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FORUM ARTICLE

Cognitive enhancement for the ageing world: opportunities and challenges

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Abstract

Population ageing and the global burden of dementia pose a major challenge for human societies and a priority for public health. Cognitive enhancement, *i.e.* the targeted amplification of core cognitive abilities, is raising increasing attention among researchers as an effective strategy to complement traditional therapeutic and assistive approaches, and reduce the impact of age-related cognitive disability. In this paper, we discuss the possible applicability of cognitive enhancement for public health purposes to mitigate the burden of population ageing and dementia. After discussing the promises and challenges associated with enhancing ageing citizens and people with cognitive disabilities, we argue that global societies have a moral obligation to consider the careful use of cognitive enhancement technologies as a possible strategy to improve individual and public health. In addition, we address a few primary normative issues and possible objections that could arise from the implementation of public health-oriented cognitive enhancement technologies.

Keywords: cognitive enhancement; public health; ethics; technology governance; policy

Introduction: global ageing and dementia

Today, approximately 12 per cent of the world's population is over the age of 60; by 2050 this proportion is expected to have more than doubled (United Nations 2015*a*). This trend is particularly recognisable in Europe, as the proportion of individuals older than 65 years is estimated to increase from 16.1 per cent in 2000 to 27.5 per cent by 2050, while the proportion of the population aged over 80 years (3.6% in 2000) is expected to reach 10 per cent by 2050 (Rechel *et al.* 2013). This demographic trend brings multiple health-related concerns, one of which is the rise in the number of older persons living with neurocognitive disabilities or experiencing age-related cognitive decline. In fact, the probability of becoming cognitively impaired significantly increases with age. Cross-sectional comparisons have consistently demonstrated that increased age is associated with lower levels of cognitive performance, with some cognitive functions beginning to decline already in young adults and then worsening dramatically after the age of 60 (Salthouse 2009). In addition, the prevalence of dementia-causing neuroprogressive disorders also correlates significantly with advancing age. For example, Alzheimer's disease, the most frequent type of age-related dementia, affects less than 1 per cent of the population under the age of 59, almost 4 per cent of the population segment aged 60–79 and over 11 per cent of those aged 80–89. With the ageing of the global population, the number of people with Alzheimer's disease worldwide is expected to nearly triple by 2050 (Alzheimer's Association 2017).

Global ageing and the consequent increasing prevalence of cognitive decline pose a 'priority for public health' in terms of financial management and care-giving burden (Frankish and Horton 2017). According to the *World Alzheimer Report 2015*, the annual societal and economic cost of dementia in the United States of America (USA) has reached US $818 billion, a 35 per cent increase compared to 2010. By 2018, it is expected to skyrocket to a trillion dollars (Prince *et al.* 2015).

These significant costs arise primarily from long-term care at nursing homes and other health-care institutions; their burden might affect not only public finances but also senior citizens, their non-professional care-givers (*e.g.* relatives) and the health-care system. At the family level, the problem of population ageing often results in a burden on informal carers. In most countries, the primary source of care, assistance and support for older and disabled adults is informal care-givers, who are mostly family members such as spouses, children and grandchildren. This informal care-giving service is highly time-consuming and requires great effort from care-givers in terms of physical and mental energy. The provision of care-giving services frequently comes at high socio-economic cost for care-givers, who often need to give up jobs, leisure time and social activities to take care of their loved ones effectively. As research shows (Schulz and Martire 2004; Sörensen and Conwell 2011; Vitaliano *et al.* 2014), the informal care-giving burden for older and disabled people is a significant source of psychological distress for carers, worsened mental health functioning, anxiety, perceived stress and depression (Vitaliano *et al.* 2014). As most care-givers of seniors with physical or cognitive disabilities are themselves growing older (average age 63), and one-third of them are reported to be in fair to poor health (Administration on Ageing 2004), the reduction of care-giving burden could play a major role in the promotion of healthy and successful ageing within society at large. In spite of this multi-domain burden, informal care is neither accounted for nor reimbursed in the health-care economy in most countries (Bhimani 2014). Finally, at the individual level, older people with dementia or age-related cognitive decline experience diminished quality of life, reduced independence and low work productivity (Prince *et al.* 2015).

Cognitive enhancement

Cognitive enhancement (CE) refers to the 'amplification or extension of core capacities of the mind through improvement or augmentation of internal or external information processing systems' (Bostrom and Sandberg 2009: 311).

Philosophers and scientists have long debated on what degree of improvement or augmentation of internal or external information-processing systems qualifies as

CE. Some authors, for example, have argued that a line can be drawn between *enhancement* and *therapy* (Juengst 1997), with the former only denoting improvements beyond the norm[1] and the latter denoting improvements aimed at restoring lower-than-normal function. In recent years, however, researchers have underscored the 'elusive nature' of this line (Colleton 2008) and expressed scepticism regarding the conceptual validity (Harris and Chan 2008) and practical significance (Bostrom and Sandberg 2009) of the enhancement–therapy distinction. While a detailed description of the conceptual debate over enhancement is beyond the scopes of this article, our analysis will use the notion of CE to define any amplification of core mental capacities, encompassing interventions aimed at both restoring function towards the norm and improving it beyond it.

CE via augmentation of internal information-processing systems usually occurs through interventions that target the underlying neurobiology of the cognising agent. This can occur either chemically or electronically. Chemical enhancement usually consists of the administration of cognition-enhancing pharmacological interventions. For example, the nootropic drug Piracetam, a cyclic derivative of GABA (γ-aminobutyric acid), has demonstrated benefits in treating neuro-degenerative diseases such as Alzheimer's disease by improving alertness and memory (Leuner *et al.* 2010), and is also prevalent amongst college students seeking cognitive performance boosts (*e.g.* during preparation for examinations).[2] Internal electronic enhancement usually occurs through the use of technologies that interface the brain of the cognising agent. Neural prostheses are devices that can repair, replace or enhance motor, sensory or cognitive capacities that might have been damaged as a result of an injury or a disease (Guggenmos *et al.* 2013). These include sensory prosthetics such as cochlear implants,[3] motor-prosthetics such as bladder control implants[4] and cognitive neural prosthetics *stricto sensu*. The latter are capable of recording the cognitive state of the subject, rather than just signals strictly related to motor execution or sensation. Using high-level cortical signals, cognitive prostheses can partly compensate for declining cognitive functions including intention, motor imagery, decision making, forward estimation, executive function, attention, learning and multi-effector movement planning (Andersen, Hwang and Mulliken 2010). Cognitive neural prosthetics *stricto sensu* need to be distinguished from technologies that non-invasively (*i.e.* from outside the skull) enhance internal information processing, like non-invasive neuromodulation (To *et al.* 2018).

Augmentation of external information-processing systems usually occurs through interventions that do not directly target the underlying neurobiology of the cognising agent but rather non-invasively modify the environment within which the cognising agent interacts, alter the agent's habits or provide external cognitive resources to support cognition from outside the skull. For example, after their extensive review of the literature, Halperin and Healey have concluded that strategies of 'environmental enrichment', *i.e.* environmental manipulations of the natural and social environment with the purpose of improving the agent's cognitive capacities, have a powerful influence as cognitive enhancers (Halperin and Healey 2011). These influences include modifications of air pollution levels, urban planning strategies, home design, quality of parenting, and creation or protection of large and reliable social networks such as family and friends, *etc.* Interventions targeting the agent's habits have also demonstrated effectiveness in

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enhancing cognitive functions. These include optimal amount of sleep, healthy nutrition, drug avoidance, regular physical exercise and sports, reading, brain-training, *etc*. Finally, several digital (both hardware and software) systems are increasingly usable as external cognitive support tools or cognitive extensions in modern societies. A paradigmatic example is the smartphone which is pervasively used as additional memory storage space, spatial orientation and navigation assistant (through the use of mapping services and Global Positioning System-tracking apps), task reminder, activity planner and verbal communication tool, hence supplementing critical intracranial cognitive functions (Barr *et al.* 2015). Today, a number of external hardware (*e.g.* robotic assistants) and software (*e.g.* mobile apps) applications 'routinely give human beings effective cognitive abilities that in many respects far outstrip those of biological brains' (Sandberg and Bostrom 2006: 202). For example, cognitive processes such as arithmetic calculus and geolocalisation are now prevalently and more effectively performed in humans through external software than through internal information processing (Carr and Harnad 2011).

With advances in cognitive neuroscience, clinical neurology, neural engineering and computer technology, the number of cognitive capacities that can be augmented through improvement of information-processing systems (both internally and externally) is increasing. These include memory, sensory, perception, attention and language.

CE raises a number of ethical questions. In 2008, an article appeared in *Nature* which raised awareness among scientists about the ethical implications of CE and called for an evidence-based approach to the cost–benefit analysis of cognitive enhancers. The authors identified three major ethical issues: safety, fairness and coercion (Greely *et al.* 2008). Since then, the ethical debate over CE has largely focused on the theoretical permissibility of cognitive-enhancing interventions rather than on the applicability of CE to specific population segments to improve public health. As Shaw (2014: 389) observes, the CE literature 'has focused on cosmetic neurology and *restoring* those of sub-par ability to the normal range', paying very little attention to developing strategies for improving the physical and psychological health of the public via CE (Shaw 2014). One exception is represented by paediatric neuroenhancement, as some studies have explored the ethics of health-improving applications of CE. For example, Singh and Kelleher (2010) have proposed that the primary care clinic should be the relevant site where young people's use of enhancement technologies can be safely and objectively managed in a manner that maximises the benefits of these technologies while minimising the risks.

In spite of the growing prevalence of age-related cognitive decline, the applicability of CE for public health purposes remains largely unexplored. In this paper, we conduct a narrative review of the existing literature on CE solutions for older people and propose an ethical stance for the safe and effective implementation of CE in light of global population ageing. We argue that, in light of the current clinical, financial and organisational burden of ageing and dementia, global societies have a moral obligation to consider the careful use of 'cognitive enhancement technologies' (Cabrera 2015) as a strategy to improve individual and public health. In addition, we address a few primary normative issues that could arise from the implementation of public health-oriented CE interventions, with the

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purpose of preparing the normative ethical terrain for such future interventions. Finally, we respond to possible objections against the use of CE among seniors.

Cognitive enhancement for the ageing world

Opportunities

Research shows that the calibrated application of CE technologies has the potential to alleviate the global burden of population ageing and age-dependent cognitive decline. Recent findings in clinical neuroscience have demonstrated that neural and cognitive functions in older adults can be enhanced using cognitive training techniques (Park and Bischof 2013). For example, several studies have focused on establishing the impact of exercise on the nervous system and the associated cognitive benefits. Daily aerobic exercise over a long period of time has been observed to increase oxygen transport and energy resources by maintaining blood vessels of the brain and improving the growth and function of brain cells (Allen and Morelli 2011). Based on this evidence, Korean researchers have developed a CE gymnastics programme for older people with dementia and verified its effects (Han *et al.* 2016). Their results show that such enhancement programmes improve gait capability, balance sense and the performance of activities of daily living in people with Alzheimer's disease or vascular dementia (average age = 80.93 years, standard deviation (SD) = 5.19). Similarly, European researchers have developed and tested a physical activity programme that can significantly slow cognitive decline and improve quality of walking in older persons living with dementia aged 81.8 (SD = 5.3) years (Kemoun *et al.* 2010). Besides physical training, environmental interventions have shown great potential too. In their extensive review, Park and Bishof (2013) have concluded that engagement in an environment that requires sustained cognitive effort facilitates cognitive function in older adults, and that modifications of the social environment such as social participation and engaged lifestyle increase behavioural performance on executive function tasks (Park and Bischof 2013). In parallel, randomised controlled trials involving pharmaceutical neuroenhancers have also achieved promising results. A double-blind trial involving 140 older individuals with mild cognitive impairment aged 76.91 (SD = 8.06) years for a period of six months has shown that a cholinesterase inhibitor called donepezil improves gait performance and reduces the risk of falling (Montero-Odasso *et al.* 2012, 2015). Finally, advances in micro-computing, mobile technology and artificial intelligence are also producing positive results. For example, tablet-based tools have shown effectiveness as cognitive assistants for the augmentation of decision-making capacities among senior citizens (Buman *et al.* 2013), reminiscence (Hellman 2014) and social interaction (Saracchini, Catalina and Bordoni 2015). Last year, the release of the ten-year findings from the Advanced Cognitive Training for Independent and Vital Elderly (ACTIVE) study showed that computer-based CE technologies can not only augment cognition but also reduce dementia risk among older adults (Parrot *et al.* 2016). Through a large randomised-controlled design (2,785 participants at six trial sites in the USA), researchers detected a 33 per cent reduction ($p = 0.012$) in the risk of developing cognitive decline or dementia over the next ten years.

Such rapid advancements in CE for senior citizens are particularly promising in the light of the current limited possibilities in geriatric medicine. Today, in spite of some promising applications of stem cell-based epigenetic regulation in human cell line (Hashizume *et al.* 2015), reversing ageing is still scientifically impracticable. In addition, most neurogeriatric disorders such as Alzheimer's and Parkinson's disease are currently incurable. Available therapeutic strategies can either delay disease progression or temporarily remediate to contingent symptoms (Prince *et al.* 2015).

As findings show that CE could be of great benefit for elderly and dementia care, we argue that there is a moral obligation to consider CE as one additional strategic avenue for addressing the global burden of population ageing worldwide and improving the lives of senior citizens. In fact, the careful and calibrated use of CE interventions could complement existing preventive and therapeutic strategies, resulting in better public health outcomes. CE technologies, in fact, could help amplify core mental capacities of senior citizens in a manner that restores function towards the norm or even improves it beyond it.

Challenges

Four considerations are important in relation to this proposal. First, CE interventions are not and should not be intended to replace prevention and therapy. In contrast, they are and should be designed with the purpose of complementing existing strategies as part of a comprehensive public health enterprise. Effective CE interventions that can mitigate cognitive decline, reduce the risk of neuroprogressive disorders, and contribute to the promotion of healthy and successful ageing among senior citizens could successfully complement and enhance existing public health strategies.

This continuity between CE and public health is confirmed by the consideration that, in the context of elderly care, the line between enhancement and treatment is, as previously observed, hard to draw. This is particularly evident in geriatric medicine. As Bostrom and Sandberg observed, CE of a person X with poor biological memory could leave that person with a memory that is still worse than that of a person Y who has retained a fairly good memory despite being recently diagnosed with an identifiable pathology, such as mild cognitive impairment or early stage Alzheimer's disease (Bostrom and Sandberg 2009). In addition, as the ACTIVE study shows, CE strategies such as long-term computer-based cognitive training among healthy older adults may be effective in preventing neurogeriatric pathologies (Parrot *et al.* 2016).

Second, the implementation of CE technologies should be guided by a procedural, evidence-based approach that prioritises those interventions that have demonstrably higher clinical effectiveness and safety over other interventions. In addition, interventions that involve low financial costs should be prioritised over more-expensive interventions, provided all other parameters (clinical effectiveness and safety) are equal. For example, easy-to-implement and inexpensive measures such as environment modifications and low-cost brain-training programmes should be prioritised – *ceteris paribus* – over costly high-tech interventions.

Third, interventions should be non-coercive (Ienca and Andorno 2017; Sententia 2004). Mentally competent older adults should have the right and liberty to choose whether to use CE technologies or refuse to do so. Following public health campaigns based on traditional CE technologies such as healthy nutrition and physical exercise, citizens should be thoroughly informed about the clinical and non-clinical benefits of adapting their habits to public health goals. While under some circumstances, seniors may be implicitly oriented towards these goals through nudging, financial incentives and other promotional strategies, we argue that CE interventions, unlike other forms of human enhancement such as immune enhancement via vaccination, should not be mandatory as a default position. The reason for that is twofold. First, because ageing and most neurological disorders that can be alleviated via CE are not communicable: in the absence of any equivalent of herd immunity, the group of individuals that will choose to enhance will not increase in any significant sense the protection of those individuals who cannot do it. Second, because CE interventions should respect the individual right to cognitive liberty, an emerging fundamental right that comprises two intimately related principles: the right of individuals to use CE technologies, and the protection of individuals from the coercive and unconsented use of such technologies. Cognitive liberty has often been presented by scholars as the fundamental level of self-determination, because 'the right and freedom to control one's own consciousness and electrochemical thought processes is the necessary substrate for just about every other freedom' (Sententia 2004: 227). It is worth noting, however, that the right to cognitive liberty may not be an absolute but a relative right. Therefore, while no form of coercion should be accepted as a default position, *soft-paternalistic* strategies (Fateh-Moghadam and Gutmann 2014) could be morally acceptable under certain circumstances. The use of nudging and soft paternalism – use of maps on the floor and environmental alarm systems to avoid wandering installed in the absence of explicit consent – is currently accepted in the care of people with advanced dementia when this is considered in the best interest of patients. Similarly, temporary limitations to cognitive liberty for the purposes of CE might be morally accepted if these are in the best interest of patients (*e.g.* proportionally reducing suffering in the absence of relevant adverse effects). However, we argue that soft paternalism may become ethically problematic if it leads to situations where CE is not mandatory but refusal of it leads to punitive financial consequences in terms of providing for one's own care.

Fourth, CE strategies should be justice-oriented and prevent the exacerbation of pre-existing socio-economic inequalities. Shaw (2014) has examined the prospect of improving health outcomes through CE among sections of the population where health inequalities are particularly pronounced. He called this enhancement of the population health through CE 'neuroenhancing public health' (Shaw 2014). In light of the considerations described above, elderly care might be at the core of this public health enterprise.

Possible objections

The proposal of neuroenhancing public health measures to alleviate the global burden of population ageing and cognitive decline might be opposed on various grounds. First, it might be argued that it represents a form of ageism, *i.e.* discrimination against older people. For example, Hertogh (2013) has argued that the focus on successful ageing is a form of ageism that works out as a negative incentive to the care for the oldest-old. The reason for that stems from the consideration that CE strategies aiming to promote successful ageing might fail to recognise the inevitable nature of ageing and age-dependent frailty or psycho-physical decline. In addition, at the pragmatic level, focusing on preventing or delaying age-dependent decline might result in reduced support for frail older adults that need care. In response to this concern, we argue that CE technologies that aim to prevent or mitigate the cognitive effects of ageing are not more ageist than preventive or therapeutic interventions in geriatric medicine that aim to prevent or cure physical age-dependent disorders. Therefore, objecting to CE on this ground would thereby imply that geriatric medicine itself is ageist in character. Second, CE interventions that can help older adults maintain their cognitive capacities, physical skills and social relationships can thereby empower them and protect their individual autonomy. Instead of being a form of discrimination, CE would enable seniors to maintain greater independence and promote their freedom to make choices and select courses of action according to their intended plans, with fewer external constraints and limitations. Finally, as it may delay or partly obviate the need for institutionalised care (Bharucha *et al.* 2009; Pollack 2007), CE is predicted to alleviate the burden on the health-care system. In a time when the provision of institutional care for the ageing population is increasingly threatened by financial and logistical limitations (*The Guardian 2016*), CE strategies might actually help allocate the available resources to those population groups – such as the oldest-old or elders with advanced dementia – that are in greater need of institutional care and skilled support. It could even be argued that it would actually be discriminatory to deny older people access to CE, given the disproportionate burden of mental problems that affects this group – particularly if CE for health reasons becomes more widespread among other age groups.

The point about resources is closely related to the possibility that CE plans for older people might be economically impracticable in a world where 12 per cent of the population is over the age of 60 (United Nations 2015*a*). While this is an empirical question that can only be answered based on existing data and statistical predictions, it is worth considering that the costs of CE should not be considered in absolute terms, but proportionally to the costs that could be potentially saved on health-care budgets through the effective implementation of CE strategies. In light of current demographic trends, the rapid erosion of the care-giver-to-patient ratio, and the consequent financial and practical unsustainability of long-term institutional care for a growing older population in the near future, CE could offer a valuable complementary solution to existing public health strategies. It is possible, however, that long-term care costs might actually increase if CE delays entry into care but prolongs time in care overall. Future research should assess the financial sustainability of this proposal in the light of current and future demo-economic variables.

Some authors have observed that most common views on CE are paternalistic (Corbellini and Sirgiovanni 2015), a problem that might become even more evident if these views are expressed through public health initiatives. However, we think that this risk applies only to CE plans that involve hard paternalistic and coercive measures or are misimplemented in a manner that violates the individual right to cognitive liberty.

A more substantial concern is the risk that unevenly distributed CE technologies could generate a neurotechnological divide which might exacerbate pre-existing socio-economic inequalities. In fact, while ageing and age-related cognitive decline are common to all socio-economic classes, there is the latent risk that only certain socio-economic groups could afford, and hence benefit from, CE technologies. This risk will be discussed in the following section.

Preserving fairness in cognitive enhancement

In regard to costs and fairness, two considerations are important. First, several forms of CE for senior citizens with reported effectiveness such as physical exercise and environment modification do not involve costly equipment. Therefore, they could be implemented in a manner that minimises socio-economic divides. Second, with the average cost of care in an assisted living facility in the USA reaching US $3,293 per resident per month (United States Department of Health and Human Services 2017), the current state of long-term care is a major threat to socio-economic inequality in the ageing world. In fact, the negative impact of age-dependent cognitive and physical decline is greater among low-middle-class people who hardly face the costs of institutional long-term care, or whose carers have to give up jobs and leisure time to care for their loved ones instead of paying for skilled facilities. This problem has global relevance given that the greatest relative cost increases related to elderly care and age-dependent cognitive disorders are occurring in low-income African and in East Asia regions (United Nations 2015*b*) where the provision of elderly care services will be seriously threatened due to the existing limitations of national budgets. In this global context, even the most sophisticated CE strategies are likely to improve current cost-effectiveness ratios if they have demonstrated efficacy.

While prioritising low-cost CE interventions might be an ethically sound kick-off strategy, there is a collateral risk of delaying the benefits of effective but higher-priced CE solutions. High-tech electronic neuro-devices such as brain–computer interfaces (BCIs) and portable neuromodulators have prices starting from over US $100, pharmacological enhancers such as Donepezil cost over US $1 per single pill and app-based cognitive programmes can be often free to download but require expensive hardware (smartphones or tablets) to work; assistive robots including cognitive assistants such as SoftBank's Pepper (Guizzo 2015) and companionship robot Paro (Sabanovic *et al.* 2013) have prices ranging from US $2,000–6,000.[5] In the absence of governmental interventions via targeted reimbursement plans, there is a risk that high-tech CE tools might be accessed solely by middle-to-upper-class citizens of industrialised countries. It might be observed that this unequal distribution is not an exclusive characteristic of enhancement, but common to the entire health-care landscape; while this is likely the case, it is not a moral justification of inequality at the policy level. However, CE should not aggravate current geographical and socio-economic inequalities but seek to mitigate them.

To avoid the exacerbation of socio-economic inequalities, we suggest that strategies that could maximise universal access by fair opportunity should be pursued. These include both technical and policy strategies. First, at the technical level, efforts need to be made to reduce hardware costs and promote open-software initiatives in the development of computer-based CE devices. Open platforms such as OpenBCI and open source repositories for the development of mobile health (m-health) solutions for people living with dementia (Zhang and Ho 2017) are positive examples of these efforts. In parallel, inclusive health policies that maximise access, availability and distribution of effective and safe CE solutions across all socio-economic groups should be designed. These policies might involve governmental subsidy and reimbursement schemes for health-promoting CE solutions, the inclusion of CE tools into basic health insurance plans, and financial incentives (*e.g.* tax reductions and credits) for virtuous developers.

In developing such policies, those people who are socio-economically most disadvantaged should be prioritised. As Shaw (2014) explains, this is because the greater beneficial impact of CE is likely to occur among the cognitively worse-off. In contrast, 'those who already make good health decisions might benefit only slightly' (Shaw 2014: 391). Such prioritisation of the most disadvantaged shows that CE could not only avoid the aggravation of pre-existing socio-economic inequalities, but holds the potential of reducing such inequalities by delaying or obviating the need for unequally accessible and geographically unevenly distributed services. As Shaw (2014: 391) puts it, successful CE 'would ultimately mean that the cognitive gap between the most and least cognitively able citizens would decrease, just as health inequalities would decrease'.

This aspect is particularly relevant in the light of what we call the *recursive nature of cognitive enhancement*. In fact, clinical evidence shows that lower intelligence (broadly defined), worse cognitive performance and poor health literacy are predictors of lower health outcomes and reduced longevity (Gottfredson and Deary 2004; Hart *et al.* 2004; Sabbah *et al.* 2009; Schutte *et al.* 2007; Sörberg, Allebeck and Hemmingsson 2013; Whalley and Deary 2001). Therefore, increasing intelligence and cognitive performance via CE will not simply improve public health by reducing the global burden of age-dependent cognitive decline and related disorders; in addition, such measures are also predicted to improve recursively general health outcomes in a number of domains including cardiovascular disease (Hart *et al.* 2004), blood pressure (Starr *et al.* 2004), mental health (Walker *et al.* 2002) and others. This recursive character of CE acquires special ethical significance in relation to socio-economic parameters. In fact, people with lower overall cognitive performance are more at risk of lower socio-economic status, which recursively increases their risk of lower health literacy and, consequently, negative health outcomes. For example, Morrow *et al.* (2006) have observed that functional health literacy scores are lower among older and less-educated citizens, in particular when they had more comorbidities, or scored lower on all cognitive ability measures.

Therefore, CE technologies that prioritise the most socio-economically disadvantaged are likely to interrupt this cycle of 'income inequality leading to educational inequality leading to health inequality' (Daniels, Kennedy and Kawachi 2000) and initiate a virtuous circle in which CE leads to increased socio-economic equality and, consequently, increased health equality. As recently stated by the Lancet Commission on Dementia Prevention, Intervention, and Care, 'we are a long way from achieving equity' (Prince 2017: 53). Consequently, CE should reduce inequities, not aggravate them.

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Conclusion

In this paper, we have argued that CE should be seriously considered as one viable solution to tackle the increased prevalence of age-related cognitive decline and promote healthy ageing. In light of the current clinical, financial and organisational burden of ageing and dementia, we argue that global societies have a moral obligation to consider the careful use of CE technologies as a strategy to improve individual and public health. There do not appear to be any strong arguments against offering CE technologies on a voluntary basis to ageing citizens, especially those affected by or likely to be affected by dementia. The only substantive ethical issues arise with regard to cost, paternalism and fair access. First, it is possible that long-term care costs might actually increase if CE delays entry into care but prolongs time in care overall. Second, lightly paternalistic measures such as nudging may be ethically problematic, if they lead to situations where CE is not mandatory but refusal of it leads to punitive financial consequences in terms of providing for one's own care. Finally, in order to avoid the exacerbation of a technology divide, effective deployment of CE technologies should aim at maximising universal access and prioritising the most socio-economically disadvantaged.

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Notes

1 It is worth noting that much debated has also focused on the definition of *normality* (*see e.g.* Daniels 2000).

2 *See* https://www.newswithviews.com/Howenstine/james182.htm and http://ieet.org/index.php/IEET/more/nicholas20120320.

3 Surgically implanted electronic devices that provide auditory function in persons who are profoundly deaf or severely hard of hearing in both ears.

4 Devices implanted over the sacral anterior root ganglia of the spinal cord, controlled by an external transmitter, which deliver intermittent stimulation to improve bladder emptying.

5 *See* https://www.ald.softbankrobotics.com/en/Launch_Sales_of_Pepper and http://www.technorms.com/37552/top-10-awesome-robots-you-can-buy-today (Accessed 27 October 2016).

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