Neo-Noumena: Augmenting Emotion Communication

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ABSTRACT
The subjective experience of emotion is notoriously difficult to interpersonally communicate. We believe that technology can challenge this notion through the design of neuroresponsive systems for interpersonal communication. We explore this through "Neo-Noumena", a communicative neuroresponsive system that uses brain-computer interfacing and artificial intelligence to read one's emotional states and dynamically represent them to others in mixed reality through two head-mounted displays. In our study five participant pairs were given Neo-Noumena for three days, using the system freely. Measures of emotional competence demonstrated a statistically significant increase in participants' ability to interpersonally regulate emotions. Furthermore, participant interviews revealed themes regarding Spatiotemporal Actualization, Objective Representation, and Preternatural Transmission. We also suggest design strategies for future augmented emotion communication systems. We intend that work to give guidance towards a future in which our ability to interpersonally communicate emotion is augmented beyond traditional experience.

Author Keywords
Emotion Communication; Mixed Reality; Brain-Computer Interfacing; Emotion Recognition; EEG; Machine Learning

CSS Concepts
• Human-centered computing • Applied computing

INTRODUCTION
The subjective experience of emotion is notoriously difficult to communicate. It has been argued that since there is currently no way to directly experience what another person is feeling, our limited communicative faculties force us to squeeze our complex emotional experiences through "information bottlenecks" to produce language and gestures [46,56]. Unfortunately, these are only approximate articulations of our emotional experiences which limit our communication and understanding. This is no trivial notion,

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Figure 1. Dynamic fractal shapes representative of each user's affect state are generated from brain activity and projected into mixed reality. The users view their fractals and their partner's via the HMDs. Two wirelessly connected laptops acting as servers and signals processing units complete the system architecture.

as the ability to effectively communicate emotion strongly interacts with overall wellbeing. It is acknowledged that communicative ability is positively related to emotional competence, the ability to recognize, interpret, and respond constructively to emotions in yourself and others (more commonly known as emotional intelligence)[8]. Considering this, it is arguable that limitations posed on the communication of emotion could adversely influence emotional competence [2]. This is important, as poor emotional competence has been associated with lower happiness, poorer mental health, less satisfying social relationships, lower occupational success, and is predictive of poorer general health [4,12,14,40]. Ultimately, the consequences of poor emotional competence have been demonstrated to cost billions due to health and interpersonal conflicts [40]. Considering this, we believe that improving emotional competency through enhancing emotional communication could have far-reaching individualistic and societal benefits.

We argue that technology has the potential to expand our abilities in emotional communication. We find that most efforts in supporting emotion communication through technology have only attempted to supplement it in areas where it is already impaired. For example; using emojis to enhance text-based communication, which lacks non-verbal cues like body language and verbal tone [37]; and developments in human-robot interaction where robots are unable to interpret emotions [11]. There is a shortage of investigation in supporting face-to-face emotional communication in everyday contexts. With the advent of new technologies such as mobile electroencephalography (EEG) devices, which allow us to assess neurogenic emotion in real time, mixed reality (MR), which affords bringing digital content into the physical space, and procedural content generation methods necessary for the creation of dynamic digital content, we believe that there is now an opportunity to better support emotion communication technologically. We propose to explore this opportunity with the design and study of our system "Neo-Noumena".

Neo-Noumena is a system that uses EEG to drive procedural content generation algorithms. The digital outputs of which augment interpersonal emotion communication via two mixed reality head-mounted displays (HMDs). The aim is to provide additional dimensions of emotion to interpersonal communication through a dynamic representation of emotion. EEG data is collected and interpreted by a support vector machine to infer the participants' emotional state. Then, these states seed procedural content generation algorithms giving rise to a flock of emotionally descriptive fractals which flock as swarm agents (fig 1). This creates a dynamic visual representation of the individual's neurogenic affect signal, which augments their communication and assists the interpretation of others. Through our work, we contribute a parametrization of the experience of augmented emotion communication, and through articulating design strategies, we contribute knowledge in how to apply these parameters as systems. We envision this work will benefit researchers and theorist in further examining, operationalizing and assessing experiences of augmented emotion communication, and practitioners in informing the design of future augmented emotion communication systems. It is our intention that the study of our system will guide us towards a better understanding of designing the augmentation of emotion communication.

RELATED WORK

Emotion Communication Systems

One early exploration of this notion is the work of Liu et al. [36] who designed a system which used EEG data to attempt to extract an individual's experience of emotion from their neural activity. This information is then used to animate the facial expression of a virtual avatar to match the emotional state of the participant. Through this system, the authors demonstrate the efficacy of including an "emotional dimension" in virtual environments like those of game worlds. However, the system only emulates human facial expressions to communicate emotion, attempting to compensate for a lack of non-verbal emotional cues. It does not attempt to augment the communication of emotion beyond our current capacity. In contrast, bioresponsive systems have demonstrated the efficacy of wearable technology in augmenting communication beyond current capabilities. For example, "Hint" [24], a thermochromic T-shirt which changes color according to the wearer's skin conductance, a measure of arousal, was found to provide an additional cue for users to engage with others. Similarly "Breeze" [18], a wearable pendant that measures and displays breathing patterns, was found to increase connectedness and empathy with loved ones, as well as aid the user to control their breathing via neurofeedback.

Neurofeedback and Procedural Content Generation

In light of the recent emphasis HCI research has placed on enabling reflection and supporting meditative practices (e.g. [33,34,41,49,54]), a number of systems have explored the representation of subjective psychophysiological states through interactive technologies. These systems are typically designed to offer some form of neurofeedback, in which the system interprets an individual's neural activity and provides a representation of their mental state in real-time, which users can observe and learn to self-monitor or regulate.

One example of this is "Inner Garden" [45], where a living world is projected onto a desktop-sized sandbox using augmented reality. This world is populated in accordance to how frustrated, or how meditative the participant is. Through monitoring any changes to this world, the participant receives information about their degree of focus in a neurofeedback loop, with a goal of encouraging mindfulness.

A similar example of neurofeedback techniques incorporating BCI was demonstrated by the art project "Inter-Dream" [48]. Inter-Dream is centered around a bed, which individuals rest in while wearing a VR headset. The participant's neural data is dynamically projected as procedurally generated abstract imagery which fluidly morphs in response to electrophysiological changes. This is projected both into the VR headset as well as the surrounding room, allowing for both participants and observers to interpret the meaning of these projections with the authors arguing the importance of facilitating self-expression by providing more grounded connections between neural data and the way it is represented.

A system which also attempts to form connections between subjective consciousness and meaningful representation is "Lucid loop" [29], a neurofeedback system designed to simulate the experience of lucid dreaming and train participants in achieving lucid dream states. EEG data is used to assess participant's degree of focused attention or "lucidity". This is then fed back to the participant through dream-like visuals generated via a deep convolution neural network (DCNN) in real time. Specifically, when participants exhibit lower levels of lucidity, the DCNN generates more "abstract" visuals to represent dreaminess. As the participants' lucidity increases, so too does the clarity of the visuals generated; resulting in an open nature scene.

Taken together, these systems demonstrate successful efforts in taking the subjective experience of cognitive processes, extending them beyond the confines of the individual's nervous system, and manifesting them in the world representationally. Furthermore, the generative methods employed in these systems allow for the communication of complex and informationally rich phenomena, without incurring the communicative and cognitive effort generated by natural language systems, ultimately highlighting EEG driven procedural content generation as a valuable component of future augmented emotion communication systems.

Interpersonal Mixed Reality

The potential for MR to be effectively employed as a communication medium has been demonstrated by "BrainShare" [15], an AR-based BCI system designed to support the communication of patients with locked-in syndrome. The system is composed of a HoloLens, a BCI controlled P300 speller, and a computer monitor. When using the system, the patient's caretaker is fitted with the HoloLens, with their point of view being streamed to the patient that they can observe through their computer monitor. Ultimately, this system demonstrates the potential for BCI and AR used in concert to serve as an effective means of supporting communication, in this case allowing for communication when it might otherwise not be possible.

Returning to emotion, there has been work demonstrating AR can be utilized to allow for an enhancement of emotive expressiveness in social pretend play, explored through the system, "FingAR" [1]. FingAR uses a "magic mirror" metaphor that superimposes imaginary objects on physical play props through AR. One notable element is the ability for players to dynamically impose facial expressions on their puppets, adding a dimension of emotive expression in their play, encouraging expression and awareness of emotion. Ultimately, these findings nonetheless highlight AR as a promising environment for emotional transactions to take place.

Opportunity for Augmenting Emotion Communication

Taken together, the systems discussed above demonstrate the potential for neurofeedback systems to interpret and represent subjective cognitive experiences and highlight MR as promising medium. Yet despite this potential, there has been so far little exploration that applies the communicative strengths of neurofeedback driven procedural generation towards augmenting the process of interpersonal communication. Additionally, there has been little exploration in combining the strengths of MR as both a communicative and an emotionally reflective system. Considering this, we aim to explore this potential through the design and study of our system, Neo-Noumena.

NEO-NOUMENA

Neo-Noumena is a system that employs BCI-driven procedural content generation, visualized using mixed reality, to augment interpersonal emotion communication through dynamic, proxemic abstract representations of affect.

EEG-Based Emotion Recognition

The system interprets EEG data to classify participants' subjective emotional experiences. To achieve this, eight channels of EEG data are collected via an electrode cap connected to an OpenBCI Cyton amplifier, being relayed over OSC to a HoloLens through a UDP server. EEG electrode placement followed the 10-20 convention [22], with data recorded from electrodes: Fp2, F4, F7, F8, C4, P3, P4, O1, AFz (ground), and CPz (reference).

The raw EEG signal is sampled at a rate of 250Hz, passed through a 50Hz notch filer, a 5-50Hz bandpass filter, and finally processed through the use of a mean smoothing filter to mitigate movement artifacts [53]. Features from filtered data are then extracted, using the six statistical features identified in section 3.1 of [44]. This is then interpreted by a support vector machine classifier to infer the participant's emotional state. This support vector machine was implemented in python with radial basis function kernel for multi-class classification, with $\gamma = 1$ and penalty parameter C of the error term = 0, yielding classification accuracy of 58.33%. The classifier was trained using the DEAP dataset [31], fractally assessing emotion based on the dimensions of arousal and valence, following procedures previously identified [36]. This approach binarily classifies EEG data for each dimension, leading to four possible classifications of affective category, these being: High-Arousal-High-Low, High-Arousal-High-Valance, Low-Arousal-High-Valance, and Low-Arousal-Low-Valance.

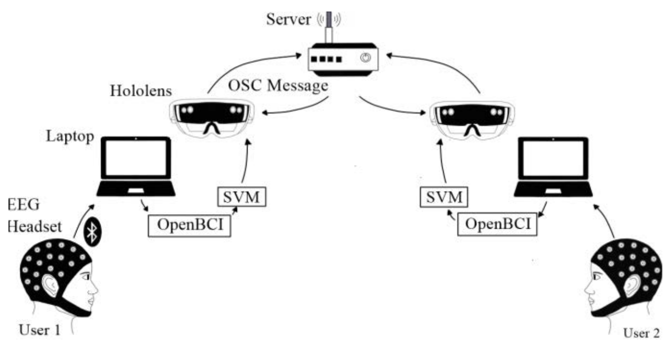

Figure 2. Neo-Noumena's System Architecture

Procedural Generation to Represent Emotion

Neo-Noumena utilizes procedural content generation, employed in the form of a fractal generator, with the participants' concurrent classification of emotion being the "seed" for the generation of fractals. Thereby, each classification of emotion generates a fractal which differs across dimensions of node count, smoothness, angle size, rate of change and color, which together create unique evolving patterns. Taken together, these properties work to generate abstract representations of neurogenic affect signal which, as discussed above in related work, has been demonstrated to reflect subjective cognitive states in neurofeedback systems using similarly abstract representations. Considering this we therefore argue they could be extended to reflect emotional states.

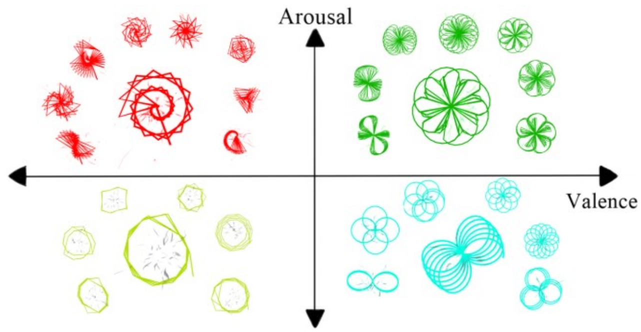

Figure 3. Four categories Neo-Noumena groups affect by

From the experiential perspective of the participant, Neo-Noumena renders their emotional state into AR as ambient swarms of fractals (with eight fractals per swarm) akin to an "aura" that surrounds and follows the participant. This fractal swarm is generated in the participants' proximity at a circular range of ca. 1.2m, consistent with the proxemics definition of personal space [20]. The appearance and movement of the fractals change according to the participant's emotional state. Additionally, using the affective sound database Audio Metaphor [16,55], we generated sets of audio files which corresponded to each emotion state. This audio was then attached to the fractals, so that sonic representations of affect could be heard through the HoloLens when participants were in close proximity to them.

The decision to implement fractals to represent emotion was informed by a body of cognitive psychology literature documenting aesthetic appraisal of fractals [5,50,52] as well as research identifying the efficacy of aesthetics as a potent medium for communicating emotion [17,39,42,43,51,52]. Considering fractals specifically, it is noted that fractal properties such as complexity are associated with arousal, while smoothness and symmetry are associated with pleasure (to which the inverse is true of displeasure) [5].

In utilizing a boid swarm [3], we intended to introduce an additional dimension of emotionality to the content being generated in the form of movement patterns of the fractals. Prior work examining emotion communication in drones and swarming behavior has demonstrated how flight path, speed and algorithmic intelligence can be used to convey specific emotions [10,13,26]. As such, the fractal swarms communicate the affect of the participant through modulating the variables of the swarm's movement speed, cohesion, avoidance and alignment in accordance to the emotion they are representing.

Lastly, in accordance with Humanistic Intelligence (HI) [38] principles, which aim to design processing systems which are inextricably intertwined with the human body, such that enhanced intelligence arises from the synergy of human and computer. Mann argues that wearable computing embodies HI in that it offers an opportunity for enhanced intelligence to arise from the human-computer interface. We argue that AR embodies these principles due to its monopolizing, unrestrictive, attentive and communicative properties. Neo-Noumena intends to augment emotional communication, rather than replace it. Considering that AR allows for the placement of virtual objects in the real world, in contrast to VR which replaces the real world with a virtual environment, we believe AR to be more suitable as a communication enhancing medium.

STUDY

Participants

10 participants were recruited for our study, including 5 males, 2 females, 2 participants preferring not to say, and one trans person. There was a mean age of 34.14 years (SD = 14.95). Participants were recruited as dyads, who experienced the system in pairs throughout the duration of the study. These pairs included four couples and a mother and son. No specific demographic was targeted during recruitment; however, by chance our final sample yielded a disproportionate number of individuals with psychologically related diagnoses. This included two participants diagnosed with ADHD, and one participant with diagnoses of a depressive disorder. All three participants are currently undergoing psychotherapeutic treatment.

Procedure

The study was approved by our ethics board. Participation in our study lasted for a period of three days where participants were given access to Neo-Noumena to use ad libitum.

Introductory Phase. An initial baseline measure of emotional competence was assessed through the self-report psychometric scale "Profile of Emotional Competence" [8]. The 50-item test measures five core emotional competencies (identification, understanding, expression, regulation and use of emotions). These dimensions are measured for intrapersonal and interpersonal factor domains, producing a total of 10 subscale scores and three global emotional competence scores: an intrapersonal score (α = .86), an interpersonal score (α = .89) and a total emotional competence score (α = .92).

Exploratory Phase. Proceeding this introductory session, participant dyads were given a pair of Neo-Noumena systems to take home, to be used for three days, at least once per day, for a minimum of an hour, synchronously with their dyad partner. On average, participants used the system once a day, for three days, most often during the evening, for approximately one hour.

Participants were encouraged to submit online journal entries after each session, documenting any information they thought may be relevant to the analysis of the experience, such as: where they were, what they were doing, how this interacted with the experience, as well as observations or insights they had made regarding their own or their partners emotions, and any interesting stories that came out of using the system.

Debriefing Phase. On returning the system, participants were involved in an open-ended qualitative interview, focusing on their experiences of the system and how it facilitated emotional communication with their dyad partner. Finally, participants provided post-test responses to the same self-report psychometric scale used in the initial baseline phase, to determine differences in emotional competence.

RESULTS

Emotional Competence

To assess the within-subject effect of Neo-Noumena on Emotional Competence, a series of paired sampled t-tests were conducted comparing pre and post-test scores for each scale. We found a statistically significant improvement between pre-test and post-test in participant measures of "emotion regulation of others" (t (1,9) = 3.24, p = .01, d = 2.13). There were no observed significant differences in measures of the other subscales of emotional competence.

Scale	Pre-Test		Post-Test	
	M	*SD*	*M*	*SD*
Intrapersonal EC	17.40	2.78	18.03	1.61
Identification	19.38	3.16	20.00	2.39
Expression	17.25	2.76	16.38	4.27
Comprehension	18.00	3.07	19.63	3.42
Regulation	15.75	3.92	16.12	3.60
Utilization	16.63	5.07	18.80	3.50
Interpersonal EC	17.98	0.98	17.33	1.86
Identification	19.50	4.11	19.13	2.80
Expression	15.75	3.92	16.13	1.36
Comprehension	18.50	1.20	19.75	2.92
Regulation*	15.13	1.46	18.13	1.36
Utilization	13.75	2.38	13.00	3.55
Global EC	17.36	2.17	18.00	.64

Table 1. Descriptive statistics for measures of Emotional Competence. * = p<0.05

Neo-Noumena Experience

In analyzing the recounts of participant experiences through interviews and participant diaries, three major themes were revealed. Analysis of this material was performed inductively through thematic analysis [9] in which three researchers independently reviewed transcripts and coded the data. Codes were iteratively clustered into high level groupings agreed upon between researchers until they were consolidated into three final themes emerging from the data.

Spatiotemporal Actualization

The theme of "spatiotemporal actualization" regards how the experience was modulated by the way emotion interacted with physical space and time. Initially, the physical component of this theme was evident in the way participants described what the system does, with their use of language predominantly emphasizing that the system is "*projecting your emotions*" (P1 & P2). Participants explained that the system does this by "*taking your thoughts, your emotional cognitive activity and then translating it into something that's more spatial or in space so people can access it without necessarily having to give it to them*" (P4), that "*it's looking at 'how were you feeling over this past half a minute?'*[...] *and then manifesting that*" (P7), and that "*it feels like someone's actively interpreting things that you don't see to show you a depiction of it*" (P8).

Participants then appraised these projections as agents embodied by their emotions, reflected in statements such as: "*Sometimes it was like having a pet. It lands on your table, kind of like a cat […] but instead of a cat it's literally a piece of your emotion*" (P4). Participants also recognized that the behavior of the representations was in correspondence with their emotions: "*I assumed red meant anger or frustration, and this seemed to make sense with the movement of the Noumena through space*" (P8); "*I like the red. I think the movement was a really big one, looking at it was like 30 minutes after taking your ADHD medication*" (P7).

Through these emotionally embodied Noumena, participants were purportedly made more aware of the interaction between emotion and time. This was typically first acknowledged as a realization of how much emotions change, "*I found it weird that the system showed that emotional state changes so frequently*" (P3). This sentiment was then built upon in their last entry of their journal: "*Still surprised about how frequently the system is suggesting these emotional states change. It is reassuring to know that these states can change and flow so quickly*" (P3). This initial awareness of the relationship between emotion and time was strengthened when participants explored how their emotions changed. This mostly took the form of recognizing patterns in the interaction between the environment and their emotional state, stating things such as "*[P2] noticed yesterday that when I was using my journal […] that I had a lot of colors other than red*" (P1), and "*I can usually gauge "oh, it's red, it has shown up after this person would be agitated", and similarly "oh this person is at a resting state, oh it's yellow"*" (P5). However, participants later took to actively experimenting by subjecting themselves to different conditions to investigate how it would affect their emotions. This took many different forms, for example P3 said "*Listening to stupid music […] was fun because if it was […] enjoyable to listen to, you could tell. As in, the emotional content of the song, the valance and the arousal usually followed that*", whereas P8 stated "*I [wanted] to see if smoking a small joint would change how they reacted. I think it increased my stress levels, which seemed to be reflected in the Noumena activity, with them being far more active both in time and space afterwards than before*". P7 described how "*last night we also watched a standup routine to see how that would interact with the system […] I'm pretty sure the colors I saw were positive ones, green and blue*". This taught the participants they can leverage control over their emotions to some degree by changing elements of their environment.

One participant demonstrated marked differences in emotional content across their three days. They recounted the first day by stating: "*On the first day my partner and I used it, it was after a long workday and we were pretty tired*" (P4). In contrast, they recounted that "*on the second day my partner and I drank a lot and listened to a lot of music. All that together produced a very noticeable difference in our mood from the day before for both of us. The whole night we were singing and dancing along with the music, and we were generating some pretty positive emotions. For me that made me even happier to see that she was happy. It felt like it was feeding back in on itself, like a nice big loop of happiness*".

These accounts demonstrate that experiencing actualized emotion through time allowed participants to experiment with changes in their own emotions and their partner's. Ultimately, this allowed participants to learn patterns, and build emotion profiles of themselves and their partners, often comparing them: "*[P4's Noumena] tended to be at least a lot more positive than mine was […] more high arousal as well. Theirs were green and red a lot, whereas mine was like yellow a lot*" (P3). Similarly, P8 stated "*[my partner was] generally more chill than me, and less likely to act on something when [the] red guys are there […] it gave me an idea of maybe the emotional leeway that [they're] willing to give*".

As a result of using the system, participants were challenged to consider how emotions can be changed; actively by the individual or passively by the environment, in favor of more fatalistic notions of prescribed emotional predispositions. This is clearly demonstrated by the responses of one dyad in tandem: "*I know I'm a sad person, so it was interesting to see that actually [being] kind of true. But also, the fact that it wasn't just sad all the time. So that's interesting to see that it could very easily change in 30 seconds […] It was quite nice to see you're not doomed to just be in one mood all the time*" (P3). This process of challenging the permanency of emotion was also mirrored in the participant's partner (P4) when considering what they learnt about P3 through the experience. "*The more negative side of the spectrum was very prevalent in my partner […] which is kind of expected. But it was interesting to see it fluctuate from that a lot. It was very relieving to see […] because sometimes I get worried that she's sad all the time*" (P4).

Objective Representation

This theme refers to how the system enabled participants to instantaneously experience emotion as a point of introspection or objective understanding about their own psychology. This was initially articulated by participants through the weighting they placed on the system's assignment of emotion, as opposed to their own self appraisals. For example, participants stated that the categories they found their emotions fell into made them think "*'Oh this makes a lot of sense', finally being able to test a hypothesis, finally, being like 'ah yes! I thought so!'*" (P7) and describe the experience by saying "*it was more like a mirror; this feels more like it's a part of you*" (P4). Similarly, P4 described how their partner would say "*oh my god you're so happy, you actually love this band"* in response to their generation of positive emotions while listening to music, almost as if the visualization of emotion was an objective confirmation of a hypothesis held previously.

This also made participants realize they were previously less aware of their emotions than they thought they were, making statements such as "*maybe subconsciously my moods did change but I wasn't really aware of them*" (P2), and similarly "*getting something wrong [when playing piano] surprised me to see that it had such a big impact on, like, how I was feeling*" (P7), P8 stated "*I would never have expected how big of a change could potentially be produced from all the little things that I think about in little moments […]maybe I'm not as aware of it as I thought I was*". From this new foundation, participants found themselves in a position to perceive and more objectively understand emotion, stating: "*It's not about what you think you feel it's about what's happening in the moment*" (P8). There were limits to this, however. For example, one participant reasoned that reducing emotion to four categories made it in times harder to interpret, stating "*more than four of them, that obviously would be great […] because there was little bits where I was just like 'Oh I'm not quite sure what this is meant to mean' and they [emotions] can be quite a wide spectrum*" (P8).

Participants also found themselves able to objectively appreciate all dimensions of emotion, both positive and negative, with statements like "*Even when it was a negative thing being generated it was still really beautiful. It was like you could appreciate like the negative moods just as much as you could appreciate the positive moods*" (P4). Considering the affordance of objectively understanding and appreciating emotions, participants suggested this allowed for Neo-Noumena to be used as a tool for reflecting on, navigating through, or challenging their own psyche, demonstrated by statements such as: "*I think I'm feeling pretty good, let's put on the Neo-Noumena's for a little and see if I'm actually feeling good or If I'm just tricking myself that I'm doing good*" (P7), "*it made me realize I have a pretty decent background level of stress all the time"* (P8). A few participants went so far as to say this would be useful in a psychotherapeutic context, stating: "*I can imagine for therapy, obvious usage there. I can only imagine it being a good thing, a boon*" (P5), "*I think I would use it whenever I did my CBT homework … like "oh when I challenge this particular idea how does it change how I'm feeling?*" (P7), and "*I think the idea of using it for CBT is really interesting […] I think it could be a really useful tool to get to become aware of when I'm encountering […] blockages and be like 'Okay, well you're like losing your shit a little bit, so why, what's going on? Can we interrupt this?'*" (P8).

This also translated interpersonally, with participants describing how the system serves as a visual reminder to consider or reflect on the sentiment that other people hold their own emotional world. For example, one participant stated: "*The best part of it is, I think, maybe being made to think more consciously about my own emotions and also about other people*" (P8). Similarly, P4 stated "*It was like a constant visual reminder to consider someone's mood [...] and just appreciate that other people have emotions as well*". This latter participant imagined a future where everyone was using Neo-Noumena: "*Everyone else is usually quiet, flat. But I'm sure that with all those flat expressions everyone's probably experiencing a massive difference in the dimension of their emotional state. [...] it would make a lot of future engagements with other people more humanistic*" (P4).

Preternatural Transmission

This theme refers to how the experience of the system was influenced by its capacity to hold and transmit information interpersonally beyond ordinary means. In reporting their experience with the system, participants often compared it to un-augmented human communication methods and identified how the system differs. In doing so, they acknowledged features of the system relevant to this theme, including automaticity, continuous flow of information, effortless communication, accurate communication, and examples of 'extrasensory' information where the system not only facilitated information exchange but provided additional information which augmented communication between dyads.

For example, participants suggested that unlike un-augmented communication, the system provides emotion information "*automatically"* (P3) and continuously, "*it was like you had an 'aura' you could always refer to, no matter what you were doing [...] it was always there"* (P4). The system provided information about emotion states, and P4 likened this process to "*asking someone 'how are you feeling right now?' But if you could do it at any point in time* (P4)", thereby distinguishing the system's automaticity through the notion that "*people can access it without necessarily having you have to give it to them*" (P4), as well as a continuous information transmission. A few participants suggested that these qualities could even make the system's widespread usage controversial, voicing concerns such as "*people would be worried if it got to the point of mind reading*" (P5).

Another feature participants identified, which differentiated our system from un-augmented communication, was that information was transmitted without effort from the communicator: "*It's cool because the whole thing technically takes no effort*" (P3). One participant explained how it made understanding their partner less effortful: *"It was like: 'Oh, you're feeling a bit frustrated at the moment' or: 'You're feeling a bit like you're feeling relaxed'. I guess took the guesswork out of trying to figure out, 'oh, what is this other person feeling?', 'What's happening with their brain?' and stuff like that*" (P8).

Participants were also interested in the accuracy of information held and transmitted by the system. As identified by participants, the continuous and effortless nature of information transmission provided the opportunity to get "*a raw data feed* (P7)" of peoples' emotions. Unlike human's un-augmented emotion communication, like speech and body language which can usually be modulated, the system provides unbiased information, and "*could in a way potentially work to bypass the filtration system* (P7)". In fact, a participant described the system as being "*like a little window into their emotional state* (P4)". When we queried whether the system is redundant considering we could just ask people how they feel, a participant responded: "*Nah, because you have to rely on what that person is saying, and they could be just making shit up [...] And also you have to rely on your own interpretation of how you're feeling as well, which might be biased [...] so it's cool to just see it automatically* (P3)". Thus, the automatic and raw nature of the emotion information appeared to provide the opportunity for more accurate communication.

Participants realized that the system was not just facilitating communication, it was augmenting - providing more information - than un-augmented communication methods. For example, P5 and P6 played a card game while using the system, and P5 explained how the system suggested that their partner was "*generally mellow if it was a good hand*" and "*red towards the end of a round where it's determined who is going to win or lose*". They explained how the system provided an extra source of information, since "*this other person wearing the lens can see [...] my reaction to the [cards] that only I can see*", which they usually must keep hidden in the game. The participant explained that this was a team-based card game, with themselves and their partner on one team, and two others not using Neo-Noumena on the other, who "*were twins that can communicate telepathically*". Considering this, P5 mused that Neo-Noumena would "*ideally even the playing field*".

Another example of the additional information the system can provide was in P7's experience of playing music while their partner worked on an essay, explaining how the system: "*enabled me to monitor seemingly drastic changes in their emotions even as they affirmed to me it was in fact okay for me to keep playing [music], They could say that everything was going okay, but whatever was happening with the AR made it apparent that at least in some instances it was not*". Similarly, participants recounted episodes of heightened levels of empathy, or "syncing up", for example "*we seemed to 'sync up', where [P7's] playing worked well with my pop-esque ukulele strumming, I noticed all our Noumena's [...] hovering in the same corner of the room and acting mostly in the same way, with their colors and shapes shifting only slowly and gently*" (P8).

However, this sense of heightened communication was sometimes disrupted when participants held different preconceptions of what each classification meant. For example, P8 explained they interpreted the High-Arousal-Low-Valance Noumenas to mean something less dire than what their partner thought, stating that "*they found them to be quite like 'oh no, what's wrong!', and I was just like 'oh, ok I must be a little stressed out*". This was exemplified in P7's concerns that their partner might misinterpret how they were feeling, thinking "*oh no, don't think I'm angry at you please, I like hearing you singing, I just have a headache*" (P7). This demonstrates that individuals having differing perceptions of a Noumena's meaning might be a source of noise in the signal being communicated.

DISCUSSION

Psychometric Analysis

Measures of emotional competence showed no significant improvements in participants after their time with Neo-Noumena save for the subscale measure of "Emotion regulation of others". While this may be evidence for the absence of efficacy on the other subscales of emotional competence, this could be argued against when considering several factors. Firstly, that emotional competency or emotional intelligence has been argued to be relatively stable [47]. Second, that interventions specifically designed to improve emotional competence are lengthy and very involved procedures, often being 15 hours in total [21,32]. In contrast, most participants engaged with Neo-Noumena 1 hour a day (the minimum we allowed), accumulating to an average of approximately 3 hours across their involvement in the study. All participants were apologetic about this while returning the system, stating they could not use Neo-Noumena any longer because the HoloLens and EEG together was heavy on their head and the headset often pinched their nose. Nonetheless, with that considered, a significant improvement in a single subscale is a promising result.

Embodied Augmented Emotion Communication

Taken together, the results of our thematic analysis demonstrate the following: That through Spatiotemporal Actualization, participants experienced emotion as something tangible that can be changed and interacted with. Through Objective Representation, participants experienced emotion as something that can be objectively appreciated and reflected on. Through Preternatural Transmission, participants experienced emotion as something that holds and transmits information, producing emergent, novel opportunities for communication.

The validity of these themes is supported when considering they bare strong alignment with Grīnfelde's "four dimensions of embodiment" [19], which became evident following the establishment of our themes independently. These being: The body as 1) a bearer of sensations; 2) a seat of free movement, characterized by the faculty of "I can"; 3) a material thing in a causal relationship with the material world; 4) a material thing embedded in a social context. "The body as a barer of sensations" most closely resonates with our theme of "Objective Representation", which acknowledges that participants experienced representations of emotion through visually and auditorily "sensing" their manifestations, in turn prompting introspection. "The body as a material thing embedded in social context" is most evidently aligned with our theme of Preternatural Transmission in which emotional information extracted from a participant's 'body' was transmitted in a 'social context'. Lastly, "the body as a seat of free movement" and "the body as a material thing in a causal relationship with the material world" is aligned with our theme of Spatiotemporal Actualization. Our analysis presents these concepts as a singular theme due to the heavily dependent relationship between time and space, but nonetheless, participants experienced their emotion as a "physical thing" interacting with the "material world" through the head-mounted display, being a seat of "free movement" through its changes across time.

Furthermore, our findings contribute to ongoing debates within affective computing. Howell et al. [25] sought to challenge the authority assigned to insights from biosensing systems for emotional reflection, by designing a system encouraging users to form their own interpretations. However, despite the design intention, participants still appraised the system's reflection of their feelings as authoritative, with little questioning of the congruence between the display and their feelings. This issue relates to our theme of "Objective Representation". This theme describes how participants appreciated emotions as impartial observers without prescribing desirability to specific emotion states. However, participants often weighted the system's classification of emotion over their own self appraisal. Howell et al. [25] provided three lenses through which to consider the design of biosensing systems for emotional reflection. First, "affect-as-interaction" [6,7] states that emotion systems should support interpretation and ambiguity, and that emotion is a dynamic, socially constructed experience. Second is a consideration of Verbeek's theory of technological mediation [57], which suggests that presentations of technology can mediate our perceptual appraisals. Lastly, biopolitics, which considers societal discourses of biosensing technology, especially in matters of health and authority, which Howell later expands on, stating that "emotional biosensing products can be seen as modulating our emotions according to feedback systems and algorithms created by designers and technologists" [23]. We retrospectively consider these lenses and how Neo-Noumena is situated within them.

Regarding "affect-as-interaction", Neo-Noumena was intentionally designed to support ambiguity and consider emotion as dynamic, socially constructed experience. In fact, emotion classifications and corresponding procedural outputs were never revealed to the participants, so that participants could prescribe meaning to the representations through their own experimentation. This decision was also motivated by considerations of humanistic intelligence, which conceives of a computational-mediated reality similar to Verbeek's theory. For these reasons, we found it important to ground representations of emotion in theory while designing Neo-Noumena. However, where Boehner [6,7] argues against any categorisation, as it may lead to treating affect as information rather than dynamic interactions, Neo-Noumena's focus on communication makes categorical representations difficult to avoid. Contemporary models of natural languages demonstrate that for human communication to be efficient, compression of meaning is necessary for communication to be informative and simple, as is accomplished by using categories [28]. Lastly, in relation to biopolitics, the design of Neo-Noumena was intentionally ateleological [27], avoiding the designation of a specific goals during use. Neo-Noumena could have been designed to facilitate downregulation of negative emotions, or upregulation of positive emotions. Instead, we acknowledge, as Howell stated [23], a need for affirmation over self-improvement. Nonetheless, the use of categories makes it difficult to assuage the "authority" of emotional biosensing systems and algorithms when designing for communicative efficiency.

Design Strategies

In considering the findings of our study and combining it with our craft knowledge of having designed Neo-Noumena, we propose a series of design strategies. These are intended to guide designers in designing systems for augmenting emotion communication.

Tactic 1. Emphasizing Spatiotemporal Actualization if Facilitating Emotion Regulation.

We have identified that the spatiotemporal mechanics of the system's interaction are instrumental in producing the experience of emotional control. Considering this, spacetime should be emphasized if the aim of the design is to facilitate emotion regulation. In Neo-Noumena, this was achieved through designing the Noumena to appear as physical objects in the environment and dynamically avoiding or bumping into physical objects via HoloLens's spatial mapping, having them follow the person they were generated by through space, allowing their visual representation to change over time, and giving them simple swarm intelligence. These same properties, largely the ability to influence change over time, gave participants the ability to perform an action in physical space, and then observe the results in mixed reality to better learn about how their emotions respond to the environment.

This extends the concept of neurocentric agency, which suggests that an expressive neuroresponsive system requires all components of the experience be controllable by the user's neural activity to avoid users feeling disconnected from the experience [48]. Neo-Noumena addressed this by ensuring all generated content is controlled by the user's brain and emphasizing transience to the user through changing the spatiotemporal properties of the fractals. This level of control over the system across time ensures the user perceives a level of control over the content of the experience, theirs and others' emotion.

Therefore, when designing a system targeted toward emotion regulation, it is recommended that emotion 1) be spatially embodied by a medium the user has neurocentric agency over, and 2) be temporally reactive to the user's emotion. This need not be carried out in AR. We believe other interaction paradigms, such as robotics, haptics, and many more, could also be effective. An example of this would be a drone whose movement is controlled by the emotion of one or even multiple users.

Tactic 2. Emphasizing Objective Representation if Facilitating Introspection.

The theme of Objective Representation was most evident when participants experienced perceptions of congruency between their brain's activity and what was being generated. It appeared that this congruency seemed to strengthen participants' faith in what they were experiencing as an accurate and objective representation of the reality of their emotional state. This provided the foundation for then using the system as an introspective tool. We achieved this in Neo-Noumena by providing four broad emotion categories participants could prescribe meaning to, as well as making sure these categories would be reliably recalled whenever the participant exhibited the same physiological activity by ensuring a high degree of accuracy with our classification model. However, the experience of Objective Representation often broke down when participants felt like what they were experiencing did not fully encapsulate their lived experiences. In our study, this was apparent when participants thought themselves to be experiencing emotions that could not clearly be bound in one category.

Considering the tendency for individuals to place personal meaning to abstract stimuli [30], designers can emphasize Objective Representation in the design of a system by providing additional channels to interpret neurophysiological activity from. For example, we could have achieved this in Neo-Noumena by having the size of the fractals modulated by raw EEG amplitude, or have their color modulated by frequency density while still having the geometric attributes of the fractal tied to classification of emotion. These additional channels of information are typically continuous and quite nebulous for a human to interpret. Thus, they provide an opportunity for users to instead assign their own meaning to the generated representations, even when measures such as emotion classification fail to maintain congruence, thereby still facilitating introspection.

Tactic 3. Considering the Social Context of Preternatural Transmission for facilitating Emergence.

As we have already seen, communicative properties of Neo-Noumena are achieved as a result of its Spatiotemporal Actualization and Objective Representation. Through improving these elements, we can ultimately improve the communicative properties of an augmented emotion communication. However, it would be remiss not to consider the impact of the social context in which communicators are participating, which determines the constraints the system must operate within, and introduces new elements the system can interact with. These different contexts allow the emergence of context-dependent Preternatural Transmission, which refers to the extension of traditional forms of communication which, phenomenologically, approach the extrasensory.

We found that participants were most likely to experience preternatural communication when participants engaged in joint activities, like singing together, dancing together, playing games together, or purposely trying to influence each other's emotions. Neo-Noumena provided information which is not usually available in traditional communication, which gave participants the opportunity to participate in their contexts in enhanced ways and better achieve the pre-defined goals of the social context, for example, informing the tactics used in a card game which capitalized on their partner's emotions, or anticipating their partner's needs while they completed a stressful task based on their emotional state.

This aligns with the finding that restrictive processes which constrain how elements interact with their environment, can paradoxically produce new degrees of freedom, emergent tactics and behaviors [35]. Similarly, we stipulate that social contexts can constrain how emotion information is interpreted and used, so that it is only relevant to goals relevant to the social context.

Therefore, we recommend that understanding the context in which participants will use the system is important so that designers can leverage unique opportunities for preternatural transmission that the context may offer to empower to better communicate and perform tasks within the social context.

Limitations & Future Work

One limitation of the present study was the length of time participants were exposed to Neo-Noumena. While participants were given Neo-Noumena for three days, there was a common sentiment through interview responses in which participants lamented that if they had more time with the system they would be able to learn new patterns of emotion, develop a greater understanding of how it works, and generally become better at using it. Nevertheless, we believe that our results are still useful as they provide a starting point towards the design of augmented emotion communication systems. Considering the themes, we have hereto established, there is now a basis for the operationalization of the experience of augmented emotion communication, which can serve as a metric for much larger future studies to improve upon and benchmark these designs.

In the design of Neo-Noumena we faced a tradeoff between the accuracy of the emotion detection model, the time it took to classify emotion, and the number of emotions that could be classified. Classification accuracy required large amounts of data, resulting in a latency of 30 seconds per classification. Training the model to each individual participant may have increased accuracy at the cost of increased setup time. This may have in turn produced a more dynamic experience with a greater potential for exploration or informationally rich communication. Future work would benefit from the exploration of such tradeoffs, possibly assessing the efficacy of different machine learning and BCI approaches geared toward a faster, more accurate and dynamic model.

Additionally, [P8] complained of eye strain while using the HoloLens, and others complained that the apparatus was bulky. There is also a possibility that the device occluded the eyes and therefore decreased participants' ability to interpret emotions through facial expressions, though this was not brought up by participants. These points largely reflect the limitations of current technology, which will improve as the designs of wearable devices evolve, highlighting the need for continued work in this area.

Conclusion

In this paper, we argue technology has the potential to expand our abilities in emotional communication. Taking inspiration from previous systems which have explored the augmentation of emotion or communication, we designed Neo-Noumena, a system employing BCI-driven procedural content generation to augment interpersonal emotion communication through mixed reality via a dynamic representation of emotion. We then assessed how Neo-Noumena interacts with the experience of emotion communication and overall emotional competence through a study involving five participant dyads (10 participants in total) using Neo-Noumena over the period of three days. Thematic analysis revealed three themes constituent of the experience of augmented emotion communication. We also synthesized a set of design strategies to inform future augmented emotion communication system designs. Through our themes, we contribute a parametrization of the experience of augmented emotion communication, and through our design strategies, we contribute knowledge in how to apply these parameters to system design. We envision this work will benefit researchers and theorist in further examining, operationalizing and assessing experiences of augmented emotion communication, and practitioners in informing the design of future augmented emotion communication systems. We hope our work guides the community towards a better understanding of designing the augmentation of emotion communication.

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