Is our perception of the spread of COVID-19 inherently inaccurate?

Alexander Maier, Vanderbilt University

Abstract

One of the most fundamental insights into the nature of our subjective perception of the world around us is that it is not veridical. In other words, we tend to not perceive information about the world around us accurately. Instead, our brains interpret new information through a host of innate and learned mechanisms that can introduce bias and distortions. One of the best studied mechanisms that guide – and distort – our perception is the psychophysical Weber-Fechner law. According to this empirically derived, mathematically formulated law we tend to put more emphasis on smaller deviations in size while underestimating larger changes. The original formulation of the Weber-Fechner law takes the shape of a logarithmic function and is commonly applied to somatosensory perception such as the weight of an object. However, later work showed that the Weber-Fechner law can be generalized and describe a large variety of perceived changes in magnitude that even go beyond the sensory domain. Here we investigate the hypothesis that our perception of data associated with the spread of COVID-19 and similar pandemics is governed by the same psychophysical laws. Based on several recently published studies, we demonstrate that the Weber-Fechner law can be shown to directly affect the decision-making of officials in response to this global crisis as well as the greater public at large. We discuss how heightened awareness of the non-linear nature of subjective perception could help alleviate problematic judgements in similar situations in the future.

Introduction

French philosopher R. Descartes (1596-1650) is commonly credited with discovering that nothing is certain, except one's own subjective experience of existing (*cogito, ergo sum*)(R Descartes, 1644; René Descartes, 1863). Ironically, it was also at least partially due to Descartes that the scientific enterprise shunned the exploration of subjective experience – the only phenomenon that we can be certain of - for centuries to come. The reason for declaring subjective experience as off-limits to science was that Descartes proposed that there is a fundamental divide between the subjective mental world of conscious experience (*res cogitans*) and the objective, material world (*res extensa*)(R Descartes, 1644). This “dualistic” divide of reality into the subjective and everything else is referred to as “Cartesian” to honor Descartes' impactful thought.

There are a several arguments in defense of Cartesian dualism that have survived centuries of debate. The pro-Cartesian argument that might be the most intuitive is that the material world can be successfully described – and thus precisely manipulated – using quantitative methods. Such precise quantitative measurements seem inaccessible for mental processes. In other words, we can measure virtually any aspect of the world around us, ranging from the age of the universe, the size of the smallest particles we have discovered, the speed of light and the fastest speed a human can run to the weight of an airplane carrier. And these measured quantities and their variance (changes) over time often follow mathematical laws that can be used to predict the future, such as the speed and direction a billiard ball will take after being hit by a cue, or the interaction of time and space near a cosmic black hole. This combination of relying on the measurable and uncovering deterministic laws is arguably a major reason why the scientific method has enjoyed such great success in investigating and describing the material world.

In contrast, we intuit that one cannot simply “measure love” or “determine if a certain smell is just the multiplicative product of two other smells”. Perception, and our subjective experience more generally, thus seem to be out of bounds for the scientific method. Our intuition also suggests that there are no stringent mathematical laws, such as Newton's law of gravity, that govern our inner world of feeling and thought.

And yet, these intuitions have long been proven wrong.

Our intuition fails us

For more than a hundred years, scientists held the tools to demonstrate that even our “subjective” experience is objectively measurable with astonishing precision. More than that, mathematical functions were found that accurately describe the relationship between our subjective experience and the objective, material events that trigger them.

To great surprise, it turned out that these mathematical functions that govern how we subjectively experience the world are not linear. That is, our perception of the world is not always accurate (**Figure 1**). These perceptual distortions are particularly pronounced when it comes to large quantities or large changes from the status quo, where they tend to manifest as underestimation.

In the next sections, we will derive how these perceptual distortions might affect real-life decision making, and use the ongoing global crisis evoked by the COVID-19 pandemic as a timely and instructive example. Following in-depth exploration of what is scientifically known about perceptual laws, we will draw from several recently published studies to test the specific

hypothesis that decision making in the face of the global pandemic might be affected by the subjective perception of various metrics that these decisions are based on. We discuss how awareness of the fact that science has produced a quantitatively rigorous understanding of certain subjective experiences - and the phenomenon of inherently distorted perception in particular - could help prevent and alleviate associated problems.

The psychophysical breakthrough

As discussed above, modern-day science incorporates frequent, precise measures of phenomena that are exclusive to the first-person perspective. In other words, there are methodologies in place that allow for rigorous, quantitative assessment of how individuals perceive new information. What are these methodological techniques?

Assigning units to perception

The first step towards measurements of subjective, perceptual quantities is the appreciation that any change in magnitude or intensity we perceive can be assigned meaningful units. In other words, we can measure exact differences in subjective perception of say, a sound, a bright light, or the perceived status that comes with net worth without resorting to fantasy numbers, such as “3 red”. Just like measurements in physics and other natural sciences are usually with reference to a concrete unit (e.g., a meter or a kilogram), magnitude perception can be measured in concrete, absolute units as well. To fully appreciate the importance of this fact, consider that one of the most frequent objections to studying subjective perception using scientific methods was that one cannot assign units to its contents. As the “father of American psychology”, William James put it: “the light of an electric arc [does not] seem to contain that of a tallow candle in itself” (James, 1890). The insight that this intuition is misleading forms the basis of the mathematical laws that describe the distortions that are inherent to perception. How was this derived?

The credit usually goes to Ernst Weber (1795–1878) and his student Gustav Fechner (1801–1887) for their utilization of perceptual thresholds (Fechner, 1860; Weber, 1834). Generally speaking, there are two types of perceptual thresholds: absolute and relative. The

first one (absolute threshold) is familiar to anyone who underwent a hearing exam. In order to test one's hearing, an audiologist often plays sounds of varying loudness and asks the patient to indicate whenever they hear a sound. Sounds that are loud enough to cross the patient's absolute threshold will be consciously perceived and thus can be reported (that is they are "just noticeable" stimuli). Sounds that are too faint, on the other hand, will not elicit a response. A careful testing procedure thus can produce a clear number (in terms of sounds loudness) for where the absolute threshold is met. Perception thus can easily be defined in a binary sense (e.g., loud enough to hear versus not loud enough to be perceived).

But 0 vs. 1 is an insufficient numerical range to provide deep insight into the laws of perception. To get there, Weber and Fechner relied on relative thresholds. Relative thresholds are related to absolute thresholds in that one starts with a certain set of stimuli that are likely to straddle the threshold. And as in the case of absolute thresholds, relative thresholds occur when perception deviates. The only difference is that relative thresholds do not start with something that is not perceivable, but something that is already perceived. Put more simply, relative thresholds are just perceived differences. In order to cross a relative threshold, stimulus changes must be large enough that a person becomes aware of (that is, perceives) the difference. Relative thresholds thus are also called just-noticeable differences.

All of this may sound a bit confusing in the abstract. Let us consider the actual experiment that is associated with the Weber-Fechner insight of the usefulness of relative thresholds: Imagine that you are blindfolded in a safe testing environment, with one of your hands stretched out as if you were holding a bowl full of water. Instead of a bowl, an experimenter places a thin sheet of paper on your hand, which you can readily feel. The experimenter then silently places a tiny piece of feather on top of the paper. Do you think you would be aware of that with your eyes closed? Most, if not all, people would still just feel the piece of paper, provided that there were no other clues to the experimenter's doing. In other words, the change in weight on the palm of your hands was too small to elicit the perception of a change. From your (first-person) perspective, there is no difference between the weight of a sheet of paper and the weight of a sheet of paper, plus the weight of a tiny piece of feather. Although they are objectively different weights, your perception of these two weights is equal. These two weights are at a point of *subjective equality*. Of course, this phenomenon is purely based on a basic limitation of your sense organs and the associated nervous system that is interpreting the data provided by the sense receptors. We simply are not capable to detect

FIGURE 2

Fig. 2: Perception of gradually changing magnitudes (*left*) is discreet (*right*). The reason for this difference between physical reality and our perception lies in the fact that our sensitivity limits our ability to detect changes. Only changes large enough to trigger a change in our sense organs will translate into a perceived change. Thus, as magnitude increases, our perception remains constant (unchanged) until the magnitude increase is large enough to be noticed as a *just-noticeable difference* (JND). Each successive JND can be conceptualized as a “step” in a staircase function. JNDs thus provide numerical units for perceptual quantities (1, 2, 3...).

such small changes in magnitude. And the result is that there are slightly different weights that translate into one of the same perceived weight.

Now, imagine that the experimenter keeps adding feathers to the sheet of paper without them falling off. Your eyes are still closed and there are no other clues to this going on. As the weight keeps increasing, there will – of course – be a point where you can perceive a change. This is an interesting moment. While all the added weight up until this moment was the same to you, you now experience a clear difference – a heavier, new experience of weight. Fechner called amount of weight that is needed for perception to change the “just noticeable difference”. Just noticeable differences thus are always with respect (relative) to a previous perceptual state. But just as in the case of the just noticeable stimuli that mark absolute thresholds, so do just noticeable differences. Except these thresholds are *relative thresholds*. So, just like in the case of absolute thresholds, something qualitatively changed in your perception. And similar to the case of absolute thresholds, we can assign numbers to this relative threshold. Except for 0 (no perception) and 1 (perception) in the case of absolute thresholds, we can now increase our numeric range. That is, if we assign the baseline weight of the paper a value such as 1, the next perceived weight that can be experienced when the just-noticeable differences was reached can be assigned a 2. If we keep adding weight, there will be another set of weights that cannot be distinguished until the next relative threshold is crossed. We can then assign this just noticeable difference the number 3 and so on and so forth (**Figure 2**).

Using this logic, Weber and Fechner were able to demonstrate that perception is discrete. In other words, our perception of, say weight in your hand, resembles more of a step function - with countable steps - than an unmeasurable, graded continuum as suggested by W. James. This marked a profound insight into the nature of perception: We can assign numbers to perceived magnitudes thanks to a meaningful unit: the just noticeable difference. This means that rather than merely speculating of, say, how bright a light is perceived, we can quantify brightness perception objectively.

At this point, the question remains how to get around the fact that there is seemingly no objective way to determine when a perceptual threshold is reached. After all, we rely on the

person that is undergoing the experiment to verbally or otherwise report that change. And there could be a large variety of circumstances that might interfere with that, a subject's honesty not being the least of them. In other words, someone could simply lie about what they actually perceive. Worse than that, some people are just more prone to "pull the trigger" while others might be more cautious and conservative in their approach. And while the former might be happy to report the slightest perceptual difference, the latter might not be so sure in their own judgement when operating at the boundaries of perception and only feel confident to report once certainty is reached. We thus seem to still be left with a barrier of subjectivity that prevents us from obtaining a reliable objective measure. This is where the second step comes in. Scientists have developed a nifty technique that allows us to mathematically circumvent such problems.

Eliminating lies and biases

To fully appreciate the problem, let us consider another pretend-experiment. Imagine you are trapped inside a bunker during wartime. Your task is to monitor a radar screen to detect any incoming missiles that would kill you and everyone else inside the bunker with you. As long as you yell out a warning and you and everyone with you evacuates the bunker while the missile approaches, everyone will be fine. As the radar sweeps around the screen, you think you might just have barely detected a blip indicating an incoming missile. You are not quite sure, though. Maybe it was just the heightened tension. Maybe it was just an unevenness of the display. Maybe it was because you blinked. You could wait for another radar sweep to come around to be certain, but at that point it might be too late. Would you wait? Most, if not all of us, would not. We would raise the alarm even at the risk that it was a false alarm. Better safe than sorry.

Now imagine that you are in the exact same scenario, except the war in question is the Cold War that put the USSR and the USA at the brink of mutual nuclear annihilation. You are in a bunker again, looking at the same radar screen and watching for incoming missiles. There is only one difference – if you raise the alarm, your country will immediately and irreversibly launch a nuclear attack and ring in Armageddon. Given these circumstances, would you be

equally likely to raise the alarm right away or rather wait for another sweep to take place to be sure? Most, if not all of us, would do exactly that.

The context and circumstances that we are in thus can determine if we report one and the same perception. In other word, we apply an internal *criterion* on top of the actual perceptual experience before making the decision as to whether we think we experienced a threshold being crossed or not. The fact that some people might be more prone than others to report a perceptual change when facing some uncertainty as well as the fact one and the same person might report their perception differently, depending on context, are worrisome for the enterprise of measuring perception accurately. This is why it is important to acknowledge that there are clever ways around that problem.

The basic idea to solve the dilemma sketched out above is to test people for their bias and criteria, and then mathematically account for these factors (Green & Swets, 1966). In practice, this means that an experimenter presents stimuli below and above threshold (e.g., an audiologist testing one's hearing). However, sometimes the experimenter just pretends that there was a presentation and still asks for an answer. This is called a "catch trial". The idea is that if someone has a bias or an internal criterion that would make them more likely to report a perceptual change, they would be more likely to say "yes" in cases where they should not have (because there was nothing to report). If this happens, we are dealing with a "false alarm". Addition of this step can expose people who just randomly answer or deliberately lie. More importantly, however, it can also be used to detect – and correct for – more subtle cases of bias (such as in our pretend-experiments).

Without going too deeply into the details, there are some rather basic mathematical tools from a field termed "signal detection theory" that can derive virtually any bias or internal criterion that might stand in the way of "truthful" or "accurate" report based on the frequency of false alarms compared to correct responses (Green & Swets, 1966). This is very powerful in practice. The combination of quantifying perception by using thresholds and accounting for distorted perceptual report via signal detection theory (and a few additional clever techniques such as having people bet money on their perceptual report (Sandberg, Timmermans, Overgaard, & Cleeremans, 2010)) has given birth to an entire discipline of research called

psychophysics. Scientists trust properly acquired psychophysical data as much as any other measurement and there are even applications in industry, such as when new foods are being designed.

Perception of magnitude is almost always distorted

The perhaps most surprising outcome of measuring perception quantitatively emerged soon after the original breakthrough by Weber and Fechner. Given everything that we discussed so far, suggests that a plot of perceived weight versus actual weight would look like flight of stairs, moving up a step each time a threshold is reached (**Figure 2**). When using actually measured data, Weber and Fechner saw something slightly, but importantly, different: The steps were not of equal size (**Figure 3**). Instead, they found that the more weight they added, the more they had to add next to cross the next relative threshold.

One way to appreciate this finding is to go back to our original example of being blindfolded and trying to detect when the weight in one's outstretched hand increases. We already established that if we start with a sheet of paper that a large number of feathers would suffice for us to notice when they are placed on top of the existing paper. Now imagine that instead of a single sheet of paper, we start out by placing not one, but two big heavy books in your hand. You will barely be able to keep your hand stretched out, but you now also would not be able to detect the same number of feathers placed on top. It will take a much larger weight now for you to perceive a difference of the already pretty heavy weight.

Measuring accurately, Weber and Fechner realized that the dependence of relative thresholds on the starting point can be expressed as a (logarithmic) mathematical function. This function now bears their name (Weber-Fechner law), and it has been shown to apply not just for holding weights in your hands, but many more types of perception. You might have experienced the Weber-Fechner law by looking at a tall building and realizing that the top floors are visually spaced much closer together than the bottom floors are from where you are

standing. Another example is that the distance between mile markers on a long, straight road seems to get smaller and smaller the further away they are.

The generality of this phenomenon is striking. It seems easy to think of examples across a multitude of sensations. A salty soup, for example, would need a lot more extra salt than a soup with little salt before a difference would become noticeable etc. Indeed, scientists have systematically tested dozens upon dozens of different things that we perceive across different intensities, or magnitudes. Many of them follow the same logarithmic law. And the ones that do not, tend to be exponential in nature (although there are a small number of linear perceptions as well (Stevens, 2017)). In either case - the fact that there is a short mathematical formula that can describe how people perceive quantity is astonishing.

There are two important consequences of this discovery: First, perception is not just measurable like most other phenomena of the material world. Perceptual measurements also follow mathematical laws, just like those found for the material world. In other words, rather than being off-limits to science, perception is very much a part of it and does not stick out as special when evaluated by the same criteria used in chemistry or physics.

Second, the mathematical laws (i.e., the Weber-Fechner law and its generalized form (Stevens, 2017)) demonstrate that perception is often “inaccurate”. Perception can significantly deviate from the actual, material world around us. While we know that our perception fails us at times in the form of illusions or hallucinations, we tend to think about these occasions as “

“unusual” and “rare”. Our intuition is that the world we see, hear, smell, taste and feel is just that – the actual world (minus the occasional illusion). Philosophers have called this mindset “naïve realism”, indicating that it is naïve to assume. And yet, none of us are constantly questioning whether and how our perceived reality deviates from the actual physical world. But, when measured carefully and precisely, we realize that our perception is not reliable – especially when it comes to perceiving change from large quantities.

Does the Weber-Fechner law affect the perception of COVID-19 metrics?

You can see from the above that there is a fundamental mismatch between our intuition and scientific insight when it comes to how accurately we perceive the world. Even knowing about this limitation of perception will not change the perceived world. The mile markers on a long straight street will seem closer and closer the further away they are, no matter if one

knows that perception of space is logarithmically distorted or not. And yet – knowledge of this fact will at least create awareness that perception of space is distorted. This knowledge can allow for accommodations when it comes to decision making.

Given all that, can the Weber-Fechner law be extended to our perception of a pandemic? If so, it would seem helpful to be aware of this fact to steer decision making accordingly. Although relatively little time (in academic standards) has passed since the outbreak of the pandemic, there are several peer-reviewed studies that have already investigated that very issue. And their findings are striking.

Dyer and Kolic investigated the relationship between epidemiological data and their public perception by analyzing twitter messages that were posted during the second quarter of 2020 across a dozen countries (Dyer & Kolic, 2020). Their hypothesis was that if the Weber-Fechner law were to govern the public perception of the course of the pandemic, expressed emotions in response to increasing numbers of fatalities would demonstrate “psychophysical numbing”. In other words, the more COVID-19 fatalities rose, the more it took for people to express the same level of emotiveness. This effect could be demonstrated via semantic network analysis that quantitatively evaluated word co-occurrences. The same authors further found that the average attention that could be attributed to each countries’ COVID-19 fatality rate was well predicted by the Weber-Fechner law and its generalized forms. In other words, scientific analysis of tweeds suggests that the public-at-large perceived the spread of COVID-19 with the predicted underestimation of larger and larger changes in numbers that was predicted by Weber and Fechner over 100 years ago. Did this effect affect decision makers as well?

Investigating the relationship between daily death counts and all 50 US states’ stay-at-home orders, Djulbegovic and co-workers found just that (Djulbegovic, Weiss, & Hozo, 2020). Their analysis showed that the Weber-Fechner law was predictive of when stay-at-home orders were issued in response to COVID-19 fatality reports. The authors did not find that these decisions were influenced by political affiliation. Rather, it was the Weber-Fechner law and its associated underappreciation of ever larger increases in numbers that drove US policy in response to COVID for several months during the summer of 2020.

Discussion

COVID-19 has posed a multitude of exceptionally complex problems around the globe. One of the perhaps less appreciated complexities is that both the perception of the public as well as that of individual decision makers is inherently biased towards noticing smaller changes in COVID-19 spread initially while numbers are still relatively low, and failing to accurately perceive larger ones once the spread takes on much more drastic levels. This “numbing” can be mathematically predicted using the logarithmic Weber-Fechner function and occurs independent of political view. Perhaps most shockingly, this perceptual distortion can be shown to affect real-life decision making in that US stay-at-home orders in 2020 also followed the Weber-Fechner law. Wider appreciation of these facts might help alleviate perceptually-biased decision making in similar situations.

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