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Review

J Neurol Res. 2022;12(2):54-68

Auditing the Impact of Neuro-Advancements on Health Equity

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Abstract

Health equity understood as the ability to live a healthy life, to have a good life, is impacted by many social determinants and by the social marginalization of various groups. "Measures" that use indicators to cover social determinants of a good life are useful tools to audit the impact of neuro-advancements on health equity. In this scoping review, I covered over 50 neurotechnologies, neuroenhancement, artificial intelligence (AI) machine learning (ML), robotics, neuroethics, neuro-governance and neurotechnology governance and various "measures" that focus on the ability to have a good life to answer three research questions: 1) Are the "measures" engaged with in the academic literature covering health equity or the chosen technologies? 2) Does the academic literature focusing on the technologies covered, neuroethics, or neurotechnology governance engage with health equity? 3) To what extent does the academic literature focusing on the technologies covered engage with the different primary and secondary indicators of four of the "measures" (social determinants of health, Better Life Index, Canadian Index of Well-Being, and community-based rehabilitation matrix)? For the scoping review, I examined the academic literature present in SCOPUS, which includes all Medline articles, and the 70 databases accessible under EBSCO-HOST and I employed a quantitative hit count approach for the analysis. I found that the term "health equity" was only mentioned in conjunction with the terms "determinants of health" and "social determinants of health" in a substantial way. Three of the terms linked to the "measures" were each mentioned in less than 10 abstracts and 16 terms linked to the "measures" were not mentioned at all in conjunction with the term "health equity". Health equity was also rarely to not at all mentioned in conjunction with the different technologies covered and not at all in conjunction with the terms "neuroethics", "neurotechnology governance" or "neuro-governance". Finally, there was uneven engagement with the primary and secondary indicators of the four chosen "measures" in conjunction with the technologies covered. The results reveal vast opportunities at the intersections of neuroethics and neuro-governance and science and technology governance in general, health equity, social justice, and wellbeing discourses.

Manuscript submitted July 6, 2021, accepted August 3, 2021
Published online August 19, 2021

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doi: https://doi.org/10.14740/jnr695

Keywords: Health equity; Robotics; Artificial intelligence; Machine learning; Neurotechnology; Neuroenhancement; Neuroethics; Well-being measures

Introduction

"Health equity means that everyone has a fair and just opportunity to be as healthy as possible" and "reducing and ultimately eliminating disparities in health and its determinants that adversely affect excluded or marginalized groups" [1]. As such, health equity is an important aspect of a good life [2, 3] and has many social determinants [4]. Various tools exist to analyze the social of health and well-being, such as social determinants of health (SDH), OECD Better Life Index (BLI), Canadian Index of Well-Being (CIWB), community-based rehabilitation (CBR) matrix, WHOQoL, The Quality of Being Scale, Aqol, and Calvert-Henderson Quality of Life Indicators, Satisfaction With Life Scale, Perceived Life Satisfaction Scale, Flourishing Scale, Scale of Positive and Negative Experience, Comprehensive Inventory of Thriving, Brief Inventory of Thriving, "The Disability and Wellbeing Monitoring Framework and Indicators", and the capability approach (from now on called "the measures") [5-31]. Many indicators of the "measures" are impacted by neuroscientific and neurotechnological advancements and the "measures" could be useful audit tools to evaluate the impact of neuroscientific and neurotechnological advancements on the ability of people and groups to experience health equity, which is one facet of the ability to have a good life. In this study, I ask three research questions covering over 50 neurotechnologies, neuroenhancement, neuroethics, neurotechnology governance, artificial intelligence (AI) machine learning (ML), and robotics and "the measures": (1) Are the "measures" engaged with in the academic literature covering health equity or the chosen technologies? (2) Does the academic literature focusing on the technologies covered, neuroethics, or neurotechnology governance engage with health equity? (3) To what extent does the academic literature focusing on the technologies covered engage with the different primary and secondary indicators of four of the "measures" (SDH, BLI, CIWB, and CBR matrix)? To answer the research questions, I performed quantitative hit counts searches on the co-occurance in academic abstracts of 1) the terms or phrases "robot*", "robotic*", "artificial intelligence", "machine learning", 50 terms and phrases linked to neurotechnologies and terms depicting neuro-related human enhancement and the "measures" [5-31]; 2) the technologies

mentioned or the terms "neuroethic*", "neuro-governance", "neurotechnology governance" and the phrase " health equity"; and 3) the primary and secondary indicators of four of the "measures" (SDH, Canadian and other interpretations, CIWB, the World Health Organization (WHO) CBR matrix and the OECD BLI) and the technologies mentioned. The findings are discussed through the premises of the "measures" and the purpose of science and technology governance.

Health Equity

It is noted that the academic literature increasingly engages with the concept of health equity [32]. Although there is a definition of health equity that equals health equity only with equal access to healthcare services [33], my article follows the WHO definition [34] and others [1-3, 35-37] that have a broader view on health equity.

The WHO definition is: "the absence of unfair and avoidable or remediable differences in health among population groups defined socially, economically, demographically or geographically. In essence, health inequities are health differences that are socially produced, systematic in their distribution across the population, and unfair. Identifying a health difference as inequitable is not an objective description, but necessarily implies an appeal to ethical norms" [34].

One other health equity definition following the WHO scope is "health equity is about the "freedom to live a long and healthy life" and "the material, psychosocial and political empowerment of individuals and communities" whereby "these dimensions of empowerment are influenced by the way society chooses to run its affairs, which shape the conditions in which people are born, live, work, play and age. Daily living conditions affect peoples' opportunities, their chances, the ways they behave and feel, and ultimately their health" [3]. And a third one states "health equity is about social exclusion" [1].

To achieve health equity one has to remove disadvantages based on one's social position [2, 36] and any other socially defined circumstance [36] that especially impact in a negative way socially marginalized groups [1] such as poverty, discrimination, lack of power and lack of access to meaningful jobs, education, housing, a safe environments, and health care [35].

It is argued that health equity has to include "intergenerational planetary health equity" [3], intersectionality [1], and an engagement with the SDH [4]. Organizational climate and capacity are important for health equity-oriented practice [38] and "significant gaps have been identified in the integration of health equity and social justice into health professions education programs in Canada across all educational levels" [39]. Measures for health equity have been proposed [1, 2, 40].

Measures

CBR and its indicator matrix

The purpose of the WHO CBR [16] is to enhance the quality of life, to equalize the opportunities and to increase the social inclusion of people with disabilities and people linked to them [17, 41] in low- and middle-income countries. The CBR guidelines have been developed by over "180 individuals and representatives of nearly 300 organizations, mostly from low-income and middle-income countries"[42]. The CBR is seen to adhere "to the principles of the Convention on the Rights of Persons with Disabilities (CRPD), e.g. non-discrimination and the need to include all people with disabilities in development initiatives" [42] and to protect the rights of people with disabilities [41].

Well-being measures

There are indexes of well-being in various countries [11-14, 43], including Canada [9, 10] and there are efforts to develop a global index of well-being [43] with the OECD BLI [15] being classified as an index of well-being [43]. One group came out in April 2020 with "The Disability and Wellbeing Monitoring Framework and Indicators" [27, 28], which covers over 193 indicators linked to health and well-being. They map the 193 indicators to the rights articulated in the CRPD [44] and domains from the International Classification of Functioning, Disability and Health (ICF) [45] to their CRE-DH Monitoring Framework domains [27]. They acknowledge that "the vision of the WHO Global Disability Action Plan 2014-2021 is a world in which all persons with disabilities and their families live in dignity, with equal rights and opportunities, and are able to achieve their full potential" and that "people with disability are more likely than those without to experience poverty, violence, social exclusion, housing insecurity, unemployment and economic inactivity" [27]. The CIWB [9, 10] has as its definition of well-being: "The presence of the highest possible quality of life in its full breadth of expression focused on but not necessarily exclusive to: good living standards, robust health, a sustainable environment, vital communities, an educated populace, balanced time use, high levels of democratic participation, and access to and participation in leisure and culture" [9]. Then there are many different quality of life measures such as WHOQoL [18], The Quality of Being Scale [31], Aqol [20] , and Calvert-Henderson Quality of Life [21], Satisfaction With Life Scale [22-24], Perceived Life Satisfaction Scale [25, 26], Flourishing Scale [29], Scale of Positive and Negative Experience [29], Comprehensive Inventory of Thriving [30], and Brief Inventory of Thriving [30]. All of the indicators of these well-being measures can be seen to be indicators of health equity and the ability to have a good life.

SDH

"The SDH [46-48] are the conditions in which people are born, grow, work, live, and age, and the wider set of forces and systems shaping the conditions of daily life" [49]. According to "Social Determinants of Health: The Canadian Facts", SDH are about "Canadian society, and what we need to put faces

and voices to the inequities, and the health inequities in particular, that exist in our midst. Only when we see a concrete description of these complex and challenging problems, when we read about their various expressions in all the regions of the country and among the many sub-groups making up Canada, can we move to action" [47].

Governance of neuro-linked science and technology

"The scope of neuro-advancements ranges from medical/therapeutic, military, education, human enhancement to recreational" [50]. Neuroethics [51-58] and neuro-governance [59] emerged as two fields covering the social, legal, and ethical issues that arise with neuro-advancements [51-54, 58-64], and it is argued that the societal discussions of science and technology advancements which would include neuro-advancements should be a constant endeavor [65, 66]. AI including ML and neuro-advancements increasingly intersect [59, 67-77], as do neuro-advancement such as brain-computer interface (BCI) and robotics [78-83] and neuro-linked enhancement beyond the species-typical [84, 85]. An extensive body of literature on the potential implications and governance of advancements exists for AI [86-92] and the ethics and governance of AI and neuro-discussions increasingly intersect [93-97].

Materials and Methods

Study design and research questions

Scoping studies are useful in identifying the extent of research that has been conducted on a given topic [98, 99] and the current understanding of a given topic. In this case, I aimed to record the co-occurance in academic abstracts of 1) the terms or phrases "robot*", "robotic*", "artificial intelligence", "machine learning", 50 terms and phrases linked to neurotechnologies and terms depicting neuro-related human enhancement and the "measures" [5-31]; 2) the technologies mentioned or the terms "neuroethic*", "neuro-governance", "neurotechnology governance" and the phrase " health equity"; and 3) the primary and secondary indicators of four of the "measures" (SDH, Canadian and other interpretations, CIWB, WHO CBR matrix and the OECD BLI) and the technologies mentioned. Three research questions were investigated: (1) Are the "measures" engaged with in the academic literature covering health equity or the chosen technologies? (2) Does the academic literature focusing on the technologies covered, neuroethics, or neurotechnology governance engage with health equity? (3) To what extent does the academic literature focusing on the technologies covered engage with the different primary and secondary indicators of four of the "measures" (SDH, BLI, CIWB, and CBR matrix)?

Data sources and data collection

On September 28, 2020 (strategy 1 and 2), and June 14, 2021 (strategy 3), the academic databases EBSCO-HOST (an umbrella database that includes over 70 other databases itself) and SCOPUS (which incorporates the full Medline database collection) were searched with no time restrictions. These databases contain journals that cover a wide range of topics from areas of relevance to answer the research questions. Scholarly, peer-reviewed journals were included in the EBSCO-HOST search and reviews, peer-reviewed articles, conference papers, and editorials in the SCOPUS search.

For strategy 1c, 2c, and 3c, 50 neurotechnology-related terms were covered: ("artificial brain") OR ("artificial hippocampus") OR ("auditory brainstem implant") OR ("Bionic eye") OR ("Brain Computer Interface") OR ("brain feedback") OR ("brain imaging") OR ("brain stimulation") OR ("Brain to speech technology") OR ("Brain-to-text technology") OR ("Cochlear implant") OR ("cognitive imaging") OR ("cognitive stimulation") OR ("Collaborative cognitive simulations") OR ("CoriQ electrocorticographic") OR ("Cortical modem") OR ("cranial electrotherapy stimulation") OR ("Darpa Ram senor") OR ("deep brain stimulation") OR ("Direct Acoustic Cochlear Implant") OR ("Ear-EEG") OR ("EEG biofeedback") OR ("Electrocorticography") OR ("exocortex") OR ("Facial Electromyography") OR ("God Helmet") OR ("Hemoencephalography") OR ("Hippocampus prosthesis") OR ("human computer Interface") OR ("intracranial electroencephalography") OR ("Muse headband") OR ("Neural stem cell") OR ("Neuralink") OR ("Neuro-chip") OR ("neuro-information") OR ("neuro-modulation") OR ("neurofeedback") OR ("neuro-imaging") OR ("neurosensing") OR ("neurostimulation") OR ("Nootropics") OR ("Optogenetics") OR ("Prosthetic memory device") OR ("Pulsed electromagnetic field therapy") OR ("Responsive neurostimulation") OR ("Sacral nerve stimulation") OR ("Speech brain computer interface") OR ("Spinal cord stimulator") OR ("Subvocal speech device") OR ("subvocal") OR ("THync mood altering headset") OR ("transcranial direct current stimulation") OR ("transcranial magnetic stimulation") OR ("virtual reality") OR ("whole brain emulation").

Data analysis

To answer the research questions, a descriptive quantitative analysis approach [100, 101] was performed generating hit counts for the search term combinations of the strategies (Table 1).

Limitations

The search was limited to databases accessible through EBSCO-HOST (70 databases) and SCOPUS and English language literature. As such, the findings are not to be generalized to the whole academic literature, non-academic literature, or non-English literature. As the data produced are based on the co-occurrence of terms, the hit counts by themselves do not indicate whether the keyword combinations really engage content wise with each other or what the actual content is. The numbers are also very likely lower as I did not elimi-

Table 1. Search Strategies Used to Obtain Quantitative Hit Counts

Strategy	Sources used	First search terms (abstract)	Second search terms (abstract)
Strategy 1a	SCOPUS/EBSCO-HOST	"Robot*" OR "robotic*"	Names of "the measures"
Strategy 1b	SCOPUS/EBSCO-HOST	"Artificial intelligence" or "machine learning"	Names of "the measures"
Strategy 1c	SCOPUS/EBSCO-HOST	50 neurotechnology-related terms	Names of "the measures"
Strategy 1d	SCOPUS/EBSCO-HOST	"Neuroenhancement*" OR "neuro enhancement*" OR "neuro-enhancement*" OR "moral enhancement*" OR "cognitive enhancement*"	Names of the "the measures"
Strategy 2a	SCOPUS/EBSCO-HOST	"Robot*" OR "robotic*"	Sub-indicators of SDH, CBR matrix, CIWB, BLI
Strategy 2b	SCOPUS/EBSCO-HOST	"Artificial intelligence" or "machine learning"	Sub-indicators of SDH, CBR matrix, CIWB, BLI
Strategy 2c	SCOPUS/EBSCO-HOST	50 neurotechnology-related terms	Sub-indicators of SDH, CBR matrix, CIWB, BLI
Strategy 2d	SCOPUS/EBSCO-HOST	"Neuroenhancement*" OR "neuro enhancement*" OR "neuro-enhancement*" OR "moral enhancement*" OR "cognitive enhancement*"	Sub-indicators of SDH, CBR matrix, CIWB, BLI
Strategy 3a	SCOPUS/EBSCO-HOST	"Health equity" and strategy 1a first search terms	
Strategy 3b	SCOPUS/EBSCO-HOST	"health equity" and strategy 1b first search terms	
Strategy 3c	SCOPUS/EBSCO-HOST	"Health equity" and strategy 1c first search terms	
Strategy 3d	SCOPUS/EBSCO-HOST	"Health equity" and strategy 1d first search terms	
Strategy 3e	SCOPUS/EBSCO-HOST	"Health equity" and "neuroethic*" or "neurotechnology governance" OR "neuro-governance"	

SDH: social determinants of health; BLI: Better Life Index; CIWB: Canadian Index of Well-Being; CBR: community-based rehabilitation.

nate duplicates of results due to articles showing up in more than one database. This could be done in follow-up studies for any of the hit counts reported by authors who want to focus for example on specific indicators. The findings also cover only specific terms depicting specific areas of scientific and technological advancements. Therefore, our findings cannot be generalized to every scientific or technological advancement. These findings, however, allow conclusions to be made within the parameters of the searches and the character of the analysis. The method section gives all the details needed to perform modified studies using for example other technologies and other databases.

Results

In this section, I provide first hit count results for the presence of the term "health equity" in conjunction with robot-related terms, artificial intelligence, machine learning, 50 neurotechnologies and neuro-related enhancements (from now on called "technologies covered") or in conjunction with the terms "neuroethics*", "neurotechnology governance" or "neuro-governance" (Table 2), then the hit counts for technologies covered and the term "health equity" in relation to the measures (Table 3), and finally the hit counts of the technologies covered in conjunction with the indicators of the four of the "measures" (SDH, Canadian and other interpretations, CIWB, WHO CBR matrix and the OECD BLI) (Tables 4-7).

Co-occurrence of health equity with technologies covered and neuroethics and neurotechnology governance

In Table 2, I report the hit counts obtained for health equity in conjunction with the technologies covered and the terms "neu-

Table 2. Hit Counts for the Term Health Equity in Conjunction With Technologies and Neuroethics and Neurotechnology Governance

Terms	"Robotic*" or "robot*"	"Artificial intelligence" or "machine learning"	50 NT	"Neuroenhancement*" OR "neuro enhancement*" OR "neuro-enhancement*" OR "moral enhancement*" OR "cognitive enhancement*"	"Neuroethic*" OR "neuro-governance" OR "neurotechnology governance"
	SCOPUS EBSCO-HOST (70 databases)				
	461,069 (100%)	353,233 (100%)	392,580 (100%)	4,611 (100%)	1,591 (100%)
Health equity	3	13	3	0	0

Table 3. Hit Counts for the Terms Used for the Various "Measures" in Conjunction With Technologies Covered or Health Equity

Terms related to "the measures"	Health equity	"Robotic*" or "robot*"	"Artificial intelligence" or "machine learning"	50 NT	"Neuroenhancement*" OR "neuro enhancement*" OR "neuro-enhancement*" OR "moral enhancement*" OR "cognitive enhancement*"
	SCOPUS EBSCO-HOST (70 databases)				
	24,416 (100%)	461,069 (100%)	353,233 (100%)	392,580 (100%)	4,611 (100%)
Aqol	0	0	0	2	0
Better Life Index	0	0	1	0	0
Brief Inventory of Thriving	0	0	0	0	0
Calvert-Henderson Quality of Life	0	0	0	0	0
Canadian Index of Well-Being	0	0	0	0	0
Capability approach	7	16	5	3	0
Community-based rehabilitation	0	4	2	6	0
Community-based rehabilitation matrix	0	0	0	0	0
Community rehabilitation	0	6	0	8	0
Comprehensive Inventory of Thriving	0	0	0	0	0
Determinants of health	2288	2	53	11	0
Flourishing Scale	0	0	4	2	0
Index of Well-Being	0	0	0	0	0
Meaning in Life	2				0
Perceived Life Satisfaction	0	0	0	0	0
Satisfaction with Life Scale	0	0	0	7	0
Scale of Positive and Negative Experience	0	0	0	2	0
Social determinants of health	1616	0	41	5	0
"The Disability and Wellbeing Monitoring Framework and Indicators"	0	0	0	0	0
The Quality of Being Scale	0	0	0	0	0
Well-Being Index	3	2	5	7	0

roethics*", "neurotechnology governance" or "neuro-governance".

Table 2 highlights that health equity is rarely engaged with, in relation to the technologies covered and not at all in relation to neuroenhancements, neuroethics and neuro-governance.

The measures and technologies covered and health equity

In Table 3, I report the hit counts obtained with the names of the "measures" and health equity and the measures and the technologies covered.

Table 3 shows that the terms linked to the "measures" rarely to not at all co-occur with the technologies covered and only the terms "determinants of health" and "social determinants of health" show substantial co-occurrence with the term "health equity".

Co-occurrence of the indicators of four of the measures with the technologies covered

In Tables 4-7, I report on the co-occurrence of the indicators of four of the measures with the technologies covered.

Tables 4-7 suggest an uneven engagement with many of the indicators suggesting that areas that could be impacted by the technologies were rarely covered or not covered at all. Furthermore, even if terms such as "discrimination" had quite a few hits, the lack of hits for other terms such as "women with disabilities" or few hits with terms depicting indigenous people the question arises who is engaged with under the term "discrimination".

Table 4. Presence of Community-Based Rehabilitation Matrix Indicators in Conjunction With Technologies Covered

Terms	Secondary indicator	"Robotic*" or "robot*"	"Artificial intelligence" or "machine learning"	50 NT	"Neuroenhancement*" OR "neuro enhancement*" OR "neuro-enhancement*" OR "moral enhancement*" OR "cognitive enhancement*"
		SCOPUS EBSCO-HOST (70 databases)			
		461,069 (100%)	353,233 (100%)	392,580 (100%)	4,611 (100%)
Health		7,965	19,380	18,049	486
	Healthcare/health care	4,195	8,532	4,427	29
	Assistive technology/assistive technologies/assistive device	1,340	238	719	13
	Health promotion	24	58	57	2
	Health prevention	0	6	5	0
	Rehabilitation	11,633	1,132	14,827	65
Education		76,176	6,467	10,798	145
	Childhood education	0	0	0	19
	Primary education	41	10	24	0
	Secondary education	62	25	35	1
	Non-formal	26	9	5	0
	Life-long learning	78	5	24	0
Livelihood		31	94	6	0
	Skills development	2,884	1,556	3,862	0
	Self-Employment	2	1	0	0
	Financial services	18	116	5	0
	Wage employment	0	1	0	0
	Social protection	0	3	1	0
Social		14,789	19,038	18,170	459
	Social relationship	116	111	76	0
	Family	3,187	5,221	9,088	38
	Personal Assistance	67	11	4	0
	Culture	1,998	2,205	5,487	29
	Arts	11,694	26,077	6,327	15
	Sport	1,105	1,310	1,553	30
	Leisure	1,112	1,241	1,893	0
	Access to justice	0	0	0	0
Empowerment		74	160	95	0
	Communication	26,533	14,539	14,110	20
	Social mobilization	0	2	1	0
	Political participation	1	6	4	0
	Self-help groups	1	3	5	0
	Disabled people's organizations	0	0	0	0

Table 5. Presence of Canadian Index of Wellbeing Indicators in Conjunction With Technologies Covered

Terms	Secondary indicator	"Robotic*" or "robot*"	"Artificial intelligence" or "machine learning"	50 NT	"Neuroenhancement*" OR "neuro enhancement*" OR "neuro-enhancement*" OR "moral enhancement*" OR "cognitive enhancement*"
		SCOPUS EBSCO-HOST (70 databases)			
		461,069 (100%)	353,233 (100%)	392,580 (100%)	4,611 (100%)
Social relationships		116	111	76	0
	Social engagement	83	27	56	0
	Social Support	58	85	333	10
	Community safety	0	2	0	0
Social norms		106	52	160	13
	Attitudes toward others	0	0	0	0
Democratic engagement		0	0	0	0
	Participation	2,437	1,296	2,735	13
	Communication	26,533	14,539	14,110	20
	Leadership	442	457	230	3
Education		7,616	6,467	10,789	145
	Competencies	631	537	806	13
	Knowledge	77,132	43,227	18,947	151
	Skill	11,539	5,122	14,857	68
Environment		93,220	29,875	35,037	143
	Air	False positive (FP)	FP	FP	0
	Energy	FP	FP	FP	0
	Freshwater	FP	FP	FP	0
	Non-renewable material	FP	FP	FP	0
	Biotic resources	FP	FP	FP	0
Healthy population		1,919	18	214	5
	Personal wellbeing	0	2	2	0
	Physical health	45	93	286	1
	Life expectancy	2,553	2,986	4,253	0
	Mental health	204	1,042	2,657	55
	Functional health	8	9	10	0
	Lifestyle	218	827	960	38
	Public health	155	1,956	1,548	27
	Healthcare/health care	4,149	8,534	4,467	29
Culture		1,998	2,205	5,487	29
Leisure		1,112	1,241	1,893	0
Living standard		39	40	13	0
	Income	382	169	778	6
	Economic security	11	15	1	0
Time		ND	ND	ND	ND

Table 6. Presence of Better Life Index Indicators in Conjunction With Technologies Covered

Terms	"Robotic*" or "robot*"	"Artificial intelligence" or "machine learning"	50 NT	"Neuroenhancement*" OR "neuro enhancement*" OR "neuro-enhancement*" OR "moral enhancement*" OR "cognitive enhancement*"
	SCOPUS EBSCO-HOST (70 databases)			
	461,069 (100%)	353,233 (100%)	392,580 (100%)	4,611 (100%)
Housing	568	381	139	6
Income	470	1,069	778	6
Jobs	2,555	2,337	384	43
Community	5,931	12,490	5,540	65
Education	7,616	6,467	10,789	145
Environment	93,220	29,875	35,037	143
Physical environment	519	152	343	0
Civic engagement	3	9	4	0
Health	7,965	19,380	18,049	486
Life satisfaction	9	31	48	2
Safety	17,975	6,692	9,841	129
Work life balance	4	5	2	0

Discussion

As to the "measures", the scoping review found that the term "health equity" was only mentioned in a substantial way in conjunction with the "measures" related terms "determinants of health" and "social determinants of health". Three of the "measures" related terms, "capability approach", "well-being index" and "meaning in life", were mentioned in less than 10 sources. The other 16 "measures" related terms were not mentioned in conjunction with the term "health equity". The term "health equity" was also rarely mentioned in relation to robotics (three times), artificial intelligence, and machine learning (13 times) and the 50 neurotechnologies (three times) and not at all in conjunction with neuro-related enhancements and the terms "neuroethics", "neuro-governance" and "neurotechnology governance". Of the "measures" [5-31], only the terms "social determinants of health" and "determinants of health" were mentioned in a substantial way in conjunction with the technologies investigated. Furthermore, there was uneven engagement with the indicators of the four "measures" investigated as examples (SDH, BLI, CIWB, and CBR matrix) in relation to the technologies covered. These findings are problematic given that it is acknowledged for all the technologies covered that they have social implications as evident by the very existence of the fields of neuroethics, roboethics and AI ethics. It also highlights vast opportunities. The findings are discussed through the premises of the "measures" and the purpose of science and technology governance.

The premise of the "measures"

All the "measures" [5-31] exist to analyze health, well-being, and quality of life of people and their indicators could be labelled as indicators of health equity. Various, academic articles make the linkage between the indicators of the "measure" (SDH) and health equity [3, 4, 102, 103]. Nearly all, if not all, indicators of these "measures" are impacted by the technologies covered in the study whether directly or indirectly. For example, it has been reported that social status is a driver for human enhancement [104], and marginalized groups have a social status problem. However, the term "social status" was rarely found. As such, all the "measures" covered by the study could and should be used to audit the impact of the technologies covered on health equity and the social in general. To look now at four of the measures, I investigated in more detail in the study.

The CBR measure and the CBR matrix [42] have been developed by groups and organizations from middle- and low-income countries for its use in making the lives of people with disabilities better in low- and middle-income countries [42]. The technologies covered in my study are also envisioned to be deployed in low- and middle-income countries [105-108] and therefore these technologies will impact the social and health equity in these countries especially of marginalized groups [105]. As such the CBR matrix and its indicators could and should be used at least by the CBR community to audit the social impact of the technologies covered. The CBR is about creating equal opportunities [41]. Health equity is about the equal opportunity for being healthy [109]. It is furthermore noted that the CBR is guided by the CRPD [42, 110] and many of the problems faced by disabled people that are flagged in the CRPD [44] are impacted by the technologies covered [84, 85, 105, 111-114]. Therefore, the CBR matrix could and should be used as a lens to investigate the impact of the technologies covered on the creation of equal opportunities to be healthy

Table 7. Presence of Social Determinants of Health (SDH) Indicators in Conjunction With the Technologies Covered

Terms	"Robotic*" or "robot*"	"Artificial intelligence" or "machine learning"	50 NT	"Neuroenhancement" OR "neuro enhancement*" OR "neuro-enhancement*" OR "moral enhancement*" OR "cognitive enhancement*"
	SCOPUS EBSCO-HOST (70 databases)			
	461,069 (100%)	353,233 (100%)	392,580 (100%)	4,611 (100%)
Canadian indicators of SDH				
Income	470	1069	778	6
Education	7,616	6,467	10,789	145
Unemployment	213	286	31	0
Job security	15	5	1	0
Employment	1,106	1,121	692	54
Early childhood development	2	6	23	19
Food insecurity	4	21	3	55
Housing	568	381	139	6
Social exclusion	18	18	97	0
Social safety network	0	0	0	0
Health services	143	381	320	
"Aboriginal" OR "first nations" OR "Metis" OR "indigenous people" OR "Inuit"	16	21	30	0
Gender	1,648	2,395	5,484	45
"Women with disabilities" OR "disabled women"	0	0	0	0
Race	ND	ND	ND	ND
Immigration	28	60	27	0
Globalization	200	287	145	0
Other social determinants of health indicators				
Coping	538	435	817	20
Discrimination	1046	3538	5454	29
Genetic	7,222	14,400	16,198	98
Stress	4,639	3,725	9,660	230
Transportation	3,519	2,986	472	2
Vocational training	27	9	50	2
Social integration	16	12	53	0
Advocacy	20	68	154	3
Literacy	344	385	390	2
Race	FP	FP	FP	FP
Ethnic	53	282	483	0
Walkability	6	13	7	0
Physical environment	519	152	343	0
Social engagement	77	27	56	0
Social status	16	26	54	0

for disabled people and beyond and to audit the impact of the technologies covered on the problems flagged in the CRPD. The CBR matrix is to my knowledge the only measure that explicitly lists Disabled People's Organizations as an indicator. As such, the CBR community has a unique indicator that one can apply to audit the impact of technologies on health equity. Finally, empowerment of disabled person is one indicator of the matrix [41]. As such, the CBR matrix could and should be used to highlight the dangers and opportunities of the technologies covered in this study for the empowerment of disabled people and others.

"SDH" are the conditions in which people are born, grow, work, live, and age, and the wider set of forces and systems shaping the conditions of daily life" [49] and with that health equity [2, 4, 115, 116]. All the technologies covered impact the very conditions of daily life and with that health equity [49]. The final report of the "Commission for the social determinants of health" outlined three main action items: 1) "Improve the conditions of daily life - the circumstances in which people are born, grow, live, work, and age; 2) Tackle the inequitable distribution of power, money, and resources - the structural drivers of those conditions of daily life - globally, nationally, and locally; and 3) Measure the problem, evaluate action, expand the knowledge base, develop a workforce that is trained in the social determinants of health, and raise public awareness about the social determinants of health" [8]. All three points suggest that the SDH could and should be used to audit and evaluate the impact of science and technology including the technologies covered on health equity and the social in general.

The CIWB is seen as "a multifaceted measurement and monitoring tool developed to engage Canadians in conversations about their health and well-being that go beyond health care or the economy, and about acting on changes that matter in their lives" [117]. As such, this measure could and should be used to audit advancements in science and technology in general and the technologies covered. The same conclusion can be reached in relation to the other quality of life measures covered under the "measures" (WHOQoL [18], The Quality of Being Scale [31], Aqol [20], Calvert-Henderson Quality of Life [21], Satisfaction With Life Scale [22-24], Perceived Life Satisfaction Scale [25, 26] Flourishing Scale [29], Scale of Positive and Negative Experience [29], Comprehensive Inventory of Thriving [30], and Brief Inventory of Thriving [30]).

Governance of science and technology advancements

Recently, people highlighted the 2017 UNESCO Recommendation on Science and Scientific Researchers as a tool that, if followed, would "transform working conditions, rights and responsibilities of researchers globally" as part of performing responsible research and innovation [118]. The 10 main points stated are: 1) Responsibility of science towards the United Nations' ideals of human dignity, progress, justice, peace, welfare of humankind and respect for the environment. 2) Need for science to meaningfully interact with society and vice versa. 3) Role of science in national policy and decision-making, international cooperation and development. 4) Promotion of science as a common good. 5) Inclusive and non-discriminatory work conditions and access to education and employment in science. 6) Any scientific conduct is subject to universal human rights standards. 7) Balancing the freedoms, rights and responsibilities of researchers. 8) Scientific integrity and ethical codes of conduct for science and research and their technical applications. 9) Importance of human capital for a sound and responsible science system. 10) Role of Member States in creating an enabling environment for science and research [118].

Auditing the "social" including health equity impact of science and technology advancements in general and the technologies covered in a cohesive and systematic fashion is essential for at least points 1-4. It is noted that "biases in science" are one topic covered in the health equity literature [32]. These "measures" could unmask biases as to how the social and health equity is engaged with in relation to the technologies covered and other scientific and technological advancements.

In the report of a recent workshop "The Endless Frontier: The Next 75 Years in Science" organized by the National Academy of Sciences, The Kavli Foundation and the Alfred P. Sloan Foundation [119] mentioned the term "social" 13 times, "society" 36 times, and "societal" nine times. It is furthermore stated in the report that "World War II demonstrated that science was becoming the single most important force driving technological, economic, and societal change" [119] and "today, society is counting on science, engineering, and medicine to respond to and recover from the COVID-19 pandemic, an unprecedented health, economic, and social crisis" [119]. The report also argues that future challenges impact societal inequities and societal polarizations [119] and concludes "The result has been an increasingly international, collaborative, and interdisciplinary science and technology system that has become an even greater force for economic growth and social change than in the postwar years" [119]. If all these statements in the report are true, the arguments made also impact health equity, and as such, the technologies covered should engage more with health equity. According to Rafael Reif, President, Massachusetts Institute of Technology, it would be useful to have "a new technology directorate at NSF focused on high-stakes technologies, with the humanities and social sciences integral to the research from the start because of these technologies' social consequences" [119]. The "measures" could be used as a tool to bring people from various backgrounds together and decrease silos benefiting health equity endeavors.

Conclusion

"Health equity means that everyone has a fair and just opportunity to be as healthy as possible" and "reducing and ultimately eliminating disparities in health and its determinants that adversely affect excluded or marginalized groups" [1]. As such, health equity is an important aspect of a good life [2, 3] and has many social determinants [4]. Neuroscientific and neurotechnological advancements and the technologies that enable such advancements impact various indicators of these social determinants as do other scientific and technological advancements. The "measures" [5-31] could be used to audit the impact of the

technologies on health equity and the social in general, which would help endeavors such as "integrating health equity and racial justice into the artificial intelligence" [120]. The "Disability and Wellbeing Monitoring Framework and Indicators" together with scales such as the Satisfaction With Life Scale [22-24] and Perceived Life Satisfaction Scale [25, 26] could be a good starting point to gain an understanding of the perception and realities (real or anticipated) of a given science and technology advancement such as the technologies covered in this study on the "social" parameters influencing health equity of disabled people.

Buchman and Wadwahan argued that neuroethics should engage "more with theories of social justice, particularly how neurotechnologies might "affect already unequal societies" [121], which they argue includes "analyses that are rooted in health equity and the social determinants of health" [121]. This study contributes to this analysis by mapping out what is covered and not using a hit count analysis. The findings of the study provide data showing that there is a lack of linkage between neuro-advancements and health equity and no linkage at all between neuroethics and neuro-governance and health equity in the academic literature covered, which reinforces the demand by Buchman and Wadwahan and suggests also that there should be more of a focus on health equity in neuroethics and neuro-governance discussions.

All the findings of the study suggest vast opportunities for the fields covering the "measures" and health equity, science and technology governance, neuroethics, AI ethics, robo-ethics, the development of the technologies covered, and other communities such as disability studies and other identity group studies, social justice studies, socially disadvantaged groups, practitioners, and policy makers to name a few groups to collaborate in an intersectional and interdisciplinary fashion.

The findings of the study suggest many possible future research agendas. One is that one can use all the indicators of the "measures" and ask various groups and individuals, including disabled people, which of the indicators they experience in the moment in a positive or negative way and how they see a given scientific or technological advancement impacting how they experience the indicators now and in the future. One can investigate why there is this disconnect between these "measures" as a whole, science and technology governance, and health equity as a concept, and further, how the "measures" can be used in curricula to increase the literacy of students on the impact of the technologies covered on health equity and the social in general. One can also use these "measures" to advance the "equity, diversity and inclusion" (EDI) agenda at universities as many of the EDI groups are negatively impacted by the social environment they experience outside universities [122, 123], which impacts their enrolment and advancements in universities. Being literate on the impact of the technologies covered and others on health equity and the social in general enables more literate EDI and other discourse in universities.

Acknowledgments

None to declare.

Financial Disclosure

This research was funded by Government of Canada, Canadian Institutes of Health Research, Institute of Neurosciences, Mental Health and Addiction ERN 155204 in cooperation with ERA-NET NEURON JTC 2017.

Conflict of Interest

None to declare.

Data Availability

The author declares that data supporting the findings of this study are available within the article.

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