Materialized Oppression in Medical Tools and Technologies*

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Abstract

It is well-known that racism is encoded into the social practices and institutions of medicine. Less well-known is that racism is encoded into the material artifacts of medicine. We argue that many medical devices are not merely biased, but materialize oppression. An oppressive device exhibits a harmful bias that reflects and perpetuates unjust power relations. Using pulse oximeters and spirometers as case studies, we show how medical devices can materialize oppression along various axes of social difference, including race, gender, class, and ability. Our account uses political philosophy and cognitive science to give a theoretical basis for understanding materialized oppression, explaining how artifacts encode and carry oppressive ideas from the past to the present and future. Oppressive medical devices present a moral aggregation problem. To remedy this problem, we suggest redundantly layered solutions that are coordinated to disrupt reciprocal causal connections between the attitudes, practices, and artifacts of oppressive systems.

A long overdue reckoning with racism is beginning to take hold in medicine and in bioethics (Danis, Wilson, & White 2016; Myser 2003; Ray 2021; Russell 2016). It is now well-known that racism is encoded into the social practices and institutions of medicine (Hammonds & Reverby 2019; Mithani, Cooper, & Boyd 2021; Roberts 2011; Sabatello et al. 2020; Wispelwey & Morse 2021; Yearby 2021). By contrast, it is not as well-known that racism is also encoded into the material artifacts of medicine. We argue that many medical tools and technologies are not merely biased, but materialize oppression. A merely biased device gives results that are inaccurate under some conditions. A device that materializes oppression—or, for short, an oppressive device—is not only biased but harmfully so, and its harmful bias reflects and perpetuates unjust power relations. By centering oppression rather than bias, we reveal the contribution that these medical tools and technologies make to the "ordinariness of racism" and, indeed, the ordinariness of oppression (Ford & Airhihenbuwa 2010).

We start with two medical devices that loom large in the midst of a respiratory pandemic: the pulse oximeter (Moran-Thomas 2020, 2021) and the spirometer (Braun 2014, 2015, 2021). Their similar biographies reveal a pattern: due to the psychological and social undercurrents of oppression in the eras in which the

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devices are developed, social differences are essentialized into biological differences; this biologically essentialized difference underwrites a bias encoded into the device that takes bodies of people in the dominant group to be the norm, and bodies of people in subordinated groups as deviations; and the bias, now covertly naturalized in the device, comes to influence new psychological and social expressions of oppression. However, the two biographies differ in one crucial respect: while the pulse oximeter is biased because it does not deliberately account for race, the spirometer is biased because it deliberately accounts for race. The juxtaposition of these two devices thus reveals the complexity of the problem with materialized oppression in medical tools and technologies. We further expand the scope of our investigation by cataloging a broad range of other medical devices that materialize oppression, and articulate some dimensions on which they vary: axes of social difference, context of use, and epistemological accessibility.

We then construct a theoretical account of how oppression can be materialized in medical devices, borrowing ideas from political philosophy and cognitive science.

From political philosophy, we borrow an account of oppression without oppressors. Oppressed groups are systematically inhibited in their ability to develop and exercise their capacities, due to unequal power relations. Oppression is concretely realized in the world: in institutions, laws, economies, schools, prisons, geographies, health care systems, and—we argue—in the material artifacts of medicine. Medical tools and technologies can *materialize* oppression, meaning they can reflect past oppression, do the work of oppression in the present day, and carry oppression into the future. They don't do this all by themselves, but insofar as they are embedded in systems that involve attitudes, practices, and other artifacts. That is, they don't do this necessarily or intrinsically or inherently, but *contingently*, to the degree that they are embedded in such a system in a specific socio-historical context. On our account, materialized oppression does not require discriminatory attitudes on the part of device designers or users, though similarly biased attitudes and practices are often inputs and outputs of oppressive medical devices.

From cognitive science, we borrow an account of our minds as embodied and embedded in the world. We think and act not only with our brains, but also our bodies, other minds, and—crucially—objects and spaces that constitute our environment, including tools and technologies. This is how medical devices, even as they do not have minds of their own, can do the work of oppression: by encoding or inscribing biased attitudes, practices, or data from the past, and carrying them into the future. Because we think *with* material artifacts, and use them to coordinate and cooperate with other minds, they can be said to shape our own cognition, even without our noticing or intending. We emphasize that some medical tools and technologies have a particularly insidious influence on our attitudes and practices because they produce quantitative data that carries the weight of objectivity.

We conclude by arguing for countering oppression instead of debiasing. Medical tools and technologies that materialize oppression pose moral aggregation problems, in which individual actions that are harmless in isolation can interact in a system to generate significant harms in the aggregate (Hutchison 2019). In response,

we suggest an aggregated solutions approach, in which solutions are layered redundantly and coordinated to disrupt the reciprocal causal connections between attitudes, practices, and artifacts that together constitute an oppressive system.

1. Biases in Medical Tools and Technologies

1.1. Pulse Oximeters

A fingertip pulse oximeter is a device that measures oxygen saturation in the blood. Modern pulse oximeters pass two kinds of light through the fingertip and measure oxygen in the blood based on the patterns of reflection and absorption of that light, after accounting for the pulsations of the heartbeat. Healthy humans normally have an oxygen saturation level between 95% and 100%; below 90%, the person likely needs supplemental oxygen. Although arterial oxygen levels can be measured by sampling the blood directly, pulse oximeters are now widely used in hospitals and other clinical settings because they are easy, expedient, noninvasive, inexpensive, and remarkably effective. When introduced, use of these devices reduced anesthesia-related deaths by 90% (Severinghaus 2007).

The general interest in measuring hypoxia dates at least to the 1800s, when adventurers needed protection from dying on hot air balloon trips; later it was pilots, mountain climbers, astronauts, and divers most at risk. As anthropologist Amy Moran-Thomas (2020) puts it, "oximetry's origins came from the sciences of safety for white flight". The specific use of light-based technology—*spectrophotometry*—to measure oxygen levels dates back at least to a device invented in 1939 in Germany that clipped to the ear (Chatburn 2004; Severinghaus 2007). In the 1960's and 1970's, Hewlett-Packard marketed an ear oximeter that was intentionally designed to fit a wide variety of users, to be accurate in a variety of skin tones, to work even when patients are very sick, and to allow individualized calibration by testing a drop of the patient's blood (Moran-Thomas 2021). When Hewlett-Packard made the corporate decision to move out of medical devices, the ear oximeter fell out of favor and was ultimately replaced by a less cumbersome fingertip device invented in the 1970's by Japanese engineer Takuo Aoyagi. It entered widespread clinical use in the 1980s (Witt 2014).

Not long after the fingertip devices gained traction in the market, laboratory studies began showing these devices were less accurate in darker-skinned people on average, systematically *overestimating* their oxygen saturation levels. The inaccuracy varies in different device models, and is greater at lower saturation levels, that is, when the patient is sicker. The degree of the bias varies proportionately with skin tone, with the darkest skin tones getting the least accurate results (Bickler, Feiner, & Severinghaus, 2005; Cecil et al. 1988; Feiner, Severinghaus, & Bickler 2007; Moran-Thomas 2020). While the fingertip device has many advantages over the bulky ear oximeter, and while the racial bias here is more likely the product of *inattention* than *intention*, it is remarkable that despite all the technological innovations that have taken place in the meantime, many of the devices in use today are more biased than a technology that was available fifty years ago. Over-the-counter wireless fingertip

oximeters became widely available to consumers in recent years, but users may not realize that these models are not regulated by the FDA the way the devices in clinics and hospitals are.

Once the racial bias is built into devices like pulse oximeters, it shapes our attitudes and practices through mundane interactions. Although laboratory studies uncovered the bias in the 1980's, its real-world significance was not recognized until Moran-Thomas (2020) brought the question to a wider audience in the middle of the COVID-19 pandemic (Rabin 2020). Researchers then confirmed the clinical significance of the racial bias using records of thousands of patients taken both during and before the pandemic. They compared pulse oximetry readings to arterial blood gas levels taken within ten minutes of each other, and found that oximeters were missing hypoxia three times as often in Black patients as white. They concluded that "reliance on pulse oximetry to triage patients and adjust supplemental oxygen levels may place Black patients at increased risk for hypoxemia" (Sjoding et al. 2020: 2478).

Pulse oximeters are widely used in critical care, but also now in home triage for COVID-19 patients, who may be told to go to the hospital if their device shows readings below 92% (Moran-Thomas 2020). With widespread use, even a small and probabilistic racial bias has significant implications for decisions by patients, clinicians, hospitals, and insurance companies. Indeed, COVID-19 is a disease marked by racism: in the U.S. alone, Black, Hispanic, and Asian patients are more likely to be infected, to be hospitalized, and to die, than white patients (Lopez et al. 2021). But far from an exception, the pandemic merely illustrates the rules that have long been in place. By encoding past oppressive conditions, under which whiteness is the norm and non-whiteness a deviation, pulse oximeters carry bias from the past to the present day, where it is apt to compound and interact with other oppressive conditions that nonwhite people face now.[1]

1.2. Spirometers

A spirometer is a device that measures lung functioning. The patient blows into a tube and the machine measures the total volume of air exhaled after a full inspiration as well as the volume exhaled in one second. Physicians use the device to evaluate patients for abnormal lung functioning, so modern spirometers are computerized devices that not only report the absolute numerical values but also

[1] Indeed, the racial bias built into pulse oximeters should not be that surprising, because it mirrors the biases found in other light-based devices outside of medicine, notably in photography (Dyer 1997; Roth 2009). Although it is becoming more widely known that some smartphones and digital cameras do a poor job photographing darker skin tones, it is less well known that even prior to digital photography, the chemical film emulsions and printing technologies used in still photography and in movie-making were systematically less good at depicting darker skin tones due to the usage of white reference models in the calibration processes. Both photography and light-based fingertip oximeters are examples where skin tone biases are encoded in technologies, and both can be traced to calibration decisions using whiteness as a norm. We think it is important to emphasize that oximetry manifests the same bias as many other light-based devices from everyday life that employ technically distinct underlying technologies—not only analog and digital cameras, but also automatic soap dispensers and night vision cameras—because it shows that the bias built into pulse oximeters is not intrinsic to the specific technology, but contingently congruent with oppression.

norm the results relative to historical population averages, via correction factors or population-specific standards (Braun 2021). The patient's results are thus reported as a percentage of the predicted normal result for someone their age, sex, height, and race/ethnicity.

As with any measurement device or diagnostic test, questions about norming arise. On average, lung capacity is lower in female patients than male patients, in Black patients than white patients, in shorter patients than tall patients, and in older patients than young ones. The logic of comparing like to like suggests the use of an algorithm that compares results to subpopulation averages rather than to the entire population. So, in the US, spirometers use correction factors of 10–15% for people racialized as Black and 4–6% for people racialized as Asian, while leaving white patient's results untouched (Braun 2015).

But given that group norms may reflect social or environmental factors rather than essential differences, and given heterogeneity within the respective groups, this means that spirometers risk contributing to underdiagnosing abnormal lung functioning in a patient racialized as Black or Asian, whose results may be deemed "normal" relative to the group's lower expected results on average, even while they are in fact sick. Moreover, there is no evidence that the race-specific predictions correlate better with the patient's actual prognosis, and some evidence that they are worse (Gaffney, Woolhandler, & Himmelstein 2020). And yet, these adjustments are routinely automatically applied. As recently as 2014, historian Lundy Braun found medical clinics using multiple machines with different standards, operators and physicians who did not know what reference values their machines used or how they were race-normed, and the use of "eye-balling" to identify a patient's race (Braun 2014: xviii, 195). In this respect, as is the case with pulse oximeters, racial bias is built into spirometers.

However, spirometers come from a longer and more deeply explored history than oximeters. The modern computerized devices inherit baggage from their primitive counterparts that were designed, calibrated, and popularized in the 19th and early 20th century. While not invented in order to further any particular racist goal, they were gradually shaped by racist undercurrents in society, and in turn began to shape these undercurrents. Seemingly innocuous stakeholders—like life insurance companies, governments adjudicating compensation claims for coal miners' lung injuries, and physical education teachers at (mostly white) elite American liberal arts colleges—had a hand in bringing this machine into broad use (Braun 2014). In particular, the common assumption of racial essentialism recurs throughout this complicated history, and manifests in two crucial respects.

First, race correction in spirometry was initially based on questionable data, then carried over from one era and industry to the next, until it was simply accepted as fact. Initially, spirometers were calibrated on white test subjects. When used to measure the lung capacity of Black patients, these devices gave lower values on average. Against the backdrop of presumed white racial superiority, including the specific 18th century myth that Blacks have weaker lungs (Braun 2014, 27), this difference in results actually made spirometers seem credible rather than flawed. And in turn, spirometers lent their epistemic credibility to the burgeoning field of

scientific racism. For example, the physician and "leading pro-slavery theorist" Samuel Cartwright (1793–1863) used them to gather evidence of racial differences, and used the differences to rationalize slavery (Braun 2014, 29). As Braun writes, "Cartwright described racial differences in the respiratory system and their implications for labor. According to Cartwright, if left free, the lungs of blacks cannot 'vitalize the blood.' Incompletely vitalized blood was a racial characteristic that produced 'lack of vitality,' cured only by forced labor" (Braun 2014, 28).

Second, spirometry essentialized social differences into innate biological differences. Historically, efforts to demonstrate racial differences in spirometric results failed to define racial groups in consistent ways and to account for the confounding effects of environmental and social forces (Braun 2014). Even in the present day, adjustment practices ignore diverse possible sources of observed racial differences in lung capacity and treat them as rooted in genetic differences, despite the fact that "there is no known major genetic locus that varies by race that can explain racial disparities in lung function" (Anderson et al. 2021, 124–125). The crude American Black/white racial dichotomy looms large in the history of the spirometer, and it was data from Black and white American asbestos workers that led to the proposal, in 1974, of the first blanket correction factor of 13.2% for Black patients relative to a white norm (Braun 2014, 164).

But the pressure to essentialize differences was so strong that even small subgroups of the "white/European" racial construct were hypothesized to have innate lung differences. For example, when the British Medical Research Council's Pneumoconiosis Research Unit (PRU) was established to help adjudicate workers' compensation claims in coal miners in South Wales, it produced a report that suggested the Welsh comprised "a separate racial group" and proposed that Welsh miners' poor spirometry results may be due to a "Welsh racial factor" (McGuire 2020, 162). While PRU researchers eventually dropped this hypothesis and lumped the Welsh in with white/European (Braun 2014, 162), it was clear that the motivation to essentialize group differences in lung functioning came from many corners, not just from America's legacy of anti-Black racism. As Braun put it, research studies sought "innate" explanations, "whether framed as 'racial', genetic, or anthropometric" (162). The advent of workers' compensation programs gave governments and private industry an incentive to find explanations for disease that would not require admitting that coal dust was killing coal miners. The market forces of capitalism and ideology of scientific racism were thus aligned.

Efforts to find racial differences via spirometry, and to introduce racial correction factors to account for them, not only reflected the view that racial and ethnic differences are essentially biological, but also helped perpetuate it.[2] By the late 20th century, racial correction was built into the machines used in many medical

[2] Whether there is anything biological about racial categories used in medicine is complicated and contested (Maglo 2010, 2011; Valles 2017). Part of this complexity is the distinction between the non-essentialized claim that race has biological reality with the essentialized claim that race has genetic reality. Racial discrimination can cause physiological changes in the body, and so the social reality of race can *create* biological reality of race without genetic reality—and even independent of socioeconomic status (Kaplan 2010; Roberts 2011). Our claim is that efforts to infer essentialized biological differences, such as genetic differences, from group differences in spirometry were unjustified.

clinics. Surely, a user might assume, this correction would not be built into this sophisticated machine if it were not based on sound evidence and reflective of some underlying reality? This is how, as Braun puts it, correction factors in spirometry are both "rooted in and enact hierarchic difference" (Braun 2021, 1673; our emphasis).

As is the case with oximetry, there have been numerous attempts to address the racial bias problem of spirometry. Yet, given that technological developments often default to carrying forward assumptions from the past to the present, these interventions tend to be partial, local, and temporary; and so they tend to merely refract the problematic lights at new angles. For example, in response to the reference values normed on white people, Chinese scientists sought to develop "ethnic reference values" for Chinese people. Yet these reference values center the politically dominant Han majority as the norm: although the study explicitly excluded non-Han subjects, the scientists nevertheless claim that "Han can be considered as a representative of Chinese" (Jian et al. 2017: 4544). As such, these reference values not only ignore the heterogeneity of people ethnicized as Chinese, they also ignore the sociohistorical construction of Chineseness and, indeed, the sociohistorical construction of "Han" as an ethnic category (Chun 1996; Dikotter 1992; Mullaney et al. 2012). Even if these reference values constitute a warranted intervention against one hierarchical difference found in spirometers, they are still rooted in and enact another hierarchical difference in the same devices.

Like pulse oximeters, spirometers exist alongside other racial disparities in medicine. The COVID-19 pandemic, once again, brings these disparities into sharp relief. Just as oximeters are used to triage patients to a higher level of care, spirometers are sometimes used to measure pulmonary function during their recovery. And it has been speculated that the racial bias built into spirometers could exacerbate racial differences in recovery (Anderson et al. 2021). Spirometers, too, encode biases from the past, carry them to the present, and leave them to interact with the oppressive conditions of a new era.

1.3. Other Examples and Variations

Biased medical tools and technologies can vary by their *axis of social difference*: while we have focused on racial biases, there are also biases along the axes of gender, class, and ability. For example, Katrina Hutchison (2019) tells the story of how articular surface replacement (ASR) hip implants reveal and recapitulate gender biases in patient care. They cause more harm to women patients because men were the norm in their design. The harm does not come from the ill-will of designers, but from the aggregation of decisions from product development and testing through regulatory approval and real-world use. Gender biases can also be found in the male-dominated field of surgery, where women surgeons disproportionately report pain and disability from instruments that don't fit their hands (Sutton et al. 2014). And although women are heavily overrepresented in nursing, and nurses spend the most contact hours with patients, much safety equipment seems still to be designed mainly for men (Criado-Perez 2019). For example, women (and Asian) healthcare

workers are less likely to pass a fit test with the most readily available N95 masks (Lin & Chen 2017; Regli, Sommerfield, & von Ungern-Sternberg 2021).

It is because medical tools and technologies tend to take the *bodies* of politically dominant groups as the norm, and others as deviations, that the same devices can be multiply biased along different axes of social difference. Fingertip pulse oximeters are not only racially biased, but also—at least compared to Hewlett-Packard's ear oximeter—gender and ability biased due to concerns about device fit (Moran-Thomas 2021). Spirometry reference values have not only been racially biased, but also class biased: early spirometry researchers fixated on cataloguing the inferiorities of working-class bodies; over-sampled athletic middle-class college students; and used spirometry to deny disability compensation for coal miners (Braun 2014; McGuire 2020). Moreover, by centering the bodies of politically dominant groups, the standardization of medical devices also contributed to the *construction* of the politically subordinated categories of disabled people and transgender people from bodies that do not conform to the inbuilt standards (Amundson 1992; Spade 2006).

Biased medical tools and technologies can also vary by their *context of use*: from patient-facing to clinician-facing, and from diagnosis to treatment. As mentioned, PPE and surgical instruments are primarily designed for clinicians. These biases take on additional social meaning in the context of the internal social hierarchies of medicine. Women, racial and ethnic minorities, and immigrants have historically been underrepresented in certain clinician roles and specialties (U.S. Department of Health and Human Services 2017). When tools and technologies make it harder for people from historically marginalized groups to do their jobs, it could be one factor (among many) hampering the recruitment and retention of clinicians from these groups. In turn, this will indirectly affect the medical care received by their patients, especially those from marginalized groups (Alsan, Garrick, & Graziani 2018; LaVeist, Nuru-Jeter, & Jones 2003).

Some tools and technologies occupy an in-between status insofar as they are primarily used by clinicians but primarily affect patients, including many diagnostic tests. Like the spirometer, the eGFR blood test, which is a measure of kidney functioning that plays a role in who gets listed for a kidney transplant, typically includes a race correction factor that might be causing an underestimation of how sick Black patients are (Ahmed et al. 2021; Roberts 2021). Indeed, race correction factors are employed in clinical algorithms across medicine: in cardiology, endocrinology, oncology, urology, and more (Vyas et al. 2020). However, as in pulse oximeters, racial biases can also arise from the absence of race-norming. One risk-assessment algorithm that uses expected healthcare cost as a proxy for risk, which is used by clinicians to decide who is enrolled into "high-risk care management" programs, can underpredict the health risks of Black patients (Obermeyer et al. 2019; Benjamin 2019). Dermatological photos used by clinicians to help identify the discoloration known as "COVID toes" were primarily of white people's feet despite the pandemic disproportionately affecting nonwhite patients (Evans et al. 2020). Finally, some have argued that tools and technologies used by clinicians in assisted reproduction, such as artificial insemination and IVF, reflect and perpetuate racist

ideologies (Russell 2018) as well as heteronormative assumptions or values (Roth 2017; Roth & Murphy 2017).

And then there are tools and technologies that are primarily used by patients and primarily affect patients. Cardiac devices (Dhruva & Redberg 2012) and tissue repair meshes (Menchen, Wein, & Smith 2012) display gender biases similar to ASR hip implants'. Fitness trackers that use light-based technologies, unsurprisingly, exhibit racial biases similar to pulse oximeters' (Shcherbina et al. 2017). When corporate wellness programs incentivize the use of fitness trackers by employees, these devices recapitulate the way spirometers were used to validate miners' claims to disability compensation, except in reverse. Drugs can also materialize biases: the controversy over BiDil, a prescription drug specifically marketed to Black patients with heart failure, illustrates the costs—and, some might argue, benefits—of racialized medicine (Kahn 2012; Roberts 2011).

Finally, biased medical tools and technologies can vary by what we will call their *epistemological accessibility*: that is, whether their bias is more overt or more covert. This dimension of variation somewhat tracks the absence vs. presence of race-norming. More covertly, for example, a risk assessment algorithm that explicitly excludes race as a factor can still build in a racial bias, but that racial bias is not discoverable without an audit of its real-world application (Obermeyer et al. 2019). By contrast, more overtly, eGFR blood test results are delivered with race-norming explicitly marked, and so the bias is readily accessible—even if the downstream harms of that bias require further investigations to uncover and evaluate. What's more, whether a bias is overt or covert may vary from user to user depending on their social location. Racism, for example, comes with its own *epistemology of ignorance* that prevents members of the politically dominant group from fully understanding its operation (Mills 1997).

We have cast a broad net and briefly cataloged a wide variety of examples not because we think all these tools and technologies materialize oppression in exactly the same way or to the same degree, but rather to show that this is a widespread phenomenon that can be missed by focusing only on one case at a time. In what follows we give a general account that explains the difference between mere bias and oppression, and shows how oppression can be realized, contingently, in particular material artifacts.

2. Materialized Oppression and Embedded Cognition

The biographies of oximeters and spirometers represent a story archetype: through psychological inattention (and sometimes intention) and social ideology, social differences are essentialized into genetic differences; this essentialized difference underwrites a bias built into medical tools and technologies that treats the dominant group as the norm and the subordinated groups as deviations; and the devices naturalize this bias and covertly shape attitudes and practices in ways that tend to perpetuate, or even exacerbate, historical and ongoing injustices. There are also, as mentioned, as many variations on this story archetype as there are biased tools and technologies in the history of medicine. Drawing on extant research on

oppression and on cognition, we can construct a theoretical account that explains and contextualizes these stories of biased medical tools and technologies. A crucial upshot of this theoretical account is that these medical devices are not merely biased, but properly oppressive: they don't simply reflect or reveal oppression of the past and the present, they also perpetuate it in the present and in the future.

2.1. Oppression and Materiality

Oppression is fundamentally a *structural* concept (Frye 1983). It involves unequal power relations between groups, and systemic constraints that those power relations impose: "in the most general sense, all oppressed people suffer some inhibition of their ability to develop and exercise their capacities and express their needs, thoughts, and feelings" (Young 1990: 40). Oppression in this structural sense does not require a specific oppressor. And it may persist even in the absence of consciously discriminatory attitudes or intentionally discriminatory behaviors. Moreover, different groups can be oppressed in different ways. Iris Marion Young (1990) names exploitation, marginalization, powerlessness, cultural imperialism, and violence as five faces of oppression, each of which can interact with one another to constrain different individuals' lives in different ways. In this respect, oppression is also fundamentally *interlocking* (Combahee River Collective 1977/2017). Individuals can be oppressed differently depending on their group memberships, and the products of different faces of oppression are not just their sums. While it can be convenient to focus on specific axes of oppression—racializing, gendering, etc.—this lens necessarily blurs a more complicated picture outside of the focal axis.

Mere bias, by contrast, exists independently of such structures. In the minimal sense, a bias simply refers to the statistical relationship between a process and an outcome, as compared to a reference class (Antony 1993, 2016; Johnson 2020). For example, a coin is biased insofar as flipping it tends to produce heads more often than random chance. On this conception, whether a tool or a technology is biased is a matter of how it tends to function in a particular context, and not a matter of any intentional design (Dennett 1990).

It is easy to see how a device can be biased, but harder to see how it can be oppressive. Indeed, there exist many tools and technologies that do encode biases but do not materialize oppression. For example, while the most common electric chainsaw might be biased against left-handedness, such that left-handed people are more likely to get injured while using it, it does not standardly materialize oppression. And the reason is that, at least in most contemporary Western industrialized societies, left-handed people are not, as a group, oppressed: they are not inhibited in their ability to develop and exercise their capacities and express their needs, thoughts, and feelings. A biased tool or technology therefore only materializes oppression in a specific contingent sociohistorical context, where there is congruence between bias and oppression. Whether a chainsaw or any other object is oppressive may be a matter of degree, and may change over time as a group becomes more or less oppressed, or as the object becomes more or less causally embedded in the respective axis of oppression.

On this picture, pulse oximeters and spirometers materialize oppression in our current context because they encode biases that are *congruent with oppression*, in the sense that these biases are (Liao & Huebner 2021):

> (1) *in the same direction* as the respective axis of oppression; and
> (2) *causally connected to* other facets of the respective axis of oppression, meaning both
> (a) downstream consequences of similarly biased attitudes or practices in the past, and
> (b) upstream antecedents of similarly biased attitudes or practices in the future.

By juxtaposing these two devices that encode racial biases in very different ways, we can avoid seeking merely technical rationalizations of how their biases came to be, and merely technical solutions to fix them. Instead, any adequate explanation and solution must attend to the contingent sociohistorical context, and how these devices are not only connected to oppression of the past and the present, but also to attitudes and practices.

Contrast our account with Achuta Kadambi's (2021) division of biases in medical devices into three broad categories: *physical bias*, which comes from "physical principles"; *computational bias*, which comes from algorithms or datasets; and *interpretation bias*, which comes from substantive inferences. On Kadambi's taxonomy, pulse oximeters and spirometers present fundamentally different problems that call for fundamentally different solutions because the oximeter's bias is physical but the spirometer's bias is computational and interpretative. Our account focuses not on the technical biases themselves, but the devices' contingent congruence with oppression.

Remember that pulse oximeters tend to overestimate the oxygen saturation level of people with darker, rather than lighter, pigmented skins. That pulse oximeters' light sensors work this way—their "physical principle", as Kadambi puts it—is arbitrary; it could have been otherwise, and one can imagine tools and technologies that err with lighter, rather than darker, pigmented skins, and that disproportionately help rather than harm an oppressed group. Indeed, it is important to our account that the device's materialization of oppression is not necessary or intrinsic or inherent in the device; it is *contingent*. While the physical principle and the direction in which it errs is arbitrary, the congruence with oppression is not. From the structural perspective, it is *not* arbitrary that pulse oximeters work this way; it is due to the racist socio-historical context that their bias was not immediately discovered, corrected for, or selected out by market forces. Testing devices primarily on subjects racialized as white, because of their lighter pigmented skins, is not arbitrary. Ignoring studies that show a problem with patients racialized as nonwhite is not arbitrary. Assuming that norms of clinician judgment and clinical practice can counteract the effects of a biased device—rather than ringing alarm bells and immediately designing corrective measures—is also not arbitrary.

Remember also that spirometers risk underdiagnosing abnormal lung functioning in a patient racialized as Black or Asian. Spirometers differ from pulse oximeters insofar as their biases come not from physics, but from race-norming in

computation and interpretation. However, the two devices trace their biases to the same context in which race is essentialized, reified, and hierarchically ordered, with whiteness the norm and nonwhiteness the deviation. Again, it is *not* arbitrary that race corrections in spirometers are in the direction that risks underdiagnosis of people in politically subordinated racial groups (Gaffney 2020). Background conditions of oppressive attitudes and practices make it harder to detect, prevent, and remedy this contingent materialization of oppression: "By using these lung function algorithms, are we blinding ourselves (and society) to the health harms of structural racism, effectively normalizing lung damage that Black Americans suffer from dirtier air, dirtier jobs, and substandard medical care?" (Gaffney, Woolhandler, & Himmelstein 2020).

By looking carefully at the social history of the spirometer, including its use in rationalizing racial hierarchies and denying compensation for work-related lung injuries, we can see how ideologies and market incentives led to a race-correction scheme that errs in the direction of *under*-diagnosis. However, in different contexts, devices and algorithms can also materialize oppression in ways that lead rather to *over*-diagnosis, resulting in potentially harmful over-treatment and the pathologization of normal bodies. Both under- and over-treatment can be manifestations of oppression. Debiasing efforts can therefore have unintended consequences if correction becomes over-correction.

From a bias-centric perspective, it can seem coincidental that medical tools and technologies tend to be multiply biased along different axes of social difference. For example, pulse oximeters are not only racially biased but also gender and ability biased (Moran-Thomas 2021), and spirometers are not only racially biased but also class biased (McGuire 2020). Even if each bias can be addressed with its own technical solution in isolation, there seems to be nothing in common between them. By contrast, from an oppression-centric perspective, it is no accident that medical tools and technologies tend to be multiply biased. Oppression, as mentioned, is interlocking. And so the biases must be addressed together with structural solutions because what they have in common is their congruence with oppression.

We are emphasizing the fact that oppression is never only social, but always material too. As Young puts this point: "The accumulated effects of past actions and decisions have left their mark on the physical world, opening some possibilities for present and future action and foreclosing others, or at least making them difficult" (Young 2011, 53). Parts of the material world—not only tools and technologies, but also spaces and surroundings—put up barriers to oppressed people's ability to develop and exercise their capacities and express their needs, thoughts, and feelings. The social and the material dynamically interact with each other, and mutually depend upon one another. Or, as Langdon Winner puts it, artifacts themselves can have political properties: "Rather than insist that we immediately reduce everything to the interplay of social forces", we should "pay attention to the characteristics of technical objects and the meaning of those characteristics [...] as political phenomena in their own right" (Winner 1980: 123). The structure of oppression consists of an environment that individuals navigate in their lives: a *world* that is inseparably social and material. This interdependence has both benevolent and

malevolent faces—as Young puts it, opening and foreclosing opportunities, enabling and constraining us.

2.2. Materiality and Cognition

Oppression can coalesce in the material world, we have argued. In turn, the material world can shape individuals' cognition—the way they think and act. As John Haugeland puts this point, "Mind, therefore, is not incidentally but *intimately* embodied and *intimately* embedded in its world." (Haugeland 1995/1998, 237). The central thought behind the research programs of embodied and embedded cognition in cognitive science is that the way people think and act is not merely the product of their brain, but the product of brain-body-world interactions. Humans use their world to minimize demands on cognition. As Andy Clark puts this point, "We use intelligence to structure our environment so that we can succeed with *less* intelligence." (Clark 1997, 180). As such, constraints in the social and material environment shape patterns of thought and action, including decision-making, value-judgment, and counterfactual-reasoning (Liao & Huebner 2021). So it is no surprise that when the world is oppressive, the patterns of thought and action engendered are also oppressive. In this respect, medical devices that materialize oppression do not merely reflect inequalities in the past, but also perpetuate inequalities for the future.

Our theoretical account combines two insights: materiality matters for oppression, and materiality matters for cognition. There are reciprocal causal connections between attitudes, practices, and—we argue—tools and technologies (Liao & Huebner 2021). The material is not merely the output of the psychological and the social, but an input to them as well (Heersmink in press). The history of spirometers vividly illustrates the role of the material device in the vicious cycle (Braun 2014). First, ideas of biological essentialism and racial hierarchy were part of the background beliefs in the era in which the device was developed. Second, well-intentioned users deployed the seemingly-neutral device in ways that seemed to confirm these background beliefs. Third, these background beliefs were lent credibility, and further entrenched, by the device's results. Fourth, well-intentioned users introduced adjustments or corrections to maintain the device's neutrality and account for group differences, but relied on shoddy datasets corrupted by the original problematic background beliefs. Fifth, the new adjusted device was adopted thoughtlessly, because it minimized demands on cognition, or co-opted by ill-intentioned ideologues. Sixth, with use of the device now widespread, the background beliefs were further reinforced; that is, race was reified. Seventh, use of the device with its inbuilt race corrections or race-normed reference ranges became further embedded in research, clinical, and legal practices. Finally, attempts to improve or remediate the device or its use were stymied by widespread adoption of reified notions of race, or by the desire to avoid unintended consequences. Once a tool or device is socially embedded, it is impossible simply to debias it without generating new harms, as can be seen in current efforts to remove race correction

from kidney function testing (Ahmed et al. 2021; Ionnidis, Powe, & Yancy 2021; Powe 2020).

As this vicious cycle makes clear, materialized oppression is dangerous because it often recedes into the background. The constraints imposed by these tools and technologies are often hidden from their users. Even when they are noticed, they can feel "objective" as part of the world that people passively experience (Young 2011). While oppression can be inscribed into almost any tool or technology, the results are especially insidious in the medical realm because these devices are thought to be a source of precise and objective data that is superior to human observation, guesswork, and bias. The medical device is granted a kind of epistemic privilege that protects it from critique and supercharges its role in the above vicious cycle. This is especially true for devices and algorithms that produce quantitative information; numbers are useful, but they give an (often false) air of precision that is presumed objective. The objectivity of numbers can then be used to rationalize rejecting insurance claims, or even to rationalize social hierarchies, all while freeing human agents from culpability or accountability for the results. Braun shows how the development of the spirometer aligned with trends toward precision and quantification in science, medical practice, and society more generally. The machine itself co-evolved with these trends. As she notes, "racialization of spirometric measurements became *embedded invisibly* into the interpretive framework of the instrument over time" (2021: 1671, our emphasis).

Medical tools and devices that materialize oppression therefore entrench patterns of thought and action at both the level of individual minds and at the level of social practices. Psychologically, these devices offer intrapersonal stability across time. An individual can come to rely on these devices because they are guaranteed to deliver a measurement without the need for constant recalibration or deliberative cognition (Nguyen in press; Smith 2018; Sterelny 2010). In turn, socially, these devices offer interpersonal stability across agents. Multiple agents can use the same device because it is guaranteed to deliver a measurement that can be compared to others, again without recalibration or deliberation. These tools and technologies exist to solve coordination problems between multiple agents, and between our multiple selves across time. That's what makes them indispensable, but that's also what makes the biases that they encode reverberate throughout diagnoses and policies.

On our account, medical tools and technologies that are harmfully biased become oppressive when they are congruent with oppression—that is, when they function in a *system* of mutual dependence and dynamic interaction with similarly biased attitudes, practices, and other artifacts. So we cannot hope to understand the oppressive work that a device does without thinking of it as the focal point of a system under analysis. More accurately, when we talk about spirometers, pulse oximeters, etc., we are really talking about a spirometry *system*, an oximetry *system*, etc., that includes medical professionals and patients, medical institutions and policies, and the medical tools and technologies themselves. As the biographies of pulse oximeters and spirometers show, the biases of these devices produce racial health disparities *in conjunction with* specific psychological processes that employ

them in decision-making, and specific social structures that employ them in offering or withholding treatment. We thus follow Alex Schafran, Matthew Noah Smith and Stephen Hall who propose "thinking like a system" when it comes to analyzing parts of the physical world that enable or constrain human agency (2020; cf. Smith 2018). As we emphasized earlier, these reciprocal causal connections between psychological, social, and material manifestations of oppression are contingent. However, the system is oppressive to the extent that its different elements perpetuate unjust power relations in the same direction, and each component is oppressive to the extent that it is causally embedded in the system.

System thinking also explains why we are ultimately skeptical of Kadambi's (2021) division of biases into physical, computational, and interpretive. In the science of measurement—as Hasok Chang's (2004) historical and philosophical study of the co-invention of temperature and thermometer shows—it is impossible to neatly disentangle these different levels of analyses. Pulse oximeters are biased not only because of the physics of light reflection, but also because of the *absence* of race correction in underlying computation and because of the way that their results are used in clinician and patient decision-making. Conversely, spirometers are biased not only because of the interpretation of their results, but also because of the *presence* of race correction in computation and because of the physical implementation of the algorithm in the devices (compare Blanchette 2011); while the settings are in principle adjustable, they are in practice as difficult to change as any other physical component of the machine.

3. Aggregation Problems and Aggregated Solutions

Our account emphasizes the importance of structures and systems. Instead of technical problems of bias, we must turn to structural problems of oppression, which demand systems thinking. In ethics, systems thinking leads us to address *moral aggregation problems*, in which "small and often separately harmless actions by individuals and/or groups in different parts of a system interact to give rise to a new harm that is more than the sum of its parts" (Hutchison 2019, 577).[3] We propose an *aggregated solutions approach* in response: solutions that are individually insufficient in isolation can still generate protection against harms in the aggregate, if their aggregation is coordinated to disrupt reciprocal causal connections between attitudes, practices, and artifacts within oppressive systems. To be clear, we are not claiming that devices like pulse oximeters are one of the *main* drivers of health disparities, nor that addressing oppressive tools and technologies should be at the top of the list of priorities for anyone working toward health justice. However, because these tools and technologies are embedded in broader systems, the solutions

[3] Many of Hutchison's examples of moral aggregation problems draw from the broader *collective action problems* literature, such as tragedy of the commons. There are two important differences between these two concepts as we understand them. First, moral aggregation problems are explicitly concerned with morality, while collective action problems are, at their core, concerned with decision and cooperation. Second, while moral aggregation problems share with collective action problems features of expediency and invisibility, they also explicitly include structural factors beyond agent preferences.

we recommend will both depend on and be complementary to other systematic health care reforms more generally.

3.1. Moral Aggregation Problems

Katrina Hutchison (2019) not only argues that the gender bias in ASR hip implants is an instance of a moral aggregation problem, but also identifies features that moral aggregation problems tend to share: *invisibility, expediency, and structural factors*. Awareness of these features helps us to discover and diagnose aggregation problems, and can also help guide solutions.

First, *invisibility.* Many of the biases in medical tools and technologies are more covert than overt. It took what Hutchison calls "detective work"—connecting the dots between biased devices and their psychological and social antecedents and consequents––to make transparent the opaque causal histories of spirometers, pulse oximeters, and ASR hip implants. Oppressive artifacts may be more invisible *because* they are oppressive: they hide in a world where oppressive patterns are ubiquitous and therefore unremarkable.

Second, *expediency*. Small incentives, rationalizations, habits, and norms encourage individual actors to make decisions that, while typically not very harmful on their own, can contribute to aggregative harms. Healthcare is a scarce resource, so expediency considerations operate in the background. It is expedient for a clinician to use the spirometer on its default settings, which automatically apply race-norming adjustments. Similarly, clinical utility and market pressures often favor ease of use over accuracy; thus cheap, fast, convenient, and generic fingertip oximeters are ubiquitous, while Hewlett-Packard's more accurate and individually-calibrated ear oximeter is a mere museum relic. The more a device can help us to succeed with less intelligence, the more likely we are to leave it in place.

Finally, *structural* factors. These include social structures, political structures, and even geographical factors. No place in the world is quarantined from the market forces of capitalism and ideologies of scientific racism. In the U.S. in particular, the regulatory structure and profit-seeking healthcare industry shape the way tools are designed and used. Different structural factors will be relevant in different cases, but it is impossible to connect the psychological and the material without "thinking like a system".

3.2. Aggregated Solutions Approach

Given the interplay between invisibility, expediency, and structural factors, Hutchison argues that neither top-down nor bottom-up solutions are tenable by themselves. Instead, she advocates for a multi-level approach that combines collectivization (bottom-up), regulations (top-down), and the cooperation of device companies and standards bodies (mid-level). In public health, a similar approach—attacking multiple causal mechanisms at the same time—has been advocated by Camara Jones (2018).

We agree that efforts aimed at any one "level", constituency, or causal mechanism are unlikely to be effective in remediating the problem of oppressive medical devices. We want to take the multi-level strategy even further, and suggest an *aggregated solutions approach* that layers interventions redundantly, analogous to the "Swiss Cheese" model of public health intervention made famous during the COVID-19 pandemic (Reason 1990, 2000). On this metaphor, harms (such as viral spread) are blocked by layered slices of protection (such as masks, social distancing, and vaccines). While every layer of protection has holes, most harms will be blocked as long as protective efforts are layered deeply.

Our proposal is that redundant anti-oppressive interventions be conceptualized and grouped by Hutchison's three pressure points of moral aggregation problems, rather than by the agents or institutions they target. For mitigating the harms caused by *invisibility*, we suggest interventions aimed at increasing transparency. Warning labels on pulse oximeters, for example, would be relatively easy to implement. But like any individual intervention, transparency initiatives alone cannot solve this problem. A patient using a pulse oximeter at home cannot know whether they are among the 10% who will get misleading results (Sjoding et al. 2020), and will face trade-offs between over-caution and under-caution. Thus any warning label initiative needs to be combined with additional, redundant layers of mitigation, including efforts to support transparency in data sets, algorithms, clinical trial design, adverse event reporting, financial conflicts of interest, professional training standards, patient outcomes, etc. (Ford and Airhihembuwa 2010; Knight et al. 2021).

The history of other transparency initiatives should be taken into consideration, to maintain a record of what biases are already known and to avoid repeating past mistakes (Moran-Thomas 2020). FDA transparency requirements for prescription drug advertisements, for example, are a mere band-aid on a practice that likely does more harm than good (Mintzes 2012). Disclosures required by the Consumer Financial Protection Bureau, such as the Closing Disclosure shared with new homebuyers, would be a better model. Or, instead of disclosure at the level of individual patients, device bias audits can be built into accreditation standards, made available to the public, and their availability advertised as part of the Patient Bill of Rights. Loopholes that deem home devices like fingertip oximeters as mere "wellness" or athletic products rather than as medical devices subject to strict accuracy standards, should be closed.

For mitigating the harms caused by *expediency*, we suggest interventions designed to change incentive structures, norms, habits, and even values. To be sure, it's hard to make choices less expedient than they are, or to incentivize doing the just action rather than the expedient one, without changing social norms or institutions more broadly. However, strategies can be borrowed from marketing and public health (such as nudging) and from safety-conscious pursuits like surgery and aviation (such as checklists and time-outs) to change what is expedient. A device's potential to materialize oppression should be treated analogously to its potential to be unsafe—as something to be proactively monitored. To that end, one layer of protection is for regulatory bodies to require stronger evidence that a device does not

introduce or recapitulate problematic biases. Additional redundant layers of protection could include: increased reimbursement for clinician "cognitive work" (as opposed to procedures), to allow clinicians more time for contextualizing and holistically assessing test results; better funding for health infrastructure (such as federally funded health centers) in geographic areas where health disparities are the worst, in order to subsidize the cognitive and relational work required to counteract the potential harms of materialized oppression; a focus on anti-oppressive education, including the history of medicine, for clinicians (Carbonell and Liao 2021; Fausto-Sterling 2016); and better attention to how accountability for structural oppression is a valid component of the *role-based* moral responsibilities of healthcare workers (Zheng 2016, 2018)

For mitigating the harms caused by *structural* factors more generally, broader health care reform and social reform is necessary. While such reforms are beyond the scope of this essay, we think many of the interventions used to address income inequality and racial oppression will also remediate the structural factors contributing to materialized oppression in medical devices. The most important point is that the reforms be *coordinated to disrupt the reciprocal causal connections between the attitudes, practices, and artifacts of oppressive systems*. That means reorienting research and advocacy efforts from group differences to group-based discrimination and hierarchy—that is, from a focus on racial differences to a focus on racism, from sex differences to sexism, etc. Not only does this framing allow solutions to be more accurately targeted at the sources of problems, it also avoids the threat of race reification (Duster 2005; Gould 1996; Hochman 2021; Yearby 2021). Our "aggregated solutions approach" calls for multiple, redundantly layered interventions targeting the invisibility, expediency, and structural dimensions of materialized oppression. Oppression is notoriously resilient. So we should expect that *any* individual intervention may be ineffective in isolation. It is only by coordinating the interventions that we have any hope of extracting the biased medical tools and technologies from the oppressive systems in which they are embedded.

It is reasonable to ask, though, how that coordination will come to fruition. Who shall coordinate? There is no easy answer to this question, but we can offer some preliminary ideas. First, coordination will by necessity take different shapes in different places, because oppression takes different shapes in different places. Likewise, the relevant institutional structures—regulatory bodies, health care delivery systems, consumer protection statutes, education from K-12 through medical training—vary from place to place. In the U.S., for example, it is obvious that a first step is both to better fund the FDA and to reform its processes so that problematic devices do not inherit the flaws of the ancestor devices on which their approval is predicated (Institute of Medicine 2011). But device regulation is only one piece of the puzzle. We have also called for reforms as diverse as increasing physician reimbursement, addressing racial disparities in the social determinants of health, and lessening income inequality. Absent the passing of new federal laws or the creation of new federal agencies, there is no one body or authority who can coordinate reforms across all of these domains.

Instead, we think that some of this coordination work can be done by independent, nonpartisan, non-industry-funded advocacy groups or academic institutes, who can propose standards as well as act as intermediaries between grassroots activists, government bodies, and industry. In the U.K., the Institute of Health Equity is one such group, and their work has recently been cited as a precursor to the Health Secretary's call for a review of systemic racism in medical devices (Vinter 2021). This is a step in the right direction. However, to be clear, our suggestion is not that there ought to be one driving force behind all reform efforts, but rather that a decentralized anti-oppression movement would include multiple nodes working to put pressure on different points of this causally complicated problem, while all working toward an overlapping set of common goals. Further specification and prioritization of those goals is urgently needed. We have merely taken the preliminary steps: pointing out some cases of materialized oppression in medicine, identifying what they have in common, theorizing about how this problem came to be and how it persists, and calling for layered solutions.

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