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The future of intelligence research in the coming age of artificial intelligence – With a special consideration of the philosophical movements of trans- and posthumanism

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ABSTRACT

Artificial intelligence (AI) is a hot topic in society as it seems to extend and challenge human cognitive capacity. Yet, it is surprising that human intelligence research in particular and psychology in general has so far contributed very little to the ongoing debates on AI and the related philosophical movements of trans- and posthumanism. Transhumanism promotes the development of technologies that aim at strongly enhancing human psychological (especially intellectual) capacities, achieved by applying neuroscience methods such as transcranial electric/magnetic stimulation (TES, TMS), brain–computer interfaces (BCIs), deep-brain stimulation (DBS), pharmacological and even nanotechnological methods aimed at brain repair or enhancement of brain plasticity. The goal is to achieve a "post-human future," in which current problems of human mankind should finally be solved. In this contribution I will (1) describe current neuroscientific and pharmacological methods that aim at enhancing human intelligence and how successful they can currently be considered; (2) outline potential implications of a wider application of cognitive enhancements (viewed from a societal perspective, and from an evolutionary perspective of individual differences); (3) outline commonalities and differences between concepts of human versus artificial intelligence; (4) discuss the promises and perils of an (artificial) "super-intelligence" (sensu Nick Bostrom); and (5) consider how psychology could or should contribute to the development of such a "super-intelligence." Finally, I will try to answer the question: What are the implications of our knowledge on individual differences in psychological traits (e.g., cognitive and social/emotional traits, values) for the further development of AI?

Worldwide, artificial intelligence (AI) has become a hot topic in many sciences as well as in public debates. AI is supposed to simulate human intelligence in order to support or even extend humans' abilities (Otte, 2019). However, the development and application of AI systems is also accompanied by challenges and risks for humanity. In the future, AI systems might, for instance, challenge human cognitive capacity.

In a Google search, combining the terms "psychology" or "psychological" with "artificial intelligence", one can find six- to-seven-digit number of hits, but searching in spring 2021 for papers in peer-reviewed journals in Google Scholar, I found only 32 papers with a clear psychological focus on AI and AI-related topics. And when combining the terms "human intelligence" with "artificial intelligence," (AI) only 22 papers were found to be relevant in the context of psychology. This could mean two things: Either the psychological concept of human intelligence is (currently considered or factually) irrelevant for AI research and development, because they are two completely different things. I will later explore this possibility in more detail. Or psychology has – so far – ignored maybe one of the most fundamental challenges for humankind, and that it is overdue to fill this gap (cf. Matthews et al., 2021). Later I will argue in favor of this position and try to stimulate further discussions of AI topics and their philosophical representations in the form of the current movements of trans- and posthumanism.

In the few psychological papers on AI that I could locate, human intelligence is only referred to in a very general sense, not to the topics of intelligence research per se, i.e., intelligence as a construct in which humans show individual differences. The only exception are a few publications that focus on the psychometric aspect of whether machine intelligence can be measured in the same way as human intelligence and in which an "anytime" or "universal" intelligence test is proposed (e.g., Bringsjord, 2011; Hernández Orallo, Dowe, & Hernández Lloreda, 2014). This seems an interesting but nevertheless a somehow ad hoc approach, and the more fundamental question of the commonalities

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versus differences between human and artificial intelligence is not under a more elaborate scientific scrutiny here.

Just while I was working on the revision of this paper, an article by van der Maas, Snoek, and Stevenson (2021) with the title "How much intelligence is there in artificial intelligence? A 2020 update" was published, that started with a status quo assessment similar to mine, namely that there still is a lack of interaction between human intelligence research and AI research. The authors tried to fill this gap in a – in my opinion – very inspiring way. In line with my reasoning they contend that – as opposed to many scholars in the field – human intelligence research is relevant for AI and vice-versa: AI developments could or even should impact the future definition of human intelligence (as an individual differences construct). Van der Maas et al. mainly focus on what AI research can learn from cognitive psychology (in general) and human intelligence research (in particular) and on the question whether AI is 'really intelligent', a question I will come back to later too. They also deliberate on implications of AI research for the development of theorizing in human intelligence research and the potentials of AI for the development of future psychometric intelligence tests. In contrast to their elaboration, my focus is to try to analyze implications of the foreseeable dramatic progress of AI on the future validity and utility of the concept of human intelligence, viewed also from a societal and an evolutionary perspective of individual differences.

Before going into it, it should also be mentioned that the lack of pertinent psychological research on AI is not only observable in the field of human intelligence research but also in the wider field of personality and individual differences research. Only a very few approaches to investigating AI from an individual differences perspective can be found. This research gap is well addressed by Matthews et al. (2021) in their article "Evolution and Revolution: Personality Research for the Coming World of Robots, Artificial Intelligence, and Autonomous Systems." They suggest that the availability of modern technology will profoundly influence the field of personality psychology and individual differences research, thus research must adapt to the challenges of such technologies to human existence. However, in their paper, intelligence as a central human trait and its relation to AI is not considered at all.

While psychology seems to lag behind other sciences like biology, theology, sociology and medicine in considering the AI topic, especially in philosophy, the topic of human versus artificial intelligence has become a big issue in the movements of so-called Transhumanism and Posthumanism. Transhumanism is a philosophical movement that deals with and promotes the development of technologies that aim to strongly enhance human psychological (especially cognitive) and physical capacities (for an overview see Ranisch & Sorgner, 2014; for critical accounts see Hansell & Grassie, 2011). The goal of transhumanists is a substantial enhancement of humans' capabilities, such as intelligence, creativity, social competencies, morality/values, and character, aiming finally at "superhumans" who are better equipped and more fit to deal with the many current problems, such as climate change, social inequality, loss of democratic values, and others (possibly even the COVID-19 pandemic?). These enhancements are to be reached through modern pharmacological or neurotechnical methods that should be widely applied on healthy individuals. According to transhumanists, only by that will it be possible to save humankind and our planet.

While some transhumanists view future human beings as *trans*formed ones, others define the "trans" only as a *trans*itory stage on the way to the final goal – the age of posthumanism. Posthumanists are skeptical that even with the most advanced methods human capabilities could be enhanced sufficiently in order to overcome the many imminent threats to humankind and the earth (see Loh, 2018, for an outline of the distinctions between trans- and posthumanism). Posthumanists envisage a "posthuman future," in which AI should play a major role, peaking in the development of a "super-intelligence" (Bostrom, 2014). This will reach considerably high levels of intelligence that even the brightest humans using the most advanced enhancement methods could never achieve. According to posthumanists, such an artificial super-intelligence will be necessary to "save the planet" because of the imminent deficits of the human "character."

For the future of intelligence research, as I will argue in this contribution, it is essential to accomplish a research agenda that addresses a multitude of questions about the relationship between trans- and posthumanistic future scenarios, artificial intelligence and human intelligence, as well as other human psychological traits. I will outline the following most relevant aspects for and of such a research agenda in this article:

1. A short overview of neuro- and pharmatechnologies envisaged to enhance human abilities and capabilities, like transcranial electric or magnetic stimulation (TES & TMS), brain–computer interfaces (BCIs), deep-brain stimulation (DBS) through implanted electrodes, or pharmacological methods (brain doping/smart drugs).
2. An elaboration of the following questions: What are the societal implications of a (more or less) wide application of cognitive enhancement, especially with regard to intelligence? Who will have access to such enhancement methods and at what stage? What might be societal effects when these enhancement methods become effective and are widely available? In addition to societal effects, I will also briefly consider an evolutionary perspective.
3. A short description of the current status of AI from the perspective of intelligence research. What can the most advanced technologies in AI (like neural networks and machine learning methods) achieve presently as well as in a foreseeable future, i.e., the coming decades / the twenty-first century? What is the IQ of the currently best AIs? What are the commonalities and differences between concepts of human versus artificial intelligence?
4. On the basis of #3, I will elaborate the promises and perils of an (artificial) "super-intelligence" (sensu Nick Bostrom). Will there be several AIs? Will they compete? What consequences would this entail? Or will (the most intelligent) one outclass all others and "take command" in the world, the final step called "singularity"? What are the implications for humans, if their – for "life success" most predictive trait – intelligence is no longer at the apex of the hierarchy of living creatures but (vastly) outmatched by a singularity? What are the implications for the highly desired trait of intelligence? Will intelligence become less important and other human traits become the "hallmark" of humans, e.g., creativity, morality, values, or others?
5. And finally, I will consider how psychology can contribute to the development of a "super-intelligence." What are implications of our knowledge on individual differences in psychological traits (e.g., cognitive and social/emotional traits, values) for the further development of AI? Must a "super-intelligence" not also have some human values implemented? Should it be creative or high in the big five trait openness? Or is it better to restrict AI to "intelligence per se" so that we humans still reserve the domains of creativity, emotions, and values for our species?

1. Enhancement methods to increase humans' psychological capabilities

Transhumanists often refer to "neurotechnical" or pharmacological methods/techniques to enhance psychological (and physical) capacities of humans, with intelligence clearly being the most frequently mentioned "object of desire" (in the majority of transhumanists' publications). This includes currently available and – partially well-researched – methods like transcranial electric/magnetic stimulation (TES, TMS), brain–computer interfaces (BCIs), as well as deep-brain stimulation (DBS) through implanted electrodes, and pharmacological interventions (e.g., brain-doping). On the other (more science-fiction) side, sometimes nanotechnological methods aiming at brain repair or the enhancement of brain plasticity are also considered. Probably the most utopian perspective is mind-uploading, i.e., loading a perfect copy of a brain (including all personality traits, memories, emotions, skills, etc.) on a computer that either could "live" there forever and communicate with other humans or androids, or be transferred into another (younger) body (e.g., Bamford & Danaher, 2017; (Laakasuo et al., 2021).

How far developed are these enhancement methods? How efficiently are they currently working? What are the possibilities in enhancing which "qualities" of humans? This issue is rarely reflected upon by transhumanists; in fact, practically all of them are philosophers, linguists, theologists, computer scientists or from some other domains, but not psychologists or neuroscientists. Transhumanists very rarely make reference to the multitude of literature that is already available, at least in the field of brain stimulation and neurofeedback techniques (e.g., Haier, 2017; Jaušovec & Pahor, 2017; Posner & Rothbart, in press). I will not discuss this topic in detail here, but the review by Jaušovec and Pahor (2017) concluded that, currently, enhancement effects in the field of intelligence are usually small and short-lasting (for a typical study see Neubauer, Wammerl, Benedek, Jauk, & Jaušovec, 2017). If there are effects at all, they show – at best – improvements of 3–5 IQ points and probably most intelligence researchers would question whether such a small enhancement has any noticeable effect in daily life, at least for the individual. Therefore, currently the impact of electrical and pharmacological enhancement techniques on one's intelligence is not as promising as most transhumanists assume (and this is rarely reflected in their writings; see Loh, 2018, for an exception).

Other neuro-techniques that are advocated by transhumanists are brain–computer interfaces (BCIs), neurofeedback methods, and deep-brain stimulation (DBS) through implanted electrodes. However, these methods so far have predominantly been used/developed for clinical purposes (e.g., as communication tools for locked-in syndrome; or in Parkinson's patients) and not to enhance cognitive functions in healthy individuals (Posner & Rothbart, in press). A potential utility for enhancing cognitive functions can, therefore, currently not be determined.

The second well-researched field is pharmacological methods using modafinil, methylphenidate (Ritalin), Adderall, and others. These are – in some countries like the USA – frequently used not only by children with attention deficit hyperactivity disorder (ADHD) but also by students to improve their learning potential. Several reviews and meta-analyses have been conducted (for an overview see Jaušovec & Pahor, 2017) and, despite working well for children with ADHD, they show mostly negligible to small effects for healthy adults. These pharmacological methods are supposed to enhance alertness/attention and executive functions; but the observed effects are often restricted to individuals of lower cognitive ability.

2. Societal implications of an application of cognitive enhancement

Given the current status of research, there are not so promising findings of substantial enhancements of intelligence and other psychological traits. But most transhumanists are very (far-)future-oriented when conceiving scenarios not for the coming decades but rather the second half of the 21st century and beyond. And indeed, given the progress in neurosciences we can surely not exclude a sudden breakthrough in the development of a drug or a (magneto-)electrical method that could substantially enhance the IQ by, let's say, more than 10 IQ points. For an individual, such an increase could probably be considered a minimum to make a difference in real-life attainments and achievements. Brain stimulation is currently an extremely active field, and with successive advances in brain stimulation techniques and also (brain MRI-based) better focalization of stimulation (e.g., Bikson, Rahman, & Datta, 2012; Edwards et al., 2013), we might face substantial advances in a not-distant future (at least in the classical current-based brain stimulation techniques, as well as in neurofeedback and BCI techniques).

If these methods become considerably more effective in the future, some serious issues have to be discussed:

a) the possible negative consequences/side effects for the individual must be considered and it is completely unclear whether using any kind of TMS/TES on a daily basis could not also have negative effects on the brain in the long run (e.g., Ali, Lifshitz, & Raz, 2014; Hills & Hertwig, 2011; Kober et al., 2015). Currently nobody knows this, but the question is a legitimate one, given that there is a not inconsiderable number of people who are worried that even the frequent use of a cell phone next to the brain may have detrimental effects on their health. Even if it does not have detrimental effects, it could mean that the usage of TMS/TES might be personality-dependent, which could introduce new (and possibly unwanted) intelligence-personality interactions, e.g. when anxious people refrain more from enhancement methods (which would introduce a new negative intelligence * anxiety correlation).
b) also, the societal implications are not to be underestimated and these would depend on several factors:

- economic factors/accessibility: What are the costs and who can afford enhancement methods such as a TES device or smart drugs?
- psychological: Are some individuals more prone to using enhancement methods than others (e.g., does the attitude towards enhancement methods depend on personality traits; (Neubauer & Grinschgl, 2021)Grinschgl, Tawakol, & Neubauer, 2021)? Who would profit most from using these methods? Is there a Matthew effect (i.e., the initially brighter individuals profit more from enhancement methods) or is there a kind of "reverse Matthew effect" (i.e. the less bright individuals gain more, also called the "compensation effect"; cf. Savi, Marsman, van der Maas, & Maris, 2019, for a discussion of both effects)? The current status of evidence rather speaks in favor of the compensation effect (Jaušovec & Pahor, 2017); but a positive Matthew effect is also conceivable. That could be derived from a meta-analysis showing that TES applied in learning phases is more effective than in the assessment phases (Simonsmeier, Grabner, Hein, Krenz, & Schneider, 2018). Electrical stimulation, then, would make sense only during learning and it is an empirical fact that learning motivation is SES-dependent (Sirin, 2005). If the wealthier people have better financial means, e.g., to supply their children with the most advanced TES machines or the best / most expensive drugs, and at the same time provide for a more-education-oriented family and/or school climate, we could face an even more extreme social stratification in the future.

In addition, a number of other concerns have been raised (see also Viertbauer & Kögerler, 2019, for an overview):

- If a psychological trait can be successfully and widely enhanced, will it in the long run be devalued? In particular, will intelligence, the trait with the hitherto most pervasive impact on educational and professional success, be "devalued"? Would it lose its societal acceptance on the one hand, and would intelligence tests become useless on the other, because their validity would decrease considerably? The answer to these questions depends on the answer to the above mentioned possibility of a Matthew vs. compensation effect, or concretely whether IQ-dispersion in the population would decrease or increase? In case of massive compensation effects, the reduced IQ-variability could render intelligence tests useless; in case of Matthew effects IQ-dispersion would increase but IQ-tests then might reflect more a (possibly unwanted) social stratification, an effect that could be viewed at odds with the main goal of intelligence tests, namely that to detect 'cognitively gifted' (more) independently of SES background effects. But even if IQ dispersion would not be affected but only the mean IQ rises that could have implications for the relevance of the construct intelligence, by considering threshold effects (like the threshold hypothesis of the intelligence-creativity relation; e.g., Jauk, Benedek, Dunst, & Neubauer, 2013): If many more people would surpass the (often assumed) IQ-threshold of 120, above which intelligence and creativity should have no more relation, then the role of intelligence for creativity might be decreasing (but see the contradictory evidence on this threshold hypothesis; e.g. Weiss, Steger, Schroeders, & Wilhelm, 2020). But, of course, also direct effects of enhancement methods on creativity must be considered, which also applies to all other traits that are a (successful) target of enhancement techniques.

- If all human beings become more intelligent, what would be the societal consequences, positive vs. negative ones? On the positive side, will there be more rationality, less adherence to fake news or conspiracy theories (e.g., Stieger, Gumhalter, Tran, Voracek, & Swami, 2013; Swami, Voracek, Stieger, Tran, & Furnham, 2014)? However, some authors would argue that higher intelligence does not mean higher rationality (Stanovich, 2009). On the negative side: How can societal demands for the current large variety of professions be met? Will we have an overabundance of doctors and no more plumbers? Is such a situation desirable or feasible?
- Can a person with an implanted BCI or DBS device in the brain be "hacked" and exploited by others?
- The autonomy of the person could be put into question. What is my, or my partner's, friend's, child's genuine personality? Is it my own decision to invest in an enhancement or will my partner, my parents, my employer influence my enhancement-related decisions? Who am I after applying enhancements? A better version of my genuine personality or a cyborg? On the other hand: Haven't humans always tried to enhance themselves, to become more intelligent, to acquire more knowledge, to do sports in order to increase brain function (cf. research on the effects of physical exercise on the brain-derived neurotrophic factor, BDNF; Huang, Larsen, Ried-Larsen, Moller, & Andersen, 2014; Szuhany, Buggati, & Otto, 2015)? Why should learning, meditation, sports, and "brain food" be accepted brain-enhancers while TES, TMS, DBS, BCI, or smart drugs are not?

Finally, I propose that an evolutionary perspective should be considered: The variations in most human traits have most likely evolved evolutionarily, and it is assumed that this has the purpose of making the survival of humans less "vulnerable" to varying environmental conditions. Basically, for most psychological traits it can be demonstrated that, although scoring high in many traits like extraversion, conscientiousness, etc. might seem advantageous, the opposite might also be true: Scoring high in a trait provides advantages with regard to some aspects, but disadvantages in others (Nettle, 2006). What might finally happen if, through wide application of enhancement methods, individual differences in personality traits are strongly diminished? What are the consequences for humankind?

Moreover, Hills and Hertwig (2011) reviewed evidence from the "smart drugs" domain, showing that often (a) inverted U-shape functions can be found in response to pharmacological interventions (higher gains for individuals with an around average ability), and (b) there can be unintended and undesired side effects on other traits, e.g., an enhancement of cognition can go alongside with negative effects in other psychological traits. In line with Nettle's (2006) account, Hills and Hertwig then discuss the enhancement issue from an evolutionary perspective and ask: "Why have we not already evolved the abilities that cognitive enhancers offer?" (2011, p. 373).

Concluding this section, it has to be acknowledged that in this section I possibly raise (too) many questions without providing answers or even trying to formulate preliminary hypotheses to those questions. I deliberately refrained from the latter, because – as I hope it might have become clear – the formulation of predictions in this field could quickly become 'reading tea leaves'; because of the many potentially interacting effects. Nevertheless, I want to briefly sum up the important questions raised: Effects of (cognitive) enhancement methods would depend on

- the effectiveness and efficiency of enhancement methods (now and in the future);
- in case they are effective: are they selective, i.e. would they change only mean levels or the dispersion of intelligence?
- if selective, would we observe compensation or Matthew effects?
- who would use enhancement methods (e.g., SES and/or personality dependence)?
- what would be the effects on other individual differences variables (e.g., abilities like creativity, but also personality traits, like the big five, and potential changes in the relationships of these constructs with intelligence?

Finally, the effects can/could be studied on three levels: the individual, the society (or – cross-culturally – societies) and, phylogenetically, the development of humankind. The whole picture might become even more complex if we consider not only the enhancements of human beings (as envisaged by the transhumanists), but we additionally take the development of artificial intelligence into account. The latter might on one side serve us humans to enhance cognitive 'potentialities' or – on the other – might aim at substituting our human intelligence by a machine-made one (as envisaged by the posthumanists). Although these many questions seem overwhelming, I urge for psychological research to start considering and investigating them.

3. Artificial intelligence versus human intelligence

The relationship between artificial intelligence (AI) and human intelligence (HI) can be viewed from a multitude of perspectives. Here, I will focus on the main commonalities/similarities vs. differences as they are relevant for the psychological concept of intelligence.

Generally, given the current ubiquity of the AI topic, it is surprising that so far very little (at least in psychology) has been published on the commonalities vs. the differences between HI and AI. In personal discussions, as well as from an anonymous reviewer, I have repeatedly received the argument that the two intelligences basically have only the term in common and not much or even *nothing* more. It could be argued that the everyday use of the term "intelligence" does not always refer to the rather stable human trait that is the focus of intelligence research but is often used when speaking of researched information, e.g., in criminology, in intelligence service (like CIA etc.) or intelligence corps. Other terms like imagery intelligence, naval intelligence, counter-intelligence are – although they definitely need human intelligence to be gained – not directly related to the intelligence definition in psychology.[1] There is not even consensus among scientists and scholars whether AI needs psychology's definition of intelligence: Should AI simulate human intelligence by using the pertinent knowledge from psychology and neurosciences? Or "is human biology as irrelevant to AI research as bird biology is to aeronautical engineering?" ("Artificial Intelligence,", 2021). There are processes like pattern recognition in huge data sets, massive data-mining in various forms of machine learning where AIs already presently outperform humans by far. On the other hand, there are cognitive processes that we usually subsume in the construct of intelligence and that are included in many current intelligence tests, where AIs fail miserably (e.g. comprehension tests like in Wechsler scale; insight and some reasoning tests; an argument that will be developed later in more detail). The question is also whether we speak of intelligence as a general human quality or the individual differences construct that is the focus of most of human intelligence research (cf. also van der Maas et al., 2021).

Already 10 years ago also the former editor of *Intelligence* Doug Detterman saw the relevance of human intelligence research for AI

[1] "Intelligence is a very general capability that, among other things, involves the ability to reason, plan, solve problems, think abstractly, comprehend complex ideas, learn quickly, and learn from experience… Intelligence, so defined, can be measured, and intelligence tests measure it well" (Gottfredson, 1997, p. 13).

developments, when he made the following proposal (in response to the computer program Watson defeating two all-time champions in Jeopardy!):

> As Editor of *Intelligence*, I would like to issue a challenge to Watson or anyone else who believes they have developed a computer program that approaches human intelligence. I, the editorial board of *Intelligence*, and members of the International Society for Intelligence Research will develop a unique battery of intelligence tests that would be administered to that computer and would result in an actual IQ score. This is identical to the situation any human faces when they take an intelligence test. (Detterman, 2011, p. 77).

Searching the literature for papers dealing with commonalities vs. differences between human intelligence and AI gives surprisingly few hits. Before going into that, we must define the AI we are referring to. In the literature the main distinction is made between weak and strong AI. Weak or narrow AI focusses only on specific pre-learned reasoning or problem-solving tasks, such as playing chess or translating languages. On the other, strong AI, sometimes also termed *full AI* or *general intelligent action,* aims at achieving or surpassing human levels in "reasoning, knowledge representation, planning, learning, natural language processing, perception and the ability to move and manipulate objects." ("Artificial Intelligence,", 2021). Here, the long-term goal is artificial general intelligence, which is defined as a "hypothetical intelligence of a computer program that has the capacity to understand or learn any intellectual task that a human being can" ("Artificial General Intelligence,", 2021). Therefore, it is the strong AI that is relevant for the present discussion; and particularly this is currently making enormous progress with the developments of so-called artificial neural networks, its variant the convolutional neural networks, deep learning, deep neural networks and reinforcement learning networks (for more detailed descriptions see van der Maas et al., 2021).

But in some notions, the AI definition goes far beyond our psychological definition of human cognitive intelligence: In these notions (e.g., the AI views of Ray Kurzweil, 2006, and Nick Bostrom, 2014; see Section 4) it is intended not only to perform human-like cognitive abilities but finally also to have a personality. Other scholars reserve the term strong AI only for computer programs that can experience self-awareness and consciousness. Following the latter definition we currently have only weak AIs, while strong AIs with self-consciousness are – by most scholars – seen as being (many) decades away, if it is possible to develop them at all (at least given the currently available computers/hardware).

Given these two presuppositions – (i) intelligence defined psychometrically / as an individual differences construct and (ii) speaking of a currently or likely soon available narrower strong AI (i.e. ANNs, CNNS, neural networks) – it seemss possible to elaborate on convergent vs. discriminant aspects of human vs. artificial intelligence. However, even 10 years after Detterman's proposal, the currently available literature offers very little insight on this. It comes mostly from scientists outside psychometric/psychological research areas and comes in two strands:

(a) The "universal psychometrics" approach by the research group around Hernández-Orallo (e.g. Hernández Orallo et al., 2014) and Bringsjord's (2011) "Psychometric AI"; on both I will outline here (a more comprehensive account also of a few other attempts will be given in (Neubauer & Grinschgl, 2021) . They both follow the goal of psychometric tests that could be applied to machines in the same or at least a very similar way as in humans. Hernández Orallo et al. (2014) have developed possibly the currently most advanced "universal intelligence tests." These so-called C-tests (based on Kolmogorov complexity) can be used to test the IQ of machines as well as of humans; and if applied in the latter, their results are highly correlated with classical intelligence tests (Hernández-Orallo & Minaya-Collado, 1998). So far, using several such tests, machines/AIs are more successful in solving those kinds of tests that can be easily formalized, like number series, (Raven-like) matrices (see also Martinez-Plumed, Ferri, Hernandez-Orallo, & Ramirez-Quintana, 2017). But they fail miserably when it comes to other tests like general comprehension from the Wechsler scales (see Besold, Hernandez-Orallo, & Schmid, 2015 for a review of diverse attempts). These latter authors also describe an inherent problem with this approach:

> …even if AI uses IQ tests as a challenging area of application, there is no need to ascribe intelligence to such programs—evaluation can be done by comparing the performance of different algorithms. Nevertheless, many researchers may still have the implicit assumption that a program which performs better is more intelligent. (p. 294).

They point to an important main difference between humans and computers: "the crucial question is not whether this model is intelligent in itself but to what extent it mimics the cognitive processes performed by humans when solving such problems, that is, whether the model can provide an explanation of human behavior." (p. 294). These authors list several other reasonable arguments for why a universal IQ measurement has strong limitations including, among others: Can speed-of-processing (as a central component of human intelligence) be measured in machines in a meaningful way as well? Probably not, as in practically all routine-based tasks computers outperform humans by far. Will machines show a g-factor as well? Can the different facets/subtests as assessed in psychometric intelligence tests be aggregated in the same way as in IQ tests? These authors, therefore, conclude:

> Most of the research in human intelligence is then, in principle, not extrapolatable to machines (not even to animals), raising delicate issues about the breadth, composition and interpretation of separate results of any test battery for machines. (p. 295 f.)

Another central issue is brought to the fore by Bringsjord (2011); see also Bringsjord & Licato, 2012) when referring to Newell's famous 1973 paper, in which the latter distinguished three ways of creating "machine intelligence." Bringsjord points to the hitherto largely neglected third way described by Newell:

> The third alternative paradigm I have in mind is to stay with the diverse collection of small experimental tasks, as now, but to construct a single system to perform them all. This single system (this model of the human information processor) would have to take the instructions for each, as well as carry out the task. For it must truly be a single system in order to provide the integration we seek. (Newell, 1973, p. 305).

The goal described here is that a single program should be devised that allows taking a standard test like the WAIS or Binet Test. On this basis, Bringsjord develops his concept, namely a psychometrics-oriented account of intelligence that fulfills this requirement: "…some agent is intelligent if and only if it excels at all established, validated tests of intelligence" (Bringsjord, 2011, p. 273). So far, so good. This would be a clear-cut operationalization from which the problem could be tackled in a systematic way. But Bringsjord goes far beyond this when he aims at a "less naïve definition of AI":

> Psychometric AI is the field devoted to building information-processing entities capable of at least solid performance on all established, validated tests of intelligence and mental ability, a class of tests that includes not just the rather restrictive IQ tests, but also – and this is important given the tests on which the papers in the present special issue are focused – tests of artistic and literary creativity, mechanical ability, and so on (2011, p.273).

The central question raised by Bringsjord is whether to aim at "narrow" as opposed to "broad" intelligence tests. Again, we are confronted with the question: Must an AI not be able to solve *any kind of cognitive task* that we can ascribe human-like intelligence to in order for it to be a general AI? But where is the border between narrow and broad? Bringsjord seems also not to be very consistent in this, when one contrasts the quote above (also demanding tests of literary and artistic creativity for a broad intelligence test) to another section of the same paper where he labels the WAIS as a broad test of intelligence. It must be admitted here that psychometric intelligence research, too, has not always been completely clear on this question, given that some multifactorial intelligence tests, for example, include divergent thinking tasks (like the Guilford, 1967, or Jäger's Berlin model of Intelligence Structure tests; Jäger, 1982, see also Bucik & Neubauer, 1996) while others do not (e.g., the WAIS).

At least we can learn from Bringsjord that we, as intelligence researchers, should come to a clear-cut proposal on what is to be included in a "broad intelligence test." Perhaps the Cattell-Horn-Carroll (CHC) model (McGrew, 2009) could actually be the best start for such an attempt (cf. also Chollet, 2019)? This would have the advantage that at least we can base our concept on *cognitive* tasks as part of an intelligence definition that could be applied to test machines regarding their "psychometric IQ." An attempt using large databases of IQ test items to test AI has been reported by Liu et al. (2019).

An alternative view of the capabilities of human vs. artificial intelligence has recently been put forward in the already mentioned article by van der Maas et al. (2021). They see current AI on par with or even superior to human intelligence when either the cognitive problems are formalized or when they refer to crystallized intelligence. But current AIs still have strong limits when they deal with completely novel situations, addressing the problem that AIs have with 'generalizability', namely that "humans are able to transfer solutions from one problem domain to another, apply general, abstract concepts…and develop solutions for completely new problems." (p. 5). AIs often fail in that or need immense amount of trainings (Lake, Ullman, Tenenbaum, & Gershman, 2017). Van der Maas et al. conclude that "generalization is still a weakness of AI systems" (p. 5). And they surmise that with the recent progress in AI we also have to rethink our definition of intelligence, putting less emphasis on information processing and problem solving and more on the ability of generalization and of dealing with completely novel cases.

But all these psychometrically oriented attempts might not be what some other scholars have in mind when they speak of a strong AI and this brings us to the second strand of these attempts:

(b) Completely different from the universal/psychometric accounts is the second strand that – among others – comes mostly from the perspective of educational scientists. It is based on a seemingly rather fuzzy and overinclusive definition of human intelligence that covers not only cognitive and social intelligences but also diverse forms of meta-intelligences, including concepts like meta-knowing, meta-cognition, meta-subjective, meta-contextual intelligences, and perceived self-efficacy (Bearman & Luckin, 2020). Not that these concepts are not relevant to intelligent human behavior, but in empirical psychology in general and in intelligence research in particular we have worked hard to clearly define the intelligence construct and to discriminate it from other constructs such as knowledge, skill, motivation, or self-efficacy and self-concept variables. Such approaches, therefore, risk falling for the jingle–jangle fallacies: Quite different psychological constructs that in empirical psychology are tackled in psychometrically very different ways (e.g., convergent tests for intelligence assessment vs. divergent tests for creativity tests vs. questionnaires for assessing constructs like self-efficacy) are all subsumed under one diffuse umbrella term "intelligence," although also empirically they are often not, or at best are weakly correlated with each other.

In some way similar are argumentations proposed by philosophers who, for example, entertain the view that a "computationalist" view of AI does not do justice to human intelligence per se. These scholars maintain that AI must reflect also the "embeddedness" of human intelligence in a world and its "embodiment" (Dreyfus, 2007; Gelernter, 2016) and some even miss concepts like "care" and "desire" as part of an AI (Olivier, 2017).

But here is the thing: As already surmised above, possibly such a fuzzy definition of human intelligence is much closer to what most other scientists and scholars have in mind when they speak of strong AI, and even more so of the super-intelligence. They mean not the defined classes of cognitive tasks as we find them in intelligence tests (some of which can in fact be handled by weak AI programs, e.g., number series; Besold et al., 2015) but rather an "intelligence" that includes emotions, motivations, and that finally has a self-awareness and even self-consciousness. And this is what the proponents of a super-intelligence / of a singularity speak of. Before we come to that, let me conclude that an exact elaboration of the convergent vs. discriminant aspects of AI vs. HI is still outstanding. As suggested by Detterman (2011), this would require an analysis of which kinds of tasks (e.g., number series or knowledge tests) an AI will easily outperform even the humans with the highest IQs, and in which it most likely will still be failing (Detterman assumed insight and reasoning tasks to be of this kind). Here, there is not enough space for such an exercise, but we are preparing that for another, more elaborate contribution (Neubauer & Grinschgl, 2021).

4. Singularity and super-intelligence

The most (and probably over-) optimistic and famous scholar regarding the AI time perspective is Ray Kurzweil. In his highly influential book, *The Singularity Is Near* (Kurzweil, 2006), he – on the basis of Moore's law (1965) describing the exponential improvement in digital technology – predicts a self-aware AI with consciousness by 2045. He depicts this super-intelligence as clearly superior to human intelligence as it also incorporates ethical human values/standards in much higher perfection than humans themselves.

A more differentiated account is provided by the also highly influential Bostrom (2014), differentiates three aspects: 1. A speed super-intelligence; 2. a collective super-intelligence; and 3. a quality super-intelligence (a more elaborate presentation of Bostrom's theory is not directly relevant for this contribution and I will reserve it for a later publication; (Neubauer & Grinschgl, 2021)). Bostrom depicts a (partly) dystopic scenario of the singularity, i.e., a single super AI that would surpass all other AIs (and of course all humans), that would take command in the world and could not be controlled by any human or any other AI anymore, because it can successfully protect itself from being shut down. This could – in the current stage of AI development – possibly be prevented only by instilling human values into it, but, contrary to Kurzweil, Bostrom is also in strong doubt as to whether this would be fully possible. Thus, the super-intelligence could also be a threat to humankind.

However, currently most (computer) scientists do not see such an imminent threat. In an older survey (see Bostrom, 2014) about human-level machine intelligence (HLMI), i.e., the level of an average individual (i.e., in our, the psychological researchers of intelligence, definition corresponding to IQ = 100) saw a 10% chance for 2022, 50% for 2040, and 90% for 2075. If we use the 2040 estimate and assume that it takes another 50 years from IQ = 100 to super-intelligence (higher than the highest measured human IQ, which is currently estimated at IQ = 228; see The Independent, 1987), then we can assume that a super-intelligence will not be around before somewhere around the next turn of the century. But even that idea might be discomforting.

Today, even the most advanced AIs are far away from the population mean IQ of 100, but the development seems to accelerate: While in 2014 the highest IQ_{AI} was estimated at 26 (corresponding to a 3-year-old), already in 2016 the level of a 6-year-old ($IQ_{AI} = 47$) was reached (Otte, 2019). However, an extrapolation from these numbers is difficult, because nobody can predict the form of the trajectory of future AI development. While some researchers assume an exponential growth, others predict a logarithmic development. Just as in transhumanistic interventions, we are confronted with the question of assuming a positive or a reverse (negative) Matthew effect: Will, with each gain of an AI by let's say 10 IQ points, the development slow down or will it accelerate? Will a less intelligent AI have better chances for improvement or – vice versa – will an already more intelligent AI have better capacities to show stronger increases? The answer to this question will depend on what AI, or more precisely what (kind of) computers we are speaking of. Given the doubling of computing power every two years, an exponential growth of "speed intelligence" could be predicted. Nevertheless, the question is whether this would translate into a similar development for Bostrom's "collective super-intelligence" and even more for his "qualitative super-intelligence." Collective super-intelligence would be '*A system composed of a large number of smaller intellects such that the system's overall performance across many very general domains vastly outstrips that of any current cognitive system*. (Bostrom, 2014, p. 54,).

Quality superintelligence is a '*system that is at least as fast as a human mind and vastly qualitatively smarter'* Bostrom, 2014, p. 56,).

Most experts predict that strong AI (with self-awareneness or even self-consciousness) could not be achieved with classical computers (using binary computation) because – among other reasons – concepts like emotions, motivation, and morality cannot be "coded" but could be realized only with so-called neuromorphic computers (Otte, 2019).

But if we refocus on the main question on the relation of current theorizing on human intelligence and artificial intelligence, we can, for now, conclude that both Bostrom's collective and qualitative intelligence concepts go way beyond current theorizing in psychological intelligence research. This needs an elaborate contrasting of the human intelligence concept and Bostrom's three intelligences (Neubauer & Grinschgl, 2021).

5. Implications for intelligence research

Someday humans might not be able to keep up with AI(s) anymore and, while currently (cognitive) intelligence could be considered one of the most important human psychological traits, this might no longer be the case in 20, 50, or 100 years. What is then left for humans? Will the "niche" of humans be the social/emotional competence and/or creativity? Currently, emotions and social processes cannot be "coded" in the form of algorithms to run on computers, thus these processes might remain the specialty of humankind.

And would that mean the "end" for intelligence research, as envisaged in Rich Haier's editorial "The End of Intelligence Research" more than 30 years ago in this journal (Haier, 1990)? At that time, Haier envisaged the end of intelligence research because of expected breakthroughs in the neuroscience approaches to intelligence. Now, 30 years later, the danger of intelligence research coming to an end might, in my view, rather arise from the field of AI. To counteract this possibility, psychology needs to become more active in contributing to future AI developments. More specifically, AI research needs the knowledge from psychological and neurobiological (including genetic) intelligence research knowledge regarding

- the definition of intelligence and its structure: What intelligence factors are more vs. less prone to AI automation and – therefore – to a replacement of human intelligence by computers/AIs?;
- the neurobiological underpinnings of intelligence: These might become relevant in case "neuromorphic computers" enter the stage (cf. Hassabis, Kumaran, Summerfield, & Botvinick, 2017);
- the genetic vs. environmental effects on intelligence development: This might be relevant for the concept of genetic design (a field that is also an issue in transhumanistic discussions, but not covered here);
- the antecedents and consequences of individual differences in intelligence: Will effects of, for instance, kindergarten/schooling/education (e.g., Ceci, 1991) on intelligence development become less relevant, or must aims, goals, and values in schools etc. be changed if intelligence is no longer a central resource of educational or occupational success? As already mentioned: Will other forms of "intelligence" (given that we call them intelligence; cf. the discussion about emotional intelligence) save the human superiority over AI / a singularity?;
- the relations of psychometric intelligence to other traits (big five, dark triad, motivation, values, interests): Should psychology not contribute much more to the design of AI, i.e., inquire into the interplay between intelligence and creativity (Kaufman & Plucker, 2011), intelligence and big five traits, or dark triad traits, and values? Should we ensure that a singularity involves central human values and that a singularity becomes accepting of all humans (e.g. Zagorsky, Reiter, Chatterjee, & Nowak, 2013)?

Whatever the answers to these questions are, it is time that the psychology of individual differences in general, and intelligence research in particular, contributes to these discussions and gets actively involved in future AI research, as well as in the trans−/posthumanism debates.

Detterman had already made this suggestion 10 years ago: "Watson gives us hope that it may someday happen and that the fields of artificial and human intelligence will grow closer together, each learning from the other" (2011, p.78).

But here is the paradox: If we gain more and more knowledge on human intelligence, emotional and social competencies, creativity etc., also a future AI can (and likely will) incorporate this knowledge and be better equipped to become a super-intelligence. In turn, this super-intelligence might no longer be controllable. Shall we, therefore, stop the further development of any research on intelligence, personality, psychology or the neurosciences? Definitely not, but at least we have to start reflecting on the possible future endeavor of the research on human intelligence. And this should take into account the quest for self-enhancements as promoted by transhumanism, but also consider a posthumanist future. If we do so, I hope we will protect ourselves against "the end of intelligence research" and instead face a bright "future for intelligence research."

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