The Effects of Age and Working Memory Demands on Automation-Induced Complacency

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Complacency refers to a type of automation use expressed as insufficient monitoring and verification of automated functions. Previous studies have attempted to identify the age-related factors that influence complacency during interaction with automation. However, little is known about the role of age-related differences in working memory capacity and its connection to complacent behaviors. The current study aims to examine whether working memory demand of an automated task and age-related differences in cognitive ability influence complacency. Higher degrees of automation (DOA) have been shown to reduce cognitive workload and may be used to manipulate working memory demand of a task. Thus, we hypothesize that a lower DOA (i.e. information acquisition stage with lower level) will demand more working memory than a higher DOA (i.e. decision selection stage with higher level) and that a lower DOA will result in a greater difference in complacency between age groups than a higher DOA.

INTRODUCTION

The World Health Organization (WHO, 2011) estimates that by 2050, there will be approximately 1.5 billion elderly (age 65 and over) in the world. A host of automated services and devices are or will be designed to help older adults maintain independence (e.g., medication reminder apps). Despite this availability of automation and its seemingly utility to maintain independent living (Haigh & Yanco, 2002), research has shown that older adults may be more complacent with automated systems compared to younger age groups (so called automation-induced complacency).

Automation-induced complacency is the “self-satisfaction that may result in non-vigilance based on an unjustified assumption of satisfactory system state” (Billings, Lauber, Funkhouser, Lyman, & Huff, 1976). It is the state in which a user fails to notice imperfect automation. The fault is not detected because the user is poorly monitoring the system, which can result in acceptable performance with reliable automation or diminished performance with unreliable automation (Parasuraman & Manzey, 2010). For instance, an older adult with diabetes may monitor their blood glucose levels while an automated tool. If the older adult perceives the device as reliable and trusts that the blood glucose readings are accurate, they may rely on the reading even when starts to falter. As older adults begin to adopt automated technologies, it is important to understand the age-related factors that contribute to increased complacency and the performance costs associated with those behaviors.

Older Adults, Working Memory, and Complacency

Older adults have been found to be more complacent with automation relative to younger adults (Ho, Wheatley, & Scialfa, 2005b). Various studies have suggested several possible explanations for older adults increased complacency. Some person-related variables range from issues such as higher levels of trust (Johnson, Sanchez, Fisk, & Rogers, 2004; Pak, Fink, Price, Bass, & Sturre, 2012), or age-related differences in abilities (e.g., working memory; Ho et al., 2005b) while some system-related variables are reliability of the automation (Sanchez et al., 2004) and workload (McBride, Rogers, & Fisk, 2011).

Researchers theorized there are two main factors that contribute to older adults’ complacent behavior with automated technologies (Ho, Kiff, Plocher, & Haigh, 2005a). The first is that while using automation, older adults form an inaccurate mental representation of the correct values used in the decision making process due to reduced working memory capacity. The second is that due to their reduced working memory capacity, older adults are able to judge the accuracy of automation. In both cases, it is assumed older adults’ relative complacency with automation is due to a mismatch between the working memory demands of the task and working memory capacity of the person (Ho et al., 2005a).

If working memory capacity plays such a central role in automation complacency, we should observe the opposite relationship as well: reduced complacency in older adults when the automation has been designed to demand relatively less working memory resources (or working memory resources are less constrained). The design of Ho et al.’s (2005b) study precludes this determination because it is unclear whether the high working memory demands of the task or the degree of automation (DOA) contributed to the difference in complacency.


How Complacency is Influenced by Automation-Related Factors

Reliability. Automation reliability is the overall accuracy of the system and is an important factor of automation-induced complacency because the number of errors it produces can impact dependence on automation.

Across different levels of reliability, age is known to produce increased effects on trust in automation. For instance, several studies found that higher reliability led to higher subjective trust in the system for both age groups, but older adults had significantly higher trust than younger adults (Sanchez et al., 2004; Ho et al., 2005b). Highly reliable automation is problematic because users can become accustomed to its high level of performance and may not expect it to fail.

Research on age differences in automation use has found that older adults tend to overestimate the actual automation reliability (Olson et al., 2009). With known differences in working memory, older adults have difficulty detecting errors and perceiving overall automation performance. A combination of unnecessarily high trust in the system and a lack of working memory may produce a lack of error prone awareness consistent with complacent behavior.

Workload. The workload or demand of a task can be taxing on an individual’s cognitive resources, especially when a task is performed over a long period of time. Greater complacency has been shown in a multitask environment instead of a single task or monitoring role for younger adults (Parasuraman, Molloy, & Singh, 1993).

Older adults have a greater tendency to monitor automation and verify the accuracy of the information, even under taxing conditions (Ho et al., 2005b). Exerting more cognitive resources to complete a task may lead the user to rely on automation after task demands become too difficult to manage. There are also age differences in complacency that have occurred under equivalent high workload conditions, where older adults display greater complacency than younger adults (Hardy, Mouloua, Dwivedi, & Parasuraman, 1995; Vincenzi, Muldoon, Mouloua, Parasuraman, & Molloy, 1996, Ho et al., 2005b). If workload only partially contributes to increases in complacency, other age-related factors must be involved as well.

Working memory capacity has been found to significantly predict younger adult performance in an automated task with varying workload (de Visser, Shaw, Mohamed-Ameen, & Parasuraman, 2010). Since working memory plays a role in predicting performance, this cognitive ability may explain some age-related differences in complacient behaviors.

Degree of Automation. Automation comes in a variety of forms, which can execute different functions for the user based on their capabilities and limitations. However, automation is not simply an all or none concept because any individual task can feature varying degrees of automation that take into account the use of various stages and levels (Wickens, Li, Santamaria, Sebok, & Sarter, 2010).

Parasuraman, Sheridan, and Wickens (2000) identified several stages of automation that are based on an existing model of human information processing: information acquisition (stage 1), information analysis (stage 2), decision and action selection (stage 3), and action implementation (stage 4). Each stage is designed to support a different aspect of the cognitive process.

Levels of automation differ from stages because they affect the role of humans and automated systems in a given task. These levels exist on a spectrum of automation, where each level between manual and fully automated changes the designation of authority for decision-making tasks. A low level of automation grants authority to the human, making the individual an active participant in the task and giving the system a secondary role of the passive monitor. These roles are reversed under a high level of automation.

Along each stage of automation, varying levels can be applied to achieve a lower or higher DOA. More automation or a greater DOA can be achieved with both higher levels within a stage and later stages (Manzey, Reichenbach, & Onnasch, 2012). Also, higher DOAs are associated with greater performance in addition to diminished workload (Wickens et al., 2010). Since workload is reduced under a higher DOA, the automation is taking on more of the cognitive demand for those tasks than the operator. This leaves the operator with more cognitive resources at higher DOAs. Thus, working memory demands should lessen as the user moves from a lower DOA towards a higher DOA.

Higher complacency can take the form of performance detriments under unreliable systems and performance gains for increasingly reliable automation. For instance, a meta-analysis found that higher DOAs lead to greater accuracy for younger adults, but only when the automation performed optimally (Onnasch, Wickens, & Manzey, 2013). However, there was a greater performance cost for imperfect automation as DOA increased. For younger adults, these findings reveal differences in performance across DOAs, which seem to indicate changes in complacent behavior. In this context of comparing performance across lower and higher DOAs, research on the older adult population has not been performed. In terms of research by Ho et al. (2005b), it is still unclear whether the high working memory demands of the task or the high DOA contributed to age-related differences in complacency.

Current Study

The aim of this study is to examine the relationship between automation-induced complacency and working memory. Age-related differences in working memory have been implicated as a possible cause of age-related differences in automation-induced complacency. However, prior automation studies (e.g., Ho et al., 2005b) have not manipulated working memory demands of the task to observe how complacency is affected. Therefore, we will use two DOAs that vary in working memory demand. This study will analyze speed and accuracy of user selections at each DOA. Performance under reliable and unreliable trials can provide information to infer the degree to which users are complacent with automation.
METHOD

Participants

Thirty-six undergraduate students will be recruited for this research and given course credit for participation. Thirty-six older adults from the local area will be recruited and will be compensated for their time.

Task

The tasks for this study will be adapted from prior research that uses an automated system in the context of a low-fidelity UAV simulation (Rovira, McGarry, & Parasuraman, 2007). The primary task for this study will be to quickly and accurately find the closest combination of friendly (green units) and enemy units (red units) in terms of distance apart on the grid (Figure 1). Automation will be presented as a table in the bottom left-hand corner of the screen, which will display the distances and unit combinations needed by participants to complete the primary task. The secondary task will consist of checking for a specific call sign and clicking a corresponding button when it appears on screen. The call sign is comprised of a single word and number combination (e.g., Hunter-6). The program will randomly alternate between 14 different call signs every 5 seconds as the participant completes the primary task.

![Figure 1. Screenshot of a low degree of automation (DOA) and low workload trial within the targeting system that features the communications panel (top-left), targeting input panel (top-left), automation table (bottom-left), and grid (right).](image)

Participants will complete blocks of trials in a random counterbalanced order, where each block will consist of a different DOA and workload level. The DOA manipulation will change the stage and level of the automation table used in the task. The lower DOA will use the information acquisition stage, which presents all possible friendly and enemy unit combinations from the grid, with a low level of automation that does not sort the information in any meaningful way. The higher DOA will use the decision and action selection stage, which will present the top 3 friendly and enemy unit combinations. In addition, the high level of automation will sort the information based on importance, so that the shortest distance combination is presented at the top. The workload manipulation will change the number of units presented in the grid. Low workload will present 3 friendly and 3 enemy units, while high workload will show 6 friendly and 6 enemy units. Each combination of DOA and workload will be presented twice for a total of 8 blocks and 240 trials.

The overall automation reliability will be set at 80%, which is above the threshold for imperfect reliability acceptance (Wickens & Dixon, 2007). In each block of 30 trials, 24 trials will be reliable and the remaining 6 trials will be unreliable. An unreliable trial will contain inflated distance values between unit combinations or incorrect optimal suggestions in the automation support table. The first aid failure will not occur until the 10th trial, so that users can build rebuild trust after each block. Also, the automation failures will be distributed randomly throughout the remaining trials.

Measures

**Ability measures.** The following abilities will be assessed: perceptual speed (digit-symbol substitution; Wechsler, 1997), working memory (automated operation span (Aospan); Unsworth, Heitz, Schrock, & Engle, 2005), and vocabulary (Shipley vocabulary; Shipley, 1986). These measures were chosen because they are reliable indicators of their respective abilities (e.g., Czaja et al., 2006; Unsworth et al., 2005). The cognitive ability measures were selected to confirm age differences in fluid and crystallized intelligence. Specifically, the working memory ability measure serves to control for differences in targeting task performance between age groups.

**NASA-Task Load Index (NASA-TLX).** Subjective workload will be measured with the NASA-TLX (Prichard, Bizo, & Stratford, 2011). A computer version of the task will present 6 items that constitute overall workload: mental demand, physical demand, temporal demand, performance, effort and frustration. Each item is rated on a Likert scale of 0 to 20, where higher values indicate increased workload. Subjective workload will be calculated as the average of the 6 combined items. The NASA-TLX will be used as a manipulation check for DOAs and age differences in perceived workload.

**Trust Questionnaires.** Subjective trust will be measured with a general rating of trust in automation (Jian, Bisantz, & Drury, 2000). This measure is a 12-item survey that is rated on a Likert scale of 1 (not at all) to 7 (extremely). The first 5 questions are negatively framed and the last 7 are positively framed. Trust is the sum of normal and reverse coded responses. Higher scores on this measure indicate greater trust in the automated system. The measure will be analyzed for age-related differences in trust towards automation.

In addition, we will use a survey adapted from Lee and Moray (1992) to measure subjective trust specifically towards each DOA and working memory manipulation. This trust measure will pose 3 questions, rated from 0 (not at all) to 100 (extremely), about the automated aid used in each set of trials. For example, the questions will ask participants to answer how much they trusted, relied upon, or benefited from using the automated aid. The overall score will consist of an average of those questions and higher scores will indicate higher trust.
Additionally, this questionnaire will be used to examine trust differences between age groups, level of workload, and DOA. 

**Complacency Potential Rating Scale (CPRS).** The CPRS measures individual potential complacency behavior (Singh, Molloy, & Parasuraman, 1993). This 20-item scale contains 4 filler items and is rated on a Likert scale of 1 (strongly disagree) to 5 (strongly agree). The CPRS scores is a sum of these responses except for the filler responses, where higher values on this measure indicate an increased complacency potential. The CPRS was selected in order to examine age differences in complacency potential.

**Design**

The current study is a 2 (age group: young or old) x 2 (DOA: low or high) x 2 (automation reliability: unreliable or reliable) x 2 (workload: low or high) mixed-subjects design. Age group will be a between-subjects independent variable. These groups will differ in working memory capacity because older adults have been shown to have less of this ability than younger adults. DOA, automation reliability, and workload will be within-subjects independent variables. The DOAs serve as our working memory demand manipulation.

The dependent variables will be targeting task accuracy, targeting task completion time, complacency potential, subjective trust, subjective workload, and working memory capacity. **Targeting task accuracy** will be measured by the mean rate of optimal responses for each automation block. An optimal response is the identification of the closest pair of friendly and enemy units on the targeting task grid. **Targeting task time** will be measured by the average duration (in milliseconds) it takes participants to complete each trial. **Complacency potential** will be comprised of scores on the CPRS. **Subjective trust** will be measured by the sum of subjective ratings on the trust questionnaire for each combination of DOA and workload level. **Subjective workload** will consist of an average of the 6 items on the NASA-TLX and will be measured for each combination of DOA and workload level. **Working memory capacity** will be measured as the sum of perfectly recalled sets of letters on the Aospan task.

**Procedure**

Participants will be seated at individual PC-computers and provided with informed consent. They will be instructed to complete the demographics form and the cognitive ability measures. The experimenter will then tell participants to open the automation program, participants will be presented with a general subjective measure of trust in automation and the CPRS. At the conclusion of the experiment, participants will be debriefed and provided compensation for their time.

**EXPECTED RESULTS**

Repeated measures ANOVAs will be performed to test these expected results. We anticipate main effects of DOA as well as age group on targeting task accuracy and task time, where younger adults should outperform older adults. Overall, we expect participants to perform better under a higher DOA (i.e. decision selection stage with higher level) than a lower DOA (i.e. information acquisition stage with lower level). Also, we will measure differences in subjective workload and trust towards specific DOAs and levels of workload. For those variables, we expect to find main effects of workload and DOA. 

Since we expect an inverse relationship between DOA and cognitive demand, we hypothesize that older adults will have a greater tendency to become complacent under a lower DOA. We can infer the extent to which participants are complacent by analyzing their pattern of performance at different reliability levels. A greater difference between performance with unreliable and reliable automation indicates higher complacency because the user is relying heavily on the system without monitoring for failures. Therefore, we will perform a repeated measures ANOVA to examine targeting task accuracy for unreliable and reliable trials across DOAs and age groups. We hypothesize a lower DOA will result in a greater difference in complacency between age groups than a higher DOA. We anticipate this result because a higher DOA should support working memory ability by taking on more cognitive demanding tasks that would otherwise burden the user. Consistent with previous findings, younger adults should be more inclined to become complacent with a higher DOA. When taking into account age group differences in working
memory ability, we expect that age-related performance effects will not be present.

Finally, we anticipate that older adults will have higher general trust and complacency potential than younger adults. We will conduct two independent samples t-tests to compare differences in complacency potential and general trust in automation between age groups.

**DISCUSSION**

It is important to understand the factors that contribute to complacent behaviors within the human-automation interaction. For the design of automated systems, it is necessary to consider factors such as reliability and workload. Since high system reliability is common in most automated technologies today and thus makes users more susceptible to complacent behaviors, it is essential to alert the user to potential automation-related failures that can occur. In terms of task demands, keeping the task manageable for the user is critical for detecting and correcting inaccuracies.

Designers should select the appropriate DOA for the known population of users. Specifically, the design of automated tasks should consider the age of the user. Automation can be presented in many different ways and can perform a wide range of tasks for the user. Depending on the type of task, some forms may demand more working memory than others. Limiting working memory demand through automation can be beneficial to both younger and older adults. This may help to reduce the occurrence of complacent behaviors during interaction with automation.

**REFERENCES**


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