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GUEST EDITORIAL

Tools for advancing research into social networks and cognitive function in older adults

Introduction

People are good for your brain. Decades of research have shown that individuals who have a larger number of people in their social network or higher quality ties with individuals within their network have lower rates of morbidity and mortality across a wide range of health outcomes. Among these outcomes, cognitive function, especially in the context of brain aging, has been one area of particular interest with regard to social engagement, or more broadly, socially integrated lifestyles. Many studies have observed an association between the size of a person's social network or levels of social engagement and the risk for cognitive decline or dementia (e.g. see review by Fratiglioni *et al.*, 2004). The dementia risk reduction associated with a larger social network or social engagement shown by some epidemiological studies is fairly large. The population effect size of increasing social engagement on delaying dementia disease progression could exceed that of current FDA approved medications for Alzheimer's disease.

The positive effects of social interactions and engagement on cognitive function have been demonstrated even at the level of biomarkers. For example, recent MRI studies found associations between the size and complexity of real-world social networks and the density of gray matter (Kanai *et al.*, 2012) and amygdala volume (Bickart *et al.*, 2011). Possible modifiable effects of larger social networks on symptomatic outcomes of Alzheimer's disease pathologies have also been shown (Bennett *et al.*, 2006). Human epidemiological studies are not free from possible reverse causations such as lower levels of social engagement being the result of presymptomatic dementia, not the cause of dementia. However, non-human research suggests that social network size could actually contribute to changes both in brain structure and function, providing further support for causal links (Sallet *et al.*, 2011).

Possible mechanisms of social interaction's effects on cognitive function

Although social interaction processes probably facilitate cognitive and brain health in different ways, for example, by helping reduce stress (Miller and O'Callaghan, 2005; Oitzl *et al.*, 2010; McCall and Singer, 2012; Schwabe *et al.*, 2012), or providing tangible support to prevent diseases that affect cognition (e.g. providing access to care), social interaction on its own is likely to have cognitively stimulating effects. People engaged in social activity are by default engaging in cognitive stimulation by virtue of interacting with others. This may increase cognitive reserve (Stern, 2006). Many types of social interactions involve intense "thinking." These interactions can span the gamut from consoling a friend, discussing issues with colleagues, consulting with a spouse over household decisions, to engaging in a negotiation for work. Often, to be effective in these more complex social interactions, a person is required to actively construct a representation of what another person is thinking, what that person believes, what they desire, and what their perspectives on issues are. For example, a fMRI study has shown that the brain areas activated in individuals expressing emotions are the same in individuals perceiving the emotions (Wicker *et al.*, 2003). Recent research also has shown that social interactions lasting a few minutes lead to increases in performance on subsequent tests of executive function (Ybarra *et al.*, 2008).

Despite considerable epidemiological as well as laboratory-based human experimental evidence of the value of social engagement or interaction, developments of effective prevention and intervention protocols aimed to expand social networks or to enhance the socially engaged life have been slow to emerge thus far. In our view, there are two factors which could facilitate the translation of past findings into practical applications for enhancing the cognitive health and well-being of the elderly:

1. Improvement of devices and metrics to objectively assess social interactions or networks beyond survey methods currently utilized in most studies.
2. Randomized controlled trials to identify effective behavioral prevention strategies that can be used widely in communities.

In this review, we focus our discussion on social interaction – an important component of any type of social engagement – and how technologies can contribute to research focused on understanding the mechanisms between cognitive health and social interactions, and the role of technology in facilitating translational studies for improving the well-being of elderly people.

Improvement of devices and metrics to objectively assess social interactions

Limitations in the current assessment of social interactions

Knowledge about social networks and cognitive function has largely been built upon structural aspects of a person's network: the simple self-enumeration of the number of people or acquaintances in an older person's life, their geographic proximity, and/or the degree to which they navigate across these social ties (e.g. how often they are in contact, familiarity among contacts). Acquiring these simple metrics has been the province of standardized questions or scales for determining the extent and structure of a person's social network.

However, the accurate collection of these critical data is challenging. First, collecting the data using surveys suffers from the common challenges of self-report data. This is particularly critical for social engagement research related to cognitive function in that one may not remember well social partners or details of interactions over time. Second, social interactions are dynamic, changing over time. This may be especially true for elderly persons who experience more frequent loss of friends through illness and death, as well as their own transitions through retirement, and change in residence. Thus, the method for capturing these data matters. Survey methods may be insensitive because of choices made in terms of particular social activities queried or the sensitivity of the levels at the intensity of activity reported. For example, in a study attempting to harmonize social activity assessments across four major studies to examine the effect of social activities on cognition, simplifications had to be made to create a comparable metric of "social activity" (Brown *et al.*, 2012). In one study used in the analysis, activities surveyed were volunteering, playing cards, phone conversations, visiting others, attending church, dancing, and partying. In a second study, activities queried were eat at restaurants, visit friend or relative, give dinner party, attend church, meetings of service organizations, meetings of clubs, and do volunteer work. In addition, the estimates of activity were highly variable and skewed such that the scores were ultimately dichotomized.

At the other end of the "forced-choice" environment of survey instruments are more direct self-report activity assessments. As an example, the American Time Use Survey (http://www.bls.gov/tus/) conducted by the Bureau of Labor Statistics in the US falls into this category. In the survey, the interviewer collects a detailed account of the respondent's activities from 4 a.m. the previous day to 4 a.m. on the interview day. The interviewer uses pre-codes to quickly record commonly reported activities, but records the respondent's verbatim responses for all other activities as well. These methods, along with others such as day reconstruction or diary methods, present their own challenges. They may miss more consistent trends or patterns, being generally limited by the particular day or time of year that the information is collected.

Contribution of technology in capturing social interactions

Channels of data sources available

Until relatively recently, there have been few advances in improving the quality and type of information captured for gauging social interactions. In the best of all worlds, we would like to objectively account for *all* human interactions over time, marking their frequency, duration, and quality. This may appear a daunting task. However, the instances of opportunity for social interaction can be readily assigned into two major categories. These include face-to-face or in-person interactions and/or interactions carried out via remote media (telephone, Internet, and written communication). Considered in this way, capturing interactions conceptually becomes simplified to an exercise in assessing the channels of communication.

Recent advances in communication technology, remote sensing, pervasive computing, and data analysis have provided the opportunity to begin to more objectively and meaningfully assess the lines of communication that are vital to social interactions. In many ways much of this progress has been the result of many of the channels of interaction becoming more amenable to automatic data capture. Several developments in particular are of note. The first is the revolution in assessing social network connectivity afforded by the cell phone or programmable mobile phones ("smart phones")(Raento *et al.*, 2009). This development is still quite new given that cellular service and the wide adoption of mobile cell phones only began in the 1990s. Nevertheless, taking advantage of this technology has facilitated large-scale and long-term study of daily patterns of activity. This activity can be captured without either the researcher or the participant needing to actively engage in data entry.

The phone itself is a natural part of everyday human interaction. Data provided from assessing human interaction by measuring aspects of cell phone use (e.g. time on calls, number of calls, an individual's location) are inherently ecologically valid. Some of the most notable work using this approach has been in enumerating, and in particular, examining the dynamics of social contacts in networks. For example, young adults in a university environment were asked about their typical proximity to other individuals in the study (Eagle *et al.*, 2009). Participant self-reports were compared with average daily proximity (within 5–10 minutes) reported through the Bluetooth scans of the smartphones issued for the study. Although most proximity was not reported (69%), when a proximity event was reported, it was usually overestimated. The average reported proximity was 87 minutes per day whereas the average observed proximity was only 33 minutes per day. Using the phone-based observational data alone, it was shown that self-identified friend dyads had distinctive temporal and spatial patterns.

Other platforms (laptops, notebooks, tablets, and interactive TV) also provide the opportunity to assess social interaction through multiple wireless channels of cellular or on-line communication. Social interaction may be captured by assessing the duration or number of events generated on a computer or via phone communication. These may take several forms: "old-fashioned" email, texting, social media interaction, or use of the computer as a phone via voice over Internet protocol.

Ultimately, face-to-face interactions may be the most salient for individuals. Much of this activity may occur spontaneously and outside of the home setting. Here multimodal (auditory and visual) aspects of engagement can be captured with automated analysis of speech and facial expression (Zeng *et al.*, 2009). In the auditory realm, one may use micro-recorders to capture person-to-person interactions. The Electronically Activated Recorder (EAR) developed by Mehl *et al.* (2001) is a modified digital voice recorder that activates periodically for brief periods of time to sample and record ambient sounds. Participants wear the EAR while going about their usual activities to capture for future analysis aspects of social life that normally go unnoticed (e.g. subtle interaction preferences and linguistic styles). Using this device, Mehl *et al.*, for example, showed that the amount of conversation male and female college students have is on average about the same despite the belief that women talk more than men (Mehl *et al.*, 2007). Currently this approach is limited to snippets or brief biopsies of time because the technologies are not capable of recording for long periods of time (typically < 48 hours) and are not totally unobtrusive.

Levels of social interactions assessable

Within these various communication environments, there is an obvious hierarchy of information about social interaction that can be considered. At the lowest level simple capture of time or duration of interaction can be a powerful metric. We have shown that simple daily total time spent on a home computer by elderly people without regard for the specific activity or nature of the potential personal interaction is a sensitive measure of change among people with mild cognitive impairment (Kaye *et al.*, 2013), along with other unobtrusively monitored in-home activities such as walking speed and its variability (Dodge *et al.*, 2012). At a higher level of information is the question of what is the nature of the interaction and with whom, such as is the individual communicating through frequent email with friends or family or as a member of an on-line community? Yet another level of abstraction is the degree to which the interaction is meaningful or valued by the individual. This latter quality may be assessed beyond self-report, facilitated or augmented by several technology-aided approaches. Phone conversations (conducted via any device) may be automatically classified into personal or business conversations (Stark *et al.*, 2012). Email or texts may be auto-analyzed (with instantaneous local processing and immediate deletion for privacy and security concerns) for emotive content (Thelwall *et al.*, 2010).

Since much more than vocal or conversational interaction is important to optimally assess social interaction, capturing other relevant activity through additional sensors worn by social contacts is a notable evolving approach. One important potential channel of information in this regard may be provided by the addition of video-based information to assess engagement especially within interpersonal exchanges. This application can become a powerful tool for advancing the science of meaningful engagement. For example, using video capture of interpersonal interactions, one may analyze facial expressions to assess the degree to which an exchange represents true amusement or simply being polite, a quality of exchange that would be near-impossible to quantify by self-report (Hoque *et al.*, 2011). In general, video capture currently requires environments where the cameras are fixed such as in an environment already outfitted with such equipment or the videocam available on a personal computing device. Google Glass represents a potential mobile system for capturing relevant visual information during interactive activities.

Other developments expanding the types of information that may be captured add multiple domains of sensed information into one device. Thus for example, a developing device, the Hitachi Business Microscope (Takaguchi *et al.*, 2011; Akitomi *et al.*, 2013) combines six infrared transceivers, an accelerometer, a flash memory chip, a microphone, a wireless transceiver, and a rechargeable lithium-ion battery in a badge-like form factor that allows recording of social interactive information for up to two days at a time. Such additional sensors can provide more contextual information such as location, distance and duration of physical contact with others one may interact with over time. Advances in power management, miniaturization, and electronics will likely see many new devices and applications developed in the coming years.

In-home monitoring

Several limitations to current worn or carried devices include their form factor (and resulting obtrusiveness), as well as their largely untested use in older populations. However, since many elderly people do not carry cell phones or similar devices and spend the majority of their day in their homes, more passive sensing techniques in the residential environment provide a unique opportunity space for expanding the capacity to assess social interactions. We have already pointed out the potential value of recording multiple types of data such as audio, activity, and video streams using single carried or interactive devices. The home environment provides some potential additional advantages toward capturing useful data unobtrusively. This can be accomplished by strategically placing passive infrared and contact sensors around a home to capture simple engagement metrics such as time out of home (a measure of outside or "public" socialization) or time in certain locations in the home (e.g. time in bed) (Kaye *et al.*, 2011). Importantly, this approach may also allow one to assess the degree to which external events in real time may affect social interactions such as the onset of or recovery from illness (Campbell *et al.*, 2011). These approaches are most readily applied to persons living alone, a growing population (approximately a third of all adults over age 65) particularly vulnerable to the potential adverse outcomes of social isolation. Currently, the presence or proximity of visitors or loved ones cannot be easily determined with precision in indoor environments where individuals do not live alone, unless body-worn sensors or tags are used. This is likely to change significantly with new developments in technology (Wan *et al.*, 2012).

Development of randomized controlled trials to translate past findings to sustain the independence of the elderly

If social interaction is good for your brain, then ultimately one may want to improve the amount of social interaction and see whether it improves cognitive function. There have been few opportunities to conduct randomized controlled clinical trials specifically targeted to this aim. One such study is currently being conducted (Dodge, NCT01571427; ClinicalTrials.gov). In this study, participants are contacted daily by interviewers using the Internet and webcams to facilitate engaging in 30–40 minutes of conversation. The conversation is semi-structured for standardizing the study protocol, but the main objective is to facilitate each participant in organizing and developing their thoughts and expressing them through face-to-face contact with others. The primary outcomes of interest are cognitive functions measured by traditional and also computerized cognitive tests. The secondary outcomes are emotional well-being. There are several technological improvements being tested in this trial: To ease the use of the Internet chat system among the elderly who might not have had any exposure to personal computers, the project team developed specific software where calls can be received by touching a monitor instead of using a mouse or keyboard. The daily interview sessions have been recorded and an automated speech-detection algorithm is being refined and tested to accurately count the number of words spoken by participants versus the interviewers. Small wearable digital recorders are worn by participants that track the time and duration of conversations occurring outside of the trial session. The level of eye contact during the trial sessions is carefully monitored. One of the innovations of this project is the cost-effective execution of the study by using PCs, webcams, and an Internet chat system similar to Skype (but with further user-friendly modifications). The advantage of using the Internet to conduct social interactions is that unlike cognitive "training" through computer-aided programs, using a webcam through an Internet application is very similar to using a telephone, and requires little effort or motivation on the part of participants. This encourages those with apathy or depression (psychological symptoms often accompanying cognitive impairment or AD) to participate in the trial. Yet unlike a telephone call where participants could engage in other activities while in conversation, eye-to-eye contacts force participants to engage in the conversation and extend their attention span. Because social interaction without attention is likely less effective in improving cognitive function, the telephone was not proposed in this trial. Communication through the Internet and video also offers a higher degree of choice and some aspects of privacy than might be available in interview settings by allowing participants to turn off the camera at their residence, while still being able to see interviewers' faces through their own monitors.

Despite an established link between social interaction and cognitive function in epidemiological studies, there have not been many randomized controlled clinical trials aimed at enhancing social interactions, especially at a large scale. We believe that behavioral randomized controlled trials should be conducted in order to find the effective protocols that can be cost-effective and easily embedded in the community at large. In dementia epidemiological studies, the focus of studies has often been the "engaged lifestyle" that may increase cognitive reserve, which mitigates aging or pathologically associated cognitive decline. As such, the indicators of so called "social engagement" in epidemiological studies of dementia or cognitive impairment often have included various cognitively stimulating activities (e.g. reading books, diary writing, completing crossword puzzles, etc), which might not necessarily require human-to-human interactions, as well as activities embedded in an interactive, person-to-person social context (e.g. participating in group activities, doing volunteer work, and visiting friends or relatives). The multi-dimensional nature of social interactions, together with a broadly defined indicator of social engagement in dementia research, pose challenges in validating past study results across different projects and also in pinpointing what is potentially effective for improving cognitive function. For example, playing games is often categorized as an intellectual activity, but playing games with someone requires social interaction. Is it the social interaction, or playing the game itself, which is more protective against cognitive decline? Or to be effective, do both components (e.g. social interaction + cognitive stimulation) have to be present at the same time? Furthermore, despite the overwhelming amount of epidemiological evidence that supports the link between the socially engaged life style and cognitive function, we still do not know exactly whether enhancing or "forcing" to enhance the level of engagement could lead to improved cognitive function or help sustain function among the elderly. We think these activities should enhance cognitive function, but the results could also depend on the characteristics of participants including their personality and predisposition to engage in specific activities.

Conclusions

There have been many advances building on the rapid growth and diffusion of wireless communications, sensor technologies and social interaction algorithms, and network analysis. Many improvements are still needed in assessment tools and methodologies, for example, to increase scalability, minimize obtrusiveness, and for developing more powerful analysis routines, to name a few. However, once available, this new way of collecting social interaction data will bring a paradigm shift in social behavioral research that currently relies mostly on self-reported time-dispersed surveys. The new collection of data will be more ecologically valid and free from subjective bias and recall errors. Once algorithms are developed in research settings, the data processing can be completed without compromising the privacy of participants. The shift in how we measure interactions could lead to early detection of cognitive impairment and dementia by providing measurements sensitive to changes in cognitive as well as social function. Potential approaches to be used in behavioral clinical trials have also been widened significantly: webcams, smart phones, Internet/PCs, and in-home monitoring could be used to enhance social interaction detection and also track their improvement or change over time. A next set of challenges would be to inform this research by the end users – the older or aging population in naturalistic settings. Modifications of existing devices would likely be required before being used among the current generation of the elderly. Also, the studies cited in this review are mostly limited to those in the U.S. Yet, the number of those with dementia is increasing worldwide with more rapid increase occurring in developing countries. Prevention and intervention protocols established as effective in one culture might not work for other ethnic groups and locations. There is a need to include a wider spectrum of the population including those of different ethnicities and socioeconomic backgrounds in developing prevention/intervention protocols. It is time to translate past observational results into evidence-based protocols of what works best in the wider community to enhance or maintain social engagement well into old age.

Conflict of interest

None.

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