Characterizing the temporal profile of meaning-making with visual art

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Abstract

Insight can play an important role in information processing and meaning making. A series of processes, from curiosity (drive state) to insight (uncertainty reduction) to pleasure (reward and reinforcement), might represent a fundamental epistemic arc for motivated learning. Here, we present a paradigm that combines measurements of curiosity, insight (*aha*), understanding and liking to outline the contours of this epistemic arc, employing the so-called "title effect" – the fact that semantic information accompanying an artwork (such as titles) can spark insight and change how an observer understands and enjoys a piece of art. In an EEG and eye tracking study, we investigated how the different ratings were represented in the observers' (neuro)physiological recordings. Using a time-resolved decoding approach, we were able to recover the graded ratings and track the temporal sequence of processing. Some correlates were found seconds after image onset, long after the time frames typically investigated in classical EEG studies.

Keywords: EEG; multimodal data; MVPA; learning; aesthetics

Background

We are constantly confronted with novel, potentially ambiguous information, and making sense of these stimuli (i.e., forming a coherent, meaningful representation) is a cornerstone of human cognition. Often, sense making involves insight: a sudden jump in understanding, such as when the solution to a previously unsolved problem becomes clear or when a new piece of information allows for better understanding (Sternberg & Davidson, 1995).

Insight could be characterized as a rapid decrease in uncertainty or a gain in information. Recent work has linked insight to the preceding state of curiosity (Van de Cruys et al., 2021) – the more curiosity, the greater the *aha* (a phenomenal feeling accompanying insight). This finding places insight within a motivational framework: curiosity is a drive state to reduce uncertainty, improved understanding is the desired outcome, and insight (or *aha*) marks moments of particularly effective uncertainty reduction. Based on their findings Van de Cruys et al. (2021) hypothesize that *aha* might act as a metacognitive feedback signal that can help us optimize learning efficiency and allocate limited cognitive resources to solvable tasks (Laukkonen et al., 2023).

If insight triggers a motivational process, it should engage reward processes and be associated with pleasure – the pleasure of understanding. In fact, some studies provide empirical evidence that *aha* can feel pleasurable (Skaar & Reber, 2020; Shen, Yuan, Liu, & Luo, 2016) and links to the reward system (Cristofori, Salvi, Beeman, & Grafman, 2018; Oh, Chesebrough, Erickson, Zhang, & Kounios, 2020).

This series of processes, from curiosity to insight to pleasure, represents a fundamental epistemic arc for motivated learning. Here, we present a paradigm that combines measurement of felt curiosity, insight (*aha*), understanding and liking during interaction with visual art to outline the contours of this epistemic arc and study their neuronal mechanisms.

Methods

This study was part of a larger research project with two related experiments, preregistered on OSF (currently embargoed).

Task procedure We presented the participants with 48 visual artworks (paintings) followed either by their original titles or dummy titles with no additional information ("no title"; balanced and randomized across participants). Experimental sequence and one example stimulus are depicted in Fig. 1. The paradigm closely followed the experiment presented by Van de Cruys et al. (2021) with Mooney images.

For each trial, participants went through the following sequence: 1) a visual stimulus was presented (5s presentation time), 2) they rated how curious they were for the title (self-paced response, using a slider on a continuous scale), 3) an additional semantic cue followed (3s presentation time); this was either the original title or a "no title" dummy (condition randomly selected, fully balanced across participants), and 4) the initial image was presented again (5s presentation time). They then rated 5) to what extent they experienced *aha*, 6) the aesthetic appeal of the image, and 7) their perceived understanding of the image (all self-paced responses on continuous slider scales).

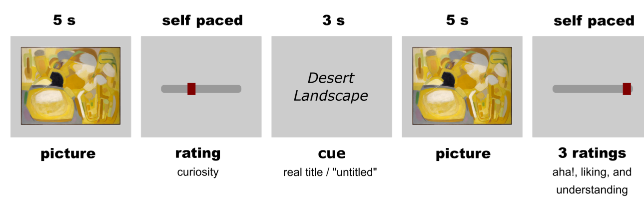

Figure 1: Experimental sequence of each trial.

Participants 50 participants enrolled and completed the data collection. One participant was excluded from the analysis, leaving 49 datasets for analysis. Full details on power analysis, sampling procedure, and participant demographics will be available in the final publication.

Decoding pipeline Time-resolved decoding was implemented in a sliding window approach: independent decoders were fit at each time sample across the 64 EEG sensors (or the 2 pupil traces, or the heart rate channel). This analysis yielded a decoding time course that indicated if and when a rating can be linearly decoded from each physiological signal. The decoding time courses were then passed on to a second-level cluster-corrected statistical test across participants.

We built 4 different continuous prediction pipelines for the different ratings (curiosity, *aha*, liking, understanding; all transformed to participant-wise z-scores).

The decoder design closely followed Gwilliams and King (2020), implemented in MNE Python and scikit-learn. We applied ridge regression for continuous prediction (default parameters: alpha = 1). Decoding performance was assessed in a 10-fold stratified cross-validation. The decoding accuracy was scored using spearman R for ridge regression. All decoders were provided with data normalized by the mean and the standard deviation in the training set.

Results

Decoding time-courses and significant time windows are shown in Fig. 2.

Ratings of curiosity for the title could be significantly decoded from the late pretitle pupil signal (4.06-4.66 s after image onset) and the early posttitle time domain EEG (0.93-1.19 s and 1.23-1.59 s after image onset).

Insight (*aha*) ratings could be significantly decoded from pupil size early in posttitle trials (0.62-1.57 s after image onset).

Ratings of aesthetic liking showed a brief peak of significant decoding in the time domain EEG signal in posttitle trials (0.46-0.68 s after image onset). The pupil signal, though not significant, generally delivered above chance decoding with a marked peak in early pretitle trials (about the first second after image onset), while not exhibiting this peak in posttitle trials but rather ramping up over time.

Felt understanding could be best decoded among the ratings. The time domain EEG allowed good decoding in the early pretitle trial (significant from 1.21–1.83 s after image onset). In the posttitle trial decoding rate is above chance throughout the whole trial, similar to the pretitle data in early trials (though not significant) but building up toward the end of the image presentation and becoming significant in 2 late time windows (2.39–3.11 s and 3.41–3.80 s after image onset). Heart rate in posttitle trials showed a marked significant decoding rate for understanding in 2 time windows (-0.50–0.50 s and 2.71–3.88 s after image onset) that are very similar to those for decoding the title condition (though a little earlier). Pupil dilation also exhibited above chance decoding, with pre- and posttitle timecourses very similar to the ERP data, but did not become significant.

Discussion

In this study, we applied time-resolved decoding to neurophysiological data to characterize the temporal profile of relevant subprocesses of meaning making and motivated learning.

Curiosity showed a very interesting profile: while the significant cluster in the late pretitle pupil signal (immediately prior to the rating) could be expected, the robust decodability from the time-domain EEG of posttitle trials came as a surprise. This might suggest that curiosity ratings do accurately reflect a distinct state of cortical activity that is sustained over several seconds from the initial presentation of an image, over seeing and processing the title cue, and well into the posttitle trial.

Aha could be significantly decoded from posttitle trials (from the pupil signal) but interestingly becomes significant only *after* the peak for liking in EEG. However, perhaps this finding

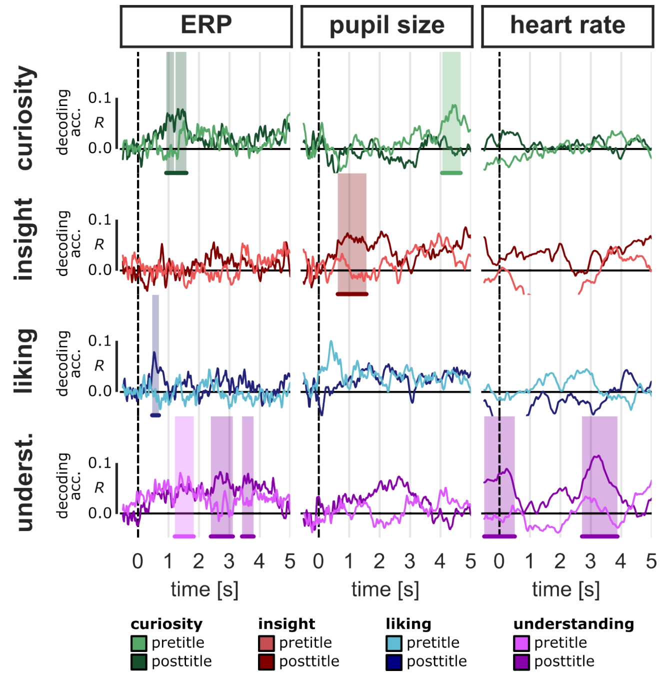

Figure 2: Time-resolved decoding physiological correlates of meaning making with visual art – curiosity for the title, *aha*, aesthetic liking, and felt understanding. X-axis reflects the chance level. Significance determined by second level cluster based permutation t-test (significance threshold $p < .05$).

is misleading, as the pupil response is a comparatively slow signal and might be unreliable immediately after image onset.

Felt understanding had the strongest signature in the EEG, with an initial phase of increased decodability in both pre- and posttitle trials. In posttitle trials, however, the decoding rate did not drop after this initial phase but rather built up and became significant later in the trial – this would be consistent with accumulating evidence leading to a sustained understanding signal. This interpretation is further supported by the relatively similar (but not significant) decoding timecourse in the pupil trace and the late significant peak of decoding rate in the instantaneous heart rate.

Liking showed a prominent peak in the first second after image onset in the time-domain EEG of posttitle trials. This offers neurophysiological evidence for a fast aesthetic response component, consistent with previous observations that some ERP components were linked to aesthetic ratings. The early peak in the pupil data of pretitle trials, though not significant, might further back this claim. It is noteworthy that we did not see significant decoding later in the trials – previous EEG (Strijbosch et al., 2021) and behavioral findings (Brielmann & Pelli, 2017) suggest that there should be slower cognitive processes contributing to a final liking response. Further research must validate or rectify these null findings.

Acknowledgments

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References

Brielmann, A. A., & Pelli, D. G. (2017). Beauty requires thought. *Current Biology*, *27*(10), 1506–1513.e3.

Cristofori, I., Salvi, C., Beeman, M., & Grafman, J. (2018). The effects of expected reward on creative problem solving. *Cognitive, Affective, & Behavioral Neuroscience*, *18*(5), 925–931.

Gwilliams, L., & King, J.-R. (2020). Recurrent processes support a cascade of hierarchical decisions. *eLife*, *9*, e56603.

Laukkonen, R. E., Webb, M., Salvi, C., Tangen, J. M., Slagter, H. A., & Schooler, J. W. (2023). Insight and the selection of ideas. *Neuroscience & Biobehavioral Reviews*, *153*, 105363.

Oh, Y., Chesebrough, C., Erickson, B., Zhang, F., & Kounios, J. (2020). An insight-related neural reward signal. *NeuroImage*, *214*, 116757.

Shen, W., Yuan, Y., Liu, C., & Luo, J. (2016). In search of the 'aha!' experience: Elucidating the emotionality of insight problem-solving. *British Journal of Psychology*, *107*(2), 281–298.

Skaar, Ø. O., & Reber, R. (2020). The phenomenology of aha-experiences. *Motivation Science*, *6*(1), 49–60.

Sternberg, R. J., & Davidson, J. E. (Eds.). (1995). *The nature of insight*. Cambridge, Mass: MIT Press.

Strijbosch, W., Vessel, E. A., Welke, D., Mitas, O., Gelissen, J., & Bastiaansen, M. (2021). On the neuronal dynamics of aesthetic experience: Evidence from electroencephalographic oscillatory dynamics. *Journal of Cognitive Neuroscience*, 1–19.

Van de Cruys, S., Damiano, C., Boddez, Y., Król, M., Goetschalckx, L., & Wagemans, J. (2021). Visual affects: Linking curiosity, aha-erlebnis, and memory through information gain. *Cognition*, *212*, 104698.