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New evidence and challenges in ERP and MEG correlates of consciousness in vision: A systematized review☆

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A R T I C L E I N F O

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A B S T R A C T

The past twenty years of research have revealed two event-related potential (ERP) components to be the most reliably occurring neural correlates of consciousness (NCC) in vision: an early visual awareness negativity (VAN) in the N2 and late positivity (LP) in the P3 time window. Three previous extensive reviews concluded that VAN is a proper visual NCC, which is solely modulated by awareness. During the last five years since the latest review was published, a large body of new evidence has emerged about the ERP correlates of visual consciousness. In this systematized review we update the results of the previous reviews by analyzing new studies published since 2020 ($N = 53$) and discussing their findings. The new evidence is consistent with the earlier reviews: VAN is still found to be the most reliable and robust ERP NCC in vision, whereas LP reflects also many other processes, not consciousness as such. However, several aspects of VAN, for example, its relationship to attention and simultaneous physiological factors, require further investigation.

1. Introduction

The most common research strategy in neuroscience is the search for the neural correlates of consciousness or minimal subset of neurons and specific physiological activity between them that will be sufficient for consciousness (Crick and Koch, 1990). Consciousness can be investigated holistically as a state or via changes in its specific content. Empirically, the goal is to create contrasts between the presence vs absence of consciousness as a global state (e.g. the loss of consciousness due to general anesthesia vs the normal conscious waking state), or between the presence vs absence of a specific content in perceptual consciousness (e.g. physically identical stimuli presented in ways that result in the content emerging into consciousness vs not entering consciousness). In this review we focus on the content of consciousness in vision and its "content-specific" NCC (Koch et al., 2016), which are the brain regions and processes associated with the subjective experience of seeing specific visual contents.

Vision is the most common model system in the neuroscience of consciousness, and the number of visual studies is greater than in other perceptual modalities (Faivre et al., 2017). Here we limit our review to electroencephalographical (EEG) and magnetoencephalographical (MEG) studies that utilized event-related potential (ERP) or event-related magnetic field (ERF) technique, because EEG and MEG have a temporal resolution compatible with and, therefore, suitable for studying changes in subjective experience. ERP and MEG correlates of visual consciousness have been extensively reviewed by Koivisto and Revonsuo (2010), who analyzed 39 studies and covered the literature before 2010, Railo et al. (2011), who made conceptual updates, discussing 17 studies, and Förster et al. (2020), who analyzed 30 studies and covered a 2010–2019 time period. These reviews have consistently resulted in identifying two main ERP components as NCCs of vision: visual awareness negativity (VAN), an earlier difference between ERPs of seeing vs not seeing a stimulus, which onsets around 100 to 200 ms post stimulus and is registered over posterior electrodes, and late positivity (LP), a difference wave that onsets around 300 ms and is registered over more anterior channels. Difference waves resembling VAN in other perceptual modalities when taken together, have been labelled by Dembski et al. (2021) as "Perceptual Awareness Negativity" or PAN, an umbrella term that covers all the similar modality-specific NCCs like VAN and the auditory AAN. LP, by contrast, is mostly modality-general

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and is elicited in a similar form by both visual and auditory stimuli (although there may be a modality-specific early part of LP, see Filimonov et al. 2022). To date the publication trend on these ERP NCC rapidly increases as demonstrated in Fig. 1, showing a growing interest in the field. Taken together, the collective conclusion from previous reviews implies that VAN is the most reliable candidate for visual NCC, while LP is modulated by consciousness only when several conditions are met, including task-relevance of the stimulus, attentional modulation, and other aspects related to post-perceptual processing.

Research on visual NCC also has a theoretical dimension. Conceptually, VAN is compatible with the recurrent processing theory of consciousness (RPT), which postulates that perceptual awareness arises during a feedback or recurrent activity from anterior to posterior brain areas (in vision, this happens especially in extrastriate areas along the ventral visual stream) (Lamme, 2000, 2010,2020), while LP is compatible with the global neuronal workspace theory (GNWT), which postulates that a widespread broadcast of the stimulus-related information to many brain systems is necessary for awareness (Dehaene and Changeux, 2011; Dehaene and Naccache, 2001; Mashour et al., 2020). In GNWT the neural generators of P3b are directly involved in Global Access by activating frontoparietal workspace neurons, so that their synchronized activities result in a "neural avalanche" wave that can be scalp-recorded as a large, slow positive potential: the P3b, from which the LP is derived as a difference wave in conscious vs unconscious stimuli. Among key differences between these theories, in addition to placing the NCC in different time-windows and anatomical areas, is the role of attention. According to the RPT, local recurrent activity in sensory areas is sufficient for consciousness, while attention amplifies, but is not necessary for it. GNWT, on the other hand, states that attention is a necessary prerequisite for awareness because it facilitates the stimulus-related activity to reach a non-linear "ignition" of large populations of neurons that will allow the global broadcast (Mashour et al., 2020; Del Cul et al., 2007; Sergent et al., 2005; Sergent and Dehaene, 2004). A recent theoretical extension of the GNWT, a Global Playground, accepts that LP per se is not always required for consciousness, but stands on the same grounds as the GNWT regarding attention and the crucial role of the frontal cortex in perceptual consciousness, postulating the necessity of the activity in the P3 time-range: this activity might not manifest itself as LP, but can be present as a bifurcation in brain dynamics (Sergent et al., 2021). These differences are a manifestation of the long-lasting debate on whether the direct, necessary mechanisms of the NCC are located in the frontal vs the posterior cortical areas (Boly et al., 2017; Odegaard e al., 2017). In the present review, we will discuss the implications of the latest empirical ERP NCC findings to the major current theories of consciousness, including the integrated information theory (IIT) (Albantakis, 2020, 2023; Ellia et al., 2021; Tononi et al., 2022) and temporospatial theory (TTC) (Northoff, 2014; Northoff and Huang, 2017; Northoff and Zilio, 2022; Northoff et al., 2023), below. Although numerous different theories of consciousness have been proposed in the literature (Seth and Bayne, 2022; Yaron et al., 2022), our selection is based on both development stage of the theory and different interpretations of the ERP NCC (Chis-Ciure et al., 2024) to demonstrate the broader context of the current findings.

There is also a philosophical dimension surrounding the NCC research, which corresponds to the conceptual distinction of "phenomenal" and "access" consciousness, initially proposed by Block (1995). By definition, the concept of "phenomenal consciousness" refers to subjective experience as such, while "access consciousness" refers to information that is globally available for cognitive processes in guiding behavior and (verbal) reports. A related distinction has been made between "phenomenal" and "reflective" consciousness, where the latter implies further and later cognitive processing of the phenomenal contents (Revonsuo, 2006). Importance of this distinction concerns different theories of consciousness that accept it, such as RPT, IIT or TTC or deny it, such as the GNWT. One empirical study was able to convincingly dissociate phenomenal from access/reflective consciousness (Amir et al., 2023). If replicated, this may imply that one can have a subjective phenomenal experience without being able to report it yet. Similar arguments have been made concerning dream experiences, that at least in some cases, dreams are phenomenally experienced even though they cannot be reported, and are thus examples of "pure" phenomenal consciousness (Revonsuo 2006). Following this distinction, VAN could correspond more to the phenomenal, while LP to the global access/reflective consciousness. This conceptual and empirical distinction is also philosophically crucial, because if one's theory or philosophy does not accept the existence of subjective phenomenal experiences independent of access or reportability (Dennett 1991; Naccache 2018) then it is of course not logically possible to interpret VAN as a correlate of phenomenal consciousness. In the present review, however, the majority of studies reported that subjective conscious vision is associated with an early ERP response. We will briefly discuss the consequences of these positions in the section on theories.

Finally, it is worth noting that in order to empirically identify the phenomena that are the true direct correlates of perceptual consciousness, one must ensure that they exclusively correspond to the visual experiences as such, and not to anything that happens before or after

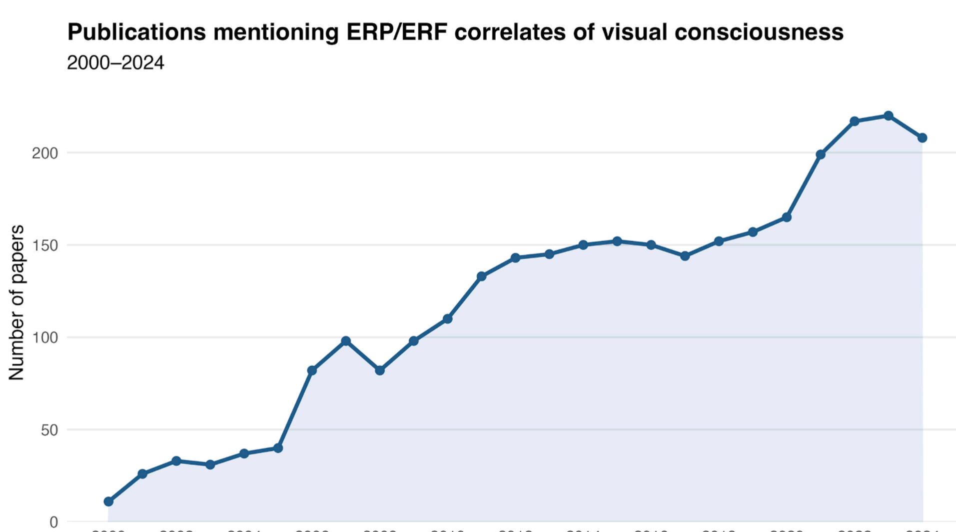

Fig. 1. Papers that mention ERP or ERF NCC in the abstract, keywords or the main text. The numbers are obtained from Google Scholar database using the same search query as in the current review (see Methods section).

that in the processing chain. Therefore, the true NCCs must be isolated from the prerequisites, the consequences, and from other co-occurring processes (Aru et al., 2012; de Graaf et al., 2012; Förster et al., 2020). Here we present a systematized review of the current studies on visual electrophysiological NCC, providing a bird's eye view on this area of consciousness research.

2. Methods

Fig. 2 demonstrates the PRISMA flow diagram. The data was collected in line with the PRISMA 2020 guidelines (PRISMA, 2020), which outline search strategies, data collection, and criteria for inclusion or exclusion. Scopus, Google Scholar, EBSCO and PubMed electronic databases were used for this review. The search process followed several selection criteria:

1. A study should report empirical findings written in English in a peer-reviewed journal.
2. A study should be focused on perceptual awareness in the visual modality and be published in 2020 or later, because the previous reviews have covered the literature up to 2019 (see Förster et al. 2020).
3. A study should utilize an EEG or MEG method, focusing on the event-related potentials.
4. A study should mention "early" and/or "late" ERP NCC in title, abstract and/or in the main text.

These criteria led to a following search query structure (see Supplementary Notes for the query and keyword list): keywords for "early" NCC **or** keywords for "late" NCC **and** keywords for awareness/consciousness **and** keywords for methods **and** $\geq$ 2020 publication year constraint

The search was done up to July 2025. No other constraints were applied on the search. Ninety three unique visual studies were selected out of 1375 search results from all databases. Full texts of these papers were closely inspected for eligibility. Reviews, theoretical or opinion

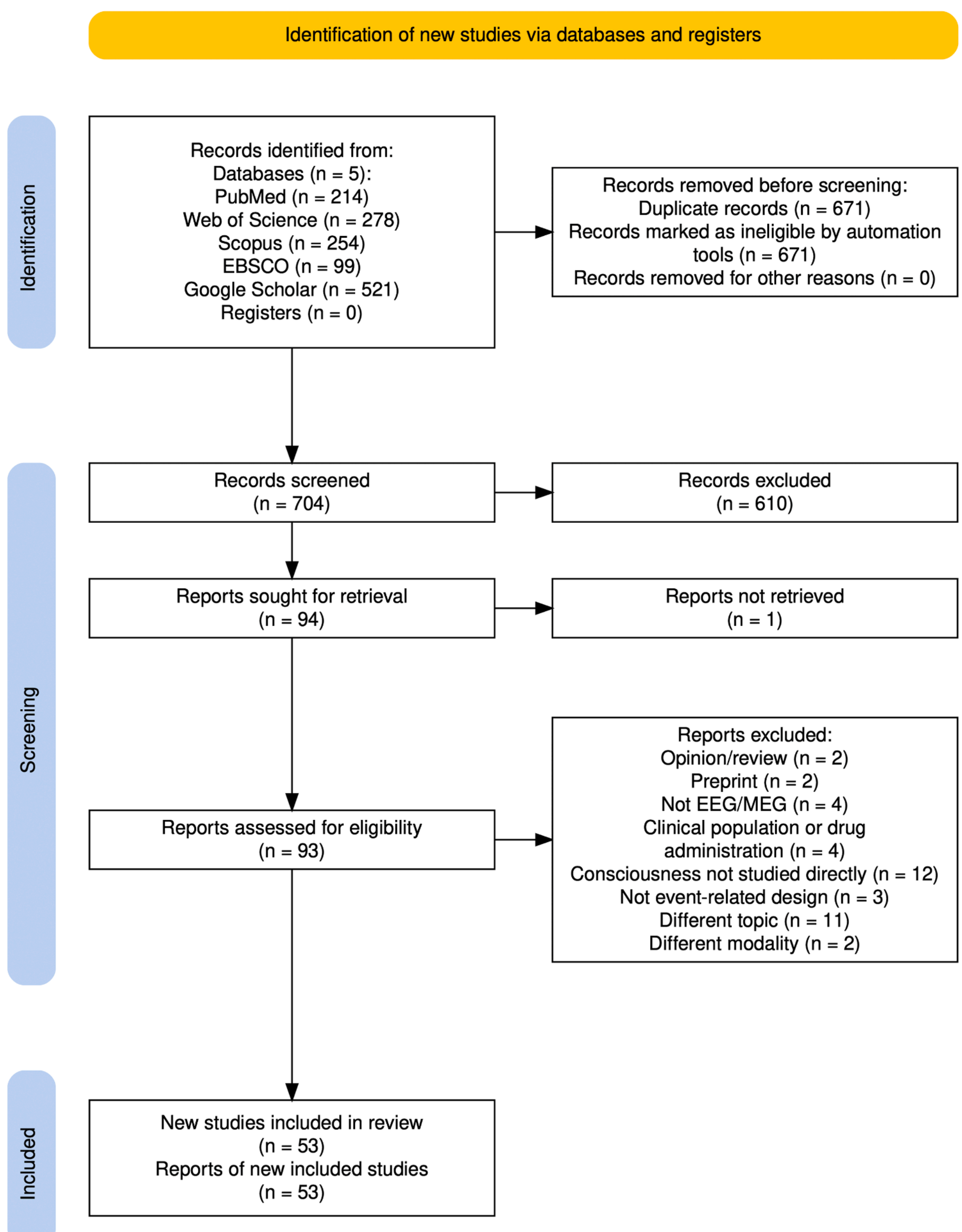

Fig. 2. PRISMA flow diagram.

papers were excluded from the analysis, as well as studies which did not directly investigate consciousness or the "early" and "late" NCCs, were conducted on clinical populations, administered drugs, was carried out in different perceptual modality or had different topic. One study could not be retrieved. In total, fifty-three published articles were selected for the review.

Following the selection process, the data was manually extracted from each paper/experiment: experimental paradigm, final sample size of included participants for the EEG experiment, within/between-subjects design, task type, stimuli type, measure of consciousness, neuroscientific technique, channel reference for the EEG, statistical analysis method, NCC included in the analysis, VAN and LP time windows and electrode clusters and findings summary. The full information is available in Supplementary Table, while studies and their main results are listed in Table 1.

3. Results

3.1. Overview of the visual studies

Figs. 3–8 demonstrate summary statistics on the studies. Most of the experiments used pre-defined time windows ($N = 30$) or electrode clusters ($N = 28$) for measuring VAN or LP informed by previous research. Others, that utilized a data-driven exploratory approach, found similar electrodes and time windows to those that were previously reported (Förster et al., 2020). The most frequently used paradigms were masking ($N = 17$), near-threshold stimuli ($N = 15$) and inattentional blindness ($N = 9$). Only seven studies implemented a no-report paradigm and the perceptual awareness scale (PAS) (Sandberg and Overgaard, 2015; Overgaard and Sandberg, 2021) was used as a measure of consciousness only by fifteen studies, while the most common ($N = 23$) method was alternative forced choice (AFC) response. Less common paradigms included fastest stimulus presentation time ($N = 1$), free visual search ($N = 1$) and response criteria shift ($N = 1$).

AFC may be considered a valid, but not the most optimal option for capturing subjective experience, which might render precision of some results. During alternative forced choice task, a person can respond based on guessing or random choices, if her subjective experience didn't fall within the AFC categories, which are usually defined in terms of task performance, such as whether the stimulus was a target or not. PAS, on the other hand, was designed and validated based on the phenomenological categories of perceptual clarity, which arguably mirrors subjective experience with a greater precision. Nevertheless, there is an ongoing debate on the methodological limitations of PAS (Overgaard and Sandberg, 2021).

The mean sample size in the studies was $N = 30.0$ ($SD = 15.1$), with the minimal number of fourteen and maximum number of ninety participants. The mode was twenty-six participants, which in sum could point on the relatively moderate to normal statistical power. Most frequent stimuli were faces ($N = 20$), followed by geometric shapes, lines or patterns of different forms ($N = 20$) and Gabor gratings ($N = 13$).

3.2. Visual awareness negativity

Results on VAN and their possible support or influence on the theories of consciousness are summarized in Table 2. VAN has been reported by most of the studies ($N = 49$), corroborating its role as a robust electrophysiological correlate of visual consciousness.

3.2.1. Temporal properties

A 4.4 ms unmasked full-contrast stimulus presentation is enough to elicit it and on these timescales, stimulus duration modulates VAN (Lanfranco et al., 2024). A minimal stimulus length for the above-chance location and identification of the stimulus was 1.4 ms and at already 1.7 ms, a noticeable, although not statistically significant, VAN trend was discovered. Lanfranco et al. (2024) also reported that minimal duration

Table 1
Studies included in the review and their main results.

Study	Main results
Andersen et al., 2022.	Stronger VAN in low-level task, stronger LP in high-level task only in weak vs unaware PAS, but weaker in clear vs almost clear PAS
Aydin et al., 2021.	VAN- and LP- like activity associated with changes in mask polarity
Catak et al., 2024.	VAN isn't and LP is modulated by behavioral performance, accuracy
Chen et al., 2022.	P3b is not modulated by changes in stimulus contrast and associated with post-perceptual processing
Ciupińska et al., 2024.	VAN isn't affected by spatial and temporal attention, LP is; VAN and LP latencies affected by cue vs no-cue conditions
Ciupińska et al., 2025.	LP is modulated by PAS and accuracy only in vision. VAN and visual LP peak onset earlier than AAN (auditory awareness negativity) and auditory LP; no cross-modal correlation of amplitudes/latencies
Cohen et al., 2020.	P3b absent in visible task-irrelevant stimuli, VAN present. Additional frontally and centrally distributed negative difference from ± 300 ms to 500 ms
Cohen et al., 2024.	P3b absent in no-report condition, VAN results inconclusive, N2 as a potential NCC. The authors didn't use classical ERP analysis
Colombari et al., 2024a.	VAN can be related to activity in lateral occipital cortex based on FNIRS
Colombari and Railo, 2024.	VAN sources in occipito-temporal regions, LP sources in frontal, parietal, temporal and occipital areas based on ICA source reconstruction
Dellert et al., 2021.	Face awareness correlates with N170 and VAN. P3b correlates with task relevance. VAN sources are in occipitotemporal regions, LP sources are widely distributed across the cortex based on fMRI
Dellert et al., 2022.	VAN is not modulated by task relevance; LP is absent in task-irrelevant condition
Doradzińska et al., 2020.	P3b amplitude is modulated by both aware and unaware self-name
Doradzińska and Bola, 2024.	VAN is dependent on exogenous and endogenous attention and might have 2 parts
Eiserbeck et al., 2022.	VAN and LP are gradually modulated by visibility ratings
Eiserbeck et al., 2024.	Negative affective knowledge influence visual awareness and amplitudes in VAN time window
Filimonov et al., 2022.	VAN and AAN are modality-specific NCC, LP has an early modality-specific and late modality-general part in bimodal stimuli
Glim et al., 2020.	VAN and LP modulated by awareness; P3 is linked to slow cortical potentials, enhanced negativity of slow-cortical potentials facilitates awareness
Hanke et al., 2024.	VAN larger for high-detection trials (less distractors), P3 not modulated by awareness and task
Harris et al., 2020.	VAN modulated by awareness and task independent, contralateral post-stimulus α-power decrease starts to overlap with VAN time-window
Hense et al., 2024.	Prolonged VAN up to 1000 ms for stimuli of the same length, no LP
Hutchinson et al., 2021.	Pre-stimulus alpha reduction is modulated by awareness, post-stimulus alpha corresponds to VAN and LP time windows, VAN modulated by awareness, LP by task relevance
Hutchinson et al., 2024.	VAN is modulated by awareness, LP by task relevance
Jimenez et al., 2021.	VAN is modulated by awareness at lower level, while LP at higher level of processing
Krasich et al., 2022.	VAN is modulated by awareness and associated with lower pre-stimulus alpha power
Krisst and Luck, 2025.	Awareness decoded in VAN time window; stimulus orientation decoded in both time windows in aware trials, while in unaware trials briefly in VAN (200 – 240 ms) and mostly in LP time window
Kronemer et al., 2022.	VAN is modulated by awareness, LP by task relevance
Lanfranco et al., 2024.	VAN is modulated by awareness, LP by awareness and exposure duration, emotion affects both VAN and LP
Leupin and Britz, 2024.	VAN and LP are present in aware vs unaware trials, VAN modulated by heartbeat and breathing phase
Maffei et al., 2024.	VAN and LP are absent in aware vs unaware condition in fearful faces, N170 is present. However, it should be

(continued on next page)

Table 1 (*continued*)

Study	Main results
	noted that authors treated PAS1 (aware face, unaware expression) as unaware condition
Mazzi et al., 2020.	VAN is modulated by awareness, LP by awareness and response criterion shift
Qiu et al., 2022a.	VAN emerges prior to N2pc, VAN and N170 are modulated by awareness of faces, LP by awareness and accuracy
Qiu et al., 2022b.	VAN is modulated by awareness and can be enhanced by, but does not require spatial attention. LP is modulated by awareness, spatial attention and emotion of the attended faces
Qiu et al., 2022c.	VAN is modulated by awareness, LP by awareness of task-relevant stimuli. Spatial attention shifting (N2Pc) to fearful faces depends on perceptual awareness (VAN time window)
Z. Qiu et al., 2023a.	VAN is absent in emotionally aware vs unaware peripherally presented faces; LP is present only in fully aware task-relevant trials
Qiu et al., 2023b.	VAN and N170 are modulated by visibility, LP is modulated by visibility and stimulus features. Subliminal fearful faces enhance amplitude in VAN time window
Qiu et al., 2023c.	VAN is not modulated by flanker features, LP is
Qiu et al., 2023d.	Awareness can be decoded in N170, VAN and LP time windows. Mere presence of fearful faces can be decoded in N170 time window
Qiu et al., 2023e.	VAN is modulated by awareness and can onset as early as 100 ms post-stimulus in free search. N170 was facilitated by fearful target faces
Rodríguez-San Esteban et al., 2025.	Awareness is decoded from around 200 ms, while unconscious stimulus processing is decoded in several time windows from 100 ms. Unconscious stimulus information can't be maintained for long time periods, but some can be present and prepare participants to respond faster although not accurately
Roth-Paysen et al., 2022.	VAN, LP and N170 showed a gradual response to face perception across time lags. Awareness of faces emerges during N170
Rowe et al., 2024.	Uses Pitts et al. (2015) study dataset. Above chance classification of face stimuli even in unaware inattentional blind trials
Sanchez et al., 2020.	Significant difference in VAN and LP time windows in aware vs unaware trials. After 300 ms a classifier trained on one modality can decode aware trials in another. Late activity in sensory cortex of one modality can decode awareness in another
Schlossmacher et al., 2020.	VAN is modulated by awareness, MNN by deviance, P3 by awareness of task-relevant stimuli
Scrivener et al., 2021.	VAN is absent for color change, LP modulated by correctly located aware stimuli
She et al., 2024.	P3b is modulated by aware and unaware deviant colors; in unaware condition, P3b is replaced by a negative activation
Sheldon et al., 2022.	P3 time window is modulated by accuracy
Sun et al., 2023.	VAN is modulated by awareness and not by selective attention, LP is modulated by task-relevant or emotional aware trials, SN modulated by selective attention, N170 modulated only by happy faces. VAN sources in lateral occipital cortex and parietal lobes for emotional, and in fusiform gyrus for neutral faces. LP sources for emotional faces are in frontal and parietal lobes, LP is absent in neutral faces
Tafuro et al., 2023.	Aware trials are associated with decrease in pre-stimulus alpha and beta power, that also continues throughout VAN and LP time windows
Teixeira et al., 2020.	VAN is modulated by aware luminance changes. LP is modulated by suprathreshold vs above threshold level of awareness and oddball target stimuli
Wiens et al., 2023.	VAN and LP are larger for detection (lower level) than identification (higher level of processing). VAN is present in both detection and identification, but more sensitive to the lower level of processing
Ye and Lyu, 2024.	LP is stronger when frequency of requirement to make report is higher. VAN is stronger when frequency of requirement to report is lower
Yu et al., 2023.	Longer high-altitude exposure leads to smaller VAN and larger LP; LP predicts faster RT and higher drift-rate

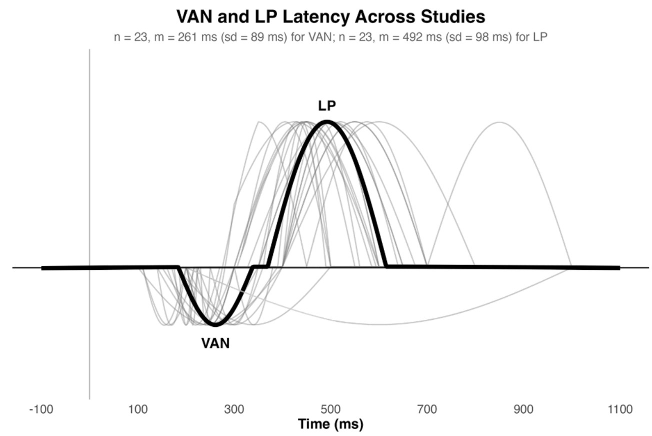

Fig. 3. VAN ad LP latencies across studies. The latencies are shown only for those studies which didn't preregister the time intervals for the analysis and reported data-driven results. VAN with the longest duration is reported by Hense et al. (2024) and LP with the longest onset latency reported by Jimenez et al. (2021).

for awareness either precedes or is equivalent to that for emotion processing. On the other end of the continuum, Hense et al. (2024) demonstrated that VAN can be prolonged and equal the stimulus length, at least up to 1000 ms. The stimuli were background face line patterns in an inattentional blindness paradigm. Although the overlapping of ERPs cannot be entirely ruled out, the authors point on the existing evidence that prolonged supraliminar stimuli have sustained representations in occipitotemporal areas, while the frontoparietal representations remain transient (Gerber et al., 2017; Melloni et al., 2023), which support VAN prolongation. This might imply that VAN corresponds to the phenomenological duration of the subjective visual experience that it indexes. Future studies could focus on investigating the minimal-maximal boundaries of VAN. Regarding its minimal length, Lanfranco et al. (2024) did not focus on the precise time window variation, predefining it after inspecting the grand averages, yet their results have shown the shortest visual awareness negativity which lasts only 30 ms. Taken together these observations imply that VAN is not only indexing an entry point to visual consciousness, but also corresponds to the duration of the percept.

3.2.2. *Spatial properties and neuroanatomical generators*

In accordance with the previous research, most of the studies locate VAN in the posterior regions (Colombari et al., 2024b; Lanfranco et al., 2024; Rowe et al., 2024), specifically in the lateral occipital cortex (Andersen et al., 2022; Colombari et al., 2024), primary visual areas and calcarine sulcus (Sanchez et al., 2020), see Fig. 3 for details. A source reconstruction figure from Lanfranco et al. (2024) indicates VAN generators around occipital and inferior occipito-temporal areas, areas V1/V2 and extrastriate cortex, possibly also in the fusiform gyrus. In an EEG-fMRI inattentional blindness study with face patterns, Dellert et al. (2021) reported that VAN correlated with BOLD signal at right fusiform and inferior frontal gyri, while the left inferior lateral occipital cortex was not conclusively correlated with ERPs. The authors also found the sources of N170 in the right fusiform gyrus which overlapped with VAN. An important discovery was made by Leupin et al. (2024), who showed that cardiac and respiratory activity modulates cortical excitability and sources in the VAN time window: specifically, an activation in the posterior insular cortex and its projections in the ventral temporal-parietal junction was detected during the raising phase of VAN only in presence of high baroreceptor activity. In the falling phase of VAN, an anterior insular cortex, inferior frontal gyrus with ventral section on temporal-parietal junction (superior temporal sulcus and angular gyrus) were activated irrespective of cardiac or respiratory phase. The authors compared awareness in conjunction with cardiac or

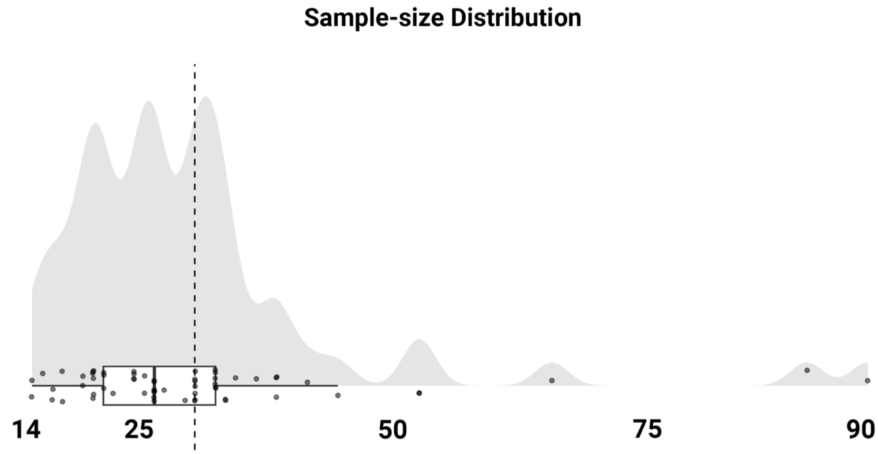

Fig. 4. Sample size distribution in the selected studies.

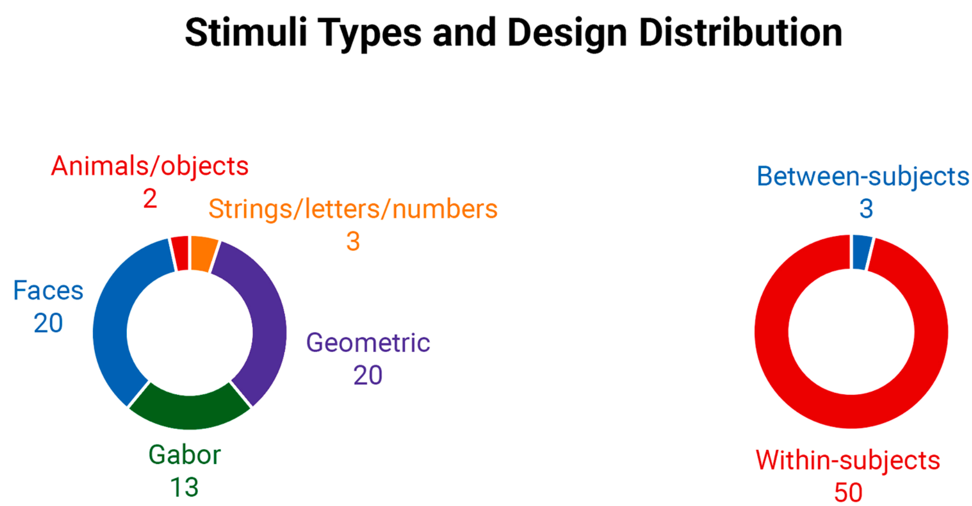

Fig. 5. Stimulus types and experimental designs from the papers included in the selected studies.

respiratory phase, which might be the reason for absence of typical VAN sources in the visual areas. EEG-based source reconstruction is vulnerable to large margins of error due to the "inverse problem", yet both the variability and dynamics of VAN generators suggest that although the component might be robust per se to reflect awareness, its sources and mechanisms may vary depending on the experimental paradigm, the stimulus types used, and on simultaneous physiological factors. This opens an avenue for future research to carefully classify VAN sources by their relation to the experimental manipulation and body signals.

3.2.3. *Properties that modulate VAN*

VAN was confirmed to be modulated by visual awareness in the majority of studies ($N = 49$). VAN was also found to be affected by stimulus features that correspond to its experiential properties, such as duration (Lanfranco et al., 2024; Hense et al., 2024), color constancy (Teixeira et al., 2020) and visibility (Eiserbeck et al., 2022; Z. Qiu et al., 2023), as well as by the level of stimulus processing (Andersen et al., 2022; Jimenez et al., 2021; Wiens et al., 2023) according to the level of processing (LoP) framework (Windey and Cleeremans, 2015; Windey et al., 2014). Beyond LoP, VAN was modulated by a mask polarity changes (Aydin et al., 2021), presence of pre-stimulus cues (Ciupinska et al., 2024) and negative affective knowledge (Eiserbeck et al., 2024), however the latter could be indexed by emotional processing negativity (EPN) or N170, which overlaps with VAN in both topography and time window. A distractor induced blindness study (Hanke et al., 2024) reported that VAN depends on the number of distractors. However, since the authors stressed that awareness was manipulated indirectly, it cannot be concluded whether this effect relates to experiential visibility of the stimulus and further investigation is required. In addition, VAN has been reported to decrease in adults living at higher altitudes (~ 3680 m) for >10 years comparing to <10 year group (Yu et al., 2023) and be modulated by the heartbeat and breathing phase (Leupin et al., 2024), which introduces body and environmental context to the equation.

3.2.4. *VAN and the levels of stimulus processing*

The level of processing framework hypothesizes that different mechanisms might exist for different depths of perception, such as for detection vs identification, or identification of color vs semantic category. It also explains why perceptual clarity can increase both gradually and dichotomously, depending on the cognitive task: a gradual increase is possible for the lower-level stimulus features, such as colors or shapes that can't be associated with a single label (see Jimenez et al., 2020 for a review). While Jimenez et al. (2021) reported VAN only for the lower-level of processing, more recent studies by Andersen et al. (2022) and Wiens et al. (2023) found it at both levels, but stronger at the lower level. Arguably, there might be more than two levels and difference in the results could be related to the "distance" between them. In the Andersen et al. (2022) MEG study, the low-level task was to assess

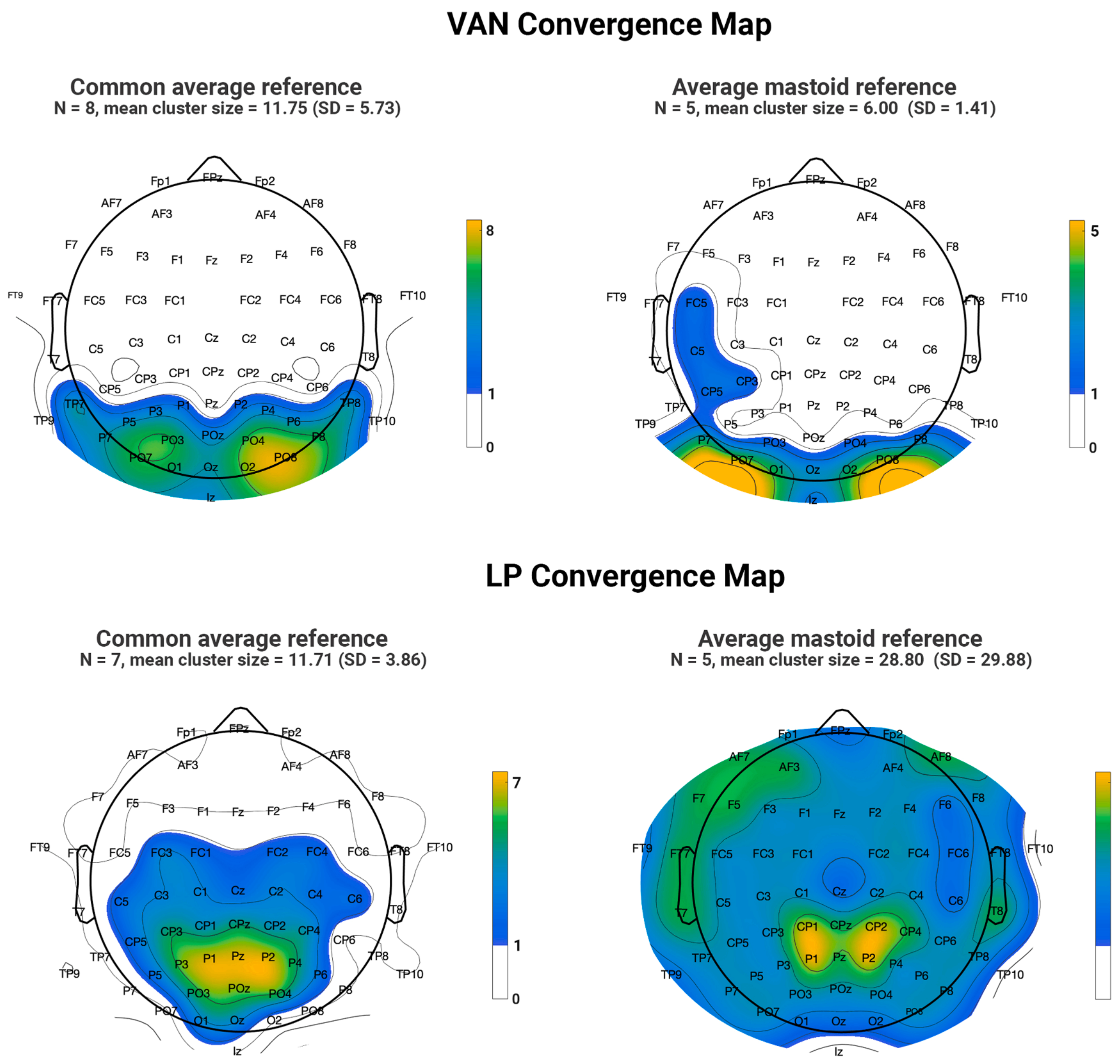

Fig. 6. VAN and LP convergence maps, showing how many studies reported similar electrode locations for VAN and LP under common average and average mastoid references (colour denotes number of studies). We included only those studies, where electrode information was available and the layout was compatible to the 10–20 coordinate system. The convergence maps are shown only for those studies which didn't preregister the electrode clusters for the analysis and reported data-driven results.

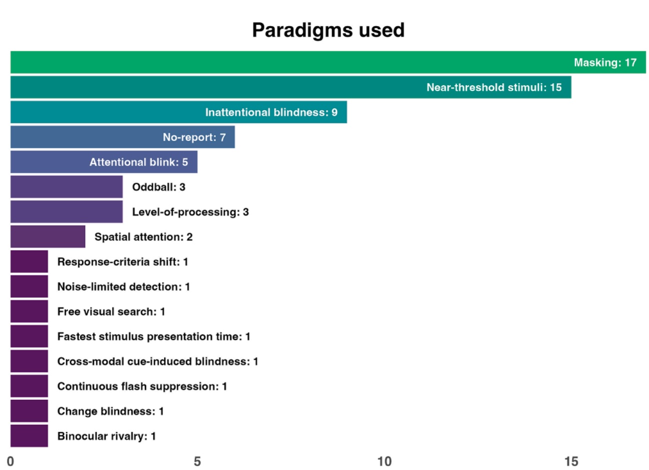

Fig. 7. Experimental paradigms used in the selected studies. Some studies implemented a combination of these paradigms.

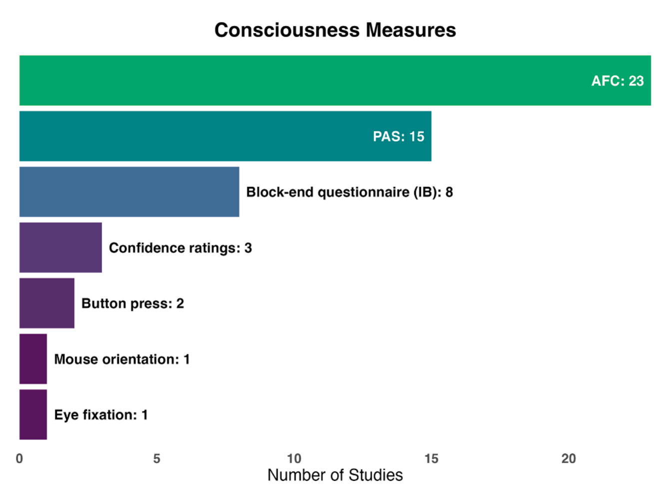

Fig. 8. Consciousness measures used in the selected studies.

whether two simultaneously appearing letters are identical, while the high-level task was to notice whether both were vowels or consonants. In the Jimenez et al. (2021) study, a low-level task was to identify the

Table 2
VAN results and their theoretical compatibility.

Feature (modulated by)	Result	RPT	GNWT	IIT	TTC
awareness	Yes (49), No (4)	Yes	No	Yes/Neutral	Yes/Neutral
stim. duration	Yes (2)	Yes	No/Neutral	Yes/Neutral	Yes/Neutral
LoP low level	Yes (3)	Yes	No	Yes/Neutral	Yes/Neutral
LoP high level	Yes (2), No (1)	Yes/Neutral	No	Yes/Neutral	Yes/Neutral
visibility	Yes (2)	Yes	No	Yes/Neutral	Yes/Neutral
color constancy	Yes (1)	Yes	No	Yes/Neutral	Yes/Neutral
reporting frequency	Yes (1)	Neutral	No/Neutral	Neutral	Neutral
mask polarity	Yes (1)	Neutral	Neutral	Neutral	Neutral
pre-stimulus cures	Yes (1)	Neutral	Neutral	Neutral	Neutral
negative affective knowledge	Maybe (1)	Neutral	Neutral	Neutral	Neutral
number of distractors	Maybe (1)	Neutral	Neutral	Neutral	Neutral
high altitude	Yes (1)	Neutral	Neutral	Neutral	Neutral
spatial attention	No (3)	Yes	No/Neutral	Yes/Neutral	Yes/Neutral
temporal attention	No (1)	Yes	No/Neutral	Yes/Neutral	Yes/Neutral
selective attention	No (1)	Yes	No/Neutral	Yes/Neutral	Yes/Neutral
stimulus-related saliency/ exogenous attention	Yes (1)	No	No/Neutral	Neutral	Neutral
task-relevancy	No (7), Yes (1)	Yes	Neutral	Neutral	Neutral
fearful facial expression in aware trials	Yes (1)	Neutral	Yes/ Neutral	Neutral	Neutral
temporally overlaps with decrease in α-power	Yes (4)	Neutral	Neutral	Neutral	Yes

Note: experimental features, number of studies that show their relation with VAN and support of the theories of consciousness based on our interpretation or the results. "Yes" denotes strongly supporting evidence (highlighted in green), while "No" denotes strongly rejecting (highlighted in red) evidence. "Yes/Neutral" underlines supporting or neutral but theory-positive result, while "No/Neutral" underlines rejecting or neutral but theory-negative result. All results including incompatible (yes + no) are discussed below.

color of a line drawing and the high-level task was to identify its animal/object category, while Wiens et al. (2023) used stimulus detection as a low-level task and a grating orientation as a high-level task. The high-level task in Jimenez et al. (2021) study could be considered most difficult, while Wiens et al. (2023) states that from perspective of LoP, both their tasks were low-level.

Another study, which can be viewed within the LoP perspective, showed that VAN is modulated by the frequency of reporting (Ye et al., 2024), where it was found to be stronger in task with rare vs frequent trials containing report. Requirement to report trials more often reduced VAN amplitude and the question is whether different reporting frequencies could trigger or be considered as different levels of processing.

Current results on LoP, therefore, remain inconclusive and call for further research on VAN across the continuum of hypothesized levels. A separate question concerns whether the levels of processing are exclusive or consecutive: for example, it is logical to suppose that stimulus identification requires detection to be done first, which, in turn, can lead to re-interpreting some of the empirical findings. For example, there can be a ceiling effect for the ERPs in preceding vs consecutive levels. Another dimension in this research is a parallel between LoP and phenomenal vs access/reflective consciousness (Block, 1995). One may relate phenomenal consciousness to the lower levels of processing, while access/reflective consciousness to the higher levels, yet the precise mapping will require both empirical and philosophical work.

3.2.5. VAN, attention and task relevancy

Research also continued to unravel the complicated relationship between consciousness and different forms of attention. This complexity partially lies within the research of attention itself (Hommel et al., 2019; Krauzlis et al., 2023). We, therefore, suggest interpreting the relations between attention and NCC cautiously, and also carefully define the type of attention investigated. From the methodological perspective, one also has to carefully dissociate VAN from the co-occurring EPN, selection negativity, posterior negativity and n2pc. These components differ in the baseline condition: unaware stimuli for VAN and attentionally irrelevant for the other components (Doradzińska et al., 2024). Since all these components compare the baseline with aware stimuli, there might be potential overlaps of effects and misinterpretations of some results. A special case is N170, which also overlaps with VAN and is related to processing of faces.

In the 2020–2025 period, studies report VAN independence from spatial (Ciupinska et al., 2024; Qui et al., 2022a, 2022b), temporal (Ciupinska et al., 2024) and selective (Sun et al., 2023) attention. However, in terms of stimulus-related saliency, defined as exogenous, and task relevancy, defined as endogenous attention, VAN was reported to depend on both (Doradzińska et al., 2024). Other studies have not found the dependence of VAN on task relevancy (Cohen et al., 2020; Dellert et al., 2022; Hutchinson et al., 2021, 2024; Kronemer et al., 2022; Schlossmacher et al., 2020; Qiu et al., 2022c). Notably, Doradzińska et al. (2024) used emotional faces and, as evolutionary important stimuli, faces could additionally influence the results. Nevertheless, different results cannot be explained either by the stimulus type, or by the consciousness measure, as some of the studies who did not find the dependency also used face stimuli (Kronemer et al., 2022; Qiu et al., 2022c) and implemented both AFC or PAS. Findings related to facial processing will be separately discussed below.

All studies which reported independence from task relevancy implemented a no-report paradigm ± inattentional blindness, except Qiu et al. (2022c) and Dellert et al. (2022), who used attentional blink, while Doradzińska et al. (2024) study used masking. In Doradzińska et al. (2024) work, the authors point out on main limitations of the attentional blink, which is manipulating awareness via attention itself. They also acknowledge the limitation of their own study, which might introduce masking and physical differences in emotional vs neutral face features as a confounding factor, however they argue against these effects by pointing out that stimuli were counterbalanced across conditions and small probability of the masking confound, which, however, should be examined in future.

What is more, the authors in Doradzińska et al. (2024) interpret some of the findings from studies that reported VAN independence from task-relevancy (Sun et al., 2023; Andersen et al., 2022; Dellert et al., 2021; Schlossmacher et al., 2020) differently, by stating that absolute ERP values in the VAN time windows were modulated by task. This inconsistency appears due to the different stances on the existence of attention-related components within the VAN time window: the EPN, selection negativity, posterior negativity, n2pc and N170. For example, Qiu et al. (2022b) reported that n2pc, not VAN, was specifically influenced by attention of face stimuli. Arguably, a separate research avenue that would define and dissociate components within the VAN range is needed: as an example, one might present a near-threshold face and non-face stimulation in order to differentiate between the electrophysiological responses. What could be added here is that a no-report paradigm might arguably provide a better dissociation between consciousness and task relevance, as in the report paradigms all stimuli are task-relevant to some extent. Although the majority of the evidence point out that VAN is task-independent, further investigation is required.

3.2.6. Studies that report VAN absence or inconclusive evidence

Finally, only three studies out of fifty three reported that VAN was absent in a classical aware-unaware trial contrast (Scrivener et al., 2021; Maffei et al., 2024; Z. Qiu et al., 2023a) and one reported inconclusive evidence (Cohen et al., 2024). Cohen et al. (2024), Qiu et al. (2023a) and Maffei et al. (2024) used face stimuli and report N170 to be modulated by awareness, while Scrivener et al. (2021) used change blindness with colored squares. Cohen et al. (2024) reported the absence of VAN in a near-threshold + masking study with varying SOA, however their VAN analysis differed from the classical contrasting, such as implemented in their previous study (Cohen et al., 2020): instead, the authors preregistered a set of criteria for confirming bifurcation of the neural signal (Sergent et al., 2021; Kouider et al., 2013) and made their decision based on it: for instance, there had to be no difference in the signal between 17 and 33 ms SOA and a significant difference between 33 and 50 ms SOA. If these criteria aren't met, the signal would not be mimicking the psychometric function from the behavioral results and should be treated as absent. The ERP figures in Cohen et al. (2024), however, show a clear difference in the VAN time window between 17 ms and other SOA lengths in both report and no-report conditions, which, in turn, could be interpreted as VAN was present but didn't vary much by the stimulus visibility. However, dependence on visibility cannot be concluded with certainty from this design: although the number of aware trials increased with longer SOA, perceptual visibility of each trial is difficult to assess without the use of perceptual awareness scale. The choice for assessing the bifurcation dynamics instead of aware-unaware contrast is probably determined by the theoretical postulates of the GNWT and to confirm that VAN was absent as an ERP difference wave, the authors might have to additionally re-analyze the data comparing aware vs unaware trials. Additionally, it is worth noting that VAN might be present when the SOA is kept constant, which methodologically avoids the stimulus-mask interaction leading to possible ERP side effects.

In another study that reported VAN absence, Qiu et al. (2023a) explains that possible reason is the peripheral stimuli presentation, which is known to reduce early ERPs (Busch et al., 2004, 2009; Capilla et al., 2014, 2016; Schindler et al., 2022). The authors also proposed alternative explanation that VAN has to reflect the perceptual difference between the stimuli, while there was no such difference between the conditions in their study. Finally, the authors pointed on the limitation of their approach critical to the VAN effect: the task could be too complex and leave participants with no resources for task-irrelevant face perception. Maffei et al. (2024) didn't find VAN and LP, in the aware fearful trials, however they treated aware face with unaware expression as unaware condition. In such scenario, activity in the VAN time window could be elicited already at the "baseline" condition without further modulation by emotion. Scrivener et al. (2021) provided two possible explanations for absence of VAN in their study: in change blindness, perceptual difficulty of the stimuli remains the same and the overall task difficulty is modulated by distractors, which rendered insensitive to color changes. However, Teixeira et al. (2020) reported that aware changes in color constancy modulated VAN. Additionally, VAN was shown to be independent from spatial attention (Ciupinska et al., 2024; Qui et al., 2022a, 2022b), which could otherwise explain the change blindness effect. Another suggestion proposed by the authors is that VAN requires both identity and location of the stimuli, while in the change blindness paradigm, the latter might be unavailable. It should be also noted, that Scrivener et al. (2021) chose rather unconventional electrodes Cz, CPz, Pz for VAN analysis and Fz as a reference, in comparison with the absolute majority of the VAN-related studies.

3.3. N170 as an NCC for faces?

Twenty studies from the current selection used face stimuli and fourteen reported N170 component that sometimes preceded VAN. In previous years, several authors have proposed that N170 could be a specific correlate of conscious face perception (Navajas et al. 2013; Sandberg et al., 2013; Shafto and Pitts, 2015). A study by Qiu et al. (2023a) reported an absence of both VAN and N170 and discussed above. Other studies (Krasich et al., 2022; Kronemer et al., 2022) might not have operationalized and differentiated N170 from VAN due to the usual temporal and topographical overlapping of the components, while some paradigms were incompatible and weren't aimed at the N170 extraction (Qiu et al., 2022c, 2023c). Lanfranco et al. (2024) reported N170, but used only a face vs object contrast, therefore the relation between N170 and consciousness in their study remains unknown. Similarly, Maffei et al. (2024) used aware face with unaware expression vs aware face and expression contrast. In Qiu et al. (2022b), the N170 was not found: the authors explain these results due to the simultaneous presentation of faces and that bilateral processing could lose in efficiency, rendering the component invisible.

Other N170 results are as follows: Doradzińska et al. (2024) stated that an early 140 – 200 ms part of VAN was not observed in attentionally irrelevant stimuli, while the late 200 – 300 ms part was present, but modulated by attention. The authors also explicitly defined an early part as N170/VAN without division; therefore, task relevance can be cautiously attributed to the N170. In Hense et al. (2024), the authors also did not specifically investigate the N170 due to its overlapping with VAN, arguing for a delayed N170 peak due to the abstract face stimuli they used. Instead, they report activity in the VAN/N170 time window with a stronger amplitude in the right hemisphere.

Several other studies reported that face visibility modulated the ERPs already in N170 time window (Eiserbeck et al., 2022; Qiu et al., 2022a, 2023b; Roth-Paysen et al., 2022; Eiserbeck et al., 2024; Dellert et al., 2021). Qiu et al. (2023e) also found that both N170 and VAN were modulated by a fearful facial expression in aware trials. Multivariate pattern analysis results in Qiu et al. (2023d) confirmed that mere presence of fearful face can be decoded from an N170 time window. Eiserbeck et al. (2024) also reported that fearful faces enhanced N170, but unlike in Qiu et al. (2023d, 2023e), they found it in classical aware vs unaware trial contrast, which implies that N170 shares the properties of the NCC. In Sun et al. (2023), N170 was modulated only by happy faces. Finally, Dellert et al. (2021) reported that N170 in their experiment was modulated by neutral faces and was localized in a right frontal gyrus, similarly as VAN.

Some of these discrepancies can be explained by different durations of the used stimuli: for instance, Sun et al. (2023) proposed that shorter durations make facial processing more difficult, while happy faces processing might have some priority. The results appear rather mixed and inconclusive and can't provide any convincing answer on whether N170 could be a separate NCC in vision for faces. The MVPA and fMRI analyses rather imply that a facial processing is happening in the N170 time window independently of awareness, and if awareness takes the stage, an early onsetting VAN can be superimposed on this time window. To test this hypothesis further, experiments that can dissociate VAN from N170 as to their respective neural sources and awareness levels, should be carried out, utilizing a paradigm that found N170 in aware vs aware emotional condition. The evidence that is available at this point does not convincingly establish that N170 is an NCC in and of itself, independent of VAN. Therefore, we suggest that N170 is not an NCC, unless further evidence turns up for it.

3.4. *VAN, slow cortical potentials and the frequency domain*

Glm et al. (2020) reported that enhanced negativity of slow-cortical potentials (SCP) facilitates awareness. The authors also reported VAN and LP and while they do not relate VAN to the SCP, LP includes the longer-lasting SCP effect. The authors did not conclude whether negative pre-stimulus SCP also enhance VAN, however this might be expected: in relationship with VAN, SCP might act as a neural predisposition for consciousness (Northoff and Lamme, 2020), a condition that can facilitate or suppress it.

Several studies report that the lower pre-stimulus α-power is associated with increased awareness and its post-stimulus time window overlaps with VAN (Harris et al., 2020; Hutchinson et al., 2021; Krasich et al., 2022; Tafuro et al., 2023) and LP time windows (Hutchinson et al., 2021; Tafuro et al., 2023). All studies confirm that VAN is modulated by awareness. Pre-stimulus α-power has been noticed to predict awareness in numerous cases (Iemi and Busch, 2018; Jensen et al., 2012; 2014; Kloosterman et al., 2019; Limbach and Corballis, 2016; Mathewson et al., 2009; Samaha et al., 2017; Schroeder and Lakatos, 2009), and recently it was also reported to predict subliminal perception (Railo et al., 2021). Association of α-power changes with the occurrence of VAN further corroborates that the latter could be an NCC proper in vision.

3.5. *Late positivity*

There were no studies that reported LP to be related exclusively to awareness. For instance, Colombari et al. (2024a), Eiserbeck et al. (2022), Glim et al. (2020), Leupin et al. (2024) found LP to be modulated by awareness of task-relevant stimuli. In She et al. (2024) study, P3b, a component that contributes to LP, was modulated by aware and unaware deviant colors, while in the unaware conditions P3b was replaced by negative activation. The authors didn't study VAN.

Besides widely established influence of task-relevancy on LP, it was also found to be modulated by the level of stimulus processing (Andersen et al. 2022; Jimenez et al., 2021; Wiens et al., 2023), performance accuracy (Catak et al. 2024; Ciupinska et al., 2025; Qiu et al., 2022a; Sheldon et al., 2022), attention (Ciupinska et al. 2024; Qiu et al., 2022b; Scrivener et al., 2021), emotion (Sun et al., 2023; Lanfranco et al., 2024; Qiu et al., 2022b; Sun et al., 2023), response criterion shift (Mazzi et al., 2020), stimulus features (Qiu et al., 2023b; Qiu et al., 2023c;) including unaware (She et al., 2024; Doradzińska et al., 2020), mask polarity (Aydin et al. 2021), reporting frequency (Ye et al., 2024), stimulus visibility (Eiserbeck et al., 2022; Qiu et al., 2023b; Teixeira et al., 2020) and exposure duration (Lanfranco et al., 2024). LP is related to the higher-level of stimulus processing (Andersen et al. 2022; Jimenez et al., 2021), however Wiens et al. (2023) reported that LP is also present at the lower-level. On the contrast with VAN, Yu et al. (2023) found that LP was stronger in longer high-altitude exposures. Since the evidence is strongly against LP being an NCC proper, as it is absent in no-report and task-irrelevant stimuli, we omit the discussion of its sources, relations with the pre-stimulus activity etc. to avoid overloading the review. Likewise, the role of LP as the NCC of access consciousness has been doubted (Sergent et al., 2021).

4. Discussion

To update and integrate the NCC findings on visual consciousness, we reviewed the most recent literature (2020–2025) on the ERP correlates, not covered by the previous reviews. We found that VAN is exclusively modulated by perceptual awareness, while LP is modulated by awareness when stimuli are task-relevant and attended to. VAN is found at the minimal stimulus durations needed to reach awareness. It can be as short as 30 ms for short stimuli and prolonged up to at least 1000 ms for long stimuli of same length. Cortical generators of VAN might overlap with other components such as N170 and be affected by cardiac activity, which should be taken into account while dissociating them. VAN is modulated by perceptual awareness as well as by the experiential features of the stimulus, such as luminance, visibility and duration. Most of the evidence suggests that VAN is not modulated by any form of attention (but see earlier studies that found VAN to be dependent on spatial attention, i.e. Koivisto et al., 2009), however its independence from task relevancy should be confirmed. Changes in α-power that can precede perceptual awareness also occur in the VAN time window. The present results on whether VAN is modulated by the higher levels of processing, where participants engage in cognitive tasks, such as semantic categorization of the stimuli, remain mixed. The present evidence strongly suggests that LP is not an NCC proper.

5. Implications for the theories of consciousness

As we mentioned in the introduction, the interpretation of the empirical results may depend on the philosophical stance one takes on consciousness (for a thorough analysis and discussion on this point, see Revonsuo, 2026). Specifically, for theories that accept some form of "illusionism" regarding phenomenal experience, such as GNWT or attention schema (AST) (Graziano, 2019), the interpretation that VAN is a correlate of phenomenal consciousness is obviously unacceptable, because the theories do not acknowledge the existence of any "phenomenal consciousness" that is separate from and independent of access consciousness. Another issue is that paradigmatic and analytical choices are theory-driven and often lead to theory-acceptable results (Yaron et al., 2022; Melloni et al., 2023; Northoff and Lamme, 2020): an example from this review is Cohen et al. (2020) and (2024) studies, where in 2020 the authors found VAN via a typical ERP analysis, while in 2024 they reported its absence by analyzing bifurcation dynamics. The method is argued to overcome some limitations of the ERPs, mainly, information loss during averaging (Sergent et al., 2021), however it rather complements than cancels the classical ERP approach, having its own limitations. Other methods, such as the time-frequency analysis, which preserves phase difference, showed spectral changes in the VAN time window. The question is, therefore, not of the methodological nature. Rather, it concerns different scopes of the theories, their explananda and explanans (Northoff and Lamme, 2020): for instance, in recent studies on GNWT (Mashour et al., 2020; Sergent et al., 2021), the authors stated that their theory is about access consciousness, introducing the concept of covert conscious access for no-report cases. Furthermore, GNWT theorists have explicitly rejected phenomenal consciousness and argued that the only type of consciousness that really exist is access consciousness, and phenomenal consciousness, if it exists at all, can be reduced to access consciousness and is nothing separate from it (Dehaene et al., 2014, 1998; Naccache 2018). Whether the authors accept phenomenal consciousness to exist beyond the theory's scope with VAN as a phenomenal NCC or not, LP is not a reliable NCC of conscious access because of its absence in the no-report paradigms and task-irrelevant/unattended stimuli. However, activity in the LP/P3 time window, for instance, in a form of bifurcation dynamics, would still be most probable access NCC as it allows the "ignition" and further activation of the global workspace. Results on VAN, therefore, are either fully incompatible or out of the scope of the GNWT. Second option would be available if another NCC will be found to always follow VAN. If exists, such NCC might be non-ERP, since LP is not an NCC proper, but must directly and specifically reflect global activation of the "workspace"/ "playground".

Theories that accept phenomenological realism may interpret ERP NCC differently. One classification was proposed by Chis-Ciure et al. (2024), who evaluated the importance of different empirical measures for various theories of consciousness according to their predictions. According to Chis-Ciure et al. (2024), LP is a "mantle" or "core" measure for the GNWT, which means that results regarding this component might either considerably support or require critical transformation of the theory. The authors also mentioned that VAN would be "peripheral" for the IIT, meaning that results regarding VAN, would require modest modifications of the theory, while for the TTC it's "orthogonal", meaning that the results would not affect it. Following the same line of argument, we further suggest that VAN is a "core" measure for the RTP.

RTP accepts phenomenal consciousness and predicts that changes in contents of consciousness occur during a feedback or recurrent/reentrant activity from prefrontal to the posterior brain regions. In vision, an activity from the retina travels via the lateral geniculate nucleus, the primary visual cortex and secondary areas towards the prefrontal areas, which is labelled a "feedforward sweep" that lasts about 100 to 150 ms post stimulus (Förster et al., 2020; Lamme, 2000, 2010). Visual awareness happens when the activation spreads backwards in form of the recurrent activity. When amplified by attention, this activity becomes more widespread or sophisticated, allowing it to reach higher levels of visual hierarchy, and trigger higher levels of processing in LoP terms. Present results on VAN are compatible with and additionally support the RPT.

The IIT proposes a set of axioms regarding consciousness, which are subjectivity, specificity, unity, definiteness and structure, and that a physical substrate should be organized in a way that allows to implement them (Albantakis, 2020, 2023; Ellia et al., 2021; Tononi et al., 2022). Subjective experience can be expressed as a dynamic cause-effect structure and a substrate is its "physical" implementation. The main measures of consciousness for the IIT are Φ (big) and φ (small) Phi, which index integrated information or integrated existence in other words (Albantakis et al., 2023; Chis-Ciure et al., 2024), however their measurement is currently impossible and IIT implements a proxy-measures that capture signal complexity, such as perturbation Lempel-Ziv complexity index (Massimini et al., 2005; Casali et al., 2013). Regarding the NCC, IIT suggests that both full and content-specific NCC would be located within the posterior "hot zone" or, temporo-parietal and occipital brain regions, since these areas satisfy most of the theoretical premises (Boly et al., 2017; Koch et al., 2016). Present results on VAN, therefore, are compatible with the posterior location of NCCs, but otherwise the VAN evidence is not directly related to the main tenets of IIT and cannot be easily applied to test the empirical plausibility of the theory.

As another example, TTC emphasizes on the temporo-spatial dynamics of conscious experience, stating that the brain can support it by creating its own temporo-spatial structure (Northoff, 2014; Northoff and Huang, 2017; Northoff and Zilio, 2022; Northoff et al., 2023). Somewhat similar concepts could be found in the operational architectonics framework (Fingelkurts et al., 2010), which also postulates that the brain's intrinsic and phenomenological spatio-temporal scales differ from that in the physical world and shape phenomenal consciousness, while the differences with the TTC are in certain brain mechanisms that support it. According to the TTC, intrinsic neural timescales are expressed by various oscillation frequencies and are nested in each other, which represents the foreground-background structure on the phenomenological level. Shorter timescales are related to stimulus-related activity and depend on longer timescales that provide a background context. According to the TTC, perceptual awareness would require that neuronal activity is temporally and spatially aligned to the intrinsic bodily and extrinsic environmental dynamics represented by the time scales (Northoff et al., 2023; Northoff and Zilio, 2022). Present results on VAN fit the theoretical assumptions, however they do not affect the main predictions of the TTC. From the theory point of view, stimulus-related activity should be aligned with the ongoing background activity for something to enter consciousness. A specific mechanism for this is a suppression of the middle neurophenomenological level represented by the lower frequencies (Northoff et al., 2023). Present results demonstrated that a decrease in the α-power also occurs in the VAN time window, which makes the TTC compatible with current empirical findings. Similarly, as for the IIT, and unlike the RPT or GNWT, VAN would be an indirect measure of consciousness for the TTC.

In sum, present findings are compatible with and fit various theories of consciousness. In case of perceptual awareness, RPT has the strongest explanatory power, specifically predicting the present results. Theories of consciousness that aim at explaining perceptual awareness should account for the present evidence or provide more robust NCC/mechanism free from preceding, succeeding and co-occurring processes. Present findings are problematic for those theories that do not accept the concept of "phenomenal" as referring to something distinct of "access"; namely the subjective, qualitative features of consciousness; while remaining "positive" or "neutral" to other theories. They directly challenge any theory that do not acknowledge the existence of phenomenal consciousness and its specific NCC, independent of access or reflective consciousness. This holds true if VAN is a phenomenal NCC, which the accumulating evidence suggest. Since the empirical evidence in favor of VAN is significant and growing, evolving theories of consciousness would have to align or specify their predictions, accounting for these results.

6. Conclusion

We provided a bird's eye view on recently published empirical findings on the event-related potential neural correlates of consciousness in vision. The recent fifty-three studies included in this review, when taken together in an integrative manner, further support the conclusions of previous reviews that early visual awareness negativity is an NCC proper. It has been shown to be robust across various experimental paradigms and be related to perceptual awareness. Future research should concentrate on its spatiotemporal constraints, relation with the bodily signals, capture the entire variety of its brain sources, confirm its specificity and range among various levels of stimulus processing, and, finally, confirm its independence from attention. Up to date, there is convincing evidence that VAN is the most reliable NCC in vision and probably reflects directly its underlying neural mechanisms.

Data availability

The data used for the present review consists of scientific articles, which were obtained via databases and search registries. The code for the search queries is available in Supplementary Notes.

CRediT authorship contribution statement

Dmitri Filimonov: Writing – review & editing, Writing – original draft, Visualization, Validation, Software, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Mika Koivisto:** Writing – review & editing, Validation, Supervision, Conceptualization. **Antti Revonsuo:** Writing – review & editing, Validation, Supervision, Conceptualization.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

Dmitri Filimonov reports financial support was provided by Signe and Ane Gyllenberg Foundation. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.neuroimage.2026.121762.

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