al. (2020) passively exposed 22 adults to pre-selected real landscape scenes, consisting of six park scenes and three busy urban spaces. They found a non-significant trend in the expected direction with higher approach motivation for park compared to urban spaces.

Games ($n = 5$)

Games were expected to be the most potent inducers of approach-avoidance effects. Indeed, this category seems to result

the in the largest proportion of significant results for main stimulus effects, but we should note the modest number of studies in this category ($n = 5$).

Rodrigues et al. (2018) asked 30 participants to move freely around in a virtual T-maze using a joystick. The maze contained monsters and sheep (emotionally negative and positive trials, respectively). The results aligned with the approach-avoidance model, with more left frontal alpha activation during the positive event condition and increased right frontal alpha activation in the negative condition. In Miller and Tomarken (2001), 60 participants underwent a delayed reaction time task with manipulations of the incentive, expectancy, and response. They found that variations in monetary incentives led to the expected changes in alpha asymmetry, i.e., more relative left frontal activation during reward conditions, and shifts to right frontal activation during punishment conditions. Similarly, Sobotka et al. (1992) manipulated reward and punishment in a sample of 15 students. Reward trials were associated with higher activation in the left frontal hemisphere and during punishment trials higher right-sided activation was found.

Two studies in the games category recorded from clinical samples. Shankman et al. (2007) used a slot machine game with reward and no incentive outcomes. Participants included 70 individuals with major depression and 37 controls. No differences in hemispheric asymmetry for the two outcome conditions were observed, and no overall difference between the depressed and non-depressed group. However, they found a trend between age of depression onset and hypothesized approach during reward trials. Participants with early depression onset seemed to exhibit less left frontal activity (less approach) during reward conditions compared to participants with late-onset depression and the control group. Harmon-Jones et al. (2008) explored frontal cortical responses of 41 individuals with bipolar disorders and 53 controls. For this they used anagrams of different difficulty levels (easy, medium and hard) and valence (win money or avoid losing money). They found that as expected, individuals with bipolar disorder showed greater left frontal activation in preparation for the hard-win task compared to controls. Furthermore, while non-bipolar subjects showed a decrease in left frontal activation from medium to hard win trials, those on the bipolar disorder spectrum did not.

Other Tasks ($n = 12$)

Tasks in this category entailed imagery ($n = 4$), modifying facial expression ($n = 2$) and speech, reading and writing tasks ($n = 6$). Overall, “other tasks” stimuli seemed quite potent in eliciting effects in interaction with participant group or condition, but relatively few main effects were reported.

Four studies used a variety of emotional imagery tasks, and all reported significant results. Mennella et al. (2015) measured EEG of a clinical sample of 23 dysphoric and 24 non-dysphoric individuals during pleasant, neutral and unpleasant narratives. They found reduced left relative to right activity irrespective of emotional condition in the dysphoric group compared to the control group, but no main effect of the different emotional tasks. Wacker et al. (2008) found significant approach-avoidance effects using emotional imagery scripts of three approach-avoidance

conflict scenarios and a sample of 93 men with either high or low behavioral inhibition system (BIS) sensitivity. Their results showed that only the group high in trait BIS sensitivity had a significant change toward right-sided activation for the imagery compared to the pre-stimulus phase. In addition, Wacker et al. (2003) induced vivid imagery with relevant soccer scripts in a sample of 109 active, male soccer players. They found significant changes in the alpha band toward left frontal activation for the group with anger-inducing scripts and toward right frontal activation for the control and fear-withdrawal stimuli. Papousek et al. (2017) used a type of imagery task, where female university students ($n = 78$) looked at anger-eliciting vignettes supplemented by matching photographs and were instructed to imagine the depicted situation happening to them. Subsequently, they wrote down possible ways to appraise the situation to diminish anger. In a comparison task, they were asked to generate novel ideas to use a conventional, emotionally neutral object. Participants with greater capacity to generate reappraisal showed greater left-sided activity in the pre-frontal cortex. No difference was found between the two types of emotional task.

Two studies aimed to induce different emotions using facial expression tasks. Both reported significant effects. In Coan et al. (2001) students' ($n = 36$) facial configurations of anger, disgust, fear, joy and sadness matched the expected frontal activation patterns, i.e., less left frontal activity in withdrawal states compared to approach and control states. In Stewart et al. (2014) a participant group with major depressive disorder ($n = 143$) showed less left frontal activity during approach and withdrawal conditions than a control group ($n = 163$).

Six studies used speech, reading and writing tasks. Pérez-Edgar et al. (2013) presented face pairs depicting angry, happy and neutral expressions in a dot-probe paradigm, followed by speech preparation to 45 students. Relative EEG asymmetry was calculated between the speech preparation and baseline. Increased right frontal alpha activation was associated with avoidance of happy, and attentional bias toward angry faces in the dot-probe task. Brooker et al. (2016) conducted a longitudinal twin study ($n = 89$) with three emotion eliciting episodes: conversation with the experimenter, with a stranger and listening to a stranger reading a script. They found that children showed increased asymmetry scores, consistent with approach, during conversing with a stranger and experimenter compared to the stranger script episodes.

In Wang et al. (2015) 92 students were informed that they had to give a speech to elicit anxiety, and they were asked to imagine the speech scenario or think of previous embarrassing experiences. This was followed by a possible writing task depending on the group: reappraisal writing, irrelevant writing and no writing. Afterwards they were asked to re-imagine embarrassing speech scenarios. Compared to the irrelevant writing group, the reappraisal writing group had lower frontal alpha asymmetry scores during the writing manipulation period and higher “approach” frontal alpha asymmetry scores following re-exposure to stress. Li et al. (2016) also used a writing task. Participants ($n = 29$ students) were instructed to think of a situation when they were irritated by people with higher or lower social power. As expected, they found a significant association

between high social power and increased left frontal alpha asymmetry compared to the low social power condition.

In Rejer and Jankowski (2017) six subjects performed a reading task, which was interrupted by internet advertisements. This caused changes in frontal alpha asymmetry though the direction of change differed between subjects. In Brouwer et al. (2015a) 71 participants performed a reading task of a novel where emotional and non-emotional sections were pre-defined. Higher frontal alpha asymmetry was found for high compared to low emotional sections.

DISCUSSION

The aim of this review was to investigate what types of affective stimuli are effective in inducing an approach-avoidance response in frontal alpha asymmetry, in the hope that this will contribute to better understanding and application of alpha asymmetry. We reviewed findings in the affective alpha asymmetry literature following five types of commonly used stimuli that were expected to differ in their effectiveness to engage the subjects: (1) Images & sounds, (2) Videos, (3) Real cues, (4) Games and (5) Other tasks. The first three of these categories represent studies where participants' task mostly consisted of passively perceiving the stimuli, going from unimodal and less realistic, to multimodal and more realistic, where we expected this to be associated with an increasing level of affective engagement and therewith, potency to induce approach-avoidance effects. Tasks were expected to be more motivationally engaging overall, in particular games.

As expected, unimodal images and sounds appeared to be the least potent to induce clear effects—significant effects were almost only reported when the stimulus was particularly relevant for the participant group. Also as expected, studies using video stimuli showed strong approach-avoidance effects more often than studies using images and sounds, both as effect of the stimuli alone and in interaction with participant characteristics and conditions. The proportion of studies finding significant effects using real cues did not seem larger, but was approximately similar, to studies using videos. As expected, the proportion of significant results for main stimulus effects was largest for games, but we should note the modest number of studies in this category, and we conclude they are in the same order as videos and real cues. “Other tasks” stimuli seemed quite potent in eliciting effects in interaction with participant group or condition, but relatively few main effects were reported. Many studies that did not report an effect of stimulus alone reported stimulus effects in association with participant characteristics or other conditions. This makes sense in that the motivational aspect of stimuli is never completely determined by a stimulus itself, but affective approach-avoidance responses arise as an interplay between stimuli and an individual who has certain characteristics and finds him/herself in a certain situation. This aligns with ideas of Coan and colleagues and the capability model, stating that motivational tendency in an individual should be studied within a clear motivational context (Coan et al., 2006). Below, we discuss our results in more detail.

In general, viewing static images may be expected to be not very emotionally and motivationally engaging. The findings of this review revealed that picture presentation could induce approach-avoidance effects if the images were particularly emotionally relevant for the sample group, for instance anxiety-relevant pictures shown to patients with panic disorder (Wiedemann et al., 1999). Thus, for a general sample group, affective images alone might be insufficient to create motivational engagement while stimulus-relevant personal characteristics can potentiate frontal alpha asymmetry (Harmon-Jones et al., 2006; Gable and Harmon-Jones, 2008; Uusberg et al., 2014; Rejer and Jankowski, 2017). Consistent with this, significant correlations have been found between frontal alpha asymmetry and differences in emotive tendencies (e.g., dessert liking) or personality traits (Wacker et al., 2008; for examples see Gable and Harmon-Jones, 2008; Uusberg et al., 2015; Winter et al., 2016). As one of the exceptions, Schöne et al. (2016) showed that presentation of erotic pictures to male students lead to clear alpha asymmetry results, even in a brief (3 s) picture presentation task. They argue that in this case, pictures are the actual desired object themselves, and therefore create a relatively strong approach motivation in contrast to pictures that are a depiction of something that is desirable, such as food. Huster et al. (2009) aimed to improve motivational engagement for pictures by successively displaying three pictures of the same affective category, and found a main effect. Showing pictures of the same category successively also allowed for computation of frontal alpha asymmetry over a longer time period, which may have increased the robustness of the measure (Huster et al., 2009). Note that this points to another overall difference between studies that use images and other stimuli besides expected engagement—the generally short interval per stimulus that used to determine alpha asymmetry may be another factor explaining weak alpha asymmetry results for images.

From the engagement perspective, and consistent with the reasoning by Schöne et al. (2016) as mentioned above, we expected real cues to be particularly effective as they are not just a depiction of something creating a tendency to approach or avoid, but can be the genuine objects to approach or avoid. Indeed, experiments using food, odors and cigarettes found significant effects for frontal alpha asymmetry. However, those employing landscapes and tasting drinks did not. In these studies, noise caused by movement could have prevented clear results. Because body movement causes noise in EEG signals, stimuli employing movement can be expected to be less effective in producing an alpha asymmetry approach-avoidance effect. In Olszewska-Guizzo et al. (2020) participants went from one scene to the other, leading to long time intervals between recordings and hence noisy comparisons between conditions. Furthermore, in Kaneko et al. (2019) participants took sips from cups themselves, which led to noise through movement. On the other hand, Lagast et al. (2020) minimized such movements by using plastic tubes but were still not able to find a significant approach-avoidance effect. Also, results of studies in other stimulus categories did not suggest that in general, modest amounts of movement prohibit finding alpha asymmetry effects.

Out of scope for the current review that focussed on the role of affective stimuli, but also relevant for the approach-avoidance alpha asymmetry effect are data recording, processing, and analysis (for an extensive review, see Smith et al., 2017). A few essential points of consideration are the EEG recording length (Towers and Allen, 2009), selection of the electrode reference (Hagemann and Naumann, 2001; Hagemann, 2004; Stewart et al., 2010) and the reliability of the EEG measurement (Hagemann et al., 2002; Allen et al., 2004a,b). With novel wearable EEG monitoring devices and processing techniques, recordings in less controlled environments are becoming more reliable (e.g., see Aricò et al., 2018; Pion-Tonachini et al., 2019), but controlled experiments and lab-grade equipment will have some advantage on signal quality. Furthermore, aspects of the design besides choice of stimulus such as the number and duration of trials and baselines, analysis (e.g., exact definition of the alpha band and methods for artifact removal) are not standardized and can lead to big differences.

This brings us to the limitations of this literature review. One is that experiments are very diverse and thus difficult to compare. We focused on the overall effect of affective stimulus category. For almost every stimulus category, studies were identified that reported no effect of stimuli on alpha asymmetry at all; but glancing through these studies did not bring to light one obvious factor underlying these null results.

Second, even though keywords were clear, it was noted that not all relevant papers were captured through the search. We do not claim that we here provide an exhaustive overview, and our results should be taken as indicative. Still, we believe that the inclusion of 61 papers results in a representative review of the literature.

Thirdly, we should note that while our choice of stimulus categories was not arbitrary, other choices and definitions of stimulus categories would have been possible as well and could have influenced the conclusions. Also, our categories were not exactly exclusive and sometimes overlapping, e.g., the cooking and tasting experiment by Brouwer et al. (2017) could be arguably belonging to tasks rather than real cues. In such cases, the stimulus' affective content led to the final categorization decision. We hope that our summarizing **Supplementary Table** facilitates potential follow-up research, viewing the results from possible other perspectives.

Furthermore, most of the papers reviewed here reported significant alpha asymmetry approach-avoidance results, or trends in that direction. Papers that reported null findings possibly did not include the keywords used in our search. An example is Walden et al. (2015), where frontal theta activity was studied as a function of approach-avoidance affective autobiographical memory recall. They mention in a footnote that no effect on alpha-asymmetry was observed. In addition, many of such findings were probably withheld from publication in the first place, commonly known as publication bias. Not reporting null-findings is a general problem that could lead to another research group investigating the same line of thought, leading to null findings again, ultimately wasting resources, distorting literature and damaging the integrity of knowledge (Jooper et al., 2012). Furthermore, negative outcomes are valuable for science

since they force critical reflection, validation of current thinking and direct new approaches (Matosin et al., 2014). Therefore, researchers should be more encouraged and journals more open to publish manuscripts reporting negative results. Taking into account the likely underreporting of null findings, and the finding that roughly 50% of studies reporting a solid effect of stimulus only for four of the five categories, where this percentage was even considerably lower for the images & sounds category, we can conclude that alpha asymmetry approach-avoidance is not an easy to find phenomenon, especially not when tested in general populations without further manipulation of context to increase stimulus relevance.

Despite of the aforementioned limitations, the exploration of frontal alpha asymmetry as an indicator of affective approach-avoidance can benefit marketing, human-computer interfaces and the diagnosis of affective disorders. Frontal alpha asymmetry may provide a more objective and continuous measure of mental state than traditional methods that are influenced by social factors and may affect the mental state itself. This review confirmed that overall, strongly engaging, salient and/or personally relevant stimuli are important to induce an approach-avoidance effect and that the selection of stimuli accounts for part of the diversity in alpha asymmetry research. More work is required to gain a better understanding of other factors influencing frontal alpha asymmetry as a marker of emotion.

AUTHOR CONTRIBUTIONS

PS, IS, DK, and A-MB: conceptualization. PS: literature search, summarizing literature, and writing first draft. All authors contributed to revising the article and approved the submitted version.

FUNDING

This research was funded by the Kikkoman Europe R&D Laboratory B.V. The authors declare that this study received funding from Kikkoman Europe R&D Laboratory B.V. Other than that one of the co-authors (Daisuke Kaneko) was employed by Kikkoman Europe R&D Laboratory B.V., the funder was not involved in the study design, collection, analysis, interpretation of data, the writing of this article or the decision to submit it for publication.

ACKNOWLEDGMENTS

We gratefully acknowledge comments of Dimitra Dodou on a previous version of this work.

SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: <https://www.frontiersin.org/articles/10.3389/fcomp.2022.869123/full#supplementary-material>

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Conflict of Interest: DK was employed by Kikkoman Europe R&D Laboratory B.V.

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