The relationship between cognitive abilities, well-being and use of new technologies in older people

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V. van der Wardt, S. Bandelow, E. Hogervorst. The relationship between cognitive abilities, well-being and use of new technologies in older people. Gerontechnology 2012; 10(4):187-207; doi:10.4017/gt.2012.10.4.001.00 The purpose of this literature review was to investigate the relationship between individual cognitive abilities, well-being and use of information and communication technology (ICT) to sustain digital engagement of older people. The analysis included 19 empirical studies investigating the association between cognitive abilities and use of new technologies as well as studies examining the relationship between well-being and ICT use. Our results showed that while several studies indicate a significant effect of cognitive abilities (in particular of working memory capacity) on the use of new technologies, it remains unclear whether ICT use can in turn improve cognition and well-being in healthy, older individuals. On the other hand, in those with mild to moderate dementia some improvements have been found when using ICT-based interventions. In addition, some ICT-based interventions for older people with depression have shown to be effective in improving mood. Further studies should take into account health, prior cognitive status, education and socio-economic status and investigate the relationship for different types of aging processes separately.

Keywords: cognition; well-being; memory; computers; ICT; Internet

Older people spend significantly more time listening to the radio and watching TV than the average population, but those over 65 years of age accounted only for 6% of Internet usage in the UK in 2010[1]. Lack of access to computers, knowledge and interest in older people were strong predictors of not accessing the Internet 10 years ago[2]. However, access to computers has since improved, with, for instance, many libraries in the UK now offering free computer and Internet use. This paper focuses on how age-related cognitive changes relate to digital engagement in older people, the role of well-being in this relationship and which steps could be taken to reduce the impact of declining cognitive abilities in order to sustain use of digital technologies as people age.

New digital technologies can improve older adults' quality of life and support their independence by providing access to online services (for instance, shopping, banking, online documents and forms), online information (for instance, healthcare, leisure activities) and unique possibilities of communication with friends and family (for instance, skype, email, mobile phones). In addition, the use of digital devices is often necessary for everyday actions such as buying train tickets, using cash machines or borrowing books at a library. Cognitive abilities are mental processes, such as perception, memory, attention, problem solving, complex information processing, reasoning and concept formation, which are necessary for most everyday activities.

Cognitive abilities change over the lifespan and in older age differences between and within individuals become more pronounced[3]. Highly overlearned functions as assessed by using implicit or procedural memory tasks (for instance, brushing your teeth, playing the piano or riding a bicycle), and crystallized intelligence (assessed by using semantic knowledge tasks, such as those testing vocabulary, knowledge, culture, etc.) appear to be stable with age[4-7]. However, other cognitive abilities show decrements with age, for example, those assessed using tests requiring processing speed. This is partly because of a general slowing of sensorimotor speed. This slowing is additionally pronounced in more complex choice reaction time tests[8]. This in turn is probably related to less efficient or slower executive processes[9], which can be seen in tests assessing cognitive flexibility, and tasks which require working memory manipulation. Test performance on these tasks declines, albeit at different ages of onset and with different rates of decline[4, 5,10]. For example, the Seattle Longitudinal Study[10], which followed participants over a period of 35 years, found that perceptual speed already started to decline in the mid-50s, while verbal memory performance did not decline until the late 70s. Similar differential declines, with performance on perceptual speed and fluid intelligence tasks decreasing much earlier than performance on verbal memory or crystallized intelligence tasks, have been found in a large number of studies using different tests to assess cognitive abilities (summarized[11]).

Maintaining cognitive ability will also depend on mood, morbidity and health status of participants, which can all accelerate decline with age. For instance, thyroid status, which can occur in 6% of elderly who view themselves as healthy, can significantly affect cognitive function and decline[12]. Depression, which can have a profound effect on cognitive ability, is quite common in those over 65 years of age and is estimated to affect around 1 in 5 older individuals[13]. Age-related pathological cognitive conditions, such as dementia, further accelerate the rate of decline of cognitive abilities[14], but again this shows a differential pattern, with even higher variability than in the normal aging process[15]. In addition, dementia in its later stages also affects those cognitive abilities that are stable in normal aging (for instance, semantic memory and knowledge). Finding older people without any morbidity that can affect cognitive ability is difficult[5], although with improved health care, many elderly are living longer healthier.

Socio-economic status and education are strong predictors of later life health and morbidity, mortality and cognitive function[16]. Use of ICT is determined by access to technology instruments, knowledge of these instruments and a perceived need or interest[2]. These factors are facilitated in white collar (as compared to blue collar) occupations, where ICT is now part of basic job-related equipment. Socio-economic status (SES), which is higher in most white collar occupations, in itself is a strong predictor of cognitive ability in older age[17], and is thus a major confound. However, education can overrule associations of low SES with cognitive status and dementia in later life[17] and this indicates that there may be a potential role for knowledge transfer through ICT use (for instance, online courses), even at an older age.

We thus examined the relationship between ICT use and cognitive abilities, in particular the direction of this relationship (effect of ICT use on cognitive abilities and effect of cognitive abilities on ICT use or both). In addition, we aimed to examine which individual cognitive abilities are involved, what role well-being has in this relationship and to what extent this relationship has been investigated separately for healthy and pathological aging processes. Lastly we examined to which extent the above confounds to this relationship (health, demographic factors such as education and occupation) had been taken into account in these studies.

METHOD

An electronic search was conducted in Pubmed and Web of Science using combi-

nations of the keywords 'cognition', 'cognitive abilities', 'working memory', 'processing speed', 'intelligence' in combination with 'technology', 'ICT', 'Internet', 'world wide web', 'well-being', 'psycho-social factors', 'old age', 'older' and 'elderly'. All abstracts were scrutinized to identify studies that are relevant to identify factors in the relationship between cognitive abilities, well-being and use of ICT that support the digital engagement of older people. Appropriate articles were collected and systematically reviewed to indicate research gaps. In addition, the reference lists of all relevant articles were searched to find further studies that contributed to our research objective.

Standard criteria were used to identify relevant studies. Firstly, studies had to be of a quantitative nature. Secondly, the focus of the research had to be on the use of the digital technologies; any articles investigating mainly technologies which required no or barely any interaction (for instance, some assistive care technologies) were not considered. Thirdly, articles were considered relevant if they investigated specific cognitive abilities and not global measures of intelligence. Finally, relevant studies had to include participants over 55 years of age (although not exclusively) and investigate the effects of age on digital technologies.

Applying these criteria led to the following: (i) reviewed articles investigating the impact of cognitive abilities on the use of ICT (Appendix A), (ii) papers examining the effect of ICT use on well-being (Appendix B), (iii) studies investigating the effect of ICT use on age-related morbidities such as dementia and depression (Appendix C), and (iv) further details for those cognitive abilities that have been shown to be associated with the use of new technologies in older adults (Table 1).

COGNITIVE ABILITIES AND ICT USE
Older people's physical, social and mental activities have all been shown to affect cognitive abilities and well-being[18,19] but, conversely, cognitive and physical disabilities can also limit access to activities. For ex-

ample, cognitive impairments might affect the learning of new activities such as the use of computer applications. Several studies investigated which particular aspects of information processing and cognitive function were most likely to limit ICT use in older people (Appendix A).

Computer use
The majority of studies examining the relationship between ICT use and cognitive abilities focused on computer and Internet use. Czaja et al.[20], for example, demonstrated, based on a large sample of community-dwelling adults, that both fluid and crystallized intelligence were significant independent predictors for breadth of computer use (experience with different aspects of computer use including experience with input devices, proficiency with basic computer operations and proficiency with computer applications) and use of the Internet when controlling for age, education, computer self-efficacy and computer anxiety. For 'experience with computers', only fluid intelligence was a significant predictor, while for 'breadth of World Wide Web experience' (number of Internet activities for which participants reported experience), only crystallized intelligence was predictive. Crystallized and fluid intelligence are factors contributing to general intelligence based on the Cattell-Horn-Carroll theory of cognitive abilities[21]. Crystallized intelligence includes verbal abilities and knowledge, such as language development, lexical knowledge, communication ability, as well as grammatical sensitivity and appears stable in non-pathological aging (see introduction). Therefore, crystallized intelligence could theoretically at least partly sustain some aspects of computer and Internet use with advancing age.

Fluid intelligence, which is a generic term for different forms of reasoning starts to deteriorate from the mid 50s onwards[10]. The impact of fluid intelligence on the performance of Internet search tasks was confirmed by Sharit et al.[22] for simple tasks. For complex Internet search tasks, however, working memory was the only significant predictor, and for overall search performance (simple

and complex tasks combined), perceptual speed was shown to be predictive, in addition to reasoning and working memory. Perceptual speed refers to the ability to recognize similarities and differences in stimuli and could, for example, influence the time it takes to distinguish between relevant and irrelevant information. Working memory is the ability to actively hold information in the mind while engaging in other activities, for example keeping in mind the purpose of an Internet search while browsing on different websites. The results of the study by Sharit et al.[22] indicate that searching the Internet requires several cognitive abilities, depending on complexity of the search.

The involvement of different cognitive abilities in Internet searching was supported by Small et al.[23] who used functional brain scans with a reading test on a computer screen versus a novel Internet search test and found that areas associated with language, reading, memory and visual abilities were all activated in the reading control test. However, only for those older individuals who had computer and Internet search experience (n=12 vs n=12, who had no such experience), additional brain areas were active during the Internet search test, which were also related to decision making, complex reasoning, memory and vision. Hence, having experience with Internet searching is associated with additional activation of brain areas that relate to several cognitive abilities. Stronge et al.[24] found that older participants were less successful than younger participants in finding correct information on the Internet because of ineffective search strategies and the amount of experience they had with the Internet, rather than this being related to age per se. Ineffective search strategies could be a result of deficiencies in reasoning ability. This in turn could be related to age-related cognitive changes, as outlined in the introduction, such as in working memory.

Task switching, another executive frontal lobe function, has also been found to be associated with computer use. Tun and Lachman[25] examined the relationship between frequency of computer use and cognitive abilities in an observational study including 2,671 people between 32 and 84 years of age. Their results showed that frequency of computer use was significantly associated with cognitive abilities after controlling for age, sex, education and health status. However, only task switching ability was analyzed individually (other cognitive abilities were combined into a composite score). Task switching ability was significantly associated with frequency of computer use with age being a significant contributor to the regression model. Task switching ability is a cognitive process that requires the individual to shift mental resources between two or more tasks.

Other investigators, such as Kubeck et al.[26] and Laberge and Scialfa[27] investigated the role of working memory for Internet search performance. However, although Kubeck et al.[26] expected to find working memory to affect the interaction between age and Internet search ability, it was not a significant mediator or covariate when investigating this relationship. In a similar study, Laberge and Scialfa[27] examined the relationship between performance on Internet search tasks and cognitive abilities. In contrast to Kubeck et al.[26], their results showed that verbal working memory (as measured with a reading span test) was significantly related to all Internet search performance measures after controlling for age, subject knowledge and Internet experience. In addition, visuo-spatial working memory was significantly related to the average time needed per task and the mean number of pages revisited, while processing speed was associated with the number of pages visited and re-visited per task. Thus, in this study, processing speed and different forms of working memory (verbal and visuo-spatial) contributed to Internet search performance. The significance of working memory is reflected upon by Sharit et al.[22] as 'recall of where one is, planning of where one wants to go, and comprehension of information on web pages need to be carried out more or less concurrently'. The simultaneous coordination of the processing

and storage of information is a critical aspect of working memory activity[11].

The importance of working memory thus seems to pertain to specific aspects relating to Internet search performance, and is more pronounced in more complex searches. For instance, one study reported that low working memory capacity was the main limiting factor in scrolling effectively across Internet pages[28]. This is probably related to the findings of Laberge and Scialfa[27], and indicates issues due to an overload of information that needs to be stored and manipulated in working memory. Similarly, a Chinese study including learning-disabled participants[29] reported that working memory played an important role in the more complex Internet searches. However, in this study visual acuity, vigilance, orientation and basic sensorimotor abilities were also important for all Internet explorer tasks. Visual acuity and basic sensorimotor speed will generally show some decline with age and are often affected in learning disability[30]. Slow sensorimotor speed will explain in turn some of the deficiencies in other cognitive abilities with age, such as the lower immediate recall of items[5], which in turn is related to working memory[31]. These studies thus indicated that Internet search performance is related to various cognitive abilities which also relate to each other.

Other new technology use
In a wider ICT context, these findings also pertain to other uses of modern technologies. For instance, in a telephone voice menu task, attention, working memory and spatial abilities were also found to have a significant effect on auditory computer navigation performance[32]. These results showed that even for non-visual use of new technologies visuo-spatial abilities are essential, in addition to attention and working memory functions. Expanding this research to the use of everyday technology in older persons, Slegers et al.[33] examined the relationship between cognitive abilities and performance in the use of different technological everyday devices (for instance, CD player, telephone, cash machine). Their results indicated that

depending on type of technology used, again different cognitive abilities were significant predictors for task performance. Only the use of an alarm-clock, a ticket vending machine and a microwave oven was not significantly predicted by any cognitive abilities, possibly because all participants would have had longer term experience with these electronic devices, which have been around for a longer time than the other items. This would reflect assessment of these tasks as having become crystallized intelligence tasks, which was also supported by Czaja et al.[20] who demonstrated that both fluid and crystallized intelligence were significant predictors for the general use of common technologies such as mobile phones and fax machines. The use of microwave ovens, which had not been predicted by any cognitive abilities in the Slegers et al. study[33] was predicted by fluid and crystallized intelligence in the Czaja et al. study[20]. This might be explained by the different ways the use of microwave ovens was measured (practical task[33] vs questionnaire[20]).

In sum, cognitive abilities show a differential pattern of change with age. Crystallized intelligence, for example, which has been found predictive for 'breadth of World Wide Web experience'[20], and use of common technology is considered to be stable throughout a normal aging process[6]. The use of most new technologies, however, seems to also require working memory, spatial abilities, reasoning and processing speed, which all decrease with age (*Appendix A*). Although some aspects of ICT use might become crystallized intelligence with practice (for instance, the knowledge how to use a search engine or the different functions of a particular software), others will remain reliant on those abilities that deteriorate with age (processing of large amounts of information presented on the screen). Systems to support digital engagement of older people should therefore focus on aiding these abilities. Furthermore, while within the older groups there was no association with age per se, there was a clear difference between young and old people (*Appendix A*). In addition, with exception of the

Tun and Lachman study[25], none of the studies above that included the general population controlled for health or well-being when investigating the relationship between cognitive abilities and the use of new technologies, or looked at the impact of different types of cognitive aging processes (for instance, normal/pathological). These aspects all need to be further investigated and controlled for in future studies regarding the association between cognition and ICT use, which should compare the relationship between different types of cognitive aging processes. However, the question remains whether use of computer and Internet promotes activation of these higher cognitive abilities, or whether people who still have these abilities are able to gain access to the Internet. This needs to be investigated in randomized controlled trials.

Cognition and new technology use

Randomized controlled trials regarding the impact of the use of new technologies on cognitive abilities are limited to one study, which investigated the effect of Internet and computer use on cognitive abilities.

Slegers et al.[34] assessed 191 healthy, older people (64 to 75 years of age) over a 12-months period in a randomized, controlled study. Participants were assigned to one of four groups: one group received computer training (three 4-hour sessions over the period of two weeks) and subsequently additional encouragement to use their computers (helpdesk and additional assignments), one group received computer training but no additional encouragement, one group used their computers but did receive neither training nor additional encouragement, and one control group. The four groups did not differ with regards to demographic characteristics or global cognition at baseline. The results of this study showed that verbal memory, information processing speed or cognitive flexibility did not significantly improve in any of the groups after 4 or 12 months. This seems to indicate that computer and Internet use in itself does not contribute to the improvement of cognitive abilities in healthy, older people. Larger studies are

now ongoing to further investigate this association, for normal, as well as pathological aging processes.

Improved cognition in dementia

In contrast to the general older population, participants with dementia symptoms have been shown to improve using Internet or computer based training programs[35-38] (*Appendix C*). Optale et al.[39], for example, have found that memory training for older individuals with cognitive impairments using a virtual reality environment significantly improved long-term verbal memory, while an equivalent training based on music therapy did not show such results. For the virtual reality memory training participants were encouraged to learn the layout of garden paths over a period of 6 months with 2-3 training sessions per week, each lasting 30 min.

Although the improvements are likely to be due to the nature of the mental activity rather than the use of a technological device, the computerized form supports the memory training better than cognitive training programs using pen and paper versions. Computerized forms have the advantage that they can easily be adapted to the individual neuropsychological needs of older persons[40]. People with mild to moderate dementia have been found to be able to still use simple electronic devices, which can enhance mood and confidence and could aid with memory and activities of daily living problems[41]. In addition, studies looking at the impact of other mental activities (not related to use of ICT) on cognitive ability of older people with and without cognitive impairments, have shown a positive effect on cognitive abilities, such as those assessing visual imagery, reasoning and reaction time[42-44]. The strength of this effect has been shown to depend on the health of participants, the degree of difficulty and type of mental activity, gender and prior cognitive status[45].

In sum, treatment using ICT only seems to be effective in those with cognitive impairments but health and baseline cognitive

status, as well as gender, education and socio-economic status have often not been controlled for in previous studies investigating the relationship between ICT use and cognition. Furthermore, additional aspects, such as dietary habits, physical and social activities, as well as lifestyle factors (for instance, smoking) should be taken into account in investigations of this relationship, as these all have been demonstrated to significantly influence cognitive functions in older people[46]. Ceiling effects in those without cognitive impairments may explain a lack of effects of ICT use on cognition of those who undergo normal aging processes, but further large randomized controlled trials are awaited to further illuminate these issues.

WELL-BEING AND USE OF NEW TECHNOLOGIES
Recent studies examining the impact of the use of new technologies on well-being have shown mixed results. While some studies indicated a positive effect of computer and Internet training on well-being, similar to findings of cognition, randomized, controlled intervention studies did not find significant effects (*Appendix B*)

Internet use
Shapira et al.[47] compared older adults who attended a computer and Internet course to adults with similar demographic characteristics who attended a crafts course. The results showed that the computer-user groups demonstrated a significantly higher life satisfaction, sense of control and self-rated life quality after 4 months, while expressing lower degrees of depression and feelings of loneliness, after controlling for pre-treatment scores. For the control group, a deterioration of well-being in these measurements was found. These findings thus indicate that the use of computers and Internet can have a positive effect on well-being of older people over and above that of a crafts course. However, these participants were all self-selected and differences in experience with ICT and personality may have affected the way they responded to or chose the course (for instance, self-esteem, computer anxiety, perceived self-efficacy, etc.).

In a telephone survey, Koopman-Boyden and Reid[48] investigated the relationship between Internet use and well-being in non-institutionalized, older individuals. Participants were classified into Internet users and non-users based on survey results. Well-being was assessed using general, as well as domain-specific questionnaires of well-being. In this study, Internet users demonstrated a significantly higher degree of general well-being than non-users. However, for the domain-specific well-being indicators no significant relationship was found, except for participation in recreational activities and better, self-rated, health. The results were not reported to be controlled for age and gender, although both had a significant effect on use of Internet.

In a comparison between younger and older Internet users, Chen and Persson[49] assessed adults using a multi-dimensional well-being scale and a survey to establish the hours spent on the Internet. Their findings showed no significant correlation between hours of Internet use and any of the dimensions of well-being, except for the well-being dimensions 'personal growth' and 'purpose of life' for which users had significantly higher scores than non-users. However, cause and effect of this association remains unclear, similar to the earlier studies.

In contrast to these outcomes, the following randomized, controlled intervention studies did not find a significant effect of computer and Internet use on well-being. White et al.[50] examined the psychosocial impact of Internet training and Internet access in residential older people. Participants either received computer and Internet training or were included in a control group and received no training. After the two training weeks intervention, no significant difference was found in the scores between baseline and follow-up measurement on any of the mood and well-being related scores for either group.

A similar outcome was found in the study by Slegers et al.[51], which examined the effects of computer and Internet training on self-reported well-being of older people. Participants

were assigned to one of four groups and received either computer and Internet training and/or a computer with Internet connection for their personal use or neither (no training, no computer). Several well-being measures (physical, social and emotional well-being, autonomy) were taken at baseline, after 4 months, and after 12 months. Computer use was measured in hours logged in per week. The results showed an inconsistent change in well-being. None of the well-being measures improved for those participants who received training and/or a computer, while it remained at the same level or decreased for the no training and no computer group.

These last two studies, which were randomized, controlled interventions, thus concluded that computer and Internet training and use does not improve well-being in older adults. All studies limited their focus on the use of computers and the Internet. The use of other new technologies, such as the use of mobile phones, healthcare devices or leisure and entertainment systems has not been considered, and therefore their effect on well-being still has to be examined In addition, even the controlled intervention studies[50,51] assessed Internet use in access to Internet or hours logged in, which does not provide detailed information of how intensively (for instance, diversity or focus of use) the Internet was used. Lastly, who provided the support (peers or young teachers) and the format in which support is given (workshops, 1:1) and the extent to which this mediates the effects of ICT on well-being and mood (by providing self efficacy, attention, distraction, company and social networks, etc.) needs further investigation. Future randomized, controlled intervention studies for different types of aging processes (with and without pathologies) using different formats of support should therefore include a broader range of ICT use to further examine the relationship and its direction between well-being and use of new technologies.

Mood in those with depression

For instance, while ICT training did not improve mood and well-being for the general older population, this may aid older people with clinical depression (*Appendix C*). Billipp[52] showed that when accompanied by weekly computer training, depression and self-esteem improved significantly in those participants who had a clinical depression. However, this was only the case if the training was accompanied by a nurse supporting the training (as compared to those who had weekly visits from a nurse but no computer training or only computer training with a familiar person, but without the support of a nurse). On the other hand, not all studies supported these results[53]. In order to be able to maximize the efficiency of support developed to sustain the use of new technologies, particularly in those who need this (for instance, those with dementia and/or depression), it is essential to investigate which factors support further improvement in well-being.

DISCUSSION

Understanding the relationship between the use of new technologies, psychosocial and cognitive factors is essential in order to develop support systems to sustain digital engagement in older age. Support systems should support those cognitive abilities that have been shown to be essential for ICT use and which deteriorate with age (*Table 1*). The analysis of the literature showed that cognitive abilities (for instance, working memory) significantly predict the use of a wide range of new technologies. However, with a large variability in cognitive abilities within and between older subjects, flexible updating of personalized applications and software is required for older people to meet their continuously changing demands (for instance, less information and a slowing of information feed, larger fonts, fewer distracting information in the visuo-spatial peripheral field, etc.). Support systems could, for example, include help buttons for memory support (for instance, pop-up window on screen with step for step instructions or tutorial videos).

Similar to cognition, studies of well-being in older people show a large variation[54,55], with factors such as poor health, personality traits (for instance, pessimism), low SES and

Table 1. Cognitive abilities relevant to use of new technologies in older adults, and the age at which the cognitive ability starts to deteriorate

Ability	Definition	Deteriorate, yrs	Associated technology use
Cognitive flexibility / Task switching	Ability to switch between tasks[64]	60 onwards[64]	Frequency of computer use[25]; Use of CD player and cash machine[33]
Crystallized intelligence	A person's acquired knowledge of language, information, concepts and application of knowledge[65]	Stable[4-7]	Diversity of experience with Internet, use of Internet and breadth of computer use[20]
Fluid intelligence	Generic term for inductive reasoning, deductive reasoning used for tasks that cannot be performed automatically but need deliberate and controlled mental processes to solve novel problems[65]	Mid 50s onwards[10]	Experience with computers, use of Internet and breadth of computer use[20]; Internet search performance for simple tasks, and for simple and complex tasks combined[22]
Information processing speed	Ability to automatically and fluently perform simple mental processes[65]	20s onwards[66]	Number of pages visited and re-visited per Internet search task[27]; Use of telephone and smart-card charging task[33]
Inhibition of a pre-primed response	Inhibition of a response that has been induced by a prime immediately preceding the target, which conflicts with the correct response[67]	30s onwards[68]	Smart-card charging task[33]
Perceptual speed	Ability to rapidly and accurately search, compare and identify visual elements presented side by side or separated in a visual field[65]	20s onwards[10]	Internet search performance for simple and complex tasks combined[22]
Spatial abilities	Proficiency in comparing and processing visuo-spatial information[65]	Mid 50s onwards[10]	Auditory computer navigation task[32]
Verbal long-term memory	Ability to store information[69]	Stable[4-7]	Use of cash machine[33]
Verbal and spatial working memory	Ability to temporarily store and manage information. It consists of a central executive element and two storage systems, the phonological loop, which is responsible for verbal information and the visuo-spatial sketch pad, which is responsible for visual information[70]	20s onwards[71]	Internet search performance for complex tasks as well as for simple and complex tasks combined[22]; Verbal working memory was related to Internet search performance ; Visuo-spatial working memory was related to average time needed per search task and to mean numbers of pages re-visited during Internet search task[27]; Auditory computer navigation task[32]

lack of social networks all negatively affecting well-being[56,57]. These need to be taken into account when investigating the association between ICT use and well-being as they can be important confounding factors.

Although the impact of well-being on cognitive functioning has been well established for older people[58-61], there is, to our knowledge, no research investigating the impact of well-being on the use of new technologies.

Furthermore, although Slegers et al.[34] did not find a significant impact of technology use on cognition, research has found that mental activities do have a positive effect on cognitive abilities in older people. This association also depends on health of the participant, and type and difficulty of the activity. Further research will have to establish to what extent and what types of use of new technology can indeed improve cognitive abilities in healthy older people. In addition, the impact of the use of new technologies on well-being still needs further investigation, as the results are contradictory and research is limited to measuring computer and Internet use, but does not include other technologies. Moreover, although the association between stress and ICT use has been established for younger adults[62], future research will have to investigate this relationship for older adults.

One major limitation of this literature analysis is the assessment of ICT use. The assessment of ICT use differs between studies in terms of how measurements were taken (for instance, practical tasks, questionnaires, hours logged in) and which types of technologies were included. This limits the comparability of results. Additionally, although the different assessments of ICT use may show face validity in their approach, psychometric properties of these instruments (validity and reliability) have not been established, to our knowledge. Therefore, the validity and generalizability of the results should be regarded with caution until further evidence confirms the appropriate psychometric requirements.

Furthermore, the use of ICT should not only be investigated in relation to different degrees of cognitive functioning and well-being but also for different aging processes and mental health disorders such as dementia and depression, for which some studies showed significant improvement with ICT training. Subsequent research should explore different formats of support for those cognitive abilities that are essential for the use of new technologies but deteriorate with age. As for seeking information on the Internet, working memory was shown in this review (for both people with and without dementia) to be a crucial factor. Consequently, information on dementia diagnoses and treatment is mainly sought by younger better educated carers but not by those with moderate to severe dementia who usually experience significant memory problems[63]. Similar issues may play a role in depression which often also is accompanied by a decline in attentional and memory functions. Ways to overcome these limitations for these groups require further research to better adapt ICT.

For instance, as working memory ability shows a general decline with depression and age (see introduction), Internet pages for the older people would in particular need to:
(i) reduce the amount of written information that needs to be stored and manipulated in verbal working memory;
(ii) reduce presentation speed of visual stimuli, i.e. by increasing the inter-stimulus interval adequately. However, this inter-stimulus interval should not be reduced to the extent that people lose their thread precisely because of their reduced working memory storage capacity (for instance, from 300 msec up to 1 second, but not up to 1.5 or 2 seconds);
(iii) reduce the amount of information presented visuo-spatially on the screen. As seen in the study by Laberge and Scialfa[26] this was shown to affect time needed per task and the need to revisit pages.

In sum, the results of these studies indicate that while some relationships are reasonably established (for instance, impact of cognitive abilities on the use of new technologies), others need further investigations (for instance, the role of well-being in use of new technologies). Furthermore, several factors, such as prior health, mood and cognitive status of the participants, the degree of difficulty of ICT tasks and the types of mental activities needed should be taken into account in future studies.

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Appendix A. Cognitive abilities and use of ICT

Participants	ICT use	Abilities	Covariates	Measuring cognitive abilities Results	Source
n=1204; age=18-91yrs; of those n=461 were 60- 91yrs; mean=70.49; SD=5.12	Composite score for use of everyday technology based on number of different devices used, e.g. mobile phone, fax machine, etc.; frequency and breadth of general computer use; frequency and breadth of Internet use	Fluid and crystallized intelligence	Demographic characteristics; computer anxiety; computer self-efficacy	Results not reported for the older age group separately; age was a significant predictor; fluid and crystallized intelligence were significant predictors for use of technology, breadth of computer use and use of Internet; for experience with computers, only fluid intelligence was a significant predictor; for breadth of Internet experience, only crystallized intelligence was significantly predictive	20
Group1: younger adults; n=30; mean=21.8yrs; SD=2.5; *Group 2*: older adults; n=29; mean=70.6yrs; SD=6.7	Web search to answer two questions (easy and difficult); number of search steps, key word searches, menu choices, back-ups and prompts required; quality of answer	Working memory	Demographic characteristics; computer attitudes; computer anxiety; web knowledge; domain knowledge regarding the web search questions	Although *Group 2* was either less efficient in their search, or less accurate in their answers compared to *Group 1*, working memory did not affect the age effects found	26
n=41; age=19-83yrs; mean=44; SD not reported	Internet navigation task (tourism related) performance; time per task; number of pages visited per task; mean number of pages re-visited per task	Reading ability; spatial ability; visuo-spatial working memory; verbal working memory; processing speed; memory for website details	Age; web experience; domain knowledge	Verbal working memory was significantly related to all Internet search performance measures; visuo-spatial working memory was significantly related to mean time needed per task and mean number of pages re-visited; processing speed was related to number of pages visited per task and mean number of pages re-visited; age effects were accounted for by age differences in cognitive abilities and Internet experience/domain knowledge	27
n=196; age=18-91yrs; mean=47.32; SD =19.78	24 telephone voice menu tasks; task performance depended on correct responses	Attention; working memory; spatial ability	Age; prior experience with telephone voice menus	Working memory, attention and spatial ability were related to task performance; working memory and attention, spatial ability accounted for a significant part of the variance in performance	32

Appendix A. Cognitive abilities and use of ICT (continued)

3 age groups; *Young*: n=10; age=18-39yrs; mean= 27.9; SD=6.39; *Younger-old*: n=20; age=60-70yrs; mean=65.2; SD=3.17; *Older-old*: n=20; age =71-85yrs; mean=76.7; SD=4.08	Task performance scores for Internet search problems with varying degrees of complexity; Internet, web browser and search engine knowledge; sub-scores for correctness of the solution to search task; task completion time; level of problem complexity;	Psychomotor speed; perceptual speed; attention; long-term memory; verbal fluency; spatial visualization; working memory; reasoning; life knowledge	Demographic characteristics; health questionnaire (not included in analysis); computer and technology experience questionnaire; Internet experience questionnaire	Results were not reported for older age groups separately; age was no longer significant after cognitive abilities were entered into regression models; Reasoning was the only significant predictor for simple Internet search task performance; Working memory was the only significant predictor for complex Internet search task performance; Knowledge, reasoning, working memory and perceptual speed were significant predictors for all Internet search problems combined	22
n=236; age=64-75yrs; no mean or SD reported	8 technological tasks, including operating a CD player, a telephone, an ATM, a train-ticket vending machine, a microwave oven, an alarm clock, a smart card charging device and a telephone voice menu	Speed of information processing; verbal memory/ learning; cognitive flexibility; psychomotor speed	Demographic characteristics; experience with the technological devices	Randomized controlled trial to take previous use of technology into account; For CD-player and telephone voice menu tasks, cognitive flexibility was a significant predictor; For telephone task, performance on the information processing speed tests was significantly predictive; For use of cash machines, verbal long-term memory and cognitive flexibility were significant predictors; For performance on smart-card charging task, information processing speed and inhibition of a pre-primed response (part of the Motor Choice Reaction Time Test) were significant predictors; Performances on alarm-clock, use of ticket vending machine and microwave-oven tasks were not significantly predicted by any cognitive abilities	23
n=2,671; age= 32-84yrs; mean = 55.28; SD=11.86	Questionnaire including questions regarding frequency of computer use	Composite score for cognition; task switching score	Demographic characteristics; self-rated health	Frequency of computer use was significantly associated with task switching performance when controlling for basic cognitive ability and demographic characteristics	25

Appendix B. Well-being and use of ICT

Participants	ICT use	Measuring well being			Source
		Well-being	**Covariates**	**Results**	
Group1: n=178; age=17-30yrs; mean=19.8; SD not reported; *Group 2:* n=218; age=60-101yrs; mean=75.6; SD not reported	Survey assessing hrs of Internet use/wk; type of activities performed; access to Internet	Autonomy; environmental mastery; personal growth; positive relations with others; purpose in life; self-acceptance;	Demographic characteristics; self-rated health; computer use	No significant relationship between hours spent on Internet and well-being for either age group; Older Internet-users scored higher in 'personal growth' and 'purpose in life' than non-users	49
n=1680; age=65-84yrs; mean and SD not reported	Survey included questions assessing ICT use	World Value Survey questions on well-being; World Health Organisation Quality of Life Indicator; questions regarding specific domains of well-being	Demographic characteristics; participation in leisure activities; use of computer, Internet, email	Internet users showed a significantly higher degree of general well-being than non-users; Only the domain-specific well-being aspects 'participation in recreational activities' and 'self-rated health' showed a significant positive relationship with ICT use; Results not reported to be controlled for age and sex, although both had a significant effect on use of Internet	48
Intervention group: n=22; age =70-93yrs; mean=80.25; SD=6.5; *Control group:* n=26; age=70-93yrs; mean=82.6; SD=5.9	*Intervention group:* 15 wks computer course to learn computer, Internet, email use and to participate in virtual communities; *Control group:* 15 wks crafts course	Life-satisfaction scale; depressive adjective checklist; revised UCLA loneliness scale; self-anchoring scale; perceived control scale	Demographic characteristics; computer experience; recent negative life events; health	*Intervention group* showed significantly higher life satisfaction, sense of control and self-rated life quality after 4 months, while expressing lower degrees of depression and feelings of loneliness when controlling for pre-treatment scores; *Control group:* a deterioration of well-being in these measurements was found.	47

Appendix B. Well-being and use of ICT (continued)

n=191; age=64-75yrs; 4 groups; *intervention group*: n=62; *training- no intervention group*: n=61; *no training group*: n=68; *basic assessment group*: n=45; Individual groups means and SDs not reported; no significant differences between groups were found at baseline	*Basic assessment group*: those not interested in computers; all others indicated ICT interest; *no-training group* received no training; *intervention and training groups*: 3x 4hrs training sessions over 2 wks including theory and practical sessions; *intervention group*: also follow-up assignments and helpdesk access	Short–Form Health Survey (SF-36); loneliness questionnaire; psychological component of the SF-36; depression, anxiety and sleep complaints subscales of 90-items Symptom Check List; neuroticism and extraversion subscales of the Eysenck Personality Questionnaire development and activity questionnaire	Demographic characteristics; Instrumental Activities of Daily Living; Belief of External Control scale; mastery scale; computer use in intervention group	None of the well-being measures improved for those participants who received training and/or a computer; It remained at the same level or decreased for the no training/no computer group	51
Intervention group: n=48; mean=71 yrs; SD=12; *control group:* n=45; mean=72 yrs; SD=11; no age ranges reported	*Intervention group:* 9 hrs of Internet training in group sessions over 2 wks; *Control group:* neither training nor substitute course	UCLA loneliness scale; CES-depression scale; perceived control of life situations scale; attitudes towards ICT	Demographic characteristics; health status; functional status; social contacts	No significant differences between groups in loneliness, depression scores and perceived control	50

Appendix C. ICT use and depression, cognitive impairment or dementia

Participants	ICT use	Measuring depression and cognitive ability				Source
		Scales	**Covariates**	**Results**		
computer use training group n=30; no computer training n=10; age≥65 yrs, mean=73; SD not reported	3 experimental computer training groups who all received introductory computer training and access to computer terminal at home; *Group 1*: one follow-up training during the weekly nurse visit; *Group 2*: weekly computer training from nurse throughout study period; *Group 3*: computer training with their carer who continued to support the computer use throughout study use independent of weekly nurse visits; *Control group*: weekly nurse visits but no computer training/access to computer terminal at home; measurements at baseline and after completion of the training	Rosenberg self-esteem scale; geriatric depression scale	Demographic characteristics; Attitudes Towards Computers questionnaire; nurse response scale	Only *Group 2* decreased in depression; Computer use was associated with an increase in self-esteem when training was supported by either a nurse (*Group 2*) or a carer (*Group 3*).		52
23 older adults in 3 groups; *Group1*: 10 patients with Alzheimer's disease; mean age=74.1yrs, SD=5.6; *Group 2*: 10 patients with mild cognitive impairment, mean age=70.6yrs, SD=6.0; *Group 3*: 2 patients with multiple system atrophy; mean age=69.0yrs, SD=9.5	Two 4-week training programs with a 4-8 week break between the programs, using computerized cognitive exercises based on the NPT software; measurements at baseline and after completion of the training	MMSE; phonemic and semantic verbal fluency; visual search; trail making test; digit symbol test; Rivermead behavioral memory test; geriatric depression scale; Advanced Activity of Daily Living Scale; state and trait anxiety	Demographic characteristics; health	Global cognitive functioning (MMSE) improved in *Group 1*, not in *Group 2* or *3*; *Group 1* improved in verbal productions and executive function; *Group 2* improved in behavioral memory; No improvement in *Group 3*; Depression, independence of living and anxiety did not improve		35

Appendix C. ICT use and depression, cognitive impairment or dementia (continued)

Sample	Intervention	Measures	Control variables	Results	
32 adults, mean age=78.6 yrs, SD=8.43, with mild or moderate cognitive impairments in an experimental (n=15) and a control group (n=17)	The Integrated Cognitive Stimulation and Training Program combined computerized and pen and paper training aimed at improving global memory processing and executive function; training on 2 consecutive days/wk for 6 wks with 3x15min session each time; measurements at baseline and after completion of the training	Cognitive functioning (MMSE and DRS); logical memory; letter-number sequencing	Demographic characteristics	Depression and logical memory improved in the experimental group; No changes for cognitive functioning or scores in letter-number sequencing; None of the cognitive variables changed significantly in the control group	36
6 adults clinically diagnosed with moderate and severe dementia, 64-93yrs; no control group	6-week cognitive training program based on the Mind Aerobics and Adaptive Computerized Cognitive Training, computerized exercises aimed at attention training visuo-spatial and motor skills problem solving, memory and visual discrimination; measurements at baseline and after completion of the training	Cognitive abilities (orientation, attention, memory, global verbal ability, construction, spatial perception, spatial ability, abstract reasoning, psychomotor speed, visual memory, cognitive flexibility); cognitive functioning (MMSE, ADAS-Cog, CDR, CFQ, FAQ); dementia level	Demographic characteristics	Global cognitive functioning improved: global verbal ability, abstract reasoning, orientation, short-term memory, and depression; Dementia level rating was reduced	37
36 residents of a nursing home; ≥65yrs; impaired memory (scores on Verbal Story Recall test <15.76) randomly assigned to an experimental and control group	The experimental group received 6 month of virtual reality (VR) memory training and auditory stimulation (3 VR sessions and 3 auditory sessions alternating every week for 3 months (=initial training) then 1 VR and 1 auditory session alternating every week for another 3 months (=booster training); control group: 1:1 music therapy instead	Cognitive functioning (MMSE, Mental Status in Neurology); verbal memory; executive functioning; visuo-spatial processing; daily living activities	Demographic characteristics; depression	Improved cognitive functioning after initial training; Improved verbal memory after initial and again after booster training; No improved executive functioning, visuo-spatial processing and daily living activities	39

Appendix C. ICT use and depression, cognitive impairment or dementia (continued)

46 patients; >65yrs, mild cognitive impairments receiving stable treatment with a cholinesterase inhibitor	*Group 1*: 15 patients, 24-week training with an interactive multimedia internet-based system (IMIS), 3x/wk 20min, and a daily cognitive stimulation program (IPP), 8hrs/day participation in activities such as music therapy, arts and craft, exercise etc.; *Group 2*: 16 patients, 24-week IPP program only; *Group 3*: 12 patients as controls; measurements at baseline, at 12 wks and after completion of the training (24 wks)	Cognitive functioning (ADAS-Cog, MMSE); syndrom Kurz test; Boston naming test; verbal fluency; Rivermead behavioral memory test, subtest 'story recall'	Demographic characteristics; dementia level (GDS); Rapid Disability Rating Scale	No differences at baseline except for slightly lower MMSE in *Group 1*; *Group 1*: improved after 12 and 24 weeks for MMSE and ADAS-Cog; *Group 2*: improved as compared to *Group 3* after 2 weeks, not after 24 weeks; No improvements in Syndrom Kurz Test, Rapid Disability Rating Scale and GDS; Changes in the other cognitive variables were not reported	38