Oscar Ferrante, Rony Hirschhorn and Alex Lepauvre discuss putting integrated information and global neuronal workspace theories of consciousness to the test

The trio is part of the adversarial collaboration launched to test various theories of consciousness, a project known as COGITATE.

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This transcript has been lightly edited for clarity; it may contain errors due to the transcription process.

[music]

Rony Hirschhorn
It didn't come out perfectly, so there are things to account for with respect to the orientation, with respect to the maintenance, and the synchrony between the areas. I look at it as an overall win in terms of both theories have some homework to do.

Alex Lepauvre
I think you could be pessimistic and say, "Well, oh, this theory, they made a wrong prediction, and therefore, I'm more prepared, and I think the theory is completely wrong, and we need to invent a completely new theory." I don't think that's a very valid approach, I think it's more trial and error and theories are work in process.

Oscar Ferrante
Even if you do this adversarial collaboration, people rarely, if never, change their mind. I don't think the aim of this project was to change Stan or Julia's mind, one project is not enough, but we are providing questions, and I'm sure there will be many, many PhD students that will start new projects just from what we did. I hope that will be the case from what we did with Cogitate.

[music]

Paul Middlebrooks
This is "Brain Inspired," powered by *The Transmitter*. Those are the voices of Rony Hirschhorn, Alex Lepauvre, and Oscar Ferrante, three of the many scientists that comprise the Cogitate Group. Cogitate is an adversarial collaboration project to test theories of consciousness in humans. In this case, testing the Integrated Information Theory of Consciousness and the Global Neuronal Workspace Theory of Consciousness.

I said it's an adversarial collaboration, what does that mean? It's adversarial in that two theories of consciousness are being pitted against each other experimentally. It's a collaboration in that the proponents of the two theories had to agree on what experiments could be performed that could possibly falsify the claims of each of their theories.

The group has just published the results of the first round of experiments in a paper titled *Adversarial Testing of Global Neuronal Workspace and Integrated Information Theories of Consciousness*. This is what Rony, Alex, and Oscar discuss with me today. The short summary is that they used a simple task, which they describe, and measured brain activity with three different methods, EEG, MEG, and fMRI, and they made predictions about where in the brain correlates of consciousness should be, how that activity should be maintained over time, and what kind of functional connectivity patterns should be present between brain regions.

The take-home, the results, are a mixed bag with neither theory being fully falsified, but with a ton of data and results for the world to ponder and build on to hopefully continue to refine and develop theoretical accounts of how brains and consciousness are related. We discuss the project itself, many of the challenges they faced along the way and continue to face, their experiences and reflections working on it and coming together as a team, the nature of working on an adversarial collaboration when so much is at stake for the proponents of each theory.

As you heard last episode with Dean Buonomano, when one of the theories, Integrated Information Theory, is surrounded by a bit of controversy itself regarding whether it should even be considered a scientific theory. Thank you for being here, I hope you enjoy this conversation. Thank you to my Patreon supporters who get full episodes, extra content, and access to the full archive of "Brain Inspired" episodes.

Here are Rony, Oscar, and Alex.

[transition]

This is going to be a real-- I was just rereading the manuscript, and oh my God, it's so much. Welcome, Rony, Oscar, Alex, thank you for being here. Let's start by just giving an overview of what you've been up to, what this project is, what Cogitate is. Alex, would you like to begin, or anyone can jump in here?

Alex Lepauvre
Yes, sure. Thanks a lot for having us. It's very exciting. I'm Alex Lepauvre, and I've been working for the past, I guess, four or five years on the Cogitate Project, which is an adversarial collaboration trying to arbitrate between two different theories of consciousness, the Integrated Information Theory and the Global Neuronal Workspace Theory. There's actually quite a few things that are specific about the project that I'm sure we'll go into, but I guess the first thing to say is it's not only me, Rony, and Oscar, but it's also a lot of other collaborators.

We have I think couple of different first authors on that paper. We have Urszula Gorska-Klimowska, Simon Henin, Aya Khalaf, Ling Liu, David Richter, and Yamil Vidal who aren't here today, and we have also three leading PIs, Lucia Melloni, Liad Mudrik, and Michael Pitts. What that means is it was special because it was an adversarial collaboration project, but also because it was a massively collaborative team science enterprise, so to speak.

Paul Middlebrooks
Just to hash out what an adversarial collaboration project is, in this case, two sides pitted against each other who have decided to come together and try to come up with testable experiments with predictions that would fit into their various theories and have to agree on those experiments. I'll leave it to you guys to say what your role is to be an impartial, not jurors, but experimenters, researchers in this case. Oscar, Rony, did Alex miss anything that you would add?

Rony Hirschhorn
It's actually even bigger than that. It's even bigger than Cogitate. Cogitate is one of a series of five such adversarial collaborations. It's not just these two theories, it's more theories that are being tested. Yes, the idea is to maybe level the playing field following this fragmentation of each of the series working on its own with its own methods and its own sets of predictions that don't really correspond.

When you look at the literature, you don't really know how to even begin to compare them, and so on. The idea from the Templeton World Charity Foundation is to start a series of collaboration bringing several theories to the table, at the same time, agreeing on sets of experiments that can test their predictions at the same time. Cogitate, as big as it is, even bigger than Alex mentioned, because this is just the center PIs and the first authors. We have, I think, 50 people on the experiment one paper. That's even just one out of-- yes, it's even bigger than that. The idea is the Kahneman idea of solving disagreements by working together instead of just--

Paul Middlebrooks
The Kahneman?

Rony Hirschhorn
Daniel Kahneman.

Paul Middlebrooks
Oh, he invented adversarial collaboration?

Rony Hirschhorn
Well, he talked about it in the beginning of 2000. Lucia Melloni really likes to mention that, so we are all affected by his impact on our project specifically.

Paul Middlebrooks
Oscar, it looked like you wanted to add something there.

Rony Hirschhorn
Yes, sorry.

Oscar Ferrante
Was about just to say that, yes, we're a big group of people and many other projects similar to Cogitate, but this was the first one. We are very proud of what we started, but also, we want to mention that this is just the beginning of something that hopefully will be bigger than our paper and what we've done so far. Also, in Cogitate, there are-- what we want to talk today is a paper that we have published on *Nature*, but there's also other projects associated with Cogitate and another experiment that we're working on. There is a lot of things, and we would like to talk about what we did so far, but also the people to keep track for what other people are doing at the same time.

Paul Middlebrooks
Well, you said that this was just the beginning, and then in a prior conversation that we were having, you guys have already sort of gone through academic levels from the beginning of the project. Maybe by way of introducing yourselves more so, talk a little bit more about who you are and

what you do and how you came to this project, and maybe your role in the project because everyone, you're all working together as a group, but you all have specialized roles if I have that correctly.

Oscar Ferrante
Who was the first one to join among us?

Alex Lepauvre
Rony probably.

Oscar Ferrante
Curious thought.

Rony Hirschhorn
It's up to join, I think, because Alex and Oscar, your vision, maybe I should have been last on this. My name is Rony, I'm a student at Liad Mudrik's lab at Tel Aviv University, now in my PhD. When I first heard of Cogitate, it was when the ad came back from Seattle, it was March 2018. I was in the second year of my bachelor's in computer science and psychology.

Paul Middlebrooks
So naive.

Rony Hirschhorn
So naive. I was an RA in her lab. I was working on another project. She came back. She was extremely excited. Then she said she's going to need some hands-on deck with the new thing. By the third year of my bachelor's, I was already piloting experiment two. I was already fully in Cogitate. That was the end of 2018.

Paul Middlebrooks
It's just the beginning, but I like that.

Rony Hirschhorn
That was just the beginning. [chuckles]

Paul Middlebrooks
Well, sure, that was the beginning for you, but then it-- anyway, all right. Oscar, maybe you want to go next?

Oscar Ferrante
Yes. I joined in 2019 after another meeting. Also, this meeting was in the US, and that meeting was in Chicago. It was the starting meeting of the project, when the project officially started and we were deciding the name of the group, and we ended up with Cogitate. I went there with Professor Ole Jensen. He works at the University of Oxford at the moment, but before, he was at the University of Birmingham, and I was a postdoc with him.

I joined the project. He presented the project to me as an opportunity to use my skills in MEG, magnetoencephalography, which is the technique that I use in Cogitate in my research. That day, I had the chance to meet in person most of the people in Cogitate. Some of them were online, like Alex, so I had the chance to exchange some words with Alex online. It was really exciting. After that, I wouldn't have imagined how things would have ended. It was unbelievable.

Paul Middlebrooks
Right. It sounds like, so far, two of the three of you were recruited but also excited to join. Was it a recruitment thing? Then, Rony, you mentioned there was an advertisement for the project. Were you guys recruited, or did you volunteer, or was it sort of in between?

Oscar Ferrante
In my case, I was already in Ole Jensen's lab and we were thinking how to continue to work together. Then there was this opportunity. He talked about the project and everything. I had a quick chat with Lucia Melloni, who was the main PI, together with Liad Mudrik and Michael Pitts. I liked the idea. It was completely different from what I did before, so I joined as a postdoc. Compared to Alex and Rony, I was more experienced, so I had more expectations probably.

Paul Middlebrooks
What do you mean more expectations, about what?

Oscar Ferrante
I joined not only for the science, but also because I thought it was a good-

Paul Middlebrooks
Move.

Oscar Ferrante
-way to go ahead with my career in academia because there is all these people involved and a super interesting topic and a big project and something that I was excited to see how that would have affected my career in academia.

Paul Middlebrooks
I didn't even think about that, but that is a shrewd move because you're automatically integrated into a vast network of people that you're going to be joined with. We'll talk about how you guys have become friends through the process soon. I hadn't thought about the networking aspect, the career aspect of it, because there's a separate way that it could maybe hurt your career even, potentially, right? I guess--

Oscar Ferrante
We can talk about that if you-- [chuckles]

Paul Middlebrooks
Yes, we'll talk about that later. Then, Alex, how did you come to the project, and what's your role?

Alex Lepauvre
I guess, in my case, it was a bit a similar story to Rony. At the time, I think, 2019, I joined the lab of Lucia Melloni. I just finished my master's in neurobiology. It was more like the biology aspect of neuroscience, molecular and cellular neuroscience type of things. Then I also got pretty interested things like consciousness research and system neuroscience and EEG and so on, so then I started looking for labs, and there was the opportunity in Lucia's lab to be a lab manager. It wasn't really an advertisement for the Cogitate project. It was more just to take care of daily operations at the lab, and I was lucky enough to get the job.

Right at the time I started, that was also when Cogitate started, meaning there was a lot of things that needed to be done, which as a lab manager, I was like just free hands that could take on any task that was floating around, so I just started working a lot on the Cogitate. That was also at the time where they were starting to put together all the teams.

I think to go back perhaps to the structure of the project itself, it all started in one meeting in Seattle where the funding agency, the Templeton World Charity Foundation, brought together a lot of PIs, including two of the founders of two leading theories of consciousness. They came together and discussed a think tank of coming up with ideas for experiments, which then later became the Cogitate project.

As part of that project, they also had the ambition of having very specific experiment that brings about contradicting prediction of the theories, but they also wanted to test them in the most detailed and precise way that was available. To do that, the strategy was to use basically all the best recording tools that exist right now in system neuroscience, so the EEG, MEG, fMRI, as well as intracranial aging.

Then they had the experiment pretty much set up. Then they started to also think of who could be leading the data collection and data analysis of each of these modalities. Then they hired PIs that was supposed to be theory-neutral and that would also be in charge of hiring postdocs or PhD students that would be theory-neutral.

At the time, one of the role that needed to be fulfilled was for the IEG team that Lucia was in charge of putting together. She thought of me as a-- then finishing up my time as a lab manager to become a PhD student specialized in the intracranial electroencephalography for the Cogitate Project. I guess for the recruitment process, I'm not too sure. I guess it depends on each of the PIs of each of the labs that was involved in each of the modality data collection was in charge of deciding whom to hire for that and how to go about it, I'd say.

Rony Hirschhorn
I think it's pretty similar, and I think Alex and I are misrepresenting the rest of the-- because most of all of the rest of the first authors are postdocs, like Oscar. After this call that Alex mentioned, they decided the theory-neutral labs that will centralize the data collection and the analysis, and each of the respective PIs hired postdocs. Alex and I starting as working in Liad and Lucia's labs we're like, "Well, you're already here, so." Then Alex came to the IEG team, and I came into the data monitoring team, which is supposed to be also a theory-neutral and also modality-neutral in the sense of overseeing all of them at the same time.

Paul Middlebrooks
They had the initial meeting where the idea was brewed up and then they had to agree on experiments. Do you have a sense of that process, how long and difficult a process that was? Because, ugh, it seems like such a difficult thing to do. We'll get into the predictions and the experiments that were made. I'll just jump the gun here and say like, even in the manuscript, I'm not sure how the one that is going to eventually be published words it, but you don't give judgment on the outcomes partially because, I think, you could poke holes in any of the results.

There's commentary from the proponents of each of the theories in the manuscript where, of course, they support the results that support their theory and then they can poke holes and the ones that don't. All of this is up for interpretation. Just given that you can always poke holes in any results because everything's open to interpretation, it seems so difficult to agree on experiments that should be run to test the hypotheses with

clean predictions. Do you have a sense of how long that took or how that process was? Then I really want to know also is, what did you think was going to happen?

Rony Hirschhorn
It did take long, again, from the perspective of-- maybe also Alex can-- from we making the stimuli themselves to piloting each of the experiments to actually getting to run them. That's after the proponents and the center PIs were already technically done with the conceptualization of the paradigms themselves. That was even months before. The entire thing was very iterative and took a long time.

Paul Middlebrooks
Do the proponents have to agree? Then you have--

Rony Hirschhorn
Yes.

Paul Middlebrooks
You make the stimuli. You have to send the stimuli to everyone and they say, "Oh, it's too bright on the left." Was it that sort of iterative process?

Rony Hirschhorn
Not to that level with the proponents every time, but with, again, Lucia and Liad didn't centralize this from both ends, but the design itself, the paradigm itself, the fact that they can make meaningful predictions to the theories using these paradigms, for example. Yes, they had to physically sign on that, by the way, to say that these experiments are good to test their predictions on these things.

I will say that it didn't start with only IIT and GNW, there were more theories in this project, and that was exactly the stage where if you didn't agree that it can test your theory, you would opt out instead of opting in. In that sense, yes, it took a long time from that meeting that they had in Seattle to bring it to the actual running it with predictions everyone agrees on. I think that to your question, yes, at least back then when they signed it and when we started running it, everyone agreed that these theories can be meaningfully tested using these experiments. That was the whole point.

Alex Lepauvre
Maybe if I can jump in on that one, it's a question like what took a long time and what we realized along the way is there's many different layers in agreeing on something. By the time we started, as you said, everything related to the conceptual idea of what are the experiments going to look like, there's two experiments, where did that come from, and so on. That all happened before we actually joined the project.

I have an impression of what happened, but I have actually no idea if that's true, because that's something none of us were there in that meeting. My impression is that the conceptual idea was a lot of the conceptual work, so to speak, was done at that one meeting where they got the project started back in Seattle in 2018 or at some point. You have sort of the broad idea of, how are we going to go about testing the theory, but then actually going down to the implementation and--

Rony Hirschhorn
Operationalization.

[laughter]

Alex Lepauvre
Basically, a lot of the time what we did is, "Oh, we have all these predictions, let's go about and just do it," and then you realize, "Oh, but we forgot to specify that to the level of detail that would be necessary." Whenever we hit such a broad block, then we'd actually have to go to the theory again and ask, "Oh, we didn't specify that to the level of details that would actually enable us to do a proper analysis. Therefore, we decided this and that. Would that be okay with you?" That's the back-and-forth process that took a really long time.

Oscar Ferrante
Also, the project evolved from the original idea, because the original idea is, we have two theories. They are both theories of consciousness, but they have different predictions. We should find ways to say, "We have these questions. We could have two possible outcomes, one in favor of theory A, in favor of IIT, and the other one in favor of GNWT."

Then while we started working on the project and when the theoretical questions became some practical hypotheses to test, we also realized that some questions were slightly different for the two theories. What we were actually testing were not exclusive. There were some questions where both could be right, and other questions where the outcome for one theory was irrelevant for the outcome of the other theory. It's also evolved from going from the theoretical idea to the actual practice.

Paul Middlebrooks
Yes, that's the way all scientific projects go, where you have a couple alternative hypotheses that you want to test, you set out to test them, and then minute 12 of day 1, you realize, "Oh, no, it's not going to be that clean." This seems like that times 20. I'm not sure what I want to ask you is, has it all been a series of headaches, [chuckles] or has it all been worth it so far?

Oscar Ferrante
I'm happy that you're not asking us which theory won, because you are speaking-- [crosstalk]

Paul Middlebrooks
I know not to ask you that, but you're impartial, you can't say, "We'll talk about it offline, don't worry."

[laughter]

Paul Middlebrooks
Immediately, to my earlier question, how did you think it was going to work out, not in terms of which theory would win, but just, would this work as an endeavor, and would we get a clean answer? The goal is to falsify, not to approve of either of the theories, but to falsify the predictions, essentially. Did you think it was all just going to work out cleanly in the beginning?

Rony Hirschhorn
I will say that to do a little justice to the cleanliness of the project, it is unique also in the aspect of, we have works showing, including works from my colleagues in my lab, for example, in Tel Aviv, showing that actually most of the experiments do not lay out the hypotheses and predictions so nicely in advance with respect to falsifying theories of consciousness. What they do is they do experiments, and then when they get the results, they post-hoc interpret them as supporting, for example, GNW or providing support for IIT. That's actually how most of them go.

Even the attempt to go in advance and detail it out as messy it ends up being, I think that's already put some things into boxes, into frameworks that make it more streamlined, even if the boxes inside are full of clutter and mess. I think even that makes it more helpful and maybe more hopeful in terms of how clean it can be if we continue with that approach of detailing these things beforehand. Exactly, because of what you said of finding out at minute 12 that, oh, it's not really detailed enough or specific enough or not really what I meant when I said I predict that this would happen, stuff like that.

Alex Lepauvre
I was also trying to think back, and one other thing we're also very worried about, I don't remember if I end up mentioning it in the paper, but there's this effect of the 15 IQ points as well, that afterwards, you imagine yourself that, oh, you knew that that's what's going to happen all along, and therefore, it's difficult to go back in time and imagine what I was thinking back then.

Even more so, because I think as me being a very junior researcher, just basically starting my PhD or barely, when I first encountered all the prediction, I really didn't know much about the theories themselves. It's been a really long learning along the way of how things hoyed. I think it took me a little bit of time to reach out a point where I could have an expectation of how it will pan out.

Paul Middlebrooks
Uh-oh. Has this ruined your outlook on science? No, actually, it's such a beautiful idea, and then the implementation is what it is. You guys did a fantastic job, it seems, of sticking to it and getting through those obstacles.

Alex Lepauvre
I think one thing that I would say that might contradict a bit what you said, Rony, I think that there was messiness in the sense of when you go to the conceptual ideal to the actual implementation, there's so many degrees of freedom that you can always go back and forth endlessly. One thing, if I remember correctly, I would need to go back to the actual first version of the pre-registration, which came out, I don't remember exactly when, but actually pretty early in the project.

Rony Hirschhorn
'19.

Alex Lepauvre
Yes, I think it was 2019, right? I think already there, we had the conceptual idea of how the theories are going to be tested didn't change all that much in the sense. In the one experiment we are talking about, we present stimuli for different durations, and there was always this idea, GNW says there's going to be decoding in the prefrontal cortex, where society says it's going to be decoding in a posterior region.

We have different stimuli durations, so according to GNW, the activation of PFC is going to scale up with the duration of the stimulus and IIT makes a similar prediction in the posterior cortex. All of that has been there since the very beginning. Now it's about when you say decoding, which classifier are you going to use, and when you say this and that, what's the actual method and what is actually the brain region that counts and doesn't count? This is where there's a lot of back and forth.

The broad idea, I would say, has been pretty consistent from the beginning of the project. I think I remember distinctively, by the time I reached the maturity of understanding what GNW was saying, I was like, "Oh, yes, this prediction seems very reasonable to me. I wouldn't be too surprised if this pans out."

Rony Hirschhorn
Being predictable and making sense when you read it is one thing and making it in advance is another thing. That's the thing that I find myself

telling people the most when I talk about the project, things that they had to come up with that beforehand. It makes sense when you read the whole thing together, it makes sense when you already perform the experiments and do the analyses and stuff like that, but it had to make sense before all of that. I think that it's not in a sense of think of ROIs. What does it mean to expect some regions then? [crosstalk]

Paul Middlebrooks
Sorry, sometimes I'm going to jump in because regions of interest. When people say IIT, it's always Integrated Information Theory, and GNW is Global Neural Workspace Theory.

Rony Hirschhorn
When a theory says, "I expect this and this activity in the front or in the back, posterior areas of the brain," that's nice. That's even backed by literature. Then, again, if you go to the literature, people can vary far and wide in what they consider to be actually posterior or what they consider to actually be frontal. Then when you come down to the nitty-gritty of that, you find that there is no literature detailing what are the specific regions that this theory predicts that will be related to the maintenance of conscious percept and stuff like that.

I think that saying it in advance had meaning because we had to go there. We had to do that. That was the first time it was actually done, is this project. This is the first time that the theories actually defined those regions of interest that are related to what we tested in experiment one, the maintenance of conscious visual stimuli. It wasn't done before. It's easy to say, "Oh, it makes sense." When you read it, it makes sense. Of course, it makes sense, but someone had to do it.

Paul Middlebrooks
Okay. Then you have to define the regions, but then you put an EEG cap on, which EEG has high temporal resolution, really low spatial resolution because you're inferring where the neural signals are coming from because it has to pass through the cranium. Then you have to decide, even if you have a really high-density EEG net, which just means there's a lot of electrodes on a lot of different places on your skull.

Then you have to decide which electrodes are we going to pay attention to and which frequencies of which electrodes with which question and which range, how to define that frequency range. It's just every step, there are decisions to be made that I think degrees of freedom, Alex, that you said earlier, where these degrees of freedom just open and then that leaves everything open to poke holes in as well. It's just so hard.

Oscar Ferrante
Yes, it's hard. Also, it's not that common. Nowadays, there are more studies that are pre-registered, but here, we have to pre-register everything before starting analyzing the data. I couldn't say something about how we approached the data analysis because that's also very peculiar of this project.

Paul Middlebrooks
Let's do that. Then I also want to-- I'm burying a lead because I want to talk about the actual predictions and why those predictions were, what they were, and then how it came out, but yes, please go ahead.

Oscar Ferrante
Yes. What we did is to collect a lot of data. We collected MEG, magnetoencephalography, electroencephalography, intracranial electroencephalography, and fMRI in six different labs all around the world, actually seven because we had an extra lab at the end. Then what we did is to take all the participants, all the data we collected, and divide them in two chunks. One small chunk of participants was used to develop the analysis. We developed analysis pipelines for all the modalities from preprocessing to the analysis required to test all the different predictions. We only have access to this limited amount of participants.

Then after that, we pre-registered the methods, and we publicly shared this also in a conference in Amsterdam some years ago. And then, only then, when we had everything pre-registered, everything was then approved by the theory leaders. Only at that time, we had access to the big data set, which is what we use in the *Nature* paper. The results that we show are results that were conducted on an independent, on an orthogonal sample compared to the one that we used to develop the analysis.

Paul Middlebrooks
When you say develop-- the goal is to pre-register. You use a small cohort of the large population sample. What are you trying to figure out there, which classifier to use?

Oscar Ferrante
Yes, for instance, yes. For instance, there is a prediction about where in the brain is the content of our conscious experience.

Paul Middlebrooks
You're not getting the results from that cohort and analyzing the results, right? You're actually just-- go ahead.

Oscar Ferrante
Yes. We are not using those results to test the theories, but we are using those data to see whether the analysis method that we are using to decode, for instance, using different classifiers, or in terms of interior connectivity, there are thousands of different measures that one can use to estimate connectivity between different brain regions.

These are all things that were on us and the lab, different modalities, PIs. These are not things that the theory can propose because they propose how the consciousness works, but not how to analyze MEG or fMRI or intracranial EG data. There was a lot of work on that side. Then only when everything was good from a technical point of view and approved from also external consultant, only at that point, we could test the actual theories, the actual predictions.

Paul Middlebrooks
Then how do you adjudicate between-- well, let's take an example. You said that there's so many analysis for inter-aerial communication. How do you figure out which one is the right one to preregister?

Oscar Ferrante
Yes, I think I can take this because-- yes, you choose the-- actually, that's my fault. [crosstalk]

Paul Middlebrooks
Okay, let's just go to decoding classifiers. That'll be more straightforward maybe.

Oscar Ferrante
Okay.

Paul Middlebrooks
See, already, we can't even-- it's not straightforward, right? It's a long hard story.

Oscar Ferrante
For decoding, for instance, what we try to do is to have control analysis and then develop the pipeline using the actual data that we're going to use, but not the final sample. Then also find control analysis, things that should be there anyway independently of what the theory predicts. If we can find those things, and then the data can be used to also test the predictions, then that means that this is how we can analyze the final sample.

Paul Middlebrooks
Okay, I think I understand that. You have to decide which analysis to use for any given question based on things that have been in the literature that have nothing to do with the theories, but it's just a reality check of whether you can use this machine learning classifier to decode whether you can decode whether someone's looking at a ball or a house or something like that?

Rony Hirschhorn
Exactly.

Alex Lepauvre
Right, exactly. I think, essentially, we use benchmarks, if that's what you want to call them. In the case of the decoding analysis, we are lucky that-- one of the predictions is we should decode faces from objects in different brain regions that are relevant for the theories. We were considering using benchmarks such as responses and so on, but the thing is, even in both of the regions, we did find decoding of faces versus objects.

We knew our classifier is sensitive to picking up something. Had that not been the case, then we would have optimized on something else to try to avoid any biases. We had decoding in both of the regions for this one particular feature, and then we tried to optimize to get the highest decoding accuracy possible by trying a couple of different things, like using pseudotrials and so on.

Paul Middlebrooks
You had to do it with a task that was unrelated to the task that you would eventually use to test the theories, right?

Alex Lepauvre
It can be on the same task, especially in the case of the MEG and fMRI, because we have this extra data set that's untouched. The question is, does our parameters generalize to another data set? If not, it's just overfitting, but that was baked in. We had the same task running hundreds of participants, and we used 20 of them to optimize our pipelines and then just check if it generalizes to the other participants.

Paul Middlebrooks
Let's say you run a classifier, and you see it in prefrontal cortex and you see it not in posterior cortex. Then that already says something about which theory that evidence leans towards. You already know something about that. In that case, you're confounding the control with the eventual-- I'm sorry, I'm harping on this. I'm just trying to understand it.

Rony Hirschhorn
No, it's totally legitimate. Not exactly, because first of all, even if you look at it like that, again, like Oscar said, we didn't use it for that. We didn't the patterns that we saw when we used the optimization data. Even once we optimized our methods, you get something. We don't use that to inform the orthogonal dataset, we have that one. That's one.

The other thing is that when you find or not find things, like Alex said, if you find the decoding that you want and you know that your methods are good enough. If you don't find, then you're right that it might be because you didn't use a sensitive enough method. You didn't use a good enough method. Then you need to go back to the drawing board and prove to yourself and also to all of your 49 other colleagues on your paper that your methods are good enough to identify something and that something is really not there and not that we could go on and try a different method or that there is some problem with the sensitivity of what we were doing and so on.

I think that controls for that. You're right that it's a risk to look at this tiny sample out of our bigger sample and start thinking, oh, what the results might be. I actually think that this is the advantage of working in such a large multimodal team that if you're tempted to do that, you always prevent it from doing that because you always need to be neutral and, again, demonstrate this neutrality in your analysis to everyone else, basically.

Oscar Ferrante
There's replication. We try to replicate everything that we did within modalities, like in this case with different samples, but also between modalities, because, for instance, what you mentioned before, deciding which frequency band to analyze when we look at the time series data, we had to standardize this between MEG-EG and intracranial EG and which classifier to use that was also standardized amongst the different teams. There was also an internal, like different levels of internal replication that we aimed for.

Paul Middlebrooks
Hopefully, the listeners will have a grand sense now of how challenging something like this is. I'm sure we'll come back to some of those challenges as we move through the meat of what you guys were testing. Right. Maybe we can go through. We don't need to go into the nitty-gritty details, but the big picture of each of the-- there are three predictions essentially that you guys tested and preregistered and then tested as we were just talking about.

Would someone like to just describe? Let's start with the decoding. Oh, Rony disappeared. Oh, you're back. Let's start with the decoding, since it's the first one in the paper and it's also the example that we were just using because there's a challenge already with decoding. Who would like to describe what the prediction was and the predicted results for both of the theories and why and then how you went about testing it?

Oscar Ferrante
Rony.

Rony Hirschhorn
Should I start?

Oscar Ferrante
Yes.

Rony Hirschhorn
Maybe I wonder if we first need to say something about the theories for it to be informative.

Paul Middlebrooks
Oh, yes, please. I will do that a little bit in the introduction as well, since we didn't-- I meant to do that beforehand, but because we could spend hours just talking about the theories themselves as well. How much weight to put on each of these topics is a challenge, right?

Rony Hirschhorn
Yes.

Paul Middlebrooks
Please, that'd be great if you say something overview about that.

Rony Hirschhorn
Just like in a nutshell. The decoding, for example, makes sense, right? The decoding question is, basically, can be simplified to, where in the brain can we find this specific information about the content that is being experienced right now? Right, because this experiment is all about suprathreshold stimuli. It's not some sort of manipulation of consciousness. We assume that you are aware of the stimuli, and like we said before, you have faces, you have objects, and they are presented for different durations. Where can we find in the brain information that is related specifically to that experience content?

Paul Middlebrooks
Why are we looking at where? Why is where? The important question.

Rony Hirschhorn
Where is the important question with respect to the theories, because, for example, if you consider Global Neuronal Workspace Theory, they view consciousness as this message that's being broadcasted, selected to be broadcasted in the brain. That workspace is located, according to GNW, in more frontal parietal regions of the brain. That's what you can derive and predict from GNW. For example, with Integrated Information Theory, IIT, because of the way they define consciousness, they actually start. It's not a cognitive neuroscience theory like GNW.

It starts from a first-person perspective and experience and its structure, that whole thing of the structured experience is expected to be actually correlated with more posterior areas of the brain. This is why where even matters. If we think about the theories and their neurobiological implementations, they expect to have different answers to the question of where, which is why decoding is an interesting prediction in the context of this experiment.

Paul Middlebrooks
Let me just pause and say, Oscar and Alex, do jump in. Feel very, very free just to jump in. Right. Anytime.

Rony Hirschhorn
Anything I missed or misrepresent? I think it's the simplest one, right? In terms of to understand, at least it's very intuitive.

Paul Middlebrooks
Not in terms of interpretation, but yes, to understand.

Rony Hirschhorn
To understand the motivation, because one can be very, very crudely simplified to front and one can be very, very crudely simplified to back also in terms of how it was presented in previous literature.

Paul Middlebrooks
You used the word correlation there. Is that why decoding, was this the proper analysis here? Because decoding, if you can decode something from a data set, it means that there is some correlation of that information. Right?

Rony Hirschhorn
We would go even further in the project. We go to like maximally decodable, right? We go to what information is, not only correlates with that, but do more areas add, like improve that decodability in the brain or not? That was, for example, a main question from integrated information theory. Do frontal areas, if we add them, does it add to the decodability or do their posterior areas, are they sufficient? It's both this correlation and also this correlation specifically to the areas that they defined, if I understand the question correctly.

Paul Middlebrooks
Yes. I just wanted to make the distinction between correlation and causation. Decoding is about correlation and not causation.

Rony Hirschhorn
Yes.

Alex Lepauvre
I guess maybe one different way of putting it, if I may, Rony, is, basically, if it makes a difference in terms of your conscious experience, whether you see a face or an object. Therefore, whatever brain region is involved in consciousness also has to have a similar distinction. Now, you can look at this in terms of a simple univariate analysis. You compare activation from one electrode or whatever between two different stimulus categories. That would be one way of looking at, does this region or electrodes or whatever represent information that's consistent with what experience is?

You could look at it in a multivariate sense, and that's what a decoding analysis does. It's like instead of looking at just one electrode, you look at the pattern of activation across many electrodes, and that tells you, oh, yes, indeed, these brain regions seems to have a similar distinction in terms of activation that is also present in experience. That's minimum requirement for that brain region to be involved in consciousness, and that is correlation.

Rony Hirschhorn
Even that is not enough in the sense of, because we don't manipulate consciousness in this experiment, that even if we find-- I think the more meaningful result would be to not find an expected pattern, because if we find the expected pattern, which goes back to the correlation, it doesn't really mean that it's unique to conscious experience. It can be representation that can also be there when you're not conscious of the stimulus. That's a point to be careful on with respect to the more positive results of the project.

Paul Middlebrooks
We should describe the task, I think. Can we do that fairly succinctly in a way that listeners could-- everything's easier visually, of course. Let's describe the task, and then we'll carry on with that first prediction and experiment.

Oscar Ferrante
We use a very simple task, like we didn't manipulate consciousness because that is something that we didn't want to do for the first experiment. What we did is just to present centrally in front of the participant, different images, so they were very clearly presented so that they were always experiencing these images. We presented images of different categories like faces, letters, objects, bold fonts so that we could use this as information about the content of the experience.

We also manipulated the duration which each of this image was presented so that we could also test the duration of the experience. Some images were presented for half a second, other images for one second, and other for one second and half. Then we also manipulated the relevance of these

images. Before presenting a series of images, we showed the participant two target pictures, and then they were presented with a series of pictures and they had to find the target, so they only had to respond when the target was in front of them.

Then sometimes the target could be a specific face, and the participant was presented with a face which was not a target. In that case, we will consider that picture as a task-relevant, non-target picture because it's same category as the target, but it's not the target itself. While other images are images that are from different categories, like objects, if you're looking for faces, for instance. In that case, we have stimuli that are non-relevant for the task. These are the main manipulation, the three main manipulations.

Paul Middlebrooks
Very simple task in ways that you can get rid of some of the confounds of responding whether it's a higher cognitive issue during the task. Whereas, a lot of consciousness-based tasks manipulate the stimuli, where it's ambiguous and whether you're attending to a house or a face, if it's half house, half face and things like that. There are lots of confounds that you guys wanted to get rid of. These are very simple images. It's very easy task. I didn't look, but I'm sure people performed at ceiling, what, 99%, something like that.

Rony Hirschhorn
90s is very good.

Paul Middlebrooks
Very clean. Everyone's happy with the task, right?

Oscar Ferrante
Yes. We have this task-relevant and task-irrelevant images also because we want to exclude the effect of responding because there's also a big topic in the search of consciousness about report task. There was another manipulation that is the orientation of these pictures. Some of the images were presented in the front view, and some in a lateral view.

When we had all these different manipulations in terms of the content of the visual, seamless, because the experience should be full, should contain all the different components of what we're seeing. Not just the category, because decoding category is one thing. Then experience should also contain information regarding the orientation of the face that we're seeing or the relevance of it.

Paul Middlebrooks
You all use the Mona Lisa as an example in the paper, where your conscious experience is, "Oh, hey, that's the Mona Lisa." Also, you notice the skin tone, the slight facial expressiveness, the background. The phenomenal experience of consciousness is, I think, multidimensional is the way that it's phrased in the paper. Did we miss anything, or should we go back now to the predictions? We have the task and now we're predicting, there's a difference between decodable of certain features in the front and back. I don't know if you want to continue, Rony.

Alex Lepauvre
Sorry, if I may jump in. One thing also, which is the very overarching theme regarding all the predictions, exactly what Rony said before, is because we don't have this confound. When you do a consciousness experiment where you have an unconscious and conscious condition, you cannot really always know, is the unconscious condition always truly unconscious, or is there sometimes conscious trials mixed in there, and the other way around and so on?

In that case, it's much simpler. There's no doubt that participant always experienced what's right in front of their eyes because it's so big. No attentional competition. No nothing. That means that if a prediction of a theory fails, they can hardly pull the card of saying, "Oh, maybe it's because the experimental contrast wasn't as clean and maybe they didn't experience it." It's a really hard argument to make to say, "Oh, maybe they didn't notice any difference between seeing a face and seeing an airplane." That wouldn't make sense.

Paul Middlebrooks
However, you could still zone out during the task and maybe not be consciously aware of one of the stimuli as it passes through. Maybe catnap, for example, et cetera.

Alex Lepauvre
That is an option, but then you would expect performances to be actually lower, not in the 95%, because they still have to respond to some of the stimuli, and there's no reason why they would zoom out less in the target stimuli that they have to respond.

Paul Middlebrooks
Magically.

Alex Lepauvre
That's the control for that critique. Basically, that runs through all the predictions. If we find it, that doesn't really tell us much because we don't know if there is unconscious processes that are mixed in with the conscious processes. If we don't find it, then that is a clear challenge for the theory.

Oscar Ferrante
There's the control experiment that you run, Alex.

Alex Lepauvre
Exactly. We also tested, do they remember after the fact the stimuli that we're presenting? Especially, is there any differences in memory performances between different task relevance condition? The simple answer is basically no, there is no such differences. They can remember not perfectly, because they're not told. It was a surprise memory test. They weren't told beforehand, "You're going to have to remember them because you're going to have a test afterwards." It was a surprise, but they still performed fairly well, which means they experience it most of them and can remember them after the fact. No significant differences between the different task relevance conditions.

Rony Hirschhorn
That combined with the behavior and the eye tracking. We see that they gaze directly at the stimuli. We see that they respond to them when they need to, when they're very accurate. All of that together. They were on task, and the task was very easy. They were looking directly at the stimuli. Then if we bring it back to the decoding, then the question is, is all that information that we have in the multidimensional conscious experience that Oscar mentioned, can we decode the category, if that's a phase or an object? Can we decode the orientation? Can we decode those bits of information in the areas that the theories a priori defined as relevant?

That's the whole meaning of doing these things beforehand. It's not like, "Let's try," and then post-hoc say, "Oh, you know what? I found something in the front that's interesting." That was the hard part of it, of being specific and saying, "Where do you expect to find it?" By it, we mean the ability to decode face versus object, the ability to decode this lateral view versus the frontal view, and the ability to do that both in the task-irrelevant and the task-relevant stimuli. There's no reason if we talk about experience that there will be a difference there. If there is, that's a problem because it means we found something related to the task, and not visual perception.

Paul Middlebrooks
Responding, as Oscar was saying?

Rony Hirschhorn
Exactly. That is the first prediction. That is basically the question of decoding.

Paul Middlebrooks
Let's go ahead and maybe talk about just how that came out, so then we can wrap up the predictions. We don't have to go through every prediction because people will read the paper and there's way too much to discuss, but just the overview. I was going to jump in when Alex earlier said, "The simple answer is that, no, it wasn't a problem." I was going to say, "Dear listeners, that is the last simple answer you will hear for the rest of this episode," which is not really true. Just overall, what were the results of that first experiment prediction?

Rony Hirschhorn
Overall, for category, it is true that we did find the decoding of category from task-relevant to task-relevant in the other way around. We found it both, but it was not only tested in the fMRI modality. It was also, like we talked before, tested in the other modality. That's also a very important point for the project. Both when we find something and when we don't find something, if it's consistent across the modalities, that makes it more robust. Even if we cannot say something about conscious perception, and it can be visual perception without consciousness, it's still something that is consistent. For example, between the fMRI and the intracranial EG recordings, that is very nice that it was consistent.

Correct me if I'm wrong here, but the orientation wasn't that simple, especially for GNW. Decoding of orientation was not found in the areas that GNW predicted. Even though it's simpler than the others, it's still not perfect in terms of brushing it off. It's still something that needs to be explained. If we have all the information about experience, why isn't the orientation there?

Paul Middlebrooks
Maybe I'll just jump in and say this. The reason why we've been talking about how complicated all this is, is because a lot of the results are a mixed bag. Lends some support for one theory, less support for the other, and then we move on. Then another one lends a little bit of support for both, and we move on. Then another experiment lends a lot of support in one modality, very little in the other modalities, for example. I'm making these things up, but that's just the way that science works, and then we're left to interpret what all that means.

Rony Hirschhorn
I would flip it, sorry, from support to challenge. I would brush up the support and say, "Here, I found this challenge." Then also challenge is something for the theory to explain. Support is something that, to me, is not interesting as a reader.

Paul Middlebrooks
Also, in the Popperian falsification since challenge is more in line with that as well. Thanks for correcting me.

Oscar Ferrante
If we support all the theories, we're not going anywhere because that means that all of the theories are right. Nobody is right. In that case, we have to challenge them.

Paul Middlebrooks
I'll restate what I said. There are lots of different challenges and lots of different modalities given the different--

Rony Hirschhorn
Yes. That's a good summary.

Paul Middlebrooks
Sorry. The end result then, Rony, in terms of the different theories, the decoding predictions, without interpreting, without giving a gloss on the interpretation, what are the challenges? Which one is more challenged?

Rony Hirschhorn
In terms of content, I would say both of them were not really challenged to the same degree. With respect to decoding of orientation, I would say that GNW was more challenged on that prediction.

Paul Middlebrooks
Overall? Neither theory was fully falsified by Prediction 1?

Rony Hirschhorn
Yes. Correct.

Paul Middlebrooks
I'm not sure if Alex or Oscar, maybe, Oscar, since you mentioned during the task about the different durations, because one of the things, the next prediction--[crosstalk]

Oscar Ferrante
Can you please give that to Alex, that one. [crosstalk]

Paul Middlebrooks
Oh, sure, sure.

[laughter]

Paul Middlebrooks
Yes. Alex, maybe you can talk about the second prediction.

Alex Lepauvre
I might be a bit biased there, but that's my favorite prediction, because that's the one I work the most on probably. [chuckles] Actually, back to what you were saying, that's the only simple answer you'll get. I think this one might also be a simple answer and also very simple source. At the end of the day, these are not very complicated predictions to understand despite the complexity of the theories involved. It present three different stimuli for three different durations.

You look at the screen, you see a face for 500 milliseconds, and you see a face for 1.5 seconds. You would expect that to make a difference in terms of your contrast experience. You'd expect, however you want to phrase it, if it's about time perception, which I don't think you necessarily need to go there. Just generally in terms of time by time, what's the content of your experience? The fact that you have a phase after 1.5 second still on the screen versus just a blank screen does make a difference in your experience. That's something that theories must be able to account for to some extent.

The Integrated Information Theory made a very simple prediction. If we have a phase that's presented for a given duration, we have a stable experience of that stimulus for that duration. Therefore, we expect sustained activation and also sustained content representation or sustained decoding, if you will, in the region that they believe is relevant to contrast on, which is the posterior cortex.

On the other hand, you have GNW, which is something a little bit more convoluted, which is what they expect at the onset of a stimulus, you have an increase of activation but then it goes back to baseline. Then at the end of the stimulus, you have a reactivation that basically marks the end. You have something that marks the beginning, something that marks the end. Importantly, both these events are somewhat content-specific. They represent distinctions in what was just on the screen. What is appearing and what is disappearing, and then you basically bridge in between the two.

Paul Middlebrooks
That first bump, that's the ignition of-

Alex Lepauvre
Yes.

Paul Middlebrooks
-Global Neuronal Workspace. Maybe just say a word about that. You mentioned that that ignition event, it's not just an ignition. It's somewhat content-specific, supposedly.

Alex Lepauvre
Yes, exactly. Basically, according to GNW, what makes something being contrast is that is, so you have a content that basically travels from lower sensory regions all the way to frontal cortex or parietal cortex. There's a couple reason why it might or might not trigger conscious experience. If it becomes conscious, what happens is you have a nonlinear ignition in the frontal parietal cortex.

That's basically a really strong increase of activation all of a sudden, and that's basically transmitting this information or making this information available to wide variety of processes that fulfill various cognitive function. This ignition is really necessary to make the information, what you experience, available to many processes. The fact that this specific information is available to the processes, that make it conscious according to GNW.

Paul Middlebrooks
It should have a slightly different "representation" that ignition event based on the different content so that it can signal what the content is when it's ignited?

Alex Lepauvre
Yes, exactly. The ignition, you can rephrase that if I'm not mistaken, as amplification of the content for it to become conscious, technically.

Paul Middlebrooks
Good.

Alex Lepauvre
Then, yes, it has to be content-specific because if it were not, there's no information there about what's in front of your eyes, so then you would experience something age-specific, which is not what experience is like.

Paul Middlebrooks
I just want to make sure I state it as clearly as possible. IIT says that, "For a long duration, the posterior cortex should come on and stay on for the duration." Whereas Global Neuronal Network space theory says that, "In frontal cortex, there should be this ignition event that amplifies the signal, and then it goes back to baseline. Then at the offset, there's another ignition event, which signals the offset and on to another conscious experience."

Alex Lepauvre
I think the slightly confusing part about that prediction, I would say, is the offset. It's like this ignition, they're always markers of two things. It's what just finished and what is starting now. You have the ignition at the beginning of the stimulus is marking that there is a new stimulus following a blank screen pretty much that signals now we have a face following a blank screen. After the offset of the stimulus predictions, now we have a blank screen, but following the face that was just there.

It's a temporal anchor. Basically, it's following the idea of Daniel Dennett, I think, of *Time and the Observer* paper. Which is you don't need to always represent things for the duration that they are there and any temporal information about them. You just need to send information with a temporal tag so that then you can re-construct based on them temporal tags of the different events that occurred, if that makes sense.

Paul Middlebrooks
I was going to say, this doesn't feel like my phenomenal experience that I'm always jumping from one conscious content experience. Then that one ends and then a new one begins. Then that one ends and a new one begins. It sounds like the dynamics could be not from the ignition but from the ongoing activity elsewhere.

Alex Lepauvre
Yes. There, that's a bit debated, I think. Whenever I talk about this to different people, I realize everybody have slightly different interpretations of that, but my personal interpretation- [crosstalk]

Paul Middlebrooks
Yes, shocking.

Alex Lepauvre
-which is I think what Stan would always say is, it's re-constructed backwards. You have the ignition at the offset. If you attend to what you've just experienced, then you'd have the impression that you had a sustained experience of something when, in fact, there was no sustained experience at the moment that it was there. That's one interpretation. The other one is the idea of activity silence, which is, I think the truth's probably in the middle. Which is between in the baseline period, information is still represented in an activity silent state. Which is basically encoded through synaptic potentiation, I think, you would say. It's saved in the synaptic way, especially later.

Paul Middlebrooks
The silence synapses?

Alex Lepauvre
Yes, exactly. That's the two interpretations. I think that's just me misunderstanding because Stan has a very precise interpretation. [chuckles]

Paul Middlebrooks
The ignition, let's say, is not itself the contents of your consciousness. It's a marker of the fact that there is a certain kind of content that will be in your consciousness, or is even? [crosstalk]

Alex Lepauvre
No, it is.

Paul Middlebrooks
It is.

Alex Lepauvre
Yes, it is the content of your consciousness.

Paul Middlebrooks
They're equated. The ignition is the content.

Alex Lepauvre
Yes. That is then broadcasted. You have the information that's amplified through the ignition, and then this information that's accessed by the processors is conscious. Maybe to reiterate on the idea of re-constructed backward. It seems like really not intuitive because that's not what our experience feels like. I think the argument from the Global Neuronal Workspace Theory, and generally speaking, the illusionist game.

We believe that consciousness is more of an illusion. That's the point. You wouldn't know, but whenever you look at it, whenever you try to capture yourself in what is your experience right now while you re-constructed, and therefore you have the impression that you had a sustained experience on experience like this or like that.

Rony Hirschhorn
You don't even have to go to that extreme, like in a sense of expecting the neural activation that happened, the patterns of information computation that happened in the brain to match experience. I think that's a whole other discussion. The fact that you have this ignition and the onset and offset, that doesn't mean that this is what it's like to have the experience.

Paul Middlebrooks
Isn't that what content means in this case? If the ignition is the content, doesn't that mean it's equated with what it's like?

Rony Hirschhorn
The ignition is what's being broadcasted, this moment of broadcasting of this content throughout the brain. Then, like Alex said, you can have many interpretations of how it's maintained. If it's silent or if you're actually on fire. In the end of the day, it's on them to explain how that accounts for this feeling of continuity that you have.

Paul Middlebrooks
This is one of the differences between Global Neuronal Workspace and integrated information, is that Integrated Information Theory starts with what it's like, the phenomenal aspect. They have axioms from which they derive the theory. Whereas Global Neuronal Workspace is just saying, "Here's the brain activity that is related to the conscious stuff." Then they have that later step to explain the feeling of what it's like.

Rony Hirschhorn
Yes. In a nutshell, yes, but in any case, for any theory of consciousness that claims to have a neurobiological implementation, it's on them to explain conscious experience, the neurobiological implementation, and the correspondence between them, which doesn't have to be as one-to-one as I expect when my experience is maintained to see a sustained activation in the brain. That's one way to go about it.

Another way might be more computationally saving resources, right? If I'm silent in between these two bursts, that might also have some justification in terms of if the representation is still there in silent synapses, and so on. That doesn't necessarily mean that I'm not consciously experiencing the stimulus at the time. I'm just saying.

Alex Lepauvre
Right. I guess also maybe another way to make that prediction a little bit more intuitive, GNW doesn't say that there will never be sustained activity in the prefrontal cortex when we are seeing a stimulus for a given duration. They actually say there will be a sustained activation and content representation if we are effortfully maintaining this information in our conscious experience.

For example, if you are told, "Attend specifically to the stimulus really precisely for as long as it's there or try to attend to its duration," and so on, basically anything that makes it such that you have to attend for the stimulus for its entire duration, then we would expect sustained activation of this. If we don't, then we just encode the beginning, the end, and reconstruct in between, and then we can build the story after the fact of us having a sustained experience if we look at it. I think that's what they would say.

Rony Hirschhorn
Just for the completion, and then I'll shut up about it. I just want to say that both theories, both GNW and IIT, and more other theories, they assume consciousness is discrete and not continuous, in terms of implementation-wise. The feeling of continuity isn't, of itself, a type of content of conscious experience, but in the matter of fact, IIT too assumes at the bottom, discreteness, just at a different level. It's not like one of them assumes this continuity, then the other one doesn't. They are both actually assuming that consciousness happens in a discrete manner, just like a different way of going about it.

Paul Middlebrooks
All right. Okay.

[crosstalk]

Alex Lepauvre
Right. Sorry, I didn't--

Paul Middlebrooks
Now I'll expect it. No, no. That's okay. All right. We have different durations of the stimuli, and you're going to test the durations based on the predictions from IIT and Global Neuronal Workspace Theory.

Alex Lepauvre
Right. Exactly. That's what we did in all three modalities, and I've worked mostly on the intracranial data. I think in general, what we find is, in the posterior cortex, there is sustained activation and sustained content representation. We use an RSA method for that, which is very similar to a decoding approach but that's, basically, we can essentially decode a phase that's presented for 1.5 seconds for 1.5 seconds, and we can decode a phase that's presented for 0.5 seconds for 0.5 seconds.

Paul Middlebrooks
I just want to say, RSA is Representational Similarity Analysis, and there are different ways of doing that. I just wanted to show out the acronym.

Alex Lepauvre
Yes. Sorry for using an acronym.

Paul Middlebrooks
That's all right.

Alex Lepauvre
In other words, we found that the prediction from IIT in the posterior cortex just works out the way they were saying. In the prefrontal cortex, what we find is that the prefrontal cortex does not care for the duration of the stimuli. I think that's one of the prediction. I think the failure of that particular prediction is really significant for GNW.

Paul Middlebrooks
Why would PFC prefrontal cortex need to care about the duration?

Alex Lepauvre
If it makes a difference in our conscious experience. The assumption of the experiment that's published in *Nature* right now is, we present stimuli for three different durations, and we experience them for three different durations. Our experience is associated with the stimuli duration, one way or another. I think that's like the minimum assumption. Duration does make some sort of a difference in our conscious experience.

It's not the same to experience the stimulus for 0.5 seconds than it is for 1.5 seconds. That's the main assumption. If that is true of conscious experience, then the fact that GNW doesn't reflect this property of conscious experience implies that something is missing either from the theory or something is wrong with our initial assumption. These are the two options, essentially.

Paul Middlebrooks
If the assumption is right, Global Neural Workspace is significantly challenged in this.

Alex Lepauvre
Exactly. I think it's also important to emphasize why that's the case at a different level. That's something, presenting the results at different conferences, I think it's something people often miss is, "All right. When we see a stimulus, you might experience it for whatever how long you

want to experience it or you're attending to it." Then, when the stimulus disappears, there is all of a sudden a massive change in the visual input. There is a stimulus disappearing, and all of a sudden, there's just a blank screen there.

According to GNW, for something to be a conscious experience, you need this ignition. The fact that we don't have an ignition at the disappearance of the stimulus, that means that participants don't experience it according to GNW. That means that they fail to notice something as drastic as the stimulus disappearing. That's the implication for the theory, if they want to stick to the core principle of the theory, which they do want to do.

Paul Middlebrooks
We have two out of three. Anything to add before we move on to the third prediction?

Alex Lepauvre
I think just one thing, and then I'll also shut up. That's actually, if you read the discussion of the paper, that's one. Again, that's completely counterintuitive in the reactions that most people have. When you say that, it's like, "Well, no. That's hardly sensical." Maybe it is true that participants don't experience that the stimulus disappears. That's essentially akin to what you were saying in the beginning. Sometimes you just zoom out.

Based on the structure of a task where we repeat the stimuli for many, many, many times, and we have the participant, they know at some point, they've learned the structure of the task. They know they only need to care about it when it first appears. Who says that you can't just zoom out as soon as you've performed the task and then go and direct your attention inwards and think about something else? Right?

Paul Middlebrooks
Right. In that case, even though the visual displayed is different, that might not make it up to the region that needs to be ignited, if you're not attending to it.

Alex Lepauvre
Exactly.

Rony Hirschhorn
On the other hand, then it would mean that GNW will have to come up with a different explanation of what accounts for you having experiences of different durations. What does differentiate seeing Alex for 20 seconds versus seeing them for half a second? We're actually very likely.

Alex Lepauvre
We're actually now working [chuckles] on a follow-up on that, actually, precisely. The answer is simple. If you have to care about it, then that will make a difference in your PFC, Frontal Parietal Complex. If you don't care about it, then it's just like irrelevant, and therefore not part of your experience.

Rony Hirschhorn
Yes. The point is that they still need to say that as a theory.

Alex Lepauvre
Yes. Right.

Rony Hirschhorn
They still need to account for that.

Oscar Ferrante
It's also tricky because one thing that we did-- I'm telling this to you, Paul, I don't know if it's something that we're going to tell because it's not something that we are reporting in the paper. We asked some questions to the participant at the end of the experiment, and we had this debriefing questionnaire. We asked them whether they noticed that the stimuli represented different durations. From the participant that I tested, I remember most of them said yes, but then also, if they say yes, what does it mean? Were they experiencing it at the moment, is something retrospective? There seems to be something there, but, yes, as Alex said, it's something that needs more research.

Paul Middlebrooks
Wait, so what are the implications of whether they said yes or no? Whether they experienced it?

Oscar Ferrante
Just to put it simply, if they would have said, "No, I didn't notice anything," then the idea that that is not in prefrontal cortex, the duration information from the prefrontal cortex, there is no offset ignition-

Paul Middlebrooks
That's fine.

Oscar Ferrante
-because it's not part of the experience.

Paul Middlebrooks
Most people did-- I don't know how you couldn't notice. They're pretty different durations.

Oscar Ferrante
Offsetting one second is not a big difference.

Paul Middlebrooks
Maybe, especially if you're in the scanner for a long time and you're tired and, whatever. All right. Oscar, inter-aerial communication, and the hair has stood up on the back of your neck a few times talking about the analyses with this prediction. Give us the overview of what the two different theories predict, and why this is tested and what was tested, and how it all turned out.

Oscar Ferrante
If we just remember what Rony said about where in the brain the neural correlates of consciousness are located based on the two theories, then it's another prediction that comes is, how does the information reach these areas? Now, let's say that we're seeing the face. We know that in the brain we have specific areas that are specialized to processing faces, like the Fusiform Face Area.

We know that when we recognize faces, that area is where the activity is happening. Now we know that we are seeing a face because the Fusiform Face Area is telling you that that is a face, but how does this information reach the neural correlates of consciousness? How does it go to prefrontal cortex for GNWT? How does it reach the posterior hold zone for IIT? This is the prediction, it's just simply that they do. This information reach.

This is also combined to what Alex said about the duration, because if the information goes from Fusiform Face Area to prefrontal cortex, and this is linked to an ignition, then the information should reach prefrontal cortex during that time window, which is a very small-time window between 200 and 500 milliseconds more or less. For IIT instead, because the duration is associated with a sustained activity, also the inter-aerial connectivity should be sustained.

Paul Middlebrooks
It should still get there quickly but then sustained, right?

Oscar Ferrante
Yes. That should remain sustained because for IIT, we have this posterior network of interconnected areas that affect each other, mirrors affects each other activity, and that should stay on until the experience is there. When it feels sense, then we shouldn't see this pattern of connectivity anymore.

Paul Middlebrooks
All right. The predictions are fairly simple, fairly straight forward, so then how do you test this?

Oscar Ferrante
That was the problem in our case. I was in charge of the MEG part of this prediction, and we use different methods to try to find this connectivity. There were different problems that we encountered. One problem is that there isn't a textbook example of connectivity. As I said before, we usually try to have some control analysis, but we couldn't find a way to control for connectivity between different areas.

Paul Middlebrooks
Do you mean like white matter axonal connection connectivity or functional connectivity?

Oscar Ferrante
Functional, yes. Talking about functional connectivity in this case. Connectivity that is depending on the task, on what is presented in front of you, this case a phase or an object. Because if you see an object, then Fusiform Face Area shouldn't be connected with PFC, probably the prefrontal cortex if GNWT is right.

The theories provide some initial guidance about what they intend in terms of connectivity, which is there's gamma band, so this activity that is closely linked to spiking and that is a measure in terms of coherence, which is a measure that also considered the phase of when the spikes and the oscillations happens. We started testing the predictions using this method, which we call Phase-Based Connectivity.

Paul Middlebrooks
Let me just stop in, sorry, and just clearly state. You said gamma band, so this is oscillatory activity and oscillations-- We don't need to go down the road of talking about whether they're causal or epi-phenomenal. It is the oscillating activity the reverberatory activity that underlie a conglomeration of lots of different neuronal activities. There are different frequencies that the oscillations can be at and the gamma band is fairly wide range of high frequencies, but it does correlate with spiking activity as Oscar already said.

That's why you focused on the gamma activity. Then you looked at the different phase lockings, and phase just means like what part of the wave of the oscillation is happening. Whether that's at the peak or the trough, and whether two different areas are in phase or out of phase, if they're both at the peak at the same time or if one is at the peak and the other is at the trough. These are all very simplified ways of doing it. I'm just trying to give a clear picture.

Oscar Ferrante
Thanks for also doing that, Paul. We try to use this method because that's what prediction were made or they were thought from the beginning. The problem is that we didn't manage to find any sign of connectivity. Not in MEG and also not in intracranial, EEG. Then we start using alternative methods, which are not that commonly used but they are also very, very good. Then, these methods that we use were methods based on the power.

Instead of looking at this oscillation in terms of phase, we just look at the spectral activity, the oscillatory activity in terms of power. Let's say if there is a lot of gamma activity in one area, at the same time, there should be a lot of gamma activity in the connected area. When this goes down, it should go down in both areas. We use some mutual information measures that are methods to look at this type of communication between different nodes.

In that case, we couldn't find strong evidence in the case of IIT. We couldn't find a strong evidence of connectivity between these procedure areas that specifically we look at early visual cortex and area that are specialized for specific category for stimuli, like phase or objects areas, specific areas. We find some evidence in intracranial EEG, and we also use some similar methods in fMRI to also look at inter-aerial connectivity based on the bold signal. We find some evidence in favor of connectivity between the specialized visual areas and prefrontal cortex.

To take home message in terms of connectivity here and for the project, is that we couldn't find evidence in favor of IIT, so we challenged the prediction of IIT, but we find some evidence, but not the evidence that was originally both, which was in face-based connectivity for JWT. In terms of connectivity, both theories were challenged, but also more in general, the way we study connectivity in functional connectivity was challenged by our project.

Paul Middlebrooks
Maybe one of the great benefits of doing a project like this because you actually have determined-- I don't know if it's better. Would you say it's a better way? You've made one way of analyzing the data maybe more established and one less established. Would that be a good way-- [crosstalk]

Oscar Ferrante
Yes. Absolutely that way. Yes. With the most established way, we couldn't find any evidence of connectivity, which is something that we are now trying to expand to other domains in neuroscience because it's something that we would like to see in general if it's a problem. Because we tested theories of consciousness but this is something that relates to every theory. Cognition.

Paul Middlebrooks
Right. It's like a new analysis where you can go back now over decades of literature and say, "Well, maybe you just weren't using the right metric." It can challenge a bunch of research.

Oscar Ferrante
The good thing about our project is also that we are sharing everything that we did. We're sharing the codes, the data, everything. Last year we organized with Ole Jensen and other people from Cogitate, a data competition challenge to a BIOMAG Conference about biomagnetism, about MEG. We asked the community to, "Okay. Take our data and prove us wrong. Tell us that there is some sort of connectivity there." We are still trying to figure out what we can do, what we can provide to the field in terms of also generally neuroscience for connectivity, like in this example that can be helpful.

Paul Middlebrooks
How many people or teams have taken that challenge up?

Oscar Ferrante
At the end we finished with only five teams. We made things very, very hard for them. We asked them to do what we did in five years, and we only gave them five months.

Paul Middlebrooks
[chuckles]

Oscar Ferrante
It was [chuckles] quite a lot but hopefully now when the paper will be out, we'll release the data and people will have a lot of time to try to find connectivity in MEG, fMRI, and then intracranial EEG.

Paul Middlebrooks
We've gone through the predictions and the results, and maybe before we move on to some of the lessons that you guys have learned, I would love to hear just in your own words, an interpretation because I know you can't do that, but how you would describe the results from a high level, in

terms of the challenges to the various theories and the balance of those challenges, et cetera. How would you describe that each of you at a high level? Rony, you haven't spoken in a little while, maybe we can start with you or whomever wants to begin.

Rony Hirschhorn
If you guys want to begin, I'm fine with it.

Alex Lepauvre
Oh. Go for it, Rony.

Rony Hirschhorn
Alex, you look like you're--

Alex Lepauvre
You go.

Rony Hirschhorn
I like that you said challenges now, because I think it's important, and like Oscar mentioned in the beginning, it's a very massive work but it's part of the project. We have another experiment. In terms of the strength of this experiments, in my opinion, it's the disconfirmatory results. Those challenges exactly. I don't know, maybe it's because I'm a pessimist and not a positive person in general that I focus on the [chuckles] negative, but to me, this is the most interesting part of the results.

In each of the predictions, like you said in the beginning, it didn't come out perfectly. There are things to account for with respect to the orientation, with respect to the maintenance, and the synchrony between the areas. I look at it as an overall win in terms of both theories have some homework to do with respect to how they specify the neurobiological implementation of conscious visual experience. That would be, in my own words, the conclusion.

Paul Middlebrooks
Yes, I like that. I wish you weren't so negative, but I do like that. No, I'm just kidding.

Rony Hirschhorn
[chuckles]

Paul Middlebrooks
This is a thing where it just dawned on me that, let's say the proponents, the worry is that the proponents can accept these challenges, but then we'll start looking for reasons why it's okay that it has been disconfirmed and then move the goalposts. Part of this endeavor is to establish the goalposts. On the theoretical side, you can be a little bit slippery if you want to, because like you said, in the past, you do an experiment and you look for confirmatory evidence or something, and then you can adjust your theory. There's still room for that here, is a worry, right?

Rony Hirschhorn
There's nothing wrong with adjusting your theory in light of evidence. It's a fine line between that and the goalpost thing. I think accepting this as evidence, accepting this as something that you need to adjust your theory by is a very positive thing for the field. The problem starts if you don't accept it and you start saying, "Maybe finding alternative explanations," things like that. I think if we take it in the positive way of taking negative, the negatives will be this need to adjust, this need to account for these things for real, and not try to find some way to avoid this interpretation of the results saying, "We did not find that. How do you deal?"

Paul Middlebrooks
Oscar, Alex, how about you guys?

Alex Lepauvre
I think I would very much agree with the perspective of Rony, which is, I think as much as the initial goal of this project was like, "Oh." I think for me, at least when I started being very naive, it's like, "Oh, yes, we do that." Then we have eliminated one theory, and then job done and then we move, and we repeat until there's only one left standing. I think now looking back, I realize this is a completely wrong idea.

It's more through the process of pushing the theories to make predictions that they wouldn't have done otherwise if they had just stayed within their realm of confirmatory science. We've highlighted a lot of things that they need to improve. I think you could be pessimistic and say, "Oh, this theory, they made a wrong prediction and therefore I'm a proparian. I think the theory is completely wrong. We need to invent a completely new theory."

I don't think that's a very valid approach. I think it's more trial and error and theories are a working process. We've just revealed stuff that we thought were really innocuous, really, in the sense that, "Oh, yes. Sure. If you present a stimulus for 1.5 seconds centrally on the screen, of course, the participant are going to have an experience that matches that duration."

Of course, when you present visual stimuli, there is bound to be some communication between low-level visual area and higher-level visual area. That's just the way it is. Then you actually do that and you realize, "Nothing is as easy as it seems," and that means there's a lot of room for improvement but also therefore room for discovery. Then that's pushing the field forward in specifying and getting better theories.

Paul Middlebrooks
Oh, I was about to jump in and ask, is one take home from this that both of these theories and likely all theories about consciousness, because the brain is so complex, consciousness and linking them, it's age-old problem. Both of these theories in this case are under specified in terms of the theoretical predictions?

Alex Lepauvre
Yes, I think that's fair to say. I don't think the theories would ever have argued otherwise. I think, for example, Stanislas Dehaene, the main advocate of GNW is always adamant in saying like, "That's a work in progress." It's by no means a done and dusted theory. We are continuously expanding it and building upon it. The same can be said for GNW. I think, when did the IIT 4.0 paper came out? I think was it 2023.

Oscar Ferrante
Yes. I think they're working on it.

Alex Lepauvre
That's part of the process of iterative, cumulative science. I think as much as the goal of eliminating theory, at least in a particular case, is premature. That doesn't mean that you shouldn't engage in such project with the aim of arbitrating between two theories, because that pushes progress in a way that's faster and more efficient than if you leave them each on their own and just looking at their own really restricted set of experimental conditions that they love and have been doing for a really long time.

Paul Middlebrooks
One reason I brought that issue up is because Integrated Information Theory has been controversial because a group of scientists has called it pseudoscience, et cetera. We're not going to talk about that. I will have Dean Buonomano on who's part of that group on a later episode, and we'll touch on that. This episode's not even about that controversy.

However, the fact that both of these theories are underspecified makes me think about philosophy of science, like what counts as a theory, because you have this broad range of how specific a theory is with its predictions. In this case, both are underspecified, not specific enough to have passed all falsification challenges. That's why I said probably all theories at this point are underspecified, because they are all works in progress as well. I don't know if you want to comment on that, but--

Oscar Ferrante
Yes, if I may. Yes, I agree. Also, I wouldn't be too harsh with them, because there are always new questions. The role of the theories is to try to answer these new questions. Being part of the project, I think both Stan and Giulio were very, very brave, because they put themselves and their theories on the spot. We asked them new questions. There were new things that they had to do because of the project.

Paul Middlebrooks
That's Stanislas Dehaene and Giulio Tononi, two of the main proponents of these two theories.

Oscar Ferrante
It's also an act of courage to challenge yourself and your theory, the theory that you build your career on. They are big scientists. They could just continue doing their own stuff. They didn't have to be part of this project if they didn't want. I think it's good to test theories, it's good to test their predictions. It's also good to give trust to science, because there is something that Lucia Melloni, one of the three main PIs in the project, always says that a lesson that she learned from Kahneman is that even if you do this adversarial collaboration, people rarely, if never, change their mind.

Paul Middlebrooks
Oh, right.

Oscar Ferrante
I don't think the aim of this project was to change Stan or Giulio's mind, because one project is not enough, but we are providing questions. I'm sure there will be many, many PhD students that will start new projects just from what we did. I hope that will be the case for what we did with Cogitate.

Rony Hirschhorn
Just to touch up on that. Sorry, Paul. Like Oscar said, we shouldn't be so harsh. I think we are not harsh enough with respect to the philosophy of science question and the field. I agree with you with the interpretation that all of the theories are currently underspecified. Underspecified in, again, if we look at the neurobiological implementation of what do they expect to happen in the brain, of course, it's not just GNW, it's not just IIT. There are many other theories out there. I think it's fair to say that all of them are kind of in the same boat.

I think that our point of view from Cogitate and the iterative process that Alex has been talking about, we are privileged to say that now, in light of Cogitate, that wasn't the case. It wasn't the case in the way it was discussed, and discussed in the literature, and in conferences, and presented to grants for years and years. Both of these theories and also many others, despite being highly underspecified, didn't really present it as such.

We think of GNW as a global workspace, and you say, "Oh, of course, the frontal parietal network," without going into the degree and understanding that there's a problem here. I think this project has revealed this uncomfortable place for all theories that, "We are underspecified. There are things that need to be done." I think in terms of really testing the theory, so-called, it's not just a problem of under-specification.

Even if you were more specified in the way that some of your hypotheses operationalize to predictions about the brain, you could say that that distance is so far away from what you started with, which is the core of your theory, then it's a question, does falsifying these results, can it even falsify what your theory is about? We have philosophers of science discussing this.

We have Niccolò Negro who wrote exactly about that, of these belts of core of this theory and the actual predictions that we end up with in the brain. In that sense, I think also, again, IIT and GNW, and all the rest of the theories are on the same boat, because no matter where you start from, from phenomenology, from the cognitive neuroscience of things, what you end up with in that prediction about the inter-aerial communication is farfetched from where you start from no matter which theory you are.

Paul Middlebrooks
That's right. When I try to keep all these things aligned in my head, I have a very abstract symbolic vision with Global Neuronal Workspace because we use terms like ignition and amplification. It's so odd just thinking, "All right. It's going to ignite in the prefrontal and then--" It is so unscientific. It's this abstract notion that we then have to get somehow to the metrics, just as you were saying.

Alex Lepauvre
I guess I might say something. I'm not sure if that's controversial, but I guess in a sense it is completely true to say that they're underspecified, and the very proof of it is, you wouldn't need to do adversarial collaborations otherwise where you actually have the advocates of each of the theories involved. Each of them are fully specified GNWT model, and then we have also really good models of like the dynamics of the brain, and so on.

You could just go about, have your experiment and have two competing GNWT models that are fully specified in existing papers. You just compare them and that's it. You don't need the person who wrote the particular GNWT model to be involved in that specific project. The fact that we need to involve the advocates to speak to the fact that they're underspecified, but at the same time, the fact that the theories are underspecified has no bearing on whether they're on the right track or not.

They can be underspecified right now, but they could still turn out to be correct in the future once healthfully specified or not. That's the fact that right now we don't have the full specification, doesn't disqualify a theory from being relevant, interesting, vertical, or whatever. Therefore, engaging in a comparison of two theories, even though they're underspecified is still a very valuable enterprise.

Paul Middlebrooks
This is also very different than making a prediction that light will bend around a star and then figuring out how to measure it, which is all very hard in relativity, but it's just way more complicated. It's way more difficult to get from this amorphous idea of ignition and amplification or integrated information. You can think intuitively, "All right. That sounds plausible," to then specify anything is difficult, [chuckles] it seems like.

Alex Lepauvre
That is true. I guess that's the workflow of the field-

Paul Middlebrooks
That's right.

Alex Lepauvre
Because if you think about it the other way on, what's the alternative? I think the alternative is just going bottom up, just look at data, whatever that may mean, and then--

Paul Middlebrooks
The alternative is panpsychism, actually.

Alex Lepauvre
[chuckles] Is it?

Paul Middlebrooks
IIT is panpsychist, but, no, let's not about pan--

Alex Lepauvre
Yes. That's--

Paul Middlebrooks
Abort. Sorry, I think I cut you off, Alex.

Alex Lepauvre
I think I was just saying, the theories are never going to be specified unless you actually build them in relationship to experimental data. I think that's part of the process of building a theory of, you state something, then you write the data, then you work your way out. If we went to do that, I'm not quite sure what else we could do with the theory. Just wait. I just think that's just the best thing we can do right now. It indeed it turns out to be fruitful because as Rony and Oscar said, we definitely learn new things, and there's definitely a lot of follow up projects that can spin out of this. From a scientific perspective, that's just progress.

Paul Middlebrooks
Speaking of now on, we don't have all day, I don't want to take your whole day and stuff. Oscar, you mentioned earlier that you're excited about what is happening moving forward. After this Herculean effort which now probably feels like it's in the rear-view mirror to you guys because that's how publication works, and I know you've been working on other things, so what is happening moving forward?

Oscar Ferrante
We have different things going on. One thing is the second experiment of Cogitate, which is an experiment in which we use a video game that was developed by a video game developer and Rony. This video game, we create condition which participant either will see stimulus or not see a stimulus. We manipulate the awareness of the stimuli. Now we are working on this data, and then things are going well, there will be news, hopefully, seeing them.

Paul Middlebrooks
Are you in that first small cohort phase where you're trying to figure out how to do the analysis to pre-register?

Oscar Ferrante
Now we're in a more advanced phase. We're writing the actual-

[crosstalk]

Oscar Ferrante
-manuscript.

Paul Middlebrooks
Oh, okay.

Oscar Ferrante
It's quite advanced but it's fine.

Paul Middlebrooks
All right. You're starting the manuscript, so we'll have you back on in, what? Six years, and it's curved up.

Oscar Ferrante
I will say-

Rony Hirschhorn
Exactly.

Oscar Ferrante
-that's the destiny. Also, very, very interesting for me is the data release because when the paper will be out, we'll release all the data, the MEG data, the intracranial data, the fMRI data, also the behavioral data. We have so much data to share. We will release the data with a lot of information, details, Wiki. As much information as we can.

Paul Middlebrooks
I always wonder about a data release like this and open science in general. I'm busy as fuck at my work, and I would be interested in this data. I don't have time. Who will this intrigue enough? Who's going to take up the task of analyzing the data?

Oscar Ferrante
I think if you imagine the time that will take someone to collect this amount of data, then it will be more convenient to just use already collected data. Also the number of participants that we collected is a huge cohort.

Paul Middlebrooks
Could I write a grant, you think? My mission on the grant is to use this data for a particular analysis. I suppose I could write a grant to that.

Oscar Ferrante
I don't see why not.

Paul Middlebrooks
That could create time for people.

Rony Hirschhorn
Also there's been massive effort within the project to actually make this data as simple to use as possible. That has been incredible separate effort. As Oscar mentioned, it includes detailed documentation. It includes storing it in very specific ways so it can be easily generalizable. We also release all of our codes and pipelines so we can pre-process it the way we did and stuff like that. There's been a massive effort to actually make it as simple as possible to use our data, not only just to dump it and share it and say, "There you go."

Paul Middlebrooks
You've architectured it a lot.

Oscar Ferrante
We're sharing also the code that we use in the project so people can use our code and replicate the destruction to run the codes. We're trying to make this as easy as possible for other people, and also something that was there since the beginning of the project. We spent a lot of time on it, and everything we did was keeping in mind that one day we're going to release everything.

Paul Middlebrooks
That's great.

Alex Lepauvre
I would hope that it's relevant data set for many people because it's unique. There's so many different questions such as, "Oh, I don't know. How does fMRI activity correlates with MEG signal and IEG signal?" You could just do a very technical paper about that. There's many different projects you can do. I'm sure a lot of people would be interested and we've heard also from several people and the machine learning community to benchmark classifiers and all that. There's I think quite a broad--

Rony Hirschhorn
People approach us and already come out with questions because they have plans. They've both basically written the paper and just waiting for our data to be available.

Oscar Ferrante
It'll be interesting also because some of the predictions that we tested are also prediction that could be proposed by other theories of consciousness. One critique of our project is why you only tested these two theories of consciousness, but the time is limited and-- [crosstalk]

Paul Middlebrooks
Time is limited, but you also stated at the beginning, other theories dropped out because it wasn't maybe relevant or appropriate, the experiments, et cetera.

Rony Hirschhorn
Exactly. Because of the need to commit beforehand to these prediction is different than taking this data now and analyzing it in light of our results and come up with new predictions. That will be, of course, useful, but it's much harder to commit for it beforehand.

Paul Middlebrooks
Briefly and then I'll have one final question. What is it like working under, for lack of a better term, controversial issues like this? Integrated Information Theory is controversial on its own, but all theories of consciousness have a measure of controversy. Do you feel pressure working under that controversy or are you walled off from that pressure because of the pre-registration? You're just the researchers carrying out the research and you don't have a dog in that fight, et cetera, or do you feel the pressure?

Alex Lepauvre
I don't mind going first. I think for me, there was definitely a lot of pressure but it wasn't the controversy. [chuckles] It was more being a cog in such a massive project and messing up something would have so much implication not just for me, but for many other people, and really qualified, and really awesome people who really need this thing to work and so on.

Paul Middlebrooks
It's a lot of responsibility.

Alex Lepauvre
Yes, exactly. For the controversy, I think consciousness is a very important field with a lot of ethical implication that is something that-- It's not really related to the project itself with most of my interest in consciousness. I think that's something I do spend time wondering about in my free time, like what are the implication of whatever we are going to find, and so on?

For the controversies related to the theories, something that often happens in conferences or as we discussed before, like, "Why this specific prediction from the theory?" I'm like, "Well, I can give you the boring answer, which is I don't have to care." I didn't came up with it. I don't have to

defend it. I just have to test it and see if that works out. That I'm just going to try to do the best I can with that, and therefore, I have a clear conscious.

Paul Middlebrooks
You still have to deal with reviewers, right? The practical aspects of working under that are-- I don't know how much you personally, the three of you, deal with the reviewers because you're part of such a large team, and maybe that takes some of the pressure off too.

Alex Lepauvre
I think it's-- [crosstalk]

Rony Hirschhorn
It's not just the reviewers. Oh, sorry.

Alex Lepauvre
I'll just say, because our PIs, especially the DPIs took that also on their back to show the brunt of the difficulty with the reviews. I guess that's also something that was probably all on our minds, which is what happens if we spend so much time and effort? Then, because of controversies, things don't come out as good as they could have. That would have been really very disappointing to put it mildly, but we were lucky that in the end it all turned out okay.

Rony Hirschhorn
I think controversy is part of that though. It's part of the project even getting this much attention, and even getting to where it got in the beginning. I think we cannot ignore where it came from. It came from controversy. It existed in a field with heated debates. People take things very personally, I think. You can say it's because, like Alex said, it has real-life implications. Of course, we see that now, not only with disorders of consciousness, with also AI, and stuff like that.

It's also been there even before these discussions. I think it's interesting how much people in the field care. I think it's because consciousness it's so trivial, it's so immediate. Why are we even continuing to fight about it and have 20 different theories at the same time? This is the mind-boggling thing, right? How come we all know what we mean, but we have 20 different theories that say different things and have different predictions?

Paul Middlebrooks
I can tell you, it's about legacy. [chuckles]

Rony Hirschhorn
It's true that the center PIs have done an incredible work of trying to separate the controversy from the work itself. When we go to conferences and also when we discuss with the adversaries themselves, you feel the controversy in the sense of feeling that this is very high stakes project. It's not just a massive collaboration. It's a massive collaboration with massive implications because of those controversies, so it does put pressure like Alex said.

I think that it's good to see that you can still work under those controversy, that it doesn't bend you over in any direction. That you can do this meaningful work, and that also when you have incredible PIs like the one in this project, that steer you in the middle of this very stormy ocean, through that, to the science within the controversy.

Paul Middlebrooks
Oscar, anything to add?

Oscar Ferrante
I'm going to say something also about the incredible first authors, the PI who did a great job. I think also the fact that we have this big team, and I think it's also related to the period which we started the project, which was during the lockdown. Each of us were in his own house, and then we were interacting with people mainly through computers. The fact that Rony is in Israel, Alex in Germany, and I'm in England, didn't make any difference. We were spending a lot of time together. We were only exposed to the controversy towards the end of the project. We were already a good group of collaborators and friends at the time.

Paul Middlebrooks
That's actually what was going to be my last question to you. Maybe you can speak to this as you finish that point is, we discussed offline before that you guys have-- I think you used the term self-organization of how you came together and also have become friends through this. Do speak to that before we're done?

Oscar Ferrante
As I was saying, we spent a lot of time together online when we couldn't spend time with other people because it was lockdown. I don't know, we're good people [chuckles] generally, and we liked each other. We liked to work with each other. When the controversy started, for instance, when we saw the letter, so the science letter--

Paul Middlebrooks
Oh, that first pseudoscience letter thing?

Oscar Ferrante
Yes. When that came out, our reaction was the reaction of a group who were supporting each other. In that moment, we were also supporting the people who were mostly exposed to this controversy, to this critic, which was the main PIs of the project. I think it would have been different if I was working on this project on my own with just another PI. The way which I would have coped with critics and the attention, the drama on the social media would've been different if I didn't have this group tackling this with me.

Alex Lepauvre
I guess also to the point related to the controversies where I remember very distinctively when that was a bit rocky time because of that, that we had a few meetings. There was never a point where people were like, "All right. I'm not interested in this project anymore." The attitude all throughout was just like, "All right. What do we do now?" Everybody was always on board with continuing-

Paul Middlebrooks
Nobody bailed.

Alex Lepauvre
-just doing more and figuring it out altogether, rather than just saying-- Also, again, we started the project, as Oscar said, COVID hit. I think there was never a point where people would get super demotivated and not willing to fight. I think we just always stick to it and just continued through the end, no matter what, kind of thing, to an extent that I don't think would also be the case in every big collaboration, I would say.

Paul Middlebrooks
To the end. We're at the end, huh?

Alex Lepauvre
No. No, no.

Rony Hirschhorn
No. No.

Alex Lepauvre
Well, we will continue collaborating until, I don't know when. [chuckles]

Paul Middlebrooks
Till the end end. Yes.

Alex Lepauvre
Yes.

Oscar Ferrante
Yes. I can advertise us as people who can test whatever theory of neuroscience you have, the influence theory, bring it to us, and we will describe it.

[laughter]

Paul Middlebrooks
Oh, man, you don't know what you just asked for.

[laughter]

Paul Middlebrooks
Well, congratulations on this Herculean effort and the results of this Herculean effort. Thank you for coming on my podcast to share this. I'll link to it in the show notes because there's lots for people to go over. Hopefully, we communicated a little bit about the results and people can take home what they will from it. Anyway, congratulations, and thanks for coming on to talk about it.

Oscar Ferrante
Thank you, Paul.

Rony Hirschhorn
Thank you so much, Paul.

Alex Lepauvre
Thank you.

[music]

Paul Middlebrooks
"Brain Inspired" is powered by *The Transmitter*, an online publication that aims to deliver useful information, insights, and tools to build bridges across neuroscience and advance research. Visit the transmitter.org to explore the latest neuroscience news and perspectives written by journalists and scientists. If you value "Brain Inspired," support it through Patreon to access full length episodes, join our Discord community, and even influence writing back to the podcast. Go to braininspired.co to learn more. The music you're hearing is "Little Wing," performed by Kyle Donovan. Thank you for your support. See you next time.

[music]
