# The "Average Human":
# Dangers of Homogeneity in Data Used to Construct Biomechanical Research Models

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## Research for the "Average Human"

Imagine the average human being. Picture the way they move, the way they look. What is their physique? What sex, race, and ethnicity are they? There is no way for you to accurately answer these questions because there is no "average human being." Even so, we live in a world whose safety and function has been analyzed, most often, for the "average human being." We drive cars and use tools all tested with this mentality every day (Park et al., 2021; Vega & Arellano, 2021). So, who is the average human that researchers have been modeling in their work? Most often, it is a white man in his 20s or 30s who is in the 50th percentile for height and weight and has no physical disabilities. The question of this research is: How does the demographically homogeneous data used to construct biomechanical models impact their efficacy? In the coming pages, the issue of data homogeneity in biomechanical model construction is analyzed through the lens of the Political Technologies Theory.

## Literature Review Methodology

To answer the research question, "How does the demographically homogeneous data used to construct biomechanical models impact their efficacy?," a literature review was conducted. The following keywords were used when searching for sources: biomechanics, sex, race, ethnicity, models, female. Given the significant underrepresentation of words such as "sex," "race," and "ethnicity" in current biomechanical research papers, the use of those keywords isolated papers focusing on populations currently underserved by such research. Using the results of the literature review, this paper addresses the ways in which the representation (or lack thereof) of sex, race, ethnicity, height, weight, athletic background, and disability in

biomechanical modeling impacts the equity of our designed world and highlights the actions being taken to rectify some of those inequities in current research efforts.

**Understanding the Strengths and Weaknesses of Biomechanical Modeling**

Biomechanical research requires large sums of data to be properly conducted. One method for data generation that is growing in popularity is computational modeling, an approach in which the human body is reproduced in a computer so that it may be manipulated and studied more easily. This method reduces the need for patient trials and increases the efficiency and precision with which biomechanical research can be conducted. However, computational modeling as a research method is certainly still fallible. Creating biomechanical computational models involves taking measurements of a set of subjects and averaging those measurements during model creation. Like all computational models, they are only as accurate as the data used to train them.

Using a diverse data set to create a single biomechanical model leads to an averaging of varying characteristics that results in a model that does not properly represent any of the groups that it is based upon (Smith et al., 1996). On the other hand, choosing only one group from which to construct a biomechanical model becomes problematic when that model is then said to be representative of the "average human," as has been historically the case. Research covering everything from the prevention of car accidents (Bose et al., 2011; Yu et al., 2020) to the design of surgical tools (Tröster et al., 2020) has been conducted using models created from data sets of exclusively males, often in the 50th percentile for height and weight, and frequently all white.

The study of sex-based differences in biomechanics has led to a definitive understanding of the presence of musculoskeletal distinctions between men and women (Blemker, 2021;

Claiborne, 2008). By using all-male data sets in studies that claim their results apply to all humans, researchers exclude women from life-altering and often even life-saving research findings. Most people are not the "average person," so 50th percentile models are not as universal as they might seem (Haden, 2018) and variation in height and mass can have a huge impact on biomechanical results. Lastly, homogeneity of subject pools in categories like race and ethnicity threaten to further diminish the population that will benefit from biomechanical research. While both race and ethnicity are social—not biological—constructs, there are observable biomechanical differences across subjects based on race and ethnicity that cannot be overlooked (Gasperino, 1996; Pierce, 1966).

**Applying Political Technologies Theory to Biomechanical Modelling**

Political Technologies Theory, famously argued by Langdon Winner, posits that technology itself can be political (Schraube, 2021; Winner, 2007). According to Winner, there are two ways in which this can occur; First, the technology itself can be the answer to a political argument, effectively representing a victory for one side of a debate. Second, the technology can be inherently political such that any decision about its design will ultimately make a political statement. Those who critique this theory claim that technology itself holds no political power and is instead solely a manifestation of the political intentions of its creator, offering no influence outside of those intentions. Hopefully, this topic will serve as a counterpoint to that notion as it is a prime example of political power residing within a technology itself and influencing the population in ways that were not intended by the technology's creator and were instead a consequence of carelessness.

One modern scholar that uses the Political Technologies Theory in her writing is Ruha Benjamin. Benjamin argues that technology furthers racist exclusionism in a way that is uniquely problematic due to the shroud of false objectivity that often surrounds it (Benjamin, 2020). She observes that in an era ripe with the "illusion of [racial] progress," American society is particularly susceptible to the notion that tools are incapable of harboring biases or impacting marginalized groups in unintended ways. This leaves the power of tools that most certainly do have these capabilities unchecked and therefore undamped. Such thinking is easily applied to biomechanical computational models. When researchers see computational modeling as a flawless and objective method, they fail to recognize the damage that inaccurate modeling can do to the groups it claims to represent and fails to account for.

Authors Nick Couldry and Ulises A. Mejias use Political Technologies Theory to warn of the dangers of technological data-collection, likening such practices to "colonizing human life and appropriating it for capitalism" (Couldry & Mejias, 2019). They draw attention to another way that technology can be political: by constructing an entirely new political category. Data privacy as a political issue did not exist in any form even somewhat similar to the way it does now before there existed technology to facilitate large-scale, continuous data collection from every person that ever interacts with a screen. The idea that technology can create such a new political environment reinforces the notion that technology is more than just a product of society and proves that, at the very least, technology has some influence over society's formation, too. Such a point is very relevant to the discussion of biomechanical computational models and their data sets. After all, it is the profound influence of biomechanical research that makes its accuracy so crucial. The other technologies, everything from hospital equipment to cars, whose development and construction are informed by biomechanical research are what give power to

biomechanical computational models at all. It is important to recognize that biomechanics as a field has created a new political category, too. One in which the life and safety of every member of society is influenced by the accuracy of the models used to design their environment.

## Learning From Past Mistakes: Disadvantaged Groups and Potential Solutions

Biomechanical modeling has created its own political category. Although it has furthered inequities forged from a society that predates it, the technology itself has created unique tools of discrimination that must be distinctly acknowledged and addressed. Langdon Winner's political technologies framework is apt for this analysis. The following sections will describe the specific ways in which biomechanical modeling, the data sets used to create it, and the subjects chosen for biomechanical research have created disparities in who they accurately represent and serve.

### *Sex*

The study of sex-based differences in biomechanics has led to a definitive understanding of the presence of musculoskeletal distinctions between men and women (Blemker, 2021; Claiborne, 2008). Despite this, an overwhelming majority of biomechanical research has been conducted on all-male data sets. For most of the field's history, male subjects were seen as the default, while including female subjects was reserved primarily for studies whose express purpose was to compare women to men. Such egregious cultural norms are being addressed by organizations such as the National Institutes of Health (NIH). The NIH now requires that researchers justify a specific reason for excluding female subjects from their data sets, and it financially incentivizes research that bridges gaps in understanding of female biology (Arnegard

et al., 2020). However, it is crucial that the importance of this cultural shift be understood not just by researchers, but by the general public.

Equal representation of female subjects in biomechanical research and modeling is more than just a matter of principle. By using all-male data sets in studies that claim their results apply to all humans, researchers exclude women from life-altering and often even life-saving research findings. All manner of tools are optimized to male hands and forms (Tröster et al., 2020). Even the safety of vehicles is typically only assessed with all-male subjects, making women more likely to die in car crashes (Bose et al., 2011). Additionally, a lack of understanding of female biomechanics has resulted historically in womens' capabilities being assumed without investigation and those assumptions have been used to justify excluding women from physical activities like sports and manual labor (Drinkwater, 2000; Yu et al., 2020). Of course, women are not the only group that has been underrepresented in the field of biomechanics.

### *Race and Ethnicity*

There has been very little research into the effects of race and ethnicity on biomechanics. Although race is a social construct, not a biological one, it still has the potential to impact average biomechanics due to its unfortunate influence on the quality of medical care in the United States. What few studies there have been on this topic have proven that to be true (Hill et al., 2020). This quote from Hill et al. sums up their motivations quite nicely: "The continued assumption that racial differences in gait mechanics do not exist causes important distinctions between patients of different racial groups to be overlooked and, as a result, limits the efficacy of the care delivered to patients belonging to racial minorities."

Unlike sex-based differences in biomechanics, the notion of considering subject race as a factor in biomechanical research remains taboo. There is no requirement for researchers to justify using all-white subject pools, for example. This means that minority racial and ethnic groups are frequently underrepresented in biomechanical research, leaving our scientific understanding of the "average" human far more accurate to white humans (particularly white Americans) than to any other kind of human. Not only does this impart on minority racial and ethnic groups the same inequities previously mentioned in the discussion of sex-based differences, but it also limits the potential for researchers to investigate the medical discrimination that is leading to some of the race-based biomechanical differences in the first place.

### *Weight*

Another common practice in assembling a subject pool for biomechanical research is to choose subjects whose weight is at about the 50th percentile for their population. This, like many of the above choices, is intended to limit variability in data and allow for a more accurate conclusion to be drawn. Of course, also like the scenarios mentioned above, in seeking to narrow down distinct characteristics of the "average" human, researchers end up excluding the majority of the population. Most people are not the 50th percentile for weight. By the definition of a percentile, most people are either above or below that marker (Haden, 2018). This means that whatever conclusion is drawn by researchers using only subjects around the 50th percentile for weight will exclude large swaths of the population, often while still claiming it is a conclusion about the "average" human.

Most biomechanical studies seeking to evaluate the impact of weight on movement kinematics and/or kinetics look at added weight in the form of backpacks worn by children or

gear loaded onto foot soldiers. The impact of a person's body weight when they are above or below the 50th percentile marker has not been studied nearly as extensively. What studies there have been on body weight have mostly focused on obesity. In these studies, it has been observed that subjects with a BMI that would classify them as overweight or obese have different gaits and posture as compared to the 50th percentile subjects used in most studies (Nantel et al., 2010). This solidifies the importance of expanding the subject pools of studies besides those explicitly evaluating obesity to include subjects of all weights in any study that claims to make statements that apply to all or even most humans.

### *Height*

Similarly, height in biomechanical research subject pools is intentionally not diverse. The subjects in most studies are selected to be around the 50th percentile for height. Unsurprisingly, height has a significant impact on most aspects of a person's biomechanical values. Some studies have attempted to account for this discrepancy by creating three distinct subject groups: short, average, and tall (Gonzalez & Hull, 1989). However, other studies have chosen to "eliminate" this factor in just the same way that many have done for sex, race, ethnicity, and weight: by creating a false homogeneity in their subject pools while still connecting their conclusions back to the larger population of humanity.

Societally, it is more common to hear concerns about discrimination on the basis of the traits in the above sections. There is less concern about equality on the basis of height. That makes this example especially interesting because regardless of whether or not it feels wrong or furthers a very historically entrenched injustice, it still makes the science factually inaccurate and thereby creates a new injustice. To make claims that are meant to apply to a broader population

based on a subject set chosen to be intentionally narrow is always going to lead to a world built for a select few. That world will always be problematic. This is a great example of why the Political Technologies framework is so apt for this analysis. Of course, in many cases throughout this paper there are groups that have been historically discriminated against, but this particular type of discrimination is new. This is an entirely novel political sphere born out of the concept of modeling and research itself. Only when we began asking questions about humans and how we work did we create the opportunity for those questions to be answered in a way that is not inclusive. Only when we took those research results and used them to make decisions about how we design our world did we make the inclusivity of those research results absolutely crucial to an equitable society.

## *Disabilities*

There is a substantial amount of literature on the biomechanics of people with physical disabilities. In the biomechanics world, funding for disability-related research is generally much more abundant than funding for other biomechanics research, like the study of sports biomechanics in non-disabled people. Despite this financial incentive, there are still many populations of people with physical disabilities that are underrepresented or misrepresented in biomechanical research. There are a few reasons for this. First, the more rare a physical disability is, the less feasible it is for researchers to obtain funding and recruit sufficient subjects for studies on that disability. Second, not all biomechanical studies are designed with the needs and wants of the disabled community in mind. For example, there has recently been a surge in research surrounding active people with disabilities in which researchers are acknowledging that people like athletes can have disabilities, too (Ardigò et al., 2021). This is an exciting new development,

but its novelty in the field does affirm how often biomechanical research that focuses on people with disabilities tends to ignore nuance and focus only on simple tasks like walking and standing.

In addition to proper representation and diversity of research topics related to physical disability, another important opportunity for improvement in the field is on the norms for subject recruitment. Currently, researchers studying the biomechanics of a certain disability tend to recruit small sample sizes of subjects (usually a result of a lack of volunteers in the area that meet the selection criteria of their study) with similar levels of physical capability (to limit variability within the already small data set they will obtain) on a volunteer basis. This excludes individuals who are at the extremes, or "tails," of the distribution of abilities from being included in research. It also limits understanding of the studied abilities to only the presentation in those with enough independence and energy to volunteer for such a study. One way to address this is to implement data collection methods in clinical settings, like rehabilitation clinics, where patients are already participating in repetitive movements in a controlled environment. Of course, such methodology is not always feasible as data collection manifests very differently depending on the research question. However, the suggestion to try data collection in clinical settings and other suggestions like it represent a shift in the field's approach to subject recruitment that is only just beginning, but could be very important to improving the accuracy and usefulness of disability-related research.

### *Machine Learning*

Machine learning has become a favorite buzzword of almost every scientific field. Biomechanics is no different. The way that machine learning is most frequently being applied to biomechanical research has very interesting implications for the future of subject-derived data.

With the help of machine learning, customizing computational models to an up individual patient or subject is becoming increasingly effortless and fast. Researchers and companies alike are working every day to refine technology that can transform motion capture and imaging data into computational models of the body. These models could then be used for everything from personalized clinical diagnostics to understanding therapeutic intervention efficacy on an individual level and even testing research hypotheses (Lindquist Liljeqvist et al., 2021; Song et al., 2021).

The ability to quickly develop accurate models of human biomechanics at a personalized level unlocks an entirely new world of possibilities, one capable of sustaining far less homogeneous data sets than its predecessor. This is because the level of detail made possible by such an innovation as rapidly-constructed personal computational modeling is unlike anything the field has ever seen before. Suddenly, much larger subject pools become reasonable as data collection sessions become shorter. When one can make an accurate and personalized model of a subject with relative ease, that model can be made to undergo all manner of testing without any need for the subject's continued presence or availability. Returning to an aforementioned point about accessibility, the opportunity to develop an accurate model of locomotion based on limited data would make the collection of data in the clinic or at home much more possible and useful. Additionally, the increase in subject sample size enabled by machine learning advances would make it much easier to intentionally parse out groups based on sex, race, ethnicity, weight, and height such that more distinct conclusions could be drawn comparing subject groups within those categories.

Of course, machine learning is still a deeply flawed tool in many ways. The majority of the problems with machine learning stem from its dependence on huge sets of data in order to be

trained. Oftentimes, the data sets used to train machine learning models impart biases onto them. In the case of machine learning for biomechanical modeling, this could lead to personalized modeling methods being more effective for some subjects than others. Historically, machine learning data sets have disadvantaged minority groups, those who were less represented in data sets or who had been disadvantaged by other aspects of society in ways that the machine learning models were not designed to consider. There is a fear in the biomechanics community that these previous patterns of coded discrimination in machine learning would continue when applied to biomechanical modeling and deepen inequities rather than helping to address them.

### *Limitations*

The scope of the research conducted for this paper is not all-encompassing. The extent of topics and the depth in which they are covered is limited by both time and expertise. Additionally, research on a lack of research on a topic is difficult to come by. As such, quantified data on many of the inequities addressed in this paper was not always attainable.

### *Future Directions*

Many improvements to the field of biomechanics in addressing data homogeneity and research inequities have been suggested in this paper. One more is yet to be discussed. As mentioned in the "Limitations" section above, there is a lack of research into underrepresentation and misrepresentation in biomechanics research. This is certainly an important future direction. There needs to be more literature both highlighting and quantifying the lack of diversity in the subjects chosen for biomechanics research. Making the problem more known will make it easier to justify work seeking to address it.

**Acting Ethically in the Progression of a Political Technology**

Biomechanical computational modeling is a political technology because the innovation itself is the origin for distinct new inequities in our society. The nature of these inequities, however, is shaped by biases ingrained in our society. Historically marginalized groups such as people of color, women, and people with disabilities are frequently underrepresented or misrepresented in biomechanics research. This is because data sets and subject pools assembled for biomechanical research and modeling are not always designed in a way that would allow their results to be deemed apt for the "average human," but the conclusions of such studies and models are often still implied to be universally applicable. Addressing these inequities in the field will require more than simply designing studies and models that reflect exact and proportional averages of the human population. Instead, care must be taken to distinguish groups from one another and amass larger sample sizes in order to independently evaluate these varying groups and account for their differences before making generalizations.

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