Using Gerontology Theory To Guide the Development Of Artificial Intelligence To Support Aging-In-Place

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Abstract

If artificial intelligence (AI) is to support aging-in-place, determining *how, when, and why* to apply AI is a crucial endeavor. A seminal gerontology meta-theory called Selection, Optimization, and Compensation (SOC) theory has the potential to conceptualize how AI can play a role in aging-in-place. The theory posits that successful aging requires *selecting* goals/domains to apply resources, *optimizing* resources to best achieve those goals, and *compensating* for losses by attaining new resources or tapping into unused resources for alternative means of pursuing those goals. In this short paper, we describe the SOC theory, and draw links to domains in which AI can support aging in place. For example, AI can assist with health-related decision-making (selection), cognitive training and reminders (optimization), and domestic task assistance (compensation). Human-centered considerations are provided for implementation of AI in the home.

Complexities of Aging-in-Place

The conceptualization of aging-in-place has evolved over time (for review, Forsyth & Molinsky, 2020; Rogers, Ramadhani, & Harris, 2020; Weil and Smith, 2016; Beer & Owens, 2024; Owens & Beer, 2024); however, the most commonly cited definition is "The ability to live in one's own home and community safely, independently, and comfortably, regardless of age, income, or ability level" (CDC, 2009). The AARP (Binette & Farago, 2021) recently reported that 77% of older adults wish to age-in-place.

Aging-in-place looks different for each older adult – it is a complex phenomenon that is predicated on both individual and environmental characteristics. Aging is a biological process that takes place over time, over the person's entire life course. There is considerable variability in older age, with physical, cognitive, and perceptual age-related changes (Czaja et al., 2019). A 65-year-old adult is likely to differ significantly from an 85-year-old adult. Similarly, two individuals who are both 85 years old can have vastly different abilities – thus impacting their goals, process, and ability to aging-in-place (Beer & Owens, 2024). Furthermore, place is more than a physical dwelling which also includes their meso-environment (e.g., community). The relationship between a person and their environment (i.e., place) governs older adults' sense of autonomy, independence, security, and social connections (Owens & Beer, 2024).

The multi-faceted nature of aging-in-place is further complicated by a pervasively technological world. Homes are becoming increasingly automated; and while older adults often lag behind younger adults in technology adoption (Czaja et al., 2019), they still do use a plethora of technology in their everyday lives. Older adults do adopt technology readily, if the benefit of the technology is clear.

Using technology within the context of aging-in-place has become a necessity. Technology facilitates many aspects of home maintenance/function and everyday health management (Owens & Beer, 2024). Home-based technology has evolved beyond a simple collection of individual hardware and software devices. Today, home technologies are increasingly moving toward a cohesive network, blurring the lines between technology and the physical environment - integrating technologies within the home, with each other, and with peripheral users such as family, friends, and healthcare providers. This interconnectedness extends beyond the older adult, allowing technology to be integrated both within and outside the physical living space to support aging-in-place

This leaves much opportunity for artificial intelligence (AI) to support successful aging within the home. Home-based technologies, utilizing the integration of AI, may serve a crucial rule in allowing older adults to age in their home longer, safer, and with increased independence. In fact, a recent review article by Czaja and Ceruso (2022) highlights the promise of AI in supporting the ever-increasing older population. In this review, the authors identify four application domains: smart home technologies, wearable activity monitors, virtual reality, and robotics. The authors also identify twelve recommendations for future research in AI for older adults. Their first recommendation is "*Identify AI applications that support the needs and preferences of aging adults for specific tasks/activities.*"

While this recommendation, at a glance, may seem evident, in actuality it is challenging to realize and requires much further research. As stated earlier, the older adult population is far from homogeneous, and how older adults conceptualize aging-in-place is extremely individualized, with varied bio-psycho-social goals and needs. For example, two older adults with a similar chronic condition, but different demographic characteristics (e.g., rural vs urban dwelling, differing educational attainment), may not only have differing needs, but varying views on what "help" looks like and preferences for how this assistance is provided. Thus, determining *how, when, and why* to apply AI is a crucial endeavor, if AI is to truly support successful aging in the home. Gerontological theory can provide some overarching guidance on understanding aging, and the ways in which AI can play a role in supporting aging in place.

A Snapshot of Social Gerontology Theories

The field of gerontology utilizes many theories that help provide organizational structure to the complexities of aging. Historically, biomedical theories of aging have been in existence for centuries and focus on disease and decline. However, social gerontology theories have more recently evolved in response to a growing demand to consider aging from a social/societal lens. Social gerontology theories are young (Hooyman & Kiyak, 2021), only emerging since the 1950s/60s, and thus primarily focus on macro aspects of aging (not meso or micro, as biomedical theories do). Social gerontology theories are less developed than biological theories (for review on the potential of AI in biological aging, see Zhavoronkov et al., 2019), and some social theories have yet to be thoroughly tested. Yet, social gerontology theories have been increasingly used in gerontology research, as many aspects of aging, such as aging-in-place, are influenced by social definitions and social structures. Figure 1 depicts a selected non-exhaustive list of recent social gerontology theories, roughly arranged chronologically.

A transformation of theoretical perspectives occurred as researchers began to emphasize the subjective, yet modifiable, nature of the aging experience. *"Successful aging"* was a term used in aging research as early as the 1960s; yet, Rowe and Kahn (1997) are credited with the seminal work on conceptualizing successful aging, defined as avoiding disease, maintaining high mental and physical functioning, and keeping actively engaged. Criticism has emerged over the terminology (i.e., can one be "unsuccessful" in aging?), primarily over its lack of emphasis on structural factors and social determinants of health. However, at the time, this work marked a paradigm shift in the field of gerontology by emphasizing modifiable aspects of one's lifestyle, such as reducing stress, eating a healthy diet, avoiding drugs and alcohol, and exercising.

Successful aging is a *perspective,* not a theory. However, it served as a backdrop for many of the more recent social gerontology theories, depicted in Figure 1. While all the theories depicted in Figure 1 could perhaps inform the use of AI (each with strengths and weaknesses), we emphasize the Selection, Optimization, and Compensation (SOC) theory as relevant for conceptualizing the intersection of technology and aging-in-place.

The SOC Theory

The Selection, Optimization, and Compensation (SOC) theory (Baltes & Baltes, 1990) is a meta-theory; applicable to the entire lifespan. The SOC theory posits there are three fundamental strategies for successful aging: selection, optimization, and compensation. Freund & Baltes (2013), applied an action-theoretical approach to the SOC theory to increase its practical underpinnings by emphasizing the process of developing goals. The action-theoretical approach suggests that successful aging requires *selecting* goals to apply resources, *optimizing* means to best achieve those goals, and *compensating* for losses by attaining new resources or tapping into unused resources for alternative means of pursuing those goals. The underlying assumption is that these three processes can be used by older adults (i.e., as strategies) to maximize age-related gains and minimize age-related losses, thus promoting successful aging (Table 1; Baltes & Baltes, 1990; Baltes & Carstenson, 2003; Freund & Baltes, 1990.

The SOC theory is strengths-based, meaning that there is an emphasis on a proactive role of the individual – by choosing, committing to, and maintaining a set of goals. With the inevitability of age-related loss, it becomes imperative for

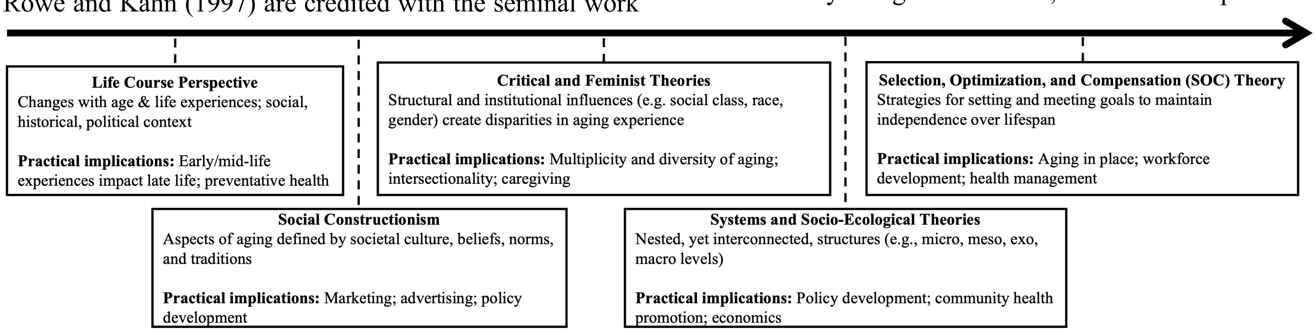

Figure 1. Selected Social Gerontology Theories

older adults to wisely choose goals in which to focus their resources and engage in strategies to meet those goals. Linking back to the spirit of successful aging definition (Rowe & Kahn, 1997), the SOC theory provides an organizational structure for how older adults can proactively utilize strategies to modify aspects of one's lifestyle.

Construct	Example Strategy
Elective Selection	• Prioritizing goals based on preferences • Choosing certain goals over others
Los-Based Selection	• Adapting or reducing standards • Selecting new attainable goals despite loss
Optimization	• Investing time / energy • Refining/improving means • Exhibiting persistence • Modelling successful others • Practice of relevant skills
Compensa-tion	• External means, resources, assistance • Using thus-far unused means or skills

Table 1. Selection, Optimization, Compensation Examples.

Selection

Selection refers to the process of determining, defining, and committing to personal functional goals. The idea is that the number of possible functional goals exceeds the resources available to the older adult (as a function of lifespan variability in capabilities, and availability of internal and external resources). Thus, older adults must reduce the number of goals. To do this, older adults strategically select a subset of goals, relevant to their individual preferences for successful aging that match their needs and demands. Selection is divided into elective and loss-based selection. *Elective selection* refers to selecting goals the older adult wishes to pursue (i.e., match persons needs and motives). Conversely, *loss-based selection* involves the reduction or elimination of tasks one can no longer perform (i.e., perhaps due to age-related changes in capabilities). The process of selection leads older adults to emphasize the most important goals, organize behavior, and guide the application of resources (Baltes & Carstenson, 2003; Freund & Baltes, 1990).

Optimization

Optimization refers to the process of improving or fine-tuning existing resources to enhance wellbeing. In other words, older adults distribute existing available resources to maintain performance in a selected goal/domain (Baltes & Baltes, 1990). This may include investing time, energy, persistence, or practice to meet their selected goals. In the context of the home, examples of optimization include: vacuum the house, even if it takes longer and requires breaks; moving kitchen items to lower shelves (Kelly et al., 2014).

Compensation

Some goals may not be easily obtained in the face of age-related loss in function. Therefore, compensation refers to the utilization of new outside resources (e.g, outsourcing) or activating unused resources to find an alternative means of compensating for loss and meeting one's goals (Baltes & Baltes, 1990). Compensation, converse to optimization, focuses on countering loss, rather than better leveraging currently available positive resources. In the context of the home, compensation may include: hiring a person to clean the home; relying on a spouse for daily reminders; or utilizing a gripper to pick up objects from the ground (Kelly et al., 2014).

Relevance to Aging-in-Place and Tech Adoption

Per Kelly and colleagues (2014, p.1021) there are several reasons why the SOC theory is useful for understanding aging-in-place: "First, the constituent, well-defined processes of the SOC theory provide insights into the actual types of behaviors that older adults use to age-in-place. Second, understanding what processes are most critical for a specific task can provide guidance for interventions. Third, using the SOC theory serves as a guiding framework for understanding and organizing how older adults deal with certain classes of home maintenance tasks."

Since the SOC theory has been introduced, it has been used widely to explore how older adults age-in-place, specifically by maintaining activities of daily living (ADL) and instrumental ADL (IADL). ADLS are considered basic, self-care tasks to live independently (e.g., bathing, feeding, toileting, transferring). IADL are less fundamental thank ADL, but still important for independent living (e.g., meal prepping, maintaining household). Many studies have focused on goal setting in the face of normal age-related changes (e.g., Bourgeois, 2001; Kelly, Fausset, Rogers, & Fisk, 2014), health decline, and chronic diseases (e.g., Carpentieri, Elliott, Brett, & Deary, 2017; Gignac, Cott, & Badley, 2002; Zhang & Radhakrishnan, 2018). Broadly, these studies supported the use of optimization and compensation strategies to manage daily activities. SOC has also been used as a framework to analyze strategies for persons aging-in-place with long-term physical disability. In this study, researchers found that persons with long-term mobility disability employed elective selection (i.e., continuing tasks, despite increased difficulty) strategies to maintain ADL/IADL routines (Remillard et al., 2019).

Today, it is difficult to disentangle aging-in-place and technology adoption. Today's homes are ever-increasingly tech-enabled. Perhaps more than any other social gerontology theory, the SOC theory has been applied to the understanding of older adults and technology adoption processes. In particular, a body of work (e.g., Hernandez-Encuentra, Pousada, & Gomez-Zuniga, 2009; Lifshitz et al., 2018; Sun, McLaughlin, & Cody, 2016) has suggested the use of technology as a compensation tool, so that the technology can compensate for age-related loss in physical, perceptual, and cognitive capability. While others, have stressed the potential for technology to support optimization. For instance, Nimrod (2020) conducted a multi-country large qualitative study with older females on the use of SOC strategies for daily technology usage. Findings suggest that optimization was the most used SOC strategy in IADL tasks, such as health management, financial management, shopping, and planning leisure activities. Specifically, technologies such as social media, video conferencing, apps, and websites was cited as optimizing strategies to save time, effort, and money. While optimization was most mentioned tech-enabled strategy, the Nimrod (2020) found evidence of technology enabling all three strategies – selection, optimization, and compensation – thus playing a role in technology adoption and usage, particularly for purposes of improving sense of autonomy and enhancement of personal resources.

SOC Theory as Guideline for AI

Several previous reviews (e.g., Czaja & Ceruso, 2022; Gantini & Langi, 2023; Sapci & Sapci, 2019; Zhavoronkov et al., 2019) have highlighted the promise of AI – defining a number of domains and applications in which AI can support aging adults. A strength of the SOC theory is to provide an organizational structure for the domains of potential AI support (as proposed in these previous reviews) for aging-in-place. It is also important to note that selection, optimization, and compensation, from an action-theoretical oriented stance, are not necessarily mutually exclusive. Previous research has suggested a combination of these strategies to age-in-place (Freund, 2008; Kelly et al, 2014). To summarize our recommendations, in Table 2, we provide an overview of how the SOC theory can categorize AI supports by linking to selection, optimization, and compensation specific strategies, and we reflect on human-centered considerations for the implementation of AI in the home. To demonstrate the application of SOC to AI and HCI practice, we have provided three diverse scenarios that are representative of the most common barriers or needs of older adults desiring to age-in-place.

Clearly, Table 2 highlights much potential for AI to support aging-in-place, particularly strategies related to the SOC theory. Over the decades, the SOC theory has received very little criticism, and many empirical studies support positive health outcomes for older adults who utilize SOC strategies, including subjective well-being, quality of life, and life success (for examples see Freund & Baltes, 1989; Zhang & Radhakrishnan, 2018). A crucial consideration is that aging is a *process*; as highlighted in Table 2, involving AI in the selection of goal setting and decision making should be a dynamic process (Elwyn et al., 2010; Elwyn et al., 2012); AI must adapt as human needs/capabilities change over time. A strength of the SOC theory is its focus on positive aspects of aging, with optimization a central component to wellbeing and satisfaction. Emphasizing ways in which AI can support existing capabilities and skills of the older adult will lead to aging with empowerment and independence. Thus, it is important not to bias AI to overly-compensate home tasks, unless that strategy is really the most beneficial to counter age-related loss.

Of equal importance to underpinning AI implementation with SOC theory is ensuring that technology development for aging-in-place adheres to common human-computer interaction principles such as those by Norman (Norman, 2013) and others (Czaja et al., 2019). These principles can be combined with community-focused frameworks to ensure that the older adults who represent the larger population have significant contributions to the end-product and result in greater investment in its long-term use (e.g., Owens, 2015). In addition, designing and deploying these systems in partnership with the user may have many other benefits such as recognizing and building on the strengths and resources of the community, identifying challenges to implementation/barriers to adoption, ensuring cultural appropriateness of the AI solution, and determining both the educational needs of the user and the appropriate balance between AI intervention and the older adult's own ability.

In closing, when designing AI systems for aging-in-place, *iterative* involvement of older adults in the design process will be essential to building technological supports that will be adopted, fully utilized, and integrated seamlessly into older adults varied aging-in-place goals and motivations. The SOC theory provides an organizational framework for considering how, when, and why to apply AI to support aging in one's home.

Broader Impact Statement

Artificial intelligence (AI) has much potential to support aging-in-place. Using theory to guide AI is important to systematically build explanations and an understanding of how technology can support, hinder, and alter the experience of aging-in-place.

The current work is in formative stage. The ideas presented in this theory paper largely reflect a large previous body of research conducted by the authors, on the topics of aging and technology. Our previous work has focused on the capabilities of commercially available AI-supported tools (e.g., virtual assistants for supporting aging in place; AI-supported supporting health decision making and augmenting care programs such as the Program of All-Inclusive Care for the Elderly; acceptance and adoption of domestic healthcare robots (Beer et al., 2017; 2012; Beer & Owens, 2024; Corbett et al., 2021; 2023; Owens et al., 2023; Owens and Beer, 2024; Mois and Beer, 2020).

Based on these previous and ongoing studies, we recognize that AI has much potential to support aging-in-place, but enhancements are needed to improve the usefulness and usability of these tools including how, when, and why to apply. Grounding this research in the SOC and HCI, we have tremendous potential to improve our AI-supported technologies for aging in place.

	Scenario	Examples of AI for Aging-in-Place	Human-Centered Considerations
Selection *Determining, defining, committing to personal goals*	77-year-old male who lives alone has experienced multiple falls which threaten his ability to age at home. Upon further investigation by a clinical team, it is suspected that his medication dosage and adherence has contributed to his increased fall risk and degrading health. The patient and his clinical team will now be tasked with developing goals for his health management and continued residence in his home.	• Precision medicine models will help the clinical team calibrate the appropriate medication dosage for the older adult considering their health history, genetics and other factors. • AI embedded decision aids will be capable of assessing older adult's values, determining social/environmental barriers and facilitators to health/medication management, and offering key questions that should be included in the shared decision about their individualized care plan. • Continuous health monitoring via home devices can produce digital biomarkers to detect how well the patient can meet their set goals (e.g., medication adherence) and predict physical/cognitive/perceptual decline.	• Keep the older adult-in-the-loop in all goal setting and decision making. This includes implementing a collaborative/shared process whereby the older adult receives some education on the capabilities of the AI and how it will be used to facilitate "selection." • Consider dynamic/adaptive AI selection support that can be adjusted as goals for the older adult changes or as their needs change. e.g., older adult ages and develops comorbid conditions that further affect fall risk. • Allow older adults to remain in control (including privacy/security) of what data is collected, how it is collected, and when it is collected. As desired, they should also have access to their personal data in a digestible format (e.g., data visualization charts).
Optimization *Improving or fine-tuning existing resources and capabilities*	80-year-old active female who lives alone in a rural community. She attends tai chi virtually once per-week which helps with her increase her leg strength, reduce stress, and promotes better balance. Since the beginning of the COVID-19 pandemic, her course has not resumed in person and it has been difficult finding age-friendly in-person activities. Therefore, this resident has been experiencing loneliness. Uncontrolled, this loneliness could begin to negatively affect her mood, sleep, cognition, and motivation to remain active.	• Virtual assistants will continuously scan the internet for virtual and local events based on the interests of the older adult. With permission from the older adult, the virtual assistant will schedule the event on their calendar, schedule transportation (if necessary), and provide multiple reminders of the event and related preparation activities (e.g., be sure to pack a hat and water bottle for the outdoor topiary exhibit). • Virtual assistants will also provide the life-, leisure-, or occupational-training, skill refinement, and cognitive exercises to support the older adult's physical and mental ability to engage in routine or new activities of interest. • Smart home devices will monitor mood, sleep, and day-to-day routine patterns to identify or concerning changes (or even predict the onset of an untoward outcome) and alert older adult, caregivers, or physician and/or arrange intervention (e.g., provide motivational messages, schedule virtual counseling session).	• Use a strengths-based approach (i.e., positive focus on capabilities) to empower older adult to adopt AI devices. • Explain how AI can support efficiency of task (e.g., performance, time, satisfaction). • Focus on training and educating older adults on use of AI devices to improve their usefulness and usability. • Allow older adults to remain in control (including privacy/security) of what data is collected, how it is collected, and when it is collected, and with whom the data is shared.
Compensation *Utilizing new or unused resources*	A 68-year-old female who lives alone in a senior apartment has mild cognitive impairment and arthritis which affects her memory and mobility. Specifically, she has trouble remembering to accomplish tasks such as turning off appliances/lighting, paying bills, etc. She also physically struggles to complete instrumental tasks such as vacuuming, lawn work, and laundry. Without additional supports, this resident will be unable to continue living independently.	• Home activities will be auto-scheduled (e.g., automatic temp control, lighting, locking doors, bill pay, and laundry service) • Home maintenance will be accomplished by domestic robots or automation (e.g., Roomba, robotic lawnmower) to accomplish home maintenance. • Smart home devices (e.g., virtual assistants capable of natural language processing) will be capable of producing digital biomarkers to detect when and how quickly a patient's cognition is declining and alert their care partner and healthcare team. • Smart home devices will also identify emergencies or situations where AI is unable to compensate and alert a care partner, healthcare provider, or the authorities.	• Be careful not to bias AI to overly compensate; it is important for older adult to remain as active in accomplishing their daily activities as possible. • Compensation does not need to be all-or-nothing; perhaps only difficult aspects of a task to be compensated. • Consider cultural humility and cultural appropriateness of any AI solution as the perception of this compensatory effort could differ based on age and race/ethnicity.

Table 2. Linking Potential AI Aging-in-Place Supports with SOC Theory

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