THE WINDOWS TO FUNCTIONAL DECLINE: EXPLORATION OF EYE MOVEMENTS IN RELATION TO EVERYDAY TASK PERFORMANCE IN YOUNGER AND OLDER ADULTS

A Dissertation
Submitted to
the Temple University Graduate Board

In Partial Fulfillment
of the Requirements for the Degree
DOCTOR OF PHILOSOPHY

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August 2017

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ABSTRACT

Research has demonstrated that everyday functional abilities are compromised in mild cognitive impairment (MCI), a transitional stage between normal cognitive aging and dementia, as well as in healthy aging. These functional changes have been shown to be strong predictors of future decline, highlighting their importance. However, early changes in everyday functioning remain poorly characterized, largely due to a scarcity of sensitive measures capable of detecting subtle disruption. Recent research suggests that eye-tracking methodology may be effective in addressing this gap. Fifty-two participants (27 younger adults and 25 non-demented older adults) completed a novel eye-tracking task involving passive viewing of a naturalistic scene and verbalization of a task goal (e.g., make coffee, pack a lunch). Participants also completed a performance-based measure of everyday action that required them to enact the same tasks (e.g., coffee, lunch) that were included in the eye-tracking paradigm, self-report measures of functional ability, and neuropsychological measures. Mixed ANOVAs were conducted to examine group (young, old) and condition (passive viewing, verbalization)/task (simple, complex) effects on eye-tracking and everyday action performance. Independent samples *t*-tests/Mann-Whitney U tests were conducted to examine group differences in eye-tracking and everyday action performance. Correlation analyses across all measures were conducted to evaluate the potential mechanisms of eye-tracking and everyday action results. Results showed no significant group differences in the primary eye-tracking variables, but both groups made a lower proportion of fixations to distractor (i.e., non-target) objects during task verbalization compared to passive scene viewing. Older adults made more inefficient actions during performance-based everyday task completion, particularly when task demands were high. Eye tracking and everyday action variables were related to different measures of self-reported functional ability. Finally, eye-tracking variables were primarily related to neuropsychological measures of executive functions/working memory, whereas everyday action performance was most strongly related to measures of verbal learning and memory. These findings suggest that age-related functional changes at the level of eye movements may occur after changes in behavioral performance of everyday tasks. Importantly, performance-based assessment of everyday action appears sensitive to age-related decline. Additionally, naturalistic eye movements and everyday task performance may reflect distinct components of self-reported functioning and may be driven by distinct cognitive processes. Future research with refined naturalistic eye-tracking tasks and samples with a wider range of impairment is necessary to further explore these findings and improve characterization and detection of risk for dementia.

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INTRODUCTION

Subtle cognitive decline is a feature of both normative aging and mild cognitive impairment (MCI), and a diagnosis of MCI is warranted when cognitive changes are greater than that expected for an individual's age (Petersen, 2011). Individuals with MCI are considered to be at increased risk of progression to dementia disorders (Petersen et al., 1999), but the reliability and predictive validity of the MCI diagnosis are weak, with many diagnosed individuals reverting to "normal" (Larrieu et al., 2002). Of further uncertainty are the nature and extent of impairment in MCI. Initial criteria proposed for the diagnosis of MCI suggested that functional impairments are not observable at this stage (Petersen et al., 1999), but a growing body of research has shown everyday functioning to be negatively impacted in MCI as measured by self and informant reports (Aretouli & Brandt, 2010; Perneczky, Pohl, Sorg, Hartmann, Komossa, et al., 2006; Reppermund et al., 2011) and performance-based measures (Giovannetti, Bettcher, Brennan, Libon, Burke, et al., 2008; Gold, Park, Troyer, & Murphy, 2014; Griffith et al., 2003; Schmitter-Edgecombe, McAlister, & Weakley, 2012). Importantly, changes in functioning more strongly predict future decline and conversion to dementia than do a range of biomarkers (Gomar et al., 2011) and even the MCI diagnosis itself (Purser, Fillenbaum, Pieper, & Wallace, 2005). These findings underscore the importance of characterizing the early stages of functional decline and call into question the utility of the MCI diagnosis in its current form.

Research examining performance-based everyday function in young adults and healthy older adults has demonstrated functional changes with aging even prior to impairment reaching the level of MCI. During performance-based everyday task completion, healthy older adults have demonstrated lower overall accuracy and higher rates of task sequencing errors and inefficient actions than younger adults (McAlister & Schmitter-Edgecombe, 2013; Schmitter-Edgecombe & Parsey, 2014). These authors suggest that problems related to task efficiency and organization emerge even in healthy aging, with more egregious errors such as failure to complete task steps developing in MCI and dementia. Taken together with research suggesting the relevance of these early functional difficulties to later decline, detection of functional change at the earliest possible stage is critical in characterizing and intervening in disease processes associated with aging.

A major challenge in the characterization of early functional decline and the differentiation of normal and pathological aging involves the development of sensitive measures that capture the subtle functional difficulty present at this stage. Subjective reports of functioning are widely used to assess functional ability, but these may be biased or otherwise inaccurate (Bangen et al., 2010; Tabert et al., 2002) and are likely lacking in the necessary sensitivity to identify mild changes in functioning. Performance-based measures are more objective and allow for standardized assessment of completion of everyday tasks, and they may thus be useful in addressing this challenge. The Naturalistic Action Test (NAT) is one such measure that has been used to characterize functional ability in a range of severely impaired populations (Giovannetti, Bettcher, Brennan, Libon, Kessler, et al., 2008; Giovannetti, Libon, Buxbaum, & Schwartz, 2002; Schwartz, Buxbaum, Ferraro, Veramonti, & Segal, 2003; Schwartz, Segal, Veramonti, Ferraro, & Buxbaum, 2002), and the NAT has also been used to evaluate more subtle aspects of everyday action such as error monitoring (Bettcher, Giovannetti, MacMullen, & Libon, 2008) and inefficient action completion (Seligman, Giovannetti, Sestito, & Libon, 2014).

Specifically, Bettcher et al. (2008) used the NAT to examine error-monitoring abilities in individuals with dementia by coding “microslips,” or rapid corrections prior to full execution of an error, demonstrating the utility of the NAT in evaluating subtle aspects of everyday action. Building on the development of sensitive NAT variables, the reliability and validity of a measure of subtle action disruption termed “micro-errors” was recently established to quantify inefficient but not overtly erroneous task execution that may reflect the early stages of decline. This study demonstrated the sensitivity of micro-errors to increasing task demands, as a sample of non-demented older adults showed a steeper increase in micro-errors than overt errors from the simple to the complex NAT task (Seligman et al., 2014).

Although the NAT has been useful in identifying subtle changes in functional ability, NAT methods are time consuming, requiring video performance and human coding of subtle behaviors, and the mechanisms underlying subtle functional difficulties remain unclear. Eye-tracking technology provides a promising method to address these limitations, as eye movements may be sampled during a relatively brief duration and analyses may be automated. This method may even offer additional insight not gained by the examination of overt behaviors of the hands, as it does not require explicit verbal report (Heine et al., 2010; Norbury et al., 2009). Eye movements can also help to elucidate the cognitive mechanisms associated with functional changes (e.g., distraction from off-task objects, inattention to target objects, etc.), supporting the potential utility of eye tracking to help explain subtle functional changes associated with cognitive decline.

In fact, eye-tracking methodology has been used to examine naturalistic action in healthy individuals (Hayhoe, Shrivastava, Mruczek, & Pelz, 2003; Land, 2006; Land & Hayhoe, 2001) and in several case studies of severe cognitive impairment (Forde, Rusted, Mennie, Land, & Humphreys, 2010; Morady & Humphreys, 2011a). Research on eye movements in healthy individuals during completion of everyday tasks has revealed striking consistency in visual patterns across individuals, suggesting the presence of a meaningful, inherent mechanism underlying naturalistic vision. Specifically, it has been shown that the distribution of fixation position and duration (Hayhoe et al., 2003; Rothkopf, Ballard, & Hayhoe, 2007) as well as saccade magnitude (Land, Mennie, & Rusted, 1999) are relatively stable across individuals and tasks during everyday action (Land & Hayhoe, 2001). Another important feature of naturalistic eye movements is their task-driven, top-down nature, which has been suggested by studies showing that healthy individuals tend to fixate on objects prior to using them (i.e., "look-ahead" fixations), rarely fixate on non-target or irrelevant objects, and that the objects fixated vary based on task instructions (Land et al., 1999; Pelz & Canosa, 2001). Thus, deviations in distractor/target fixations and/or look-ahead fixations may be useful in identifying subtle action disruption associated with cognitive decline.

Although the literature on naturalistic eye tracking in the context of impairment is sparse, several case studies of individuals with severe impairment have been reported in which eye movements during everyday tasks differ from healthy individuals. Specifically, individuals who sustained significant brain damage resulting in profound action disruption showed increased numbers of fixations on irrelevant objects and differing numbers of look-ahead fixations during naturalistic tasks (Forde et al., 2010; Morady & Humphreys, 2011a). A comparison patient in one of these studies diagnosed with Alzheimer's disease also made fewer fixations overall despite intact task completion, suggesting that eye movement differences may provide helpful insight into cognitive impairment beyond that of overt behavioral performance (Forde et al., 2010). Together, these initial cases suggest that cognitive impairment leads to a more salience-based, or bottom-up, pattern of eye movements as a result of either weaker planning mechanisms or degraded knowledge of task goals/objects. However, it remains unknown whether these deviant visual behaviors can be detected early in the course of impairment, when the potential for effective intervention is greatest.

To date, no studies have explored whether eye movements can reveal mild changes in everyday function that may occur in aging and the early stages of cognitive decline. The present study aimed to determine whether eye-tracking methodology can be used to detect and characterize subtle deviations in everyday action as individuals age with the ultimate goal of identifying those at risk for decline and revealing effective targets for prevention and intervention strategies.

Study Aims

The current study examined features of eye movements in relation to execution of a naturalistic, everyday task in samples of young adults and healthy older adults. The long-term goal of this work is to improve identification of older adults at greatest risk for disability and dementia through the development of sensitive indicators of subtle changes in functional ability.

Aim 1: Determine whether young adults and healthy older adults show meaningful differences in eye movements during passive viewing of naturalistic scenes and subsequent verbalization of everyday tasks. There is evidence that healthy individuals demonstrate consistent patterns of eye movements during everyday tasks and that these visual patterns reflect cognitive processes, such as planning and monitoring. It was hypothesized that older adults would differ from young adults in their patterns of eye movements due to cognitive changes associated with aging, such as increased distractibility, slowed access to semantic representations of objects/tasks, and weaker action plans. It was also expected that eye movement patterns would differ more for younger than older adults between passive viewing and verbalization of the task, reflecting an intact shift from bottom-up to top-down processing in the young adult group. This group effect was predicted to be strongest with high task demands.

Aim 2: Determine whether eye movements are more sensitive to subtle changes in everyday action with aging than performance of a naturalistic action task. It was expected that older adults would commit more errors on the Naturalistic Action Test (NAT), a performance-based measure of everyday action, particularly when task demands were high. As previously demonstrated in a sample of non-demented older adults, it was hypothesized that younger and older adults would demonstrate a comparable number of errors during execution of a relatively simple action task with few distractor objects, but older adults would commit more errors during execution of a more complex action task with more distractor objects present due to increased inefficiency when cognitive load is high. It was further predicted that eye movements would more reliably classify participants into their correct groups (i.e., younger or older adults) than NAT errors, implicating eye movements as a more sensitive marker of functioning.

Aim 3: Explore relations between eye tracking, action performance, and self-report of functioning to validate eye-tracking variables as indicators of functional abilities. Significant correlations were expected among eye movement patterns, action errors, and self-reported functioning across groups that support eye-tracking discrepancies as a proxy for subtle functional difficulties. We predicted that visual behaviors suggestive of cognitive weakness (e.g., more fixations to distractor objects or neutral space) would be positively related to action errors and increased levels of self-reported functional disruption.

Aim 4: Explore relations between eye tracking, action, and cognitive measures to determine potential mechanisms underlying eye movement patterns. Significant correlations were expected among eye movement patterns, action errors, and cognitive test performance supporting the notion that eye-tracking discrepancies are driven by cognitively based functional decline. It was predicted that measures of episodic memory and executive function would best predict action errors and eye-tracking variables given the predominance of relations with these domains in the literature on cognition and everyday function. Exploratory analyses were conducted to determine whether specific action and cognitive patterns might aid in characterizing visual behaviors.

CHAPTER 2

METHODS

Participants: Two groups were recruited (*N*=52): a young adult group (*N*=27), ages 18-22, and a healthy, non-demented older adult group (*N*=25), ages 60-75. This sample size is larger than the sample size of all currently published studies of eye tracking during everyday tasks. The younger adult group was comprised of Temple University college students. Older adults were recruited through e-mail and flyer advertisements throughout Philadelphia, and the majority of the older adult sample was comprised of individuals participating in Temple University's Osher Lifelong Learning Institute. All participants were fluent in English, living independently in the community, and had no history of disorders that might affect cognitive abilities such as psychiatric disorders (e.g., schizophrenia, bipolar disorder) or nervous system infections or disorders (e.g., dementia, epilepsy, brain tumor, large-vessel stroke, major head trauma). Participants also did not have any current disorders that might affect cognitive abilities, such as severe depression (Geriatric Depression Scale; GDS>20; Yesavage, 1988) or anxiety (Geriatric Anxiety Inventory; GAI>10; Pachana et al., 2007), severe sensory or motor impairments, metabolic or systemic disorders (e.g., B12 deficiency, renal failure, cancer). Participants were excluded if estimated IQ as measured by the Wide Range Achievement Test, 4th Edition (WRAT-4; Wilkinson & Robertson, 2006) fell below 70. Finally, older adult participants had no evidence of dementia determined by self-report and a passing score on the Telephone Interview for Cognitive Status (TICS; ≤22)(Brandt, Spencer, & Folstein, 1988; Manly et al., 2011).

Procedures: Older adults underwent a cognitive screening (i.e., TICS and brief interview) over the phone to determine their eligibility for the study. The in-person portion of the study consisted of one approximately two-hour session. All participants completed in-person study procedures in the same order: they first completed the eye-tracking task followed by the everyday action task. Finally, participants completed a protocol of neuropsychological measures as well as several self-report questionnaires about their emotional and functional status. Younger adults were compensated for their participation with course credit and older adults were given financial compensation. All study procedures were approved by the Temple University Institutional Review Board (IRB).

Eye Tracking: Eye-tracking data were collected using a SensoMotoric Instruments (SMI) RED-m 120 Hz remote eye tracker while participants completed a two-part screen-based task. Stimuli were presented on a 17-inch Dell monitor using Experiment Center Software, and eye-tracking analyses were carried out using BeGaze software. Only participants who met calibration parameters of less than 0.75 degrees completed the study. Participants were given different instructions for each part of the task. In part one, participants viewed a scene of a table with the necessary objects to complete an everyday task and were simply instructed to look at the scene as though they walked into a room and saw the objects on a table (i.e., Passive Viewing instruction). The amount of time participants viewed the scene was standardized across participants (60 seconds). In part two, they viewed the same scene and were instructed to verbalize the steps they would take to complete the task, thus imposing a task goal on visual behaviors (i.e., Verbalize

Goal instruction). Participants varied in their verbal responses in part two; therefore, the time spent viewing the scene differed across participants in the Verbalize condition.

Each participant completed both parts under two conditions that differed according to task complexity/cognitive load (simple, complex). In the *simple* condition five objects to make coffee with cream and sugar and four distractor objects were presented. In the *complex* condition eight objects to pack a lunchbox with a sandwich, a drink, and a snack and four distractor objects were presented (see Figure 1). The simple and complex conditions differed in both the total number of objects presented (Passive Viewing instruction and Verbalize Goal instruction) and the number of steps to necessary to complete the task (Verbalize Goal instruction).

Figure 1. Eye-Tracking Images for Simple (Coffee) and Complex (Lunch) Tasks

The simple and complex conditions were counterbalanced across participants. It is important to note that these specific simple and complex everyday tasks have been extensively studied in older adults; compared to the simple task, the complex task elicits a greater number of errors in healthy controls and a wide range of clinical populations (Giovannetti, Bettcher, Brennan, Libon, Burke, et al., 2008; Giovannetti et al., 2002;

Humphreys et al., 2000; Schwartz et al., 1998; Schwartz et al., 2002). Patterns of eye movements were recorded and the following variables were collected:

- *Total number of fixations:* The total number of fixations made at any location on the screen was collected for the Passive Viewing – simple and Passive Viewing – complex tasks. For the simple and complex tasks in the Verbalize Goal instruction, the total number of fixations was divided by total time, given that the timing of this subtask was not held constant.
- *Proportion of irrelevant fixations:* Irrelevant fixations were defined as those made to distractor (non-target) objects as well as those made to white (neutral) space. The proportion of irrelevant fixations was calculated by dividing each total (i.e., distractor and white space, separately) by the total number of fixations. This variable was obtained for all four tasks (Passive Viewing – simple; Passive Viewing – complex; Verbalize Goal – simple; Verbalize Goal – complex).
- *Proportion of perseverative fixations:* Perseverative fixations were defined as those made to objects previously fixated (equivalent to regressions or revisits in classical eye-tracking research). The proportion of perseverative fixations was calculated by dividing the total number of perseverative fixations by the total number of fixations. This variable was obtained for all four tasks (Passive Viewing – simple; Passive Viewing – complex; Verbalize Goal – simple; Verbalize Goal – complex).
- *Proportion of look-ahead fixations:* Look-ahead fixations were collected only during part two (Verbalize Goal) and were defined as those within five fixations prior to a verbalized "action" that were towards the target object most relevant to

that “action,” as described by Forde and colleagues (2010). For example, if a participant fixated on the peanut butter followed by the jelly and the bread bag and then verbalized use of the peanut butter, the initial fixation to the peanut butter was scored as a “look-ahead.” The proportion of look-ahead fixations was calculated for each Verbalize Goal task (simple and complex). Because participants differed in their verbal responses, such that not all participants mentioned each task step, the proportion of look-ahead fixations was calculated by summing each participant’s look-ahead fixations and then dividing by the total number of steps coded. This corrected for different numbers of opportunities for look-ahead fixations across participants.

- *Proportion of initial target fixations:* Initial target fixations were obtained by summing the number of fixations to target objects prior to the initial verbalization of action during part two (Verbalize Goal) of each task (simple and complex). The proportion of initial target fixations was calculated by dividing the total number of initial target fixations by the total number of fixations prior to speaking.

Performance-Based Assessment of Everyday Action: The Naturalistic Action Test (NAT) is a performance-based measure of everyday action in which participants complete three everyday tasks while seated at a U-shaped table. The simple and complex tasks described in the eye-tracking task above comprise tasks 1 (coffee) and 3 (lunch) from the NAT, and the objects, their placements, and the table were modified from the original NAT to be equivalent to those presented in the eye-tracking task (see Figure 2). For both tasks, participants were told to complete the task as quickly as possible and without making errors; they were explicitly directed not to touch or move any of the objects until they were ready to use the objects. For the coffee task, participants were instructed to make a cup of instant coffee with cream and sugar. For the lunch task, they were told to pack a lunch box with a peanut butter and jelly sandwich, a drink, and a snack. They were asked to repeat the task instructions and then were told to begin the task. The examiner did not interact with the participant until she/he completed the task.

Figure 2. NAT Object Placement

Performance was video recorded and scored for overt errors, which comprise the Comprehensive Error Score (CES; Schwartz et al., 2002; Giovannetti, Bettcher, Brennan, Libon, et al., 2008) and subtle inefficiencies, or “micro-errors” (see Appendix for NAT psychometric properties). Overt errors include failure to perform a step or subtask (i.e., omission error) and inaccurate performance of a step or subtask (i.e., commission error). Micro-errors are defined as the inefficient but not overtly erroneous execution of task steps and may include extra actions, imperfect sequencing not meeting commission criteria, or microslips, which have been previously defined as the initiation and termination of an incorrect action before the error was completed (Bettcher et al., 2008; Giovannetti, Schwartz, & Buxbaum, 2007; Seligman et al., 2014). See Table 1 for descriptions and examples of micro-errors.

Table 1. Descriptions of Micro-Errors

Description	Example
Unwanted object is reached for and touched	Reaches for and touches the jelly jar without using the jelly
Unwanted object is reached for but not touched	Reaches for the jelly jar, but does not touch it
While holding an object, hand is moved towards a non-target location	Picks up and puts down sugar bowl without use
Object is lifted and moved or put back down without increasing efficiency	Adds peanut butter to bread, then packs cookies, then adds jelly to bread
Order of actions is inefficient but does not warrant a sequencing error	Reaches for and touches the jelly jar without using the jelly

Self-Report Questionnaires of Everyday Function: Self-report measures included the Functional Activities Questionnaire (FAQ; Pfeffer, Kurosaki, Harrah, Chance, & Filos, 1982) as well as a functional assessment based on the Lawton and Brody (1969) instrumental activities of daily living (IADL) scale. The FAQ was administered by the examiner and participants were asked to rate their level of independence in various daily activities (independent without difficulty, independent with some difficulty, requires assistance, dependent). For the IADL scale, participants rated their level of independence on four items (telephone use, mode of transport, medication management, and financial management) using a graded response system (e.g., "operates telephone on own initiative, looks up and dials numbers" to "unable to use telephone"). Given the overall high level of functioning of our sample, the IADL scale variable was dichotomized and participants were classified as either IADL restricted or non-IADL restricted, similar to the method used in a previous study (Peres et al., 2006). For both self-report measures, higher scores indicate greater IADL dependence/restriction.

Neuropsychological and Emotional Function Measures: Tests of episodic memory, executive function, working memory, and language were administered to all participants (see Table 2 for specific measures and descriptions). Neuropsychological measures were included to characterize participants' cognitive functioning, and specific measures of executive functions (Trail Making Test – Sequencing and Switching conditions, WMS-III Spatial Span) and learning/episodic memory (CVLT-II Trials 1-5, Delayed Free Recall, and Recognition Discriminability) were included for aim 4 correlation analyses because these cognitive abilities are most strongly associated with action difficulties in older adults (Giovannetti, Bettcher, Brennan, Libon, Kessler, et al., 2008; McAlister, Schmitter-Edgecombe, & Lamb, 2016; Seligman et al., 2014).

Analysis Plan: All variables were checked for normality, and those with non-normal distributions were either transformed or analyzed using nonparametric methods if transformations did not make distributions normal. The following variables were not normally distributed: proportion white space fixations in all four tasks (Passive Viewing – simple; Passive Viewing – complex; Verbalize Goal – simple; Verbalize Goal – complex), proportion perseverative fixations (Verbalize Goal – simple task), proportion initial target fixations (Verbalize Goal – complex); all NAT variables; FAQ, IADL; WRAT Reading, Trail Making Test (all conditions), CVLT Long Delay Free Recall, CVLT Recognition Discriminability. As mentioned, the IADL questionnaire was dichotomized into IADL restricted (IADL>8) and non-IADL restricted (IADL=8) participants. Trail Making Test – Letter Sequencing achieved a normal distribution with log transformation, which was applied for all analyses. Trail Making Test – Scanning and Number Sequencing achieved a normal distribution when two extreme values in each

Table 2. Neuropsychological Protocol

Test	Description	References
Estimated IQ		
Wide Range Achievement Test, 4th Edition (WRAT-4), Word Reading subtest	The dependent variable was the number of words correctly read aloud (possible range 0 – 70 including identification of 15 letters). An estimated IQ score may be derived from the raw score. For both raw score and estimated IQ, higher scores reflect better performance.	(Wilkinson & Robertson, 2006)
Episodic Memory		
California Verbal Learning Test, 2nd Edition (CVLT-II)	Participants were asked to remember a 16-word list. The dependent variables were number of words retrieved during five learning trials (possible range 0 – 80) and on delayed free recall (possible range 0 – 16); higher scores reflect better learning and recall, respectively. Accuracy on delayed recognition memory also was calculated (Recognition Discriminability, *d'*; possible range -4.02 – +4.02); higher scores reflect better performance.	(Delis, Kramer, Kaplan, & Ober, 2000)
Executive Function		
Delis-Kaplan Executive Function System (DKEFS), Trail Making Test	Participants completed visual scanning, number sequencing, letter sequencing, and number-letter switching conditions using pencil and paper. The dependent variables of interest were time to completion for sequencing and switching conditions. For all Trail Making test scores, higher scores reflect slower/poorer performance.	(Delis, Kaplan, & Kramer, 2001)
Working Memory		
Wechsler Memory Scale, 3rd Edition (WMS-III), Spatial Span subtest	Participants were instructed to tap an array of blocks in the same order, and then in reverse order, as those tapped by the examiner. One point was awarded for each correct sequence. The dependent variable was total number of points awarded, summing the forwards and backwards conditions. Higher total scores reflect better task performance.	(Wechsler, 1997)
Language		
DKEFS Verbal Fluency	Participants were asked to name all the words they could think of that begin with a certain letter (phonemic condition) and all the words they can think of that fit a certain category (semantic condition). The dependent variable was the number of words retrieved in one minute for each condition. Higher scores reflect better performance.	(Delis et al., 2001)
Boston Naming Test, Short Form	The dependent variable is the number of pictures correctly named spontaneously or after a semantic cue (possible range 0 – 15). Higher scores reflect better performance.	(Kaplan, Goodglass, & Weintraub, 2001)

were replaced with the largest values. Group differences were examined using independent samples *t*-tests or Mann-Whitney U tests. When both group and condition effects were examined in the same analysis, mixed ANOVAs were performed.

Finally, Pearson correlation analyses were conducted for all normal variables and those that achieved normality with log transformation (i.e., Trail Making Test – Letter Sequencing). Spearman correlations were conducted for the remaining variables that were not successfully normalized with transformation attempts. Despite being the largest study of its kind, the current sample is somewhat underpowered for the correlation analyses in aims 3 and 4, and a qualitative approach is applied in interpreting these analyses. Specifically, relations of moderate or greater strength are highlighted (r>0.30), but Bonferroni-corrected cut points for significant *p*-values are also noted when reporting multiple correlations. It is acknowledged that correlation analyses are exploratory in nature and warrant further investigation.

CHAPTER 3

RESULTS

Characteristics of the Sample: See Table 3 for demographic and clinical characteristics of the sample. As expected, older and younger adults were significantly different in age. The groups also differed in level of education; however, this difference is likely due to age, as younger adults were all college students and are expected to complete at least 16 years of school. The groups did not differ in the distribution of men/women. There was a significant difference in race/ethnicity, such that the older adults group was comprised of more individuals who identified as Caucasian.

On cognitive tests, older adults obtained higher reading scores than younger adults (raw score and scaled score). However, older adults were significantly slower on all conditions of the Trail Making Test (raw scores). They were also less accurate on the tests of working memory and episodic memory (raw scores). However, compared to their same-age peers (scaled scores), the older adult group performed in the average to high average range across these cognitive measures. The groups did not differ on tests of language fluency or naming (raw or scaled scores). Older adults reported greater independence than younger adults in their daily functioning on one self-report IADL measure (FAQ), which is likely due to dependence on parents for activities such as paying bills and completing tax forms in the younger adult group. When asked about somewhat more basic activities (i.e., shopping, transportation, etc.), the groups did not differ (IADL). CVLT-II scores for three younger adult participants were excluded; in two cases it was discovered that the participants had recently completed this measure rendering it invalid, and a third younger adult was deemed proficient but not fully fluent in English, resulting in exclusion of her scores on verbal measures.

Table 3. Demographic and Clinical Characteristics

	Older Adults (*n*=25)		Younger Adults (*n*=27)		Significance
	Mean, SD		**Mean, SD**		
Age	69.08, 4.21		19.52, 1.22		***p*<0.001**
Education	16.92, 2.81		13.33, 0.92		***p*<0.001**
Sex (% Male)	40.00		22.00		*p*=0.17
Race/Ethnicity (% Cauc)	80.00		52.00		***p*=0.03**
Cognitive Measures	**Mean, SD**	**Scaled Score, SD**	**Mean, SD**	**Scaled Score, SD**	***P*-Value for Comparison of Mean Scores**
WRAT Reading	65.32, 5.57	[2]120.50, 17.08	60.67, 3.77	[2]102.04, 8.94	***p*=0.001**
Trail Making - Scanning	20.84, 3.53	13.30, 1.29	16.07, 3.05	12.04, 1.26	***p*<0.001**
Trail Making - Numbers	35.68, 10.10	12.91, 1.76	23.04, 7.63	11.78, 2.14	***p*<0.001**
Trail Making - Letters	37.50, 13.82	12.21, 1.91	22.74, 8.84	11.93, 2.57	***p*<0.001**
Trail Making - Switching	100.38, 68.43	11.21, 4.05	60.85, 15.49	10.63, 1.90	***p*<0.01**
Spatial Span	14.08, 3.76	10.72, 3.71	17.67, 3.74	10.70, 3.14	***p*=0.001**
CVLT Trials 1-5	44.88, 10.35	[3]52.40, 9.81	52.42, 8.50	[3]48.42, 9.47	***p*<0.01**
CVLT Long Delay Free	9.52, 3.73	[4]0.00, 1.00	12.33, 2.73	[4]0.02, 0.96	***p*<0.01**
CVLT Recog. Discrim.	2.74, 0.88	[4]-0.02, 1.06	3.52, 0.57	[4]0.26, 0.86	***p*<0.01**
Letter Fluency	45.84, 15.64	12.88, 4.27	40.46, 7.14	11.69, 2.46	*p*>0.05
Category Fluency	42.40, 10.95	13.00, 4.01	42.38, 6.34	12.00, 2.53	*p*>0.05
Boston Naming Test	13.96, 1.51		13.92, 1.26		*p*>0.05
Self-Report of Function	**Mean, SD**		**Mean, SD**		
FAQ	1.28, 1.49		5.48, 3.07		***p*<0.001**
IADL	8.80, 1.53		9.48, 1.63		[5]*p*>0.05

[1]Total Errors = CES + Micro-Errors; [2]Standard Score; [3]T-Score; [4]Z-Score; [5]Chi-Square for dichotomized variable

Aim 1: Determine whether young adults and healthy older adults show meaningful differences in eye movements during passive viewing of naturalistic scenes and subsequent verbalization of everyday tasks. This aim was tested using independent samples *t*-tests/Mann-Whitney U tests comparing young versus older participants and mixed (Group x Instruction) ANOVAs with eye-tracking measures as the dependent variables.

Total Number of Fixations, Total Time, and Fixation Rate: As stated earlier, the amount of time spent on the Passive Viewing Instruction was held constant and therefore was the same for both groups. Within the fixed Passive Viewing time, older adults made a significantly greater number of total fixations than younger adults for the Passive Viewing instruction – simple (coffee) task (t=2.73, p<0.01, d=0.77), with a trend in the same direction for the Passive Viewing instruction – complex (lunch) task (t=1.86, p=0.07, d=0.53). Fixations rates are presented in Table 4 below for consistency with the Verbalize Goal instruction.

The Verbalize Goal instruction was self-paced, and older adults took significantly longer to complete the Verbalize Goal instruction than younger adults on both the simple (coffee; t=4.00, p<0.001) and complex (lunch; t=4.49, p<0.001) tasks. Thus, a fixation rate was computed and compared across the groups. Results showed no difference for the Verbalize Goal – simple (coffee) task but a trend was seen in the Verbalize Goal – complex (lunch) task in which younger adults had a greater rate of fixations per time than older adults (coffee t=1.38, p=0.17, d=0.41; lunch t=-1.75, p=0.09, d=0.52). See Table 4 for summary statistics.

Table 4. Summary of Total Fixations and Total Time

	Older Adults		**Younger Adults**		**Summary of Group Difference**
	M	**SD**	**M**	**SD**	
Rate of Fixations per Second					
Passive View – simple (coffee)	2.92	0.42	2.56	0.51	Older > Younger
Passive View – complex (lunch)	2.99	0.40	2.72	0.61	Older > Younger – trend
Total Time on Task					
Verbalize Goal – simple (coffee)	39.76	16.33	25.54	7.19	Older > Younger
Verbalize Goal – complex (lunch)	66.24	29.20	38.88	8.97	Older > Younger
Rate of Fixations per Second					
Verbalize Goal – simple (coffee)	3.20	0.59	2.94	0.69	Older = Younger
Verbalize Goal – complex (lunch)	2.87	0.44	3.09	0.41	Younger > Older – trend

Irrelevant Fixations: In order to evaluate whether younger adults showed a greater shift in fixations away from distractors in the Verbalize Goal condition, mixed (Group x Instruction) ANOVAs were conducted with irrelevant fixations (i.e., fixations on distractor objects and white space) as dependent variables. In order to account for variability in time and the number of fixations made throughout the Verbalize Goal condition, a proportion score was used in this analysis with total fixations in the denominator. For both tasks, there was a significant effect of Instruction (Passive Viewing vs. Verbalize Goal – simple [coffee] F=63.37, p<0.001, d=1.69; complex [lunch] F=158.04; p<0.001, d=2.44) but no effect of Group (old vs. young – simple [coffee] F=0.29, p=0.59, d=0.13; complex [lunch] F=0.04, p=0.84, d=0.00) or interaction effect (simple [coffee] F=0.61, p=0.44, d=0.41; complex [lunch] F=0.47, p=0.50, d=0.48) for distractor fixations. In both cases, all participants made a lower proportion of distractor fixations during the Verbalize Goal instruction than the Passive Viewing instruction across groups (see Figure 3).

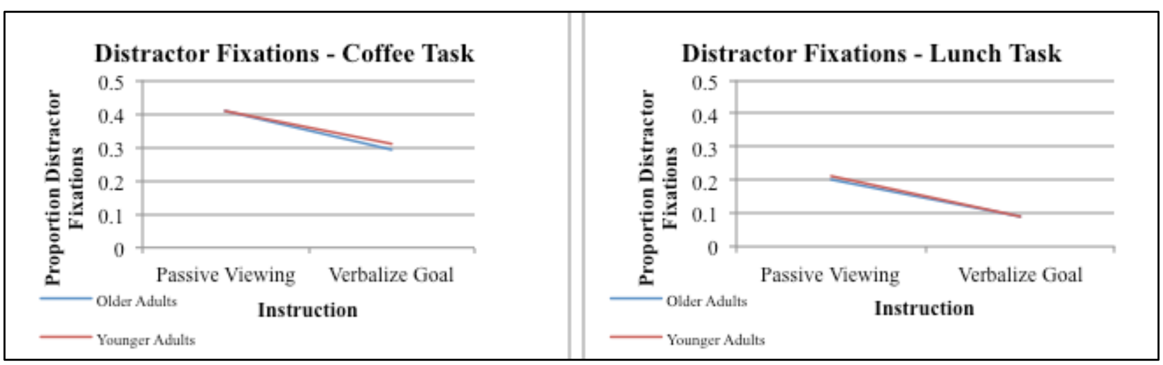


Figure 3. Distractor Fixations Mixed ANOVAs

Regarding fixations to white space controlling for total number of fixations, there was no main effect of Instruction (Passive Viewing vs. Verbalize Goal – simple [coffee] F=0.23, p=0.63, d=0.00; complex [lunch] F=0.62, p=0.44, d=0.12) or Group (old vs.

young – simple [coffee] F=0.33, p=0.57, d=0.18; complex [lunch] F=0.48, p=0.49, d=0.13) and no interaction effect (simple [coffee] F=0.15, p=0.71, d=0.05; complex [lunch] F=0.81, p=0.37, d=0.00) in either task (see Figure 4).

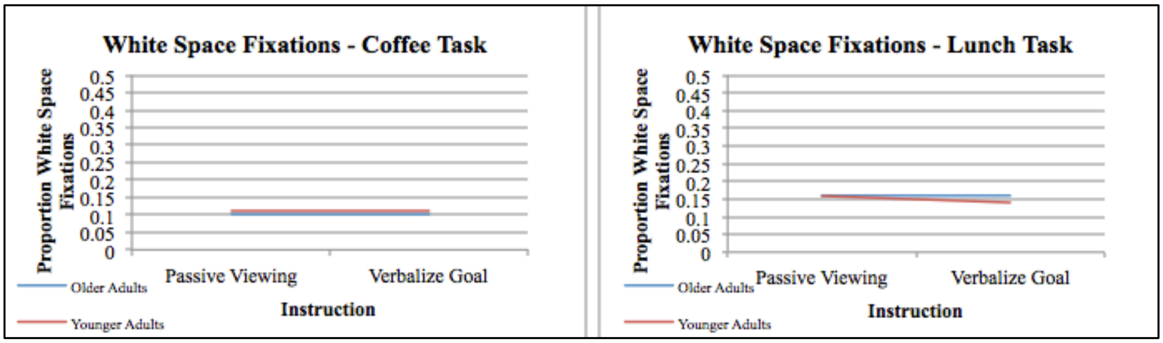


Figure 4. White Space Fixations Mixed ANOVAs

Perseverative Fixations: The number of times participants revisited previously fixated objects controlling for total number of fixations was also examined. Results showed no significant main effect of Instruction (coffee F=0.58, p=0.45, d=0.12; lunch F=3.01, p=0.09, d=0.38), Group (coffee F=2.07, p=0.16, d=0.35; lunch F=0.07, p=0.79, d=0.12), or interaction effect (coffee F=0.36, p=0.55, d=0.06; lunch F=0.53, p=0.47, d=0.06) for either task. The effect of Instruction did suggest a trend in the lunch task, with a lower proportion of revisits in the Verbalize Goal compared to the Passive Viewing instruction (see Figure 5). However, when only considering the proportion of revisits to distractor objects, there was a highly significant effect of Instruction (coffee F=15.68, p<0.001, d=1.00; lunch F=130.79, p<0.001, d=1.71) but not Group (coffee F=2.06, p=0.16, d=0.18; lunch F=0.54, p=0.47, d=0.00) and no interaction effect (coffee F=0.34, p=0.56, d=0.19; lunch F=0.02, p=0.90, d=0.38) for both tasks.

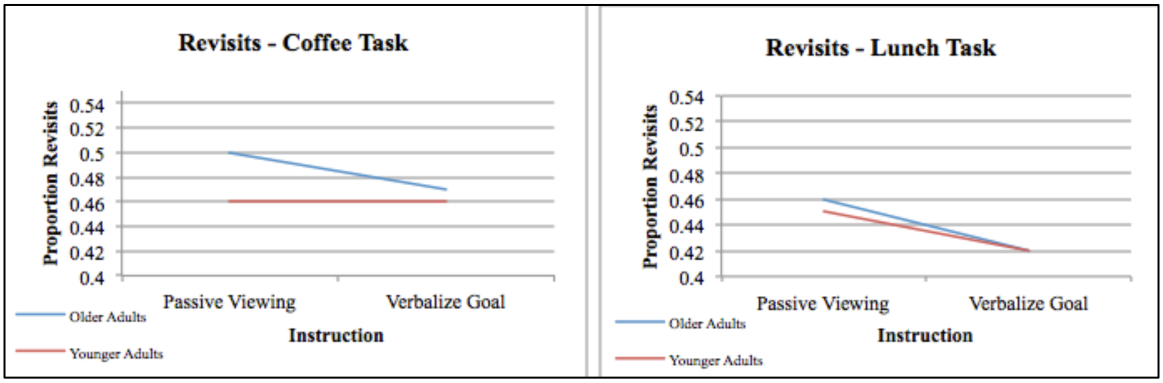


Figure 5. Perseverative Fixations (Revisits) Mixed ANOVAs

Look-Ahead Fixations: Independent samples *t*-tests were conducted to examine look-ahead fixations (i.e., fixations to an object within 5 fixations prior to verbalizing use of that object). No significant difference in the proportion of look-ahead fixations was found between older and younger adults for either the Verbalize Goal – simple (coffee) task (t=0.72, p=0.48, d=0.21) or the Verbalize Goal – complex (lunch) task (t=0.35, p=0.73, d=0.09) task (see Table 5 for summary statistics).

Initial Target Fixations: The proportion of initial fixations to targets prior to speaking was compared between groups using a nonparametric Mann-Whitney U test given the non-normal distribution of this variable. No significant difference was found between older and younger adults for either the coffee (U=322.00, p=0.66, d=0.36) or the lunch (U=304.50, p=0.93, d=0.07) task (see Table 5 for summary statistics).

Table 5. Proportion Look-Ahead/Initial Target Fixations

	Older Adults		**Younger Adults**			**Older Adults**		**Younger Adults**	
	M	**SD**	**M**	**SD**		**M**	**SD**	**M**	**SD**
Look-Ahead					*Initial Target*				
Coffee	2.14	0.98	1.97	0.67	Coffee	0.49	0.11	0.53	0.11
Lunch	2.18	0.65	2.13	0.44	Lunch	0.74	0.15	0.74	0.14

See Figures 6 and 7 for images of cumulative fixations for the participants in each group (Figure 6) and fixations made by a single "representative" participant in each group. In Figure 6 half of the participants in each group (who were administered the coffee and lunch tasks in the same order) are shown in each panel of the figure. Representative participants were defined as those who spent the average amount of time for their respective group on the Verbalize Goal condition of each task (Figure 7).

Aim 2: Determine whether eye movements are more sensitive to subtle changes in everyday action with aging than performance of a naturalistic action task. There were no significant differences in old versus young participants in the primary eye-tracking variables. Therefore, this aim was not pursued. However, analyses were conducted to examine group differences on the performance-based test of everyday action (see Table 6).

Table 6. Group Differences in NAT Variables

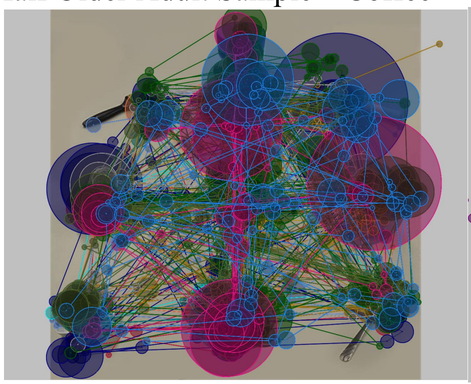
	Older Adults (*n*=25)	**Younger Adults (*n*=27)**	**Significance**
NAT Errors	**Mean, SD**	**Mean, SD**	
Overt Errors - Coffee	0.56, 0.65	0.56, 0.70	$p>0.05$
Overt Errors - Lunch	0.72, 1.02	0.67, 0.78	$p>0.05$
Micro-Errors - Coffee	0.60, 0.76	0.41, 0.93	$p>0.05$
Micro-Errors - Lunch	3.00, 2.22	1.19, 1.18	$\mathbf{p=0.001}$
Total Errors - Coffee	1.16, 1.11	0.96, 1.09	$p>0.05$
Total Errors - Lunch	3.72, 2.72	1.85, 1.41	$\mathbf{p<0.01}$

Note: NAT Total Errors = overt errors + micro-errors

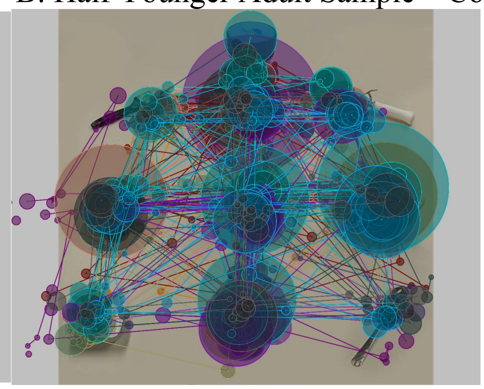
Overt Errors: Independent samples Mann-Whitney U tests were used to compare overt errors given their non-normal distribution. No group differences were found for overt errors in either the simple (coffee) task (p=0.90, d=0.00) or the complex (lunch) task (p=0.79, d=0.06).

Micro-Errors: A mixed (Group x Task) ANOVA was conducted to examine the effect of group and task complexity on rates of micro-errors. Older adults made significantly more micro-errors than younger adults overall (F=10.70, p<0.01, d=0.93), and participants made a greater number of micro-errors in the complex task compared to the simple task

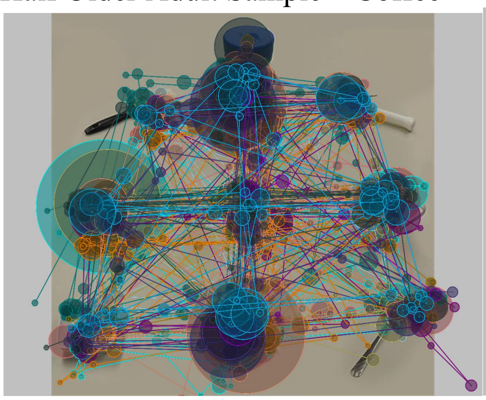
A: Half Older Adult Sample – Coffee



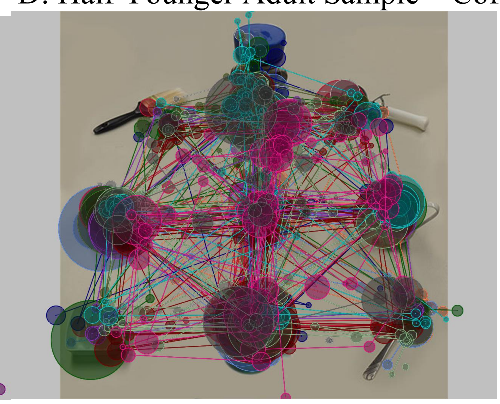
B: Half Younger Adult Sample – Coffee



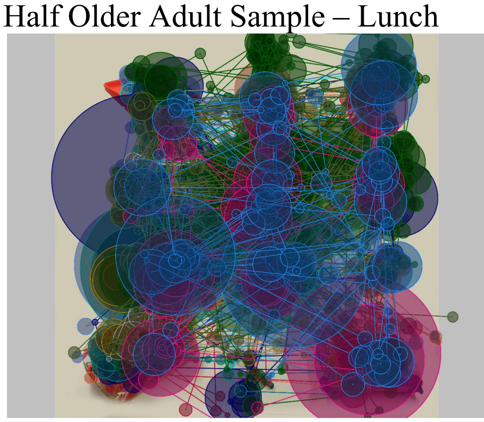
C: Half Older Adult Sample – Coffee



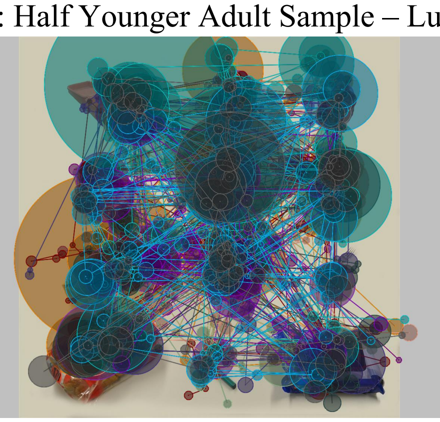
D: Half Younger Adult Sample – Coffee



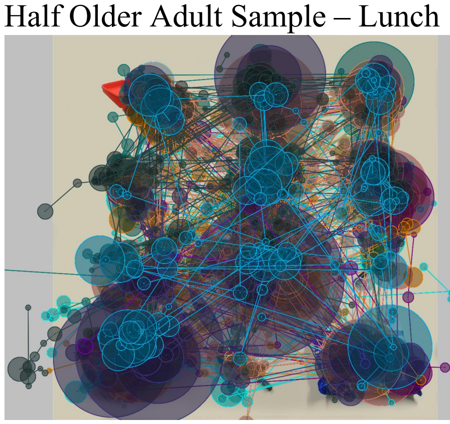
E: Half Older Adult Sample – Lunch



F: Half Younger Adult Sample – Lunch



G. Half Older Adult Sample – Lunch



H. Half Younger Adult Sample – Lunch

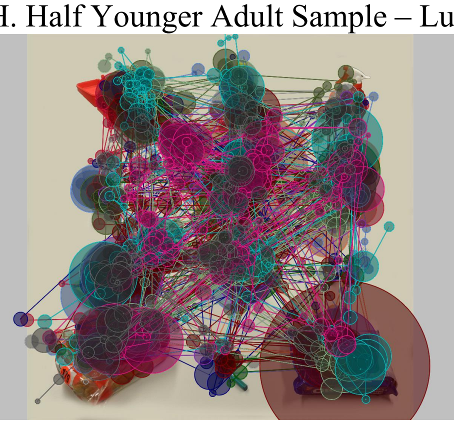
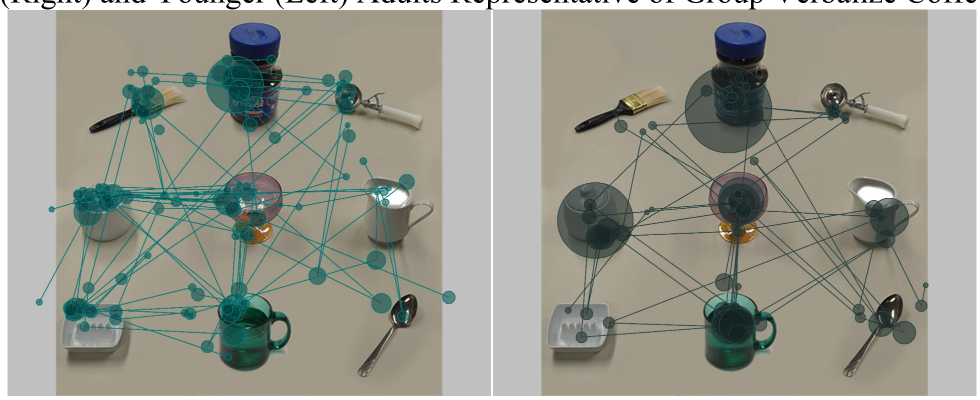


Figure 6. Aggregate Fixations During Verbalize Goal Instruction. Each color represents the scan path and fixation for a single participant. Circles represent fixations, with the size of the circle reflecting the duration of the fixation (i.e., larger circles = longer fixations), and lines represent scan paths between fixations. A: older adults who were administered lunch first; B: younger adults who were administered lunch first; C: older adults who were administered coffee first; D: younger adults who were administered coffee first; E: older adults who were administered lunch first; F: younger adults who were administered lunch first; G: older adults who were administered coffee first; H: younger adults who were administered coffee first

Older (Right) and Younger (Left) Adults Representative of Group Verbalize Coffee Time



Older (Right) and Younger (Left) Adults Representative of Group Verbalize Lunch Time

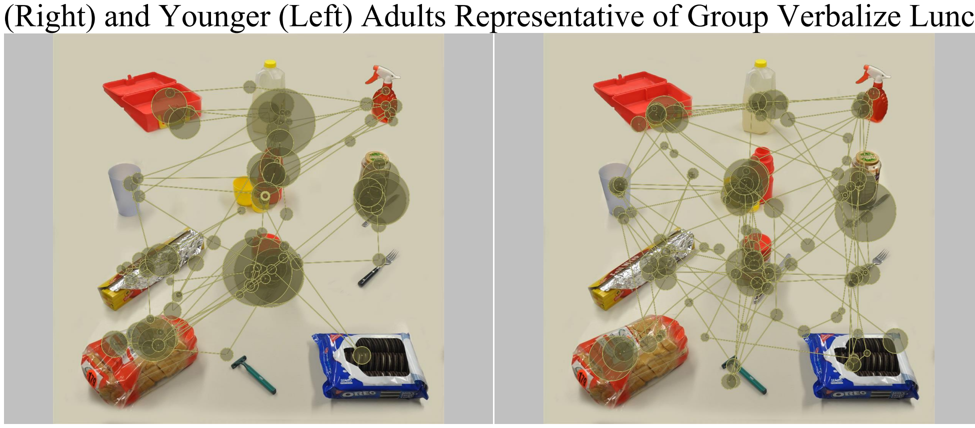


Figure 7. Fixations by Individual Participants with Average Verbalize Time for Group. Circles represent fixations, with the size of the circle reflecting the duration of the fixation (i.e., larger circles = longer fixations), and lines represent scan paths between fixations.

(F=47.96, p<0.001, d=1.11). There was also a significant interaction such that older adults showed a greater difference in micro-errors than younger adults between the simple and complex task (F=12.50, p=0<0.01, d=0.50; see Figure 8).

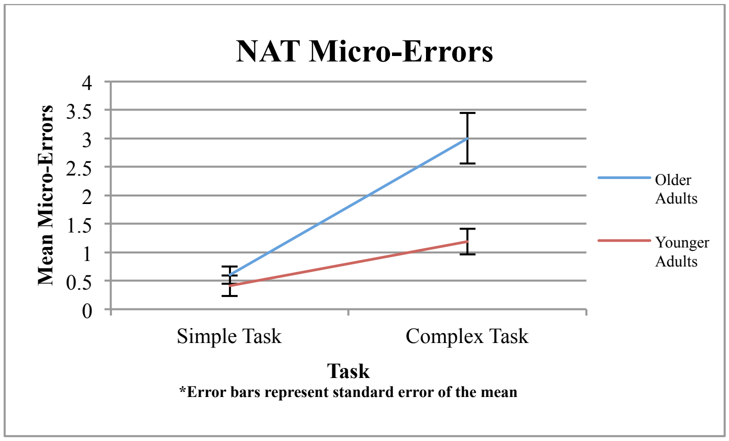


Figure 8. NAT Micro-Errors by Group for the Simple and Complex Tasks

Aim 3: Explore relations between eye tracking, action performance, and self-report of functioning to validate eye-tracking variables as indicators of functional abilities.

Relations Between Eye Tracking and Everyday Action: Spearman correlations did not reveal any significant relations between the proportion of irrelevant fixations, proportion of look-ahead fixations, or proportion of initial target fixations and overall action errors (overt errors plus micro-errors) in either the coffee or lunch task (all ρ's<0.27, all *p*'s≥0.07); see Table 7.

Table 7. Relations Between Eye Tracking and Everyday Action

	Distractor Fixations		White Space Fixations		Look-Ahead Fixations		Initial Target Fixations	
	Coffee	Lunch	Coffee	Lunch	Coffee	Lunch	Coffee	Lunch
NAT Total Errors Coffee	ρ=0.11 *p*=0.45	ρ=-0.07 *p*=0.64	ρ=0.10 *p*=0.50	ρ=-0.02 *p*=0.91	ρ=-0.01 *p*=0.93	ρ=-0.06 *p*=0.67	ρ=-0.10 *p*=0.52	ρ=0.09 *p*=0.52
NAT Total Errors Lunch	ρ=0.26 *p*=0.07	ρ=0.03 *p*=0.85	ρ=0.14 *p*=0.35	ρ=0.25 *p*=0.08	ρ=-0.07 *p*=0.62	ρ=-0.04 *p*=0.81	ρ=-0.01 *p*=0.96	ρ=-0.17 *p*=0.23

Note: NAT Total Errors = overt errors + micro-errors; All eye-tracking variables are proportions and refer to Verbalize Goal instruction

Relations Between Eye Tracking and Self-Report of Everyday Function: Correlation analyses with self-report measures of everyday function were examined separately for older and younger adults as it was observed that functional difficulties were reported for different reasons between groups. Generally, older adults tended to report problems related to changes with age, whereas younger adults appeared to be reliant on a parent or other close acquaintance for numerous tasks (e.g., had never paid taxes or managed bills independently). FAQ scores were not normally distributed, so Spearman correlations were conducted. There were no significant relations between eye-tracking variables and FAQ scores in older adults (all ρ's<0.30, all *p*'s>0.16). However, within younger adults there was a significant moderate correlation between the proportion of initial target fixations in the lunch task and FAQ score (ρ=0.56, *p*=0.003), such that participants who made a greater proportion of target fixations at the outset were more dependent on parents for functional activities.

Regarding the IADL self-report measure, independent samples *t*-tests or Mann-Whitney U tests were conducted as appropriate given the dichotomized IADL variable. Within the older adult group, IADL restricted older adults made a significantly greater proportion of distractor fixations during the Verbalize Goal – complex (lunch) task compared to non-IADL restricted participants (*t*=-2.79, *p*=0.01). No other eye-tracking variables were significantly different between IADL groups. For younger adults, there were no significant differences but a trend in which IADL-restricted participants made a greater proportion of distractor fixations during the coffee task compared to non-IADL restricted participants (*t*=-2.05, *p*=0.053). See Table 8.

According to strict Bonferroni correction, these results do not reach the significance level required to account for multiple analyses (*p*<0.002). However, because these analyses were exploratory, relations were interpreted according to the strength of the result (i.e., correlation coefficients ≥0.30; *t*/Mann-Whitney U *p*-values ≤0.01).

Table 8. Relations Between Eye Tracking and Self-Report of Everyday Function

	Distractor Fixations		White Space Fixations		Look-Ahead Fixations		Initial Target Fixations	
	Coffee	Lunch	Coffee	Lunch	Coffee	Lunch	Coffee	Lunch
FAQ - Older Adults	ρ=0.17 *p*=0.43	ρ=0.26 *p*=0.22	ρ=0.21 *p*=0.34	ρ=-0.11 *p*=0.60	ρ=-0.08 *p*=0.72	ρ=-0.06 *p*=0.80	ρ=0.30 *p*=0.16	ρ=0.01 *p*=0.97
FAQ - Younger Adults	ρ=0.37 *p*=0.07	ρ=0.04 *p*=0.87	ρ=-0.09 *p*=0.67	ρ=-0.23 *p*=0.28	ρ=-0.03 *p*=0.87	ρ=-0.12 *p*=0.58	ρ=-0.19 *p*=0.36	**ρ=0.56** ***p*=0.003**
IADL - Older Adults	*t*=-0.94 *p*=0.36	***t*=-2.79** ***p*=0.01**	U=101.00 *p*=0.07	U=79.00 *p*=0.63	*t*=0.76 *p*=0.46	*t*=1.33 *p*=0.20	*t*=-0.37 *p*=0.71	U=63.50 *p*=0.71
IADL - Younger Adults	*t*=-2.05 *p*=0.053	*t*=0.74 *p*=0.47	U=57.00 *p*=0.67	U=51.00 *p*=1.00	*t*=1.39 *p*=0.18	*t*=1.31 *p*=0.20	*t*=0.90 *p*=0.38	U=77.00 *p*=0.07

Note: All eye-tracking variables are proportions and refer to Verbalize Goal instruction; IADL values are independent samples comparisons (*t*- or Mann-Whitney U tests) between IADL groups (restricted vs. non-restricted)

Relations Between Everyday Action and Self-Report of Everyday Function: Spearman correlations revealed significant moderate relations in the older adult group only between FAQ score and overall NAT errors (overt errors plus micro-errors) on the complex (lunch) task (ρ=0.44, *p*=0.027), which appeared to be driven by micro-errors (ρ=0.42, *p*=0.036) as overt errors on the lunch task were not significantly related to FAQ score (ρ=0.31, *p*=0.14). It is again acknowledged that these relations do not meet the Bonferroni-corrected significance of *p*<0.002 for these analyses. No significant relations were found between FAQ score and NAT errors in the younger adult group.

Relations between NAT errors and the IADL self-report measure were also examined. Independent samples Mann-Whitney U tests revealed no significant differences in NAT errors between IADL restricted and non-IADL restricted older or younger adults (all U's<108.00 *p*'s≥0.07). See Table 9.

Table 9. Relations Between Everyday Action and Self-Report of Everyday Function

	NAT Total Errors		NAT Overt Errors		NAT Micro-Errors	
	Coffee	Lunch	Coffee	Lunch	Coffee	Lunch
FAQ - Older Adults	ρ=0.19 *p*=0.37	**ρ=0.44 *p*=0.027**	ρ=0.31 *p*=0.14	ρ=0.31 *p*=0.14	ρ=-0.02 *p*=0.92	**ρ=0.42 *p*=0.036**
FAQ - Younger Adults	ρ=0.34 *p*=0.09	ρ=0.11 *p*=0.59	ρ=0.08 *p*=0.70	ρ=0.04 *p*=0.85	ρ=0.21 *p*=0.31	ρ=0.26 *p*=0.20
IADL - Older Adults	U=93.00 *p*=0.34	U=107.50 *p*=0.07	U=101.50 *p*=0.14	U=104.00 *p*=0.12	U=73.00 *p*=0.94	U=100.00 *p*=0.18
IADL - Younger Adults	U=81.00 *p*=0.32	U=66.50 *p*=0.84	U=63.00 *p*=1.00	U=61.00 *p*=0.93	U=81.00 *p*=0.32	U=74.00 *p*=0.55

Note: NAT Total Errors = overt errors + micro-errors; IADL values are independent samples comparisons (*t*- or Mann-Whitney U tests) between IADL groups (restricted vs. non-restricted)

Aim 4: Explore relations between eye tracking, action, and cognitive measures to determine potential mechanisms underlying eye movement patterns.

Relations Between Eye Tracking and Neuropsychological Performance: Correlations between measures of discrete cognitive functions and eye-tracking variables were conducted, with Spearman correlations performed for non-normal variables. Across groups, significant moderate correlations emerged for the proportion of initial target fixations in the complex (lunch) task with Trail Making Test – Switching (ρ=-0.47, *p*=0.001), Spatial Span (ρ=0.40, *p*=0.005), Trail Making Test – Letter Sequencing (ρ=-0.31, *p*=0.03), and CVLT-II Learning Trials 1-5 (ρ=0.37, *p*=0.01). Negative correlations with the Trail Making Test variables here indicate a lower proportion of targets fixated in the initial period before speaking relating to more time spent on the Trail Making task (i.e., poorer performance).

Significant moderate relations were also found between the proportion of white space fixations during the complex task and Spatial Span (ρ=-0.44, *p*=0.002), Trail Making Test – Number Sequencing (ρ=0.45, *p*=0.001), and Trail Making Test – Letter Sequencing (ρ=0.40, *p*=0.005), with a mild relation at trending significance for Trail Making Test – Switching (ρ=0.28, *p*=0.056). Negative correlations with the Trail Making

Test variables here indicate that a higher proportion of fixations to white space predicted more time spent on the task (i.e., poorer performance). Bonferroni correction here would require significance levels of *p*<0.0009 to account for multiple analyses. See Table 10.

Table 10. Relations Between Eye Tracking and Neuropsychological Performance

	Distractor Fixations		White Space Fixations		Look-Ahead Fixations		Initial Target Fixations	
	Coffee	Lunch	Coffee	Lunch	Coffee	Lunch	Coffee	Lunch
Trail Making Test - Numbers	*r*=-0.06 *p*=0.67	*r*=-0.04 *p*=0.79	ρ=0.03 *p*=0.85	**ρ=0.45** ***p*=0.001**	*r*=0.02 *p*=0.90	*r*=-0.26 *p*=0.08	*r*=-0.08 *p*=0.59	ρ=-0.20 *p*=0.16
Trail Making Test - Letters	*r*=-0.26 *p*=0.08	*r*=-0.22 *p*=0.13	ρ=-0.06 *p*=0.68	**ρ=0.40** ***p*=0.005**	*r*=0.24 *p*=0.10	*r*=-0.11 *p*=0.47	*r*=-0.01 *p*=0.92	**ρ=-0.31** ***p*=0.03**
Trail Making Test - Switching	ρ=-0.08 *p*=0.57	ρ=-0.13 *p*=0.37	ρ=-0.16 *p*=0.27	ρ=0.28 *p*=0.056	ρ=0.18 *p*=0.22	ρ=-0.13 *p*=0.37	ρ=0.14 *p*=0.33	**ρ=-0.47** ***p*=0.001**
Spatial Span - Total	*r*=-0.20 *p*=0.17	*r*=0.17 *p*=0.25	ρ<0.01 *p*=0.99	**ρ=-0.44** ***p*=0.002**	*r*=-0.06 *p*=0.70	*r*=0.14 *p*=0.34	*r*=0.21 *p*=0.14	**ρ=0.40** ***p*=0.005**
CVLT-II - Trials 1-5	*r*=0.09 *p*=0.57	*r*=-0.06 *p*=0.69	ρ=-0.14 *p*=0.35	ρ=-0.26 *p*=0.08	*r*=0.09 *p*=0.56	*r*=0.26 *p*=0.09	*r*=0.01 *p*=0.97	**ρ=0.37** ***p*=0.01**
CVLT-II - Delayed Recall	ρ=0.05 *p*=0.76	ρ=-0.12 *p*=0.41	ρ=-0.13 *p*=0.39	ρ=-0.18 *p*=0.23	ρ=0.10 *p*=0.51	ρ=0.21 *p*=0.17	ρ=0.03 *p*=0.86	ρ=0.29 *p*=0.053
CVLT-II - Recog. Discrim.	ρ=0.11 *p*=0.46	ρ=-0.05 *p*=0.72	ρ=-0.18 *p*=0.22	ρ=-0.06 *p*=0.68	ρ=0.16 *p*=0.28	ρ=0.17 *p*=0.25	ρ=0.10 *p*=0.49	ρ=-0.11 *p*=0.44

Note: All eye-tracking variables are proportions and refer to Verbalize Goal instruction

Relations Between Everyday Action and Neuropsychological Performance: No significant relations were found between NAT overt errors and neuropsychological measures (all ρ's<0.02, all *p*'s>0.15). Spearman correlations revealed significant moderate relations between micro-errors on the complex (lunch) task only with Trail Making Test – Letter Sequencing (ρ=0.40, *p*<0.01), CVLT-II Learning Trials 1-5 (ρ=-0.38, *p*<0.01), and CVLT-II Long Delay Free Recall (ρ=-0.32, *p*=0.025). Several weaker but notable correlations were also observed between micro-errors on the complex task and Trail Making Test – Number Sequencing (ρ=0.29, *p*=0.037), Trail Making Test – Switching (ρ=0.29, *p*=0.04), Spatial Span (ρ=-0.28, *p*=0.049), and CVLT Recognition Discriminability (ρ=-0.27, *p*=0.06). Bonferroni correction for these correlations would require significance levels of *p*<0.001 to account for multiple analyses. See Table 11.

Table 11. Relations Between Everyday Action and Neuropsychological Performance

	NAT Total Errors		NAT Overt Errors		NAT Micro-Errors	
	Coffee	Lunch	Coffee	Lunch	Coffee	Lunch
Trail Making Test - Numbers	ρ=0.17 *p*=0.24	ρ=0.16 *p*=0.26	ρ=0.17 *p*=0.23	ρ=-0.20 *p*=0.15	ρ=0.17 *p*=0.24	ρ=0.29 *p*=0.037
Trail Making Test - Letters	ρ=0.16 *p*=0.27	ρ=0.25 *p*=0.08	ρ=0.10 *p*=0.49	ρ=-0.14 *p*=0.35	ρ=0.23 *p*=0.11	**ρ=0.40** ***p*=0.003**
Trail Making Test - Switching	ρ=-0.03 *p*=0.82	ρ=0.21 *p*=0.14	ρ=-0.02 *p*=0.92	ρ=-0.04 *p*=0.78	ρ=0.06 *p*=0.69	ρ=0.29 *p*=0.04
Spatial Span - Total	ρ=-0.08 *p*=0.55	ρ=-0.24 *p*=0.08	ρ=-0.16 *p*=0.26	ρ=0.07 *p*=0.63	ρ=-0.03 *p*=0.84	ρ=-0.28 *p*=0.049
CVLT-II - Trials 1-5	ρ=-0.08 *p*=0.58	**ρ=-0.33** ***p*=0.02**	ρ=-0.15 *p*=0.31	ρ=-0.01 *p*=0.96	ρ=-0.04 *p*=0.81	**ρ=-0.38** ***p*=0.007**
CVLT-II - Delayed Recall	ρ=-0.09 *p*=0.52	ρ=-0.26 *p*=0.07	ρ=-0.12 *p*=0.42	ρ=-0.04 *p*=0.80	ρ=-0.06 *p*=0.67	**ρ=-0.32** ***p*=0.025**
CVLT-II - Recog. Discrim.	ρ=0.02 *p*=0.87	ρ=-0.17 *p*=0.24	ρ=0.12 *p*=0.40	ρ=0.13 *p*=0.38	ρ=-0.12 *p*=0.41	ρ=-0.27 *p*=0.06

Note: NAT Total Errors = overt errors + micro-errors

CHAPTER 4

DISCUSSION

The purpose of the current study was to examine the utility of eye-tracking methodology in the assessment of subtle disruption in everyday task completion with the goal of improving characterization and detection of risk for cognitive and functional decline in older age. Young adults and non-demented older adults completed a novel eye-tracking task, a performance-based measure of everyday action, self-report questionnaires of functional ability, and neuropsychological measures. Results did not reveal group differences in irrelevant, perseverative, or look-ahead fixations, but both younger and older participants made fewer fixations on distractor objects when a task goal was imposed compared to passive viewing. Regarding everyday action performance, younger adults made more micro-errors than older adults, especially when task demands were high, but no difference in overt errors was found between groups. Within the older adult group, self-reported IADL restriction was related to distractor fixations and micro-errors. Finally, eye movements were most strongly correlated with neuropsychological measures of executive function and working memory, whereas everyday action performance was most strongly correlated with processing speed, verbal learning, and delayed recall.

Regarding aim 1, it was generally hypothesized that older adults would differ from younger adults in their patterns of eye movements and that eye movement patterns would differ more for younger than older adults between passive viewing and verbalization of the task. Significant group differences were found in the total number of fixations made during the Passive Viewing condition as well as a trend in the rate of fixations during the Verbalize Goal condition (i.e., total number of fixations divided by total time to verbalize the task). Specifically, older adults made more fixations overall than younger adults in the Passive Viewing condition, whereas there were no significant differences in fixations rates during the Verbalize Goal condition. However, a trend was observed during the Verbalize Goal condition suggesting a lower rate of fixations in older adults than younger adults with a task goal imposed, and older adults took significantly longer to complete the Verbalize Goal condition of both tasks than younger adults.

Although there was no specific prediction regarding group difference in total fixations in the Passive Viewing instruction, it was observed that older adults made more fixations during Passive Viewing. This difference may reflect a lower-level attentional difference between the groups that emerged when participants were not given goal-directed instructions. In support of this account, significant moderate relations emerged between total fixations during Passive Viewing and measures of basic attention and processing speed such that longer completion times on the cognitive measures predicted a greater number of fixations for both the simple (coffee) task (Trail Making Test – Number Sequencing, r=0.41, p<0.01; Trail Making Test – Letter Sequencing, r=0.43, p<0.01) and the complex (lunch) task (Trail Making Test – Letter Sequencing, r=0.34, p=0.015). No other cognitive variables predicted total fixations. In contrast, the trend towards a lower fixation rate among older adults in the Verbalize Goal condition is consistent with the original hypothesis as well as a previous case study demonstrating fewer fixations made by an individual diagnosed with Alzheimer's disease whose behavioral performance on the naturalistic task was comparable to healthy comparison participants (Forde et al., 2010). In line with this explanation, the longer time taken to complete the Verbalize Goal condition by older adults may also reflect labored retrieval of task knowledge, poorer planning ability, or slowed processing speed in the older adult group.

There was no evidence for the hypothesized group differences in irrelevant fixations (white space fixations, distractor fixations), perseverative fixations, or look-ahead fixations examined both during and at the initiation (i.e., initial target fixations) of the Verbalize Goal condition. However, for both groups the difference in distractor fixations during the Verbalize Goal compared to the Passive Viewing condition was highly significant, with participants making a lower proportion of distractor fixations during the Verbalize Goal instruction. A trend also emerged suggesting a lower proportion of perseverative fixations during the Verbalize goal condition for the complex (lunch) task. This finding is consistent with prior research indicating that irrelevant objects are rarely fixated during everyday task execution and that fixations differ meaningfully based on task instructions (Ballard, Hayhoe, & Pelz, 1995; Hayhoe et al., 2003; Johansson, Westling, Backstrom, & Flanagan, 2001; Land, 2006; Pelz & Canosa, 2001; Rothkopf et al., 2007). It also supports the validity of this novel eye-tracking paradigm and the distractor fixation specifically in that eye movements became more directed and efficient when a task goal was imposed. Fixations to distractor objects may thus be useful in future studies examining changes or population differences in top-down control or goal-driven search.

That no group differences in these variables were observed may suggest that healthy older adults do not meaningfully differ from their younger counterparts in the efficiency of their eye movements during everyday tasks. This could imply that plan-driven behavior at the level of the eyes is not impacted by normal age-related changes, counter to our hypothesis. It may thus be the case that these changes occur later when more impairment is present at the level of MCI or dementia (Forde et al., 2010; Morady & Humphreys, 2011a). Alternatively, subtle changes in eye movements during everyday action may occur in normal aging that the current task was not sufficiently sensitive to detect.

It is also worth noting that, during the Verbalize Goal condition, participants made a significantly lower proportion of distractor fixations and revisits in the complex (lunch) task compared to the simple (coffee) task. In contrast, participants made a significantly higher proportion of white space and initial target fixations in the complex compared to the simple task. Although these findings are confounded by the lack of equivalence in proportion of distractor objects and amount of white space present between the coffee and lunch tasks in our eye-tracking paradigm, they may suggest differences at the level of eye movements based on task complexity. Specifically, distractibility towards neutral or off-task space may be greater, while the salience of actual distractor objects may be lower, when task demands are high. Future research examining complexity differences in naturalistic eye movements will be interesting to further investigate this question.

Regarding aim 2, it was hypothesized that older adults would commit more errors on the Naturalistic Action Test (NAT), a performance-based measure of everyday action, particularly when task demands were high. Previous work has shown that individuals with MCI perform worse than healthy older adults on the NAT (Giovannetti, Bettcher, Brennan, Libon, Burke, et al., 2008), but to date no studies have compared non-demented older adults to healthy younger adults well before any age-related changes would be expected. Consistent with predictions, no significant group differences were found in overt errors on either task, but older adults made significantly more micro-errors than younger adults across both tasks, particularly during the complex (lunch) task when cognitive load was highest. This suggests that micro-errors are more sensitive to age-related changes in everyday function than are overt errors. The group-by-task interaction supports and extends results from a recent study that demonstrated a steeper increase in micro-errors than overt errors from the simple to the complex task in a sample of non-demented older adults (Seligman et al., 2014). The current finding is the first demonstration of a group effect and supports the sensitivity of micro-errors to both increasing cognitive load and age-specific difficulties. Taken together with the lack of group effects at the level of visual behaviors, it may be the case that subtle changes in everyday task execution occur prior to changes at the level of eye movements, in opposition to predictions. It is possible that task knowledge driving eye movements remains intact in healthy aging but that fixations to task objects lead to impulsive hand movements (i.e., micro-errors). This speculation is supported by the observation that micro-errors were almost exclusively made to target objects, even in the older adult group.

Aim 3 addressed the validity of eye-tracking variables as indicators of functional ability by exploring relations among eye tracking, everyday action, and self-report of functioning. As indicated previously, older and younger adults were analyzed separately for self-report measures of functioning, and results for older adults will be discussed here given this study's focus on functional changes in older age. Contrary to hypotheses, no significant relations were found between eye-tracking variables of interest and everyday action error categories. However, a significant relation was found between the proportion of distractor fixations during the Verbalize Goal – complex (lunch) task and self-reported level of IADL restriction in the older adult group, such that greater IADL restriction was associated with a higher proportion of distractor fixations. This suggests that distractibility or degraded action planning at the level of visual behaviors may be relevant to an individual's perceived difficulty accomplishing daily activities. Further examination of distractor fixations across a greater range of impairment will help clarify the implications of this finding. Finally, within the older adult group overall NAT errors as well as micro-errors alone were positively related to self-reported dependence in everyday activities on the complex task. Together, these findings suggest that eye tracking and everyday action may be targeting aspects of daily ability that are both relevant but distinct components of perceived functional status.

The fourth and final aim was designed to explore the potential cognitive mechanisms underlying eye-tracking and everyday action patterns. It was generally hypothesized that measures of executive functions and episodic memory would be most strongly related to eye-tracking and action variables given the predominance of relations with these in the literature. Across participants significant relations were found for the proportion of initial target fixations with measures of executive control/switching and visual working memory. No such relations were found with the look-ahead fixation itself, suggesting that initial target fixations or similar variables that capture pre-action scene scanning may best capture visual planning mechanisms. Significant relations also emerged for the proportion of white space fixations with processing speed and visual working memory. This was somewhat consistent with our prediction in that measures of executive function including a complex sequencing and visual working memory task were predominantly associated with eye-tracking variables. However, the expectation that episodic memory would relate to performance on the eye-tracking task was largely unsupported. Relations between executive functions and naturalistic eye movements are in line with the conceptualization of complex task organization relying on prefrontal cortex and related functions, including a frontal-parietal attentional system influencing visual control of actions (Land et al., 1999; Posner & Petersen, 1990). Evidence for this top-down visual control of everyday action has also been suggested to challenge the notion that routine, everyday tasks can be performed automatically, without monitoring or active cognitive processing (Land, 2006; Land & Hayhoe, 2001).

Interestingly, all cognitive relations with eye-tracking variables were found for the complex task only, suggesting that this increased cognitive load may facilitate the use of higher-order cognitive functions such as working memory and executive control. Consistent with the notion that visual planning and executive control mechanisms are employed when cognitive demands are imposed, Delerue and colleagues (2013) found differences in eye movements between patients with schizophrenia and healthy participants only in a passive-viewing condition of a sandwich-making task but not in the active sandwich-making task itself. They concluded that patients were able to normalize their visual patterns by employing executive control resources when they were actively involved in tasks with higher demands. In support of this, it has been suggested that direct instruction may facilitate action-planning behavior in schizophrenia at the level of eye movements thought to be driven by prefrontal cortical activity associated with executive control (Frith, 1987; Robbins, 1990; Tonoya, Matsui, Kurachi, Kurokawa, &

Sumiyoshi, 2002). Although these results were specific to schizophrenia, they suggest a mechanism for relations between executive functions and visual behaviors in complex tasks that may be more widely relevant to difficulties imposed by either the aging process or the taxing of cognitive resources with increased task demands.

Relations between everyday action and cognition were also examined and revealed significant moderate associations between micro-errors and processing speed, verbal learning, and delayed recall, again for the complex task only. This finding is interesting in light of recent research suggesting that micro-errors may be driven by early breakdown in episodic memory (Seligman et al., 2014). Further support for the importance of episodic memory in early functional decline comes from research showing the most severe functional impairment in skills that relied heavily on memory and, to a lesser extent, on executive functions based on informant-report (Farias et al., 2006) as well as evidence that individuals with amnestic MCI (i.e., MCI with memory impairment) report greater IADL impairment than those with non-amestic MCI (Teng, Becker, Woo, Cummings, & Lu, 2010; Wadley et al., 2007). Several weaker but notable relations between micro-errors and other cognitive measures including executive control, visual working memory, and verbal recognition memory further suggest that micro-errors may, in fact, capture a wider and more complex range of cognitive domains, though additional work will be necessary to determine the nature and extent of these relations.

Several weaknesses in the current study should be noted. Given limitations of the eye-tracking equipment and the feasibility of eye movement data collection, it was not possible to examine eye movements while participants simultaneously completed everyday tasks. It is therefore possible that our task involving verbalization of action steps was limited in terms of ecological validity, which may have precluded the detection of group differences. However, the finding of reduced distractor fixations in the Verbalize Goal condition supported the overall validity of this paradigm, as imposing a task goal appeared to elicit more efficient visual behaviors. Additionally, the older adult sample was relatively homogeneous and comprised primarily of highly educated (mean >16 years education), Caucasian (80%) individuals, which may limit the generalizability of our findings. That older adults consistently performed more poorly than younger adults across most neuropsychological measures does, however, suggest the presence of expected age-related cognitive decline in this sample. Finally, though larger than any sample size of similar studies in the eye-tracking literature, the sample size of 52 participants (25 older adults and 27 younger adults) may have been somewhat underpowered to detect small but meaningful effects in our analyses.

The current study has several notable strengths. The use of sophisticated eye-tracking technology allowed for the collection of many features of visual behaviors without requiring labor-intensive, subjective behavioral coding. Further, this is the first study of its kind to examine group differences in eye movements during naturalistic tasks; prior studies have either focused on samples of healthy individuals or case studies of severe impairment. The recruitment of a non-demented older adult sample allowed for examination of subtle age-related changes in comparison to a healthy younger sample, which has never been explored to date. The combination of eye-tracking methodology, performance-based assessment of everyday action, self-report, and neuropsychological testing is an additional strength of the current study. This range of measures allowed for examination of visual behaviors associated with everyday task completion in the context of overt behavioral performance using identical target and distractor objects, as well as exploration of perceived functional status and potential cognitive mechanisms. Importantly, the use of a performance-based measure of everyday task completion provides information on daily functioning without the potential for bias or inaccuracy of self-/informant-report and allows for standardized scoring of performance.

Conclusions and Future Directions

The present study provided support for the validity of a novel eye-tracking paradigm and suggested that a performance-based measure of everyday action is sensitive to detect subtle changes in functional ability with age. Group differences at the level of behavioral performance but not in hypothesized visual patterns suggest that overt behavioral differences may be first to emerge when mild cognitive decline is present. Degradation of the action plan at the level of eye movements may thus occur later as impairment progresses, contrary to predictions. It may be the case that the process of completing the complex task itself taxes the system, resulting in a breakdown in performance in older adults. This question constitutes an important future research direction, and the implementation of eye-tracking technology simultaneously with behavioral task completion or a touchscreen/mouse-driven computerized task incorporating an action component will be useful in this endeavor.

Additional specific questions for future research include further investigation of the look-ahead fixation, which is useful in examining the influence of knowledge and planning mechanisms on visual behaviors (Land et al., 1999; Pelz & Canosa, 2001). For example, using the current eye-tracking paradigm, it would be interesting to compare look-ahead fixations made to the target object of a given action with those towards objects not directly relevant to that action step. Perhaps the number of look-ahead fixations immediately preceding an action is less susceptible to action disruption than the ratio of fixations on target versus non-target objects during that period. Consideration of other eye-tracking variables such as saccade amplitude may also provide further insight. Moreover, comparison of eye movements during tasks varying in complexity will be important to further investigate the impact of cognitive load and increasing task demands on naturalistic visual behaviors. Given differences in task parameters of our simple and complex eye-tracking tasks, we were unable to objectively evaluate this in the current study. However, preliminary differences in complexity suggested by the eye-tracking data as well as the significant effect of task complexity in the action task support exploration of this question in future research. Further, all significant associations found in the exploratory aims involved solely the complex (lunch) task, suggesting that tasks of high cognitive load may yield the greatest insight into mechanisms of subtle functional decline in future studies.

Another remaining question is whether multiple eye movement variables together better represent subtle disruption in everyday functioning than any of the proposed variables alone. Preliminary analyses using binary logistic regression with the primary eye-tracking variables all entered into a single model did not yield any significant group differences for the simple (coffee) task, but the model for the complex (lunch) task yielded a trending significance (χ^2=8.78, p=0.067). Within this model, total fixation rate (β=1.41, p=0.072) and proportion of white space fixations (β=-14.25, p=0.034) best distinguished between older and younger adults. These variables, or analogous variables that capture the total number of fixations accounting for time and the number of neutral or off-task fixations, may therefore be useful in future studies of visual behaviors as a marker of subtle functional decline.

Finally, an important broader future research direction involves the inclusion of participants with a greater range of impairment such as diagnoses of MCI and dementia to better understand changes in eye movements across the aging spectrum. Relatedly, longitudinal studies following older adults from healthy aging along normal and pathological aging trajectories will be useful in determining the progression of everyday action decline. Such studies will help resolve the question of whether the current eye-tracking task was lacking in sensitivity to subtle changes or whether these changes indeed arise later when greater impairment is present.

The use of efficient technology such as the current eye-tracking paradigm holds great promise for reducing the labor intensive, time-consuming process often inherent in everyday action research, which presents many implications for the efficiency and scale of future research. It also presents exciting possible clinical applications, as findings from this line of research may yield results that allow for the streamlining of tasks to be used in clinical evaluation of age-related decline. In addition to improving detection of risk for dementia, this research can identify targets for intervention or prevention of functional deficits associated with aging and age-related impairment, which has enormous public health implications given the aging population. This preliminary study provides an initial step in a line of research that aims to characterize the early stages of cognitive and functional decline, determine those at greatest risk for future decline and dementia, and identify effective targets to intervene and promote positive outcomes in older age.

CHAPTER 5

EXTENSIVE LITERATURE REVIEW

Mild cognitive impairment (MCI) refers to the intermediate period between the typical cognitive decline of normal aging and more severe decline associated with dementia. It is typically characterized by a subjective cognitive complaint, objective decline in at least one cognitive domain, and preserved independence in everyday life. However, the extent to which functional independence is preserved in MCI is highly controversial, and a growing body of research has suggested that everyday functioning is, indeed, negatively impacted at this stage. Moreover, functional difficulties in MCI have been associated with specific cognitive deficits, suggesting direct links between the cognitive decline in MCI and functional changes that have become increasingly evident. Our understanding of functional limitations in MCI is hindered by a scarcity of adequate methods, as subjective reports may be inaccurate, and objective measures do not always capture subtle changes in everyday function. The first half of this review will describe the literature on everyday functioning in MCI and will conclude that the development of sensitive, objective measures is crucial to improve understanding of the breakdown of functioning in MCI, to aid with early detection of risk for decline, and to provide meaningful outcome measures for treatment studies.

The second half of this review focuses on eye tracking as a potential solution to the challenges associated with functional assessment in MCI. This section begins with a review of recent research utilizing eye-tracking technology in healthy individuals, which has provided promising results regarding the ability to capture subtle behavioral characteristics that can reveal mechanisms underlying complex everyday task completion. Then, the few studies that have used this methodology to examine naturalistic action in the context of severe impairment as well as eye-tracking studies that distinguish healthy individuals from those with MCI will be reviewed. In conclusion, we will propose that the identification of divergent visual behaviors during everyday tasks and their cognitive underpinnings constitutes a promising research direction to better characterize the changes in MCI that impede efficient completion of daily activities and may herald future decline.

Everyday Functioning in Mild Cognitive Impairment

Controversy of Functional Ability

Individuals with MCI exhibit minor deficits across a spectrum of cognitive domains and are at increased risk of progression to dementia disorders (Petersen et al., 1999). The current diagnostic criteria for MCI stipulate the presence of a cognitive complaint, objective decline in at least one cognitive domain, and generally preserved functional independence/complex activities of daily living (M. S. Albert et al., 2011; American Psychiatric Association, 2013). Initial criteria proposed for the diagnosis of MCI suggested that functional impairments are not observable at this stage, and went so far as to maintain that the presence of functional deficits differentiates between individuals with AD and MCI (Peterson et al., 1999). Over time this distinction has been called into question. Nygard (2003) highlighted the importance of considering informant- and self-report of changes in daily functioning when diagnosing MCI, as subtle everyday difficulties may be the earliest signs of illness. Further, Winblad and colleagues (2004) have suggested that basic activities of daily living (ADL; e.g., bathing, eating) are preserved in MCI, but that complex or instrumental activities (IADL; e.g., meal preparation, medication management) may be either intact or minimally impaired. Applying these criteria that incorporate a change in activity level was shown to better identify individuals that went on to convert to dementia (Artero, Petersen, Touchon, & Ritchie, 2006). However, a recent revision to the MCI criteria by Peterson (2011) only acknowledged the possibility of mild functional inefficiencies while maintaining that MCI "does not compromise the ability to function" (Petersen, 2011, p. 2227). Recently, Morris (2012) has suggested that allowing functional deficits as a criterion for MCI is misleading and premature. Table 1 lists several conflicting quotes on this topic from the MCI literature. Clearly, a high degree of inconsistency and ambiguity continues to surround the inclusion of functional impairment in the diagnosis of MCI (see Gold, 2012 for a review).

Table 12. Quotes from the MCI Literature Demonstrating Confusion and Controversy Regarding Everyday Functional Difficulties

Author(s), Year	Quote	Page #
Petersen, 1999	"The diagnosis of MCI was made if the patient met the following criteria: 1) memory complaint, 2) normal activities of daily living…"	304
Nygard, 2003	"In current publications, there seems to be no clear consensus concerning how IADL is affected in cognitive impairment or MCI in comparison with mild dementia. However, it seems possible to conclude that we have evidence of subtle but important changes in everyday functional competence in very early stages of cognitive impairment."	45
Winblad et al., 2004	"The specific recommendations for the general MCI criteria include the following: (i) the person is neither normal nor demented; (ii) there is evidence of cognitive deterioration shown by either objectively measured decline over time and/or subjective report of decline by self and/or informant in conjunction with objective cognitive deficits; and (iii) activities of daily living are preserved and complex instrumental functions are either intact or minimally impaired."	241
Petersen, 2011	"Amnestic mild cognitive impairment is clinically significant memory impairment that does not meet the criteria for dementia. Typically, patients and their families are aware of the increasing forgetfulness. However, other cognitive capacities, such as executive function, use of language, and visuospatial skills, are relatively preserved, and functional activities are intact, except perhaps for some mild inefficiencies."	2227
Albert et al., 2011	"Persons with MCI commonly have mild problems performing complex functional tasks which they used to perform previously, such as paying bills, preparing a meal, or shopping. They may take more time, be less efficient, and make more errors at performing such activities than in the past. Nevertheless, they generally maintain their independence of function in daily life, with minimal aids or assistance. It is recognized that the application of this criterion is challenging, as it requires knowledge about an individual's level of function at the current phase of their life. However, it is noteworthy that this type of information is also necessary for the determination of whether a person is demented."	271-272
Morris, 2012	"The original diagnosis of MCI was limited to individuals with cognitive impairment in a single domain (memory), thus distinguishing MCI from dementia, but more recently its differentiation from dementia has come to rest solely on the preservation of functional activities. The revised criteria for MCI, however, allow considerable latitude as to what represents functional independence and thus blur the categorical distinction between MCI and dementia."	700

Evidence of Functional Difficulties in Mild Cognitive Impairment and Healthy Aging

Recent research has emphasized the importance of recognizing and characterizing functional deficits in the initial phases of cognitive decline, and many have thus argued for the incorporation of IADL deficits into the MCI diagnostic criteria (S. M. Albert, Tabert, Dienstag, Pelton, & Devanand, 2002; Artero, Touchon, & Ritchie, 2001; Brown, Devanand, Liu, & Caccappolo, 2011; Goldberg et al., 2010; Griffith et al., 2003; Nygard, 2003; Perneczky, Pohl, Sorg, Hartmann, Komossa, et al., 2006; Tam, Lam, Chiu, & Lui, 2007). Self and informant reports of independence in IADLs have revealed impairment in individuals with MCI compared to healthy older adults (Ahn et al., 2009; Aretouli & Brandt, 2010; Bombin et al., 2012; Perneczky, Pohl, Sorg, Hartmann, Komossa, et al., 2006; Perneczky, Pohl, Sorg, Hartmann, Tosic, et al., 2006; Reppermund et al., 2011; Tam et al., 2007; Tuokko, Morris, & Ebert, 2005). Moreover, faster decline in self-reported everyday function has been shown in MCI compared to healthy older adults over a three-year period (Wadley et al., 2007). In one study, IADL items with high versus low cognitive demand determined by factor analysis showed differential impact in MCI as reported by informants, with differences between MCI and healthy older adults emerging for high, but not low, cognitive demand items (Reppermund et al., 2011). This finding emphasizes the potentially subtle nature of functional difficulties and the need for detailed and sensitive evaluation to capture meaningful changes in MCI. Jefferson and colleagues (2008) addressed this measurement issue by examining several different informant-rated assessments of functioning in MCI. They found that an error-based informant report measure (Functional Capacities for Activities of Daily Living, FC-ADL) identified functional differences between MCI and healthy older adults, whereas no differences emerged using a more global measure of functioning (Lawton and Brody Instrumental Activities of Daily Living and Physical Self-Maintenance Scale).

Discrepancies in results across studies using different functional measures may account, in part, for inconsistent conclusions regarding functional status in MCI.

Functional impairments in MCI have also been demonstrated on performance-based measures of functioning, which can provide more objective information on the degree of functional impairment. An early study in the context of this body of literature demonstrated poorer performance in MCI on an objective financial capacity measure (Financial Capacity Instrument, FCI) relative to healthy older controls, with less impaired performance than that of a mild Alzheimer's disease (AD) group (Griffith et al., 2003). Schmitter-Edgecombe, McAlister, and Weakley (2012) also found that MCI participants performed more poorly than healthy older adults on the Day-Out Task (DOT), a naturalistic test of functional ability that requires participants to complete multiple tasks and plan for an outing. Functional difficulties in MCI have also been revealed using "smart-home" technology in which participants were videotaped while performing daily activities in a room equipped with everyday objects (Sacco et al., 2012). In one study, although individuals with MCI completed a performance-based test of IADLs with comparable accuracy to healthy older adults, their performance was significantly slower (Wadley, Okonkwo, Crowe, & Ross-Meadows, 2008), suggesting reduced efficiency during everyday task completion.

In several studies using performance-based measures (e.g., UCSD Performance-Based Skills Assessment, UPSA; Everyday Cognition Battery, ECB), those with MCI displayed greater impairment than healthy older adults even in the absence of self-reported (Allaire, Gamaldo, Ayotte, Sims, & Whitfield, 2009) or informant-reported functional problems (Goldberg et al., 2010). Giovannetti and colleagues (2008) also found that despite caregiver reports of intact functional abilities, individuals with MCI performed worse than healthy participants on even simple tasks of everyday action as measured by the Naturalistic Action Test (NAT). This suggests that difficulties may not be limited to higher-order functioning and that the capacity to perform basic abilities may also be impacted in MCI. Similarly, a recent study showed that individuals with MCI made more overt errors on a test of everyday action than healthy controls. However, MCI and control participants showed similar error profiles, which these authors interpreted as evidence that the hierarchical structure for naturalistic action (i.e., nested sub-goals within higher-level task goals) remains intact in MCI, despite greater overall impairment (Gold et al., 2014).

Research examining performance-based everyday function in young adults and healthy older adults has demonstrated functional changes with aging even prior to impairment reaching the level of MCI. During performance-based everyday task completion, healthy older adults have demonstrated lower overall accuracy and higher rates of task sequencing errors and inefficient actions than younger adults (McAlister & Schmitter-Edgecombe, 2013; Schmitter-Edgecombe & Parsey, 2014). These authors suggest that problems related to task efficiency and organization emerge even in healthy aging, with more egregious errors such as failure to complete task steps developing in MCI and dementia. Taken together with research suggesting the relevance of these early functional difficulties to later decline, detection of functional change at the earliest possible stage is critical in characterizing and intervening in disease processes associated with aging.

Everyday Functioning and Risk for Dementia

Several studies have demonstrated the relevance of functional difficulties with regards to risk for developing dementia, highlighting the importance of targeting these early changes. In one study, cognitively impaired individuals who went on to develop dementia over a three-year period demonstrated higher rates of baseline disability as measured by a sensitive informant report than those who did not develop dementia (Artero et al., 2001). These authors thus stressed the danger of denying home help to individuals who may be deemed functionally adept because they do not carry a diagnosis of dementia. In a striking longitudinal examination of rates of conversion to dementia, Purser and colleagues (2005) found no differences in conversion rates between healthy adults and individuals with MCI, but significant conversion differences did emerge between MCI participants with and without self-reported IADL impairments (i.e., difficulty or dependence). This is consistent with the finding in another study that MCI associated with self-reported difficulties in one of nine IADLs (e.g., transportation, managing finances, etc.) conferred greater risk of conversion to dementia than MCI without functional difficulties (Luck et al., 2011). Relatedly, self-reported restrictions in two of four IADLs (i.e., telephone use, transportation, finances, medications) have been shown to predict conversion to dementia over two years, even among individuals with normal cognitive profiles (Peres et al., 2008). In one study, change scores representing rates of decline in informant reports of everyday functioning were shown to be larger than those of cognitive or biological measures, indicating that conversion to dementia may be driven more strongly by functional decline than by changes in the neurobiological disease trajectory (Gomar et al., 2011). These findings suggest that functional status is compromised in MCI and may be more relevant in predicting future decline than the MCI diagnosis itself, which challenges the clinical utility of this diagnosis in its current form and necessitates further investigation of the processes underlying functional decline.

Cognitive Processes and Everyday Functioning

Parsing out the cognitive underpinnings of specific everyday skills constitutes an important step in characterizing functional difficulties in MCI and informing prevention and intervention strategies. This is also important with regards to determining the extent to which IADL dysfunction is driven by cognitive deficits as opposed to physical limitations that are common in older age. In support of the relation between cognition and functional ability in MCI, specific subscales of the Dementia Rating Scale (DRS-2) related to memory and executive functions have been shown to be significantly associated with informant-rated IADLs (Greenaway, Duncan, Hanna, & Smith, 2012), and significant relations have been found between semantic dysfunction and performance on the on the UPSA, a performance-based measure of functional ability (Kirchberg et al., 2012). Artero and colleagues (2001) also found relations between informant-reported competence in everyday activities and several cognitive domains, specifically attention, memory, language, and visuospatial ability. Further, changes in episodic memory and executive functions independently predicted rates of change in informant-rated IADLs (Tomaszewski Farias et al., 2009), and measures of cognitive function and performance-based everyday function were shown to change together over time (Tucker-Drob, 2011), highlighting the relevance of cognitive changes to functional decline in MCI.

Several studies on functional difficulties in MCI have suggested that cognitive deficits, particularly episodic memory difficulties and executive dysfunction, are not only broadly associated with functional ability but are also associated with unique functional deficits. Studies have linked episodic memory impairment with specific deficiencies in managing money (Bangen et al., 2010; Barberger-Gateau, Fabrigoule, Rouch, Letenneur, & Dartigues, 1999; Teng et al., 2010), whereas executive dysfunction has been shown to impact health and safety, and more specifically management of medication (Bangen et al., 2010; Mariani et al., 2008). In contrast, one study found executive function to be significantly associated with financial management (Okonkwo, Wadley, Griffith, Ball, & Marson, 2006), although methodological differences may account for these disparate findings. In the study by Schmitter-Edgecombe and colleagues (2012), different cognitive functions predicted specific functional difficulties, with retrospective (i.e., episodic) memory deficits relating to incomplete and inaccurate subtask completion, and prospective memory (i.e., planning) problems specifically predicting sequencing difficulties. Moreover, Bangen et al. (2010) found that functional difficulties were even more powerful in differentiating between MCI subtypes (with and without episodic memory impairment) than between MCI and healthy participants, emphasizing the importance of considering the distinct functional profiles associated with MCI subtypes.

The severity of functional deficits has also been associated with specific cognitive domains in MCI. For example, individuals with the amnestic subtype of MCI (aMCI; episodic memory impairment present) have been shown to display greater IADL deficits than non-aMCI participants (Teng et al., 2010; Wadley et al., 2007). Farias and colleagues (2006) found the most severe functional impairment in skills that rely heavily on memory and, to a lesser extent, on executive functions, based on informant report. Memory, along with processing speed, also emerged in one study as the most frequent unique predictor of specific everyday task ability in MCI (Tuokko et al., 2005). These relations are supported by neuroimaging findings showing that within MCI, those with intact functioning as measured by informant ratings (Pfeffer Functional Activities Questionnaire, FAQ) had greater hippocampal volumes as well as better performance on tests of auditory verbal memory and processing speed compared to those with moderate or severe FAQ ratings (Brown et al., 2011). Consistent with this, episodic memory impairment in MCI has been associated with elevated risk for conversion to Alzheimer's disease (AD) compared to other cognitive dysfunction (Aggarwal, Wilson, Beck, Bienias, & Bennett, 2005; Luck et al., 2011), although this is in contrast to findings by Kohler and colleagues showing non-amnestic MCI to have the highest risk of dementia, above that of amnestic subtypes (Kohler et al., 2013).

When evaluating cognitive contributions to functional ability in MCI, it is important to acknowledge variable inclusion criteria for MCI samples across the literature. For example, in studies including solely aMCI participants (Brown et al., 2011; Gold et al., 2014; Griffith et al., 2003), findings of greater dysfunction in MCI than controls may reflect aMCI as a more severe subtype of MCI than non-aMCI, and conclusions may not capture the full range of functional status in MCI. Interestingly, however, Gold and colleagues (2014) showed a prominent role for episodic memory in action errors in both their MCI and healthy control groups (Gold et al., 2014), suggesting that episodic memory may be a particularly important cognitive function for everyday action regardless of severity of impairment or diagnosis. This is consistent with a recent study from our group, in which subtle action inefficiencies, termed "micro-errors," were significantly predicted by episodic memory in a single group comprised of both healthy older adults and individuals with MCI (Seligman et al., 2014).

Functional status may thus be linked to specific cognitive profiles of mild impairment, and may effectively differentiate between groups of individuals in the early phases of decline. However, the combination of executive and episodic memory impairments in MCI is common (Libon et al., 2010), and multi-domain MCI (i.e., multiple cognitive functions impaired) has been associated with greater functional impairment than single-domain MCI (Alexopoulos, Grimmer, Perneczky, Domes, & Kurz, 2006; Aretouli & Brandt, 2010; Bombin et al., 2012; Seelye, Schmitter-Edgecombe, Cook, & Crandall, 2013; Tam et al., 2007). Further, a combination of cognitive domains, including episodic memory, semantic ability, executive function, and processing speed/attention, together have been shown to explain the majority of variance in a performance-based measure of functioning (Goldberg et al., 2010). Thus, it is important to consider the influence of different cognitive processes along a continuum of functioning, eliminating the arbitrary cut-off scores that determine group placement. Increased understanding of the independent roles of specific cognitive domains in the early phases of decline, along with their potential interaction in a prevalent subtype of MCI, may provide valuable insight into the mechanisms of functional decline and optimal intervention strategies early in the progression of illness.

Challenges in Assessing Everyday Functioning in MCI

Despite the importance of addressing initial signs of functional impairment in older adults, methods to assess and meaningfully group functional abilities are limited. In evaluating functional ability, researchers and clinicians use a variety of measures that can produce inconsistent impressions of an individual's level of functioning. Specifically, subjective reports are not necessarily accurate in depicting functional abilities, as self-report measures tend to inflate ability (Tabert et al., 2002) and caregiver/informant reports can be influenced in either direction by emotions or motives (Bangen et al., 2010). Variability in older adults' daily activities (e.g., working full time vs. attending a senior center once per week) and variability in the complexity of daily activities (e.g., managing one medication vs. ten medications) also presents difficulties for systematic measurement of IADL and comparisons across individuals and groups. Further, as previously mentioned, the use of disparate methods to measure functional status likely contributes to the wide variability in reports of relations between cognitive and functional abilities (Burton, Strauss, Bunce, Hunter, & Hultsch, 2009; Gold, 2012; Royall et al., 2007) as well as in reports of the degree to which functional ability is compromised in MCI (Goldberg et al., 2010). Indeed, the use of different formats of self-reported functioning (i.e., subjective judgment of disability vs. reported rates of completing IADLs) was shown to yield variable sensitivity regarding functional status in MCI (Bombin et al., 2012). Winblad and colleagues (2004) point out the additional challenges posed by a lack of longitudinal age-specific and decline-rate norms, given the goal of characterizing cognitive and functional decline, which suggests that the use of current test score cut-offs to diagnose individuals with MCI may be premature.

Attempts to address these problems are also inconsistent across the literature, with some advocating for a combination of self and informant report. For example, Rueda and colleagues (2014) have suggested that self report should be used early in the course of decline with later precedence given to informant ratings, whereas Tabert and colleagues

(2002) have suggested that a discrepancy score between self and informant reports may be more informative than either report interpreted in isolation. Other investigators have emphasized the need for objective assessment of functional ability that does not rely on reports by individuals impacted by these difficulties (Pereira et al., 2010). Pereira and colleagues (2010) provided evidence that an informant questionnaire was, in fact, less accurate than an objective assessment (Direct Assessment of Functional Status; DAFS) in distinguishing between control participants, those with MCI, and those with AD. In a study by Tucker-Drob (2011), changes in self-reports of everyday function among older adults over five years were shown to be weakly correlated with changes in cognitive function, compared to strong relations between changes in performance-based tasks and cognition. Although limitations regarding the ecological validity of a laboratory setting for assessment of daily functioning should be acknowledged, the shift towards objective assessment of functioning may be crucial in establishing a consistent, accurate classification of individuals at greatest risk for dementia.

A challenge posed by objective assessment of early decline is the development of reliable and valid measures that can detect subtle impairment in daily functioning. The Naturalistic Action Test (NAT; Schwartz, Buxbaum, Ferraro, Veramonti, & Segal, 2003; Schwartz, Segal, Veramonti, Ferraro, & Buxbaum, 2002) requires participants to complete goal-directed tasks (e.g., make toast and coffee) at varying levels of complexity and has been used primarily to assess everyday action abilities in patient populations with moderate to severe impairment. Bettcher et al. (2008) used the NAT to examine error-monitoring abilities in individuals with dementia by coding "microslips," or rapid corrections prior to full execution of an error, demonstrating the utility of the NAT in evaluating subtle aspects of everyday action. Building on the development of sensitive NAT variables, the reliability and validity of a measure of subtle action disruption termed “micro-errors” was recently established to quantify inefficient but not overtly erroneous task execution that may reflect the early stages of decline (Seligman et al., 2014). Examination of micro-error rates can provide useful information regarding the manifestation of cognitive decline in everyday task completion, but the mechanisms underlying micro-errors remain unclear and are important to our understanding of the functional impact of degenerative processes. The following section of this paper will focus on the literature describing eye movements during everyday activities. This review will conclude with the proposal to use eye tracking during everyday tasks as a method to detect and study early functional difficulties in individuals with MCI.

Eye Movements as Sensitive Indicators of Early Disruption of Everyday Function

Human eye movements during cognitive tasks have been studied since the 1800’s. In early studies an examiner directly observed and documented movements of the eyes while reading; today eye-movement data are collected using non-invasive eye tracking technologies that may be worn on the head while the participant moves freely in the environment and performs everyday activities. Eye trackers collect information regarding the position of the pupil in a scene (i.e., fixation location/duration) and the distance moved by the eyes from one location to another (i.e., saccade magnitude/sequence). Studies have shown that saccades and fixations recruit the same neuroanatomical circuitry as “covert” shifts of attention that do not include eye movements, suggesting that eye movements may be useful indicators of the focus and direction of attention

(Corbetta et al., 1998; Findlay & Gilchrist, 2003; Jovancevic, Sullivan, & Hayhoe, 2006; Shinoda, Hayhoe, & Shrivastava, 2001).

While attention and eye movements may be captured by compelling and salient perceptual stimuli (i.e., bottom-up influences), eye movements during a range of tasks, including the viewing of pictures and scenes, have also been shown to be strongly influenced by participants' goals and knowledge (i.e., top-down influences; Olivia, Torralba, Castelhano, & Henderson, 2003; Yarbus, 1967). One fascinating and important advantage to studying eye movements is that they do not involve explicit verbal report and may offer additional insight that may not be gained by the examination of overt behaviors alone (Heine et al., 2010; Norbury et al., 2009). Thus, the examination of both eye movements and overt behaviors may offer an especially rich analysis of cognition (Mogg, Bradley, Field, & De Houwer, 2003). Examining eye movements during completion of everyday tasks rather than inferring cognitive mechanisms from stationary scene-viewing or laboratory cognitive tasks is critical for many reasons, including the active and dynamic nature of real-world task completion (Tatler, Hayhoe, Land, & Ballard, 2011), and this will therefore be the focus of this review.

Despite the seeming simplicity of eye movements during everyday tasks, visual behaviors may reveal complex cognitive processes related to object identification, place memory, task execution, and monitoring. The analysis of eye movements has led investigators to reconsider the notion that routine, everyday tasks can be performed automatically, without monitoring or active cognitive processing (Land, 2006; Land & Hayhoe, 2001). This is also consistent with the findings of Tucker-Drob (2011), who described direct links between declines in cognition with age and declining everyday function on a performance-based task in healthy older adults and concluded that this link dispelled the myth that daily activities could be performed "automatically" and were impervious to the subtle cognitive decline associated with normal aging. That these early functional changes are not always reported may thus be due to lack of insight rather than preserved functioning in the face of cognitive dysfunction (i.e., there was no association with self-reported IADL functioning and cognition). In support of this conceptualization, sensitive measures such as fixation duration have been used to characterize visual routines that are not normally accessible to consciousness and can therefore yield important insights into task execution that may be lost in self report and gross behavioral observation (Hayhoe, 2000; Pelz & Canosa, 2001). Further, eye movements may reflect error detection and reformulation of the plan (i.e., preemptive error correction) before detectible (erroneous) actions of the limbs are launched. This form of preemptive error correction may occur implicitly or without conscious awareness. Thus, exploration of saccade sequences and fixation patterns during task completion may reveal subtle but crucial information regarding early changes in everyday function that may not be detected through analysis of manual behaviors or self-report.

Naturalistic Eye Movements in Healthy Individuals

Consistency Across Individuals

Research to date on eye movements in healthy individuals has revealed several important features of visual processes during completion of naturalistic tasks such as tea and sandwich making. Durations of fixations vary widely within individuals (Land et al., 1999), ranging from 100 ms to 1500 ms. However, both fixation position and duration (i.e., the objects/locations fixated and for how long) show strikingly little variation in their distribution across individuals (Hayhoe et al., 2003; Rothkopf et al., 2007). This suggests the potential to reveal a meaningful, inherent mechanism underlying visual processes, as fixation durations do not appear random or unique to an individual (Tatler et al., 2011). The duration of short fixations across individuals in a sandwich-making task was shown to be particularly reliable, ranging from 66 ms to 133 ms. Interestingly, the time required to program a saccade has been consistently shown to be between 200 and 250 ms, which is compatible with Land and colleagues' (1999) report of inter-saccadic intervals (i.e., timing of fixation plus saccade) ranging from 200 ms to 500 ms. This suggests that a series of multiple very brief fixations (i.e., shorter than 200 ms each) reflects a pre-programmed sequence of saccades as opposed to independent reactions to stimuli (Becker & Jurgens, 1979; Hayhoe et al., 2003). Most fixations during everyday tasks appear to constitute these shorter events, with longer fixations relating to prolonged actions that require continuous guidance such as pouring water into a cup (Hayhoe et al., 2003).

Analyses of saccades also show consistency across individuals. Land et al. (1999) found a high degree of consistency across participants in the distribution of saccade magnitude during a tea-making task, with a peak identified between 2.5 and 10 degrees and a tail of less frequent longer saccades. Within individuals, saccade magnitude varied significantly across different actions. For example, saccades occurring during manipulation of a single object or within a single task step (e.g., transferring bread to the plate; *within-action saccade)* demonstrated a clear peak and tended to be relatively short, whereas saccades between task steps, during transfer of gaze between objects, or during search (e.g., between transferring bread to the plate and retrieving the peanut butter;

between-action saccades) were larger and more variable. These differences likely represent distinct cognitive mechanisms that are associated with different types of saccades: between-action saccades are likely driven by stored task knowledge (i.e., schema) that inform the next object to be used in a sequence, whereas within-action saccades may be more strongly associated with direct visual cues or an "itch-like need" for the eyes to move small distances (Land & Hayhoe, 2001, p. 3563). Interestingly, differences in within- and between-action saccade magnitude were similar across different everyday tasks (e.g., tea-making and sandwich-making), again suggestive of meaningful consistency of eye movements in naturalistic action (Land & Hayhoe, 2001; Tatler et al., 2011).

Consistency in the relation between eye and hand movements during everyday tasks has also been observed across studies. Most hand movements during naturalistic action are accompanied by fixations to objects involved in the task step, with the exception of placing an object on a stable surface (e.g., table), which can likely be achieved using proprioceptive and peripheral detection or visual memory (Hayhoe et al., 2003). Closely timed eye-hand relations are more likely to occur within a single task step and have been described as "local" processes relying on dorsal visual regions that facilitate immediate reach and grasp actions. By contrast, eye-hand movements that occur between task steps may be governed by stored knowledge (i.e., schema) or goals that rely on the prefrontal cortex or the ventral visual stream (Morady & Humphreys, 2011a). This point will be discussed again later in more detail. With regards to the sequence of events involving eye and hand movements, particularly between actions, it has been reported that in healthy individuals the eyes typically lead the hands, rather than reacting to motor manipulation (Land et al., 1999). Land and colleagues used the term "object-related action" (ORA), which they defined as "the sets of acts (including eye movements) associated with the current object of fixation," (Land et al., 1999, p. 1315), to characterize temporal relations between visual and motor actions in tea making. They found that the order of ORA components typically involved an initial gross body movement, suggesting that the trunk is first to receive action information. The first saccade to the intended object occurred, on average, 0.61 seconds following trunk movement, and initial signs of hand/arm movement began 0.56 seconds following the saccade.

Interestingly, Land and colleagues (1999) found "remarkable consistency" in the timing of the body, eyes, and hands (i.e., ORAs) during everyday tasks, supporting the presence of a common program across individuals. They reported that gaze shifted to the next object to be manipulated in the sequence an average of 0.61 seconds prior to completion of the previous motor act, which suggests the presence of a buffer that can store visual information for up to a second before its use and can inform hand movements for up to a second even in the absence of visual input (Land, 2006; Land & Furneaux, 1997; Land & Hayhoe, 2001; Land et al., 1999). However, it is important to note that in both tea- and sandwich-making tasks, standard deviations of eye-hand latencies within individuals were quite large, with a number of instances in which the hands led the eyes or hand and eye movements occurred virtually simultaneously, particularly in the sandwich-making task (Hayhoe et al., 2003; Land & Hayhoe, 2001). Hayhoe and colleagues (2003) interpreted this variability as a function of the opportunity to plan for motor action afforded by a continuously available scene along with the need to alternate control between hands. More work is necessary to explain differences in eye-hand latencies.

In addition to specifying consistency in the properties of eye movements and the timing and order of eye and hand movements in naturalistic action, eye-tracking research has aimed to describe the typical specific roles served by the eyes during completion of everyday tasks. The primary functions of eye movements have been described with relative consistency (Hayhoe, 2000; Land, 2006; Land & Hayhoe, 2001; Land et al., 1999) and have been labeled by Land et al. (1999) as "locating," "directing," "guiding," and "checking" (see Table 2 for a description of each). They found that a third of all fixations fell explicitly into these categories and many others appeared loosely associated with them. The classification outlined does not apply to other, non-naturalistic tasks such as copying of blocks (Ballard, Hayhoe, Li, & Whitehead, 1992) or sketches or to continuous tasks such as reading text or music (Land, 2006). This underscores the importance of examining eye movements in naturalistic tasks to understand everyday behavior rather than attempting to apply conclusions from vision research in other domains.

Table 13. The Functions of Eye Movements in Everyday Activities (Land et al., 1999; Pelz & Canosa, 2001)

Label	**Description of Function**
Locating/Look-Ahead	Eye movement to target objects that will be used later in the task and are not immediately relevant to the task at hand; establish the location and identity of the object for future use.
Directing	Eye movement to a location or object about to be targeted by the hand; determine location information and physical properties relevant to the motor system when approaching the object.
Guiding	Eye movements that shift between two objects used simultaneously; provide continuous feedback to allow coordination of the hands/objects.
Checking/Monitoring	Eye movements to a target object or location; identify the state of an object or action and determine whether a given criterion (e.g., desired water level in the kettle) has been met.

Figure 9 represents a theoretical model for the flow of information during an ORA that incorporates the eye movement characteristics just described. Specifically, when a task step is activated, the semantic (i.e., schema) and spatial representations of task objects and actions inform the body and eyes to orient towards the relevant object. Actions are then performed under supervision of the eyes, which determine when a given criterion has been met and the step is complete. The spatial representation of objects is updated if objects in the scene have been moved. Once the step is complete, the next step is selected, and the process repeats. Directing, guiding, and checking/monitoring eye movements occur during the execution of a task step (i.e., within-action saccades), whereas locating/look-ahead fixations may occur at any point during the task but typically occur prior to or between task steps (i.e., between-action saccades) to maintain the spatial representation of objects (see Figure 9).

Top-Down Versus Bottom-Up Visual Processing

An important debate in vision research, particularly with regards to naturalistic action, is whether the eyes are driven by inherent salience of objects in the environment in a "bottom-up" approach (Itti & Koch, 2000) or a targeted search is employed using planned, "top-down" mechanisms (for a review, see Tatler et al., 2011). Indeed, naturalistic vision is unique compared to the predominance of research using tasks that involve a single visual or motor operation across repeated trials in that the observer is the active initiator of complex behaviors, and as such more complex cognitive processes may drive eye movements during everyday tasks. The "locating" (Land et al., 1999) or "look-ahead" (Pelz & Canosa, 2001) fixation category of eye movements reveals the influence of knowledge and planning mechanisms on visual behaviors and has received a great deal of attention because of its relevance to this important debate. Thus, the research on locating/look-ahead fixations will be the focus of our review on the categories of eye movements.

The term look-ahead fixation has been used to refer not only to initial search fixations that establish the location and identity of target objects at the start of the task, but also to fixations made during task execution to objects that are used later in the task. Through active location of objects necessary for future use, look-ahead fixations may serve as a mechanism to "stitch together" visual stimuli during the preparatory phase of everyday task execution, facilitating the presence of a seemingly continuous environment in both time and space that is not captured on the retina (Pelz & Canosa, 2001). This

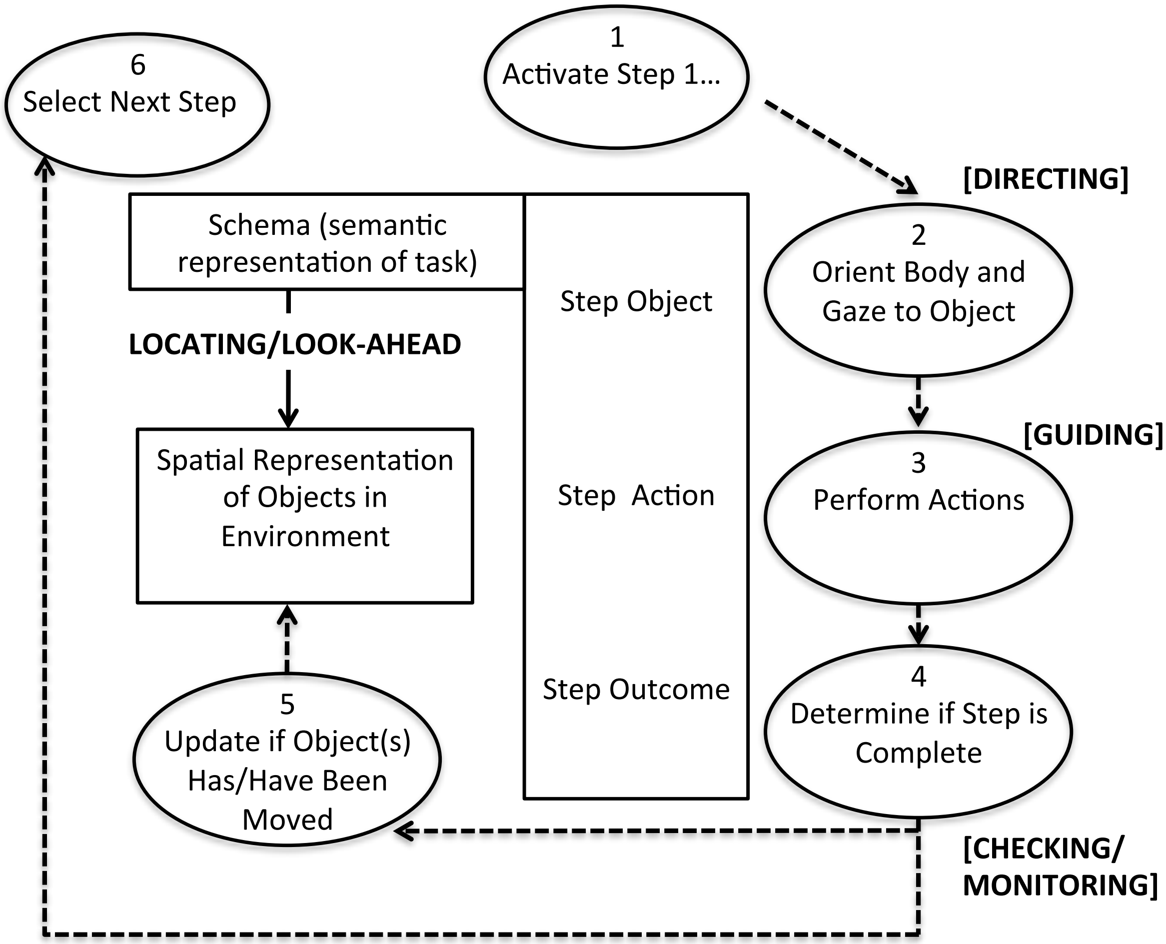


Figure 9. Six Stages of an Object-Related Action (ORA). Six stages of an objected-related action (ORA) are numbered and depicted in ovals. Representations that influence performance are depicted in boxes and include "Schema" (i.e., long-term semantic knowledge of the task that informs the objects, actions, and goals/outcomes associated with each task step) and "Spatial Representations" (i.e., temporary representations of the locations of task objects in the environment that are constructed and modified during performance). The four types of eye movements are shown in bold capital letters adjacent to the stage in the task during which they are likely to occur. Eye movements within brackets (i.e., [ ]) reflect within-action saccades; eye movements without brackets reflect between-action saccades. Dotted lines depict the flow of information during an ORA. The solid line from "Schema" to "Spatial Representation of Objects in Environment" depicts a process that may occur at any time, but typically occurs before or between ORAs.

representation is continuously updated throughout task execution (Hayhoe et al., 2003; Pelz & Canosa, 2001). The brief fixations of shorter duration than the time required to program a saccade (previously described as a pre-programmed sequence) are likely based on this spatial memory representation, as well as the task goals (Becker & Jurgens, 1979; Hayhoe et al., 2003). The notion that saccadic eye movements work to piece together a mental representation of a visual scene has been proposed multiple investigators (Irwin, 1991; O'Regan & Levy-Schoen, 1983).

Additional features of look-ahead fixations support an influence of task knowledge and goals. Pelz and Canosa (2001) highlighted the findings that targeted objects are rarely fixated after their use, objects irrelevant to the task are rarely fixated, and the specific objects fixated vary based on task instructions. Further, look-ahead fixations comprise specific, targeted saccades and fixations to objects needed in the future rather than indiscriminate sweeping saccades to the full array of objects in a scene, strongly suggesting that they constitute a targeted search process using “top-down” mechanisms. Top-down influences also help explain the observation of eye movements described as “in path” fixations by Hayhoe et al. (2003), as these occurred primarily to task-relevant objects for future steps along the path of a saccade towards an object for an immediate task step. This suggests that the spatial representation that is being built by the visual system is highly relevant to the task plan and future goals. Further, it seems that this representation is continuously updated by the visual system during everyday task execution. Pelz and Canosa (2001) suggest that building a representation of needed objects may help to ease the processing demands on the visual system during complex activities.

Rothkopf et al. (2007) specifically examined the question of whether a top-down, task-driven or bottom-up, salience approach best characterized vision during everyday, goal-directed tasks. Using a virtual reality environment, they tracked individuals' eye movements while they completed a series of approach and avoidance tasks involving target objects and obstacles. They demonstrated that the task goals consistently influenced participants' behavior, with fixations on identical objects showing striking variability depending on whether the goal was to approach or avoid the object. Consistent with other studies (Ballard et al., 1995; Hayhoe et al., 2003; Johansson et al., 2001; Land, 2006), Rothkopf et al. (2007) also found that the majority of fixations during task execution were made to task-relevant objects rather than those irrelevant to the task, implying the influence of task goals on visual search and gaze allocation. They also noted that their findings could not be accounted for by a saliency model proposed by Itti and Koch (2000), in which visual behaviors are influenced by salient visual features (i.e., bottom-up processes).

Another line of research that supports the notion that internal spatial representations are influenced by knowledge and goals describes the phenomenon of "change blindness," or the failure of individuals to notice changes to the visual scene that occur during saccades (Hayhoe, 2000; Irwin, 1991; Irwin, Zacks, & Brown, 1990; O'Regan, 1992). The inability to detect physical changes in the environment has been interpreted as evidence that only limited and highly relevant information is included in the internal visual representation of a scene (Hayhoe, 2000). Others have provided further support for this notion, demonstrating the importance of task goals in determining what visual information is detected (Folk, Remington, & Johnston, 1992; Hayhoe, Bensinger,

& Ballard, 1998; Hayhoe et al., 2003; Wallis & Buthoff, 2000). According to Hayhoe (2000), change blindness is likely facilitated by task specificity, with task-irrelevant changes to a scene going unnoticed as a means of computational efficiency that prioritizes the task at hand. Prior research has revealed effects of attention and behavioral context on activity in visual cortex, even primary visual cortex (Gilbert, 1998), supporting the theory that task goals influence what is perceived even at the most basic level.

It has also been widely demonstrated that fixations are often tightly locked to the ongoing task, with eye movements directly tracking the hands during object manipulation (Hayhoe, 2000; Hayhoe et al., 2003; Land & Hayhoe, 2001; Land et al., 1999; Pelz & Canosa, 2001). This has led to the conclusion that visual information is obtained, at least to some degree, on an "as needed" basis rather than entirely proactively. Taken together with evidence that the eyes do, in fact, locate relevant objects prior to and during task completion, it may be the case that look-ahead fixations actively piece together a gross depiction of the scene that provides general location information for future use. During task completion, the eyes must still acquire specific information that hones this representation to facilitate both efficient and accurate task execution (Land & Hayhoe, 2001).

Some have proposed that task conditions may influence the extent to which the eyes are influenced by top-town as opposed to bottom-up processes. For example, in a study using both sparse and cluttered scenes, fixations to task-relevant objects during initial search were more prominent in the sparse scene, whereas equal numbers of initial search fixations to relevant and irrelevant objects were observed in the cluttered condition

(Hayhoe et al., 2003). In this study, irrelevant object fixations still markedly declined during task performance in the cluttered condition, likely representing a shift from target selection based on intrinsic salience (bottom-up) to an instruction-driven (top-down) approach during task execution (Land, 2006). This suggests that perhaps a salience or bottom-up strategy is only employed if the visual system is overtaxed or relevant objects are less easily targeted. The bottom-up strategy may be the default or "back-up" strategy, with task-guided visual search taking precedence when possible or when behavior must be directed by a goal. Consistent with this account, Tatler et al. (2011) suggested that the visual system "might only prioritize surprising stimuli when there is no other pressing demand" (p. 13), supporting a shift in strategy based on available cognitive resources (see also Lavie, 2005). This shift is also evident in other tasks such as driving, in which both task instructions and local context appear to influence fixations to different degrees during different task segments (Shinoda et al., 2001).

Naturalistic Eye Movements in Cognitive Impairment

As suggested, understanding the contribution of visual processes to the completion of everyday tasks in healthy individuals can help characterize functional difficulties experienced by individuals with cognitive impairment. For example, the task-driven, top-down characteristics of eye movements described previously suggest that degraded task knowledge due to illness or injury may result in more bottom-up, salience-driven eye movements and fewer look-ahead fixations that rely on intact mechanisms for planning upcoming actions (Forde et al., 2010). Bottom-up driven visual search also may lead to an increase in fixations to irrelevant, off-task objects. Importantly, these perturbations may not be evident in overt actions. The evaluation of such hypotheses is critical to establish an informed and testable theory of everyday action breakdown in neurocognitive disorders. Although the literature on naturalistic eye tracking in the context of impairment is sparse, this technology has been applied in several studies of individuals with cognitive impairment.

One case study described a patient, FK, who suffered carbon monoxide poisoning that caused widespread brain damage and impeded his ability to complete many everyday tasks (Forde et al., 2010). On a tea-making task in this study, FK committed 19 behavioral errors consisting of perseverations, step omissions, semantic, sequencing, and spatial errors, compared to no errors made by two healthy participants and an individuals with Alzheimer's disease (AD). FK's eye movements were similar to those of healthy individuals in many aspects including his ability to scan the environment and the time locking of fixations and use of fixated objects, but several important differences were noted. Specifically, he fixated on more task-irrelevant objects, did not make orienting or look-ahead-type fixations, and made shorter eye movements than normal during perseverative errors. It is also notable that FK's fixations on task-irrelevant objects were made even during correct actions (Forde et al., 2010). The authors took these differences to suggest that FK's actions were not successfully driven by knowledge of task actions and goals, resulting in increased competition among objects for response selection (Forde et al., 2010). This account was supported by prior evidence that FK's stored knowledge of everyday tasks was impaired (Humphreys & Forde, 1998). Increased competition for response selection as suggested by FK's saccades to irrelevant objects may also explain his subsequent behavioral errors, emphasizing the contributory value of eye movement data to action research.

Eye movements during errors were evaluated for their potential to offer insight into the cognitive mechanisms that contributed to FK's poor performance. Forde and colleagues (2010) interpreted the brief eye movements to both the object being used and to neutral locations during perseverations to imply high distractibility during these errors. Another interesting aspect of FK's behavior was that although he omitted more actions than normal, his eye tracking data showed that he did fixate on subsequently omitted task objects. Similarly, despite committing semantic errors (i.e., substitutions), FK fixated on the correct target objects that should have been used in the task. These data argue against impairment at the level of perceptual selection associated with more posterior brain regions, which would likely have led to a reduced number of fixations on target objects. Instead, these features of FK's eye movements suggest a breakdown at the level of action selection and resolution of object competition subserved by an anterior attentional system (Forde et al., 2010; Posner & Petersen, 1990). Consistent with this dissociation, Forde et al. (2010) pointed out that fixating on the object of perseveration was not sufficient to prevent the error and concluded that response monitoring may not always occur even when visual attention is directed towards an object.

Another interesting aspect of the study by Forde and colleagues (2010) was the performance of the comparison patient, EC, who was diagnosed with AD. EC's performance on the tea-making task was errorless, similar to the healthy control participants. Despite her intact behavioral performance, EC made strikingly fewer fixations overall than the healthy controls and even FK. She also had generally longer fixation durations, which may be explained by the reduced number of fixations compared to the other three participants. With regards to her eye-tracking profile, EC demonstrated a higher proportion of neutral fixations (e.g., looking out the window but not at relevant or irrelevant objects) and a lower proportion of relevant fixations compared to the healthy control participants. These data were not discussed by Forde and colleagues, (2010), as FK was the focus of the paper. However, we suggest that EC's data are quite fascinating and provide support for the potential to detect discrepancies in visual behavior in individuals with cognitive impairment and functional disability (i.e., a diagnostic criterion for AD) who do not commit overt behavioral errors in laboratory tasks of everyday activities.

Morady & Humphreys (2011a) described the eye movements associated with everyday task completion in another patient, BL, following a stroke affecting the left occipitotemporal cortex. BL suffered a range of neuropsychological impairments, including deficits in reading, object recognition, semantic knowledge, and executive functioning. Her perceptual processing, in contrast, was relatively preserved. Her performance of everyday tasks was shown to be severely impaired, even compared to brain-lesion comparison patients (Morady & Humphreys, 2011b). On tasks of tea- and sandwich-making (Morady & Humphreys, 2011a), BL made omission, sequencing, and spatial errors, as well as a "toying" error involving manipulation of an object that was not subsequently used, and she performed the sandwich-making task more slowly than comparison participants. With regards to her eye movements, BL showed comparable time relations between fixations and object use to control participants (two patient and two healthy controls), similar to FK. She also was comparable to controls in her number of directing, guiding, and checking eye movements (as defined by Land et al., 1999; see Table 2). However, unlike FK, BL's number of look-ahead fixations was *higher* compared to controls, as was the number of “other” eye movements that did not fall into the four categories previously defined in this review (see Table 2). She also made more irrelevant fixations than all control participants. Further, BL’s eyes departed from objects earlier than control participants’ relative to action completion.

The authors suggested that these atypical eye movement patterns could be due to task knowledge deficits and resulting failures in task planning or to difficulty resolving object or action competition. The authors also noted that BL made multiple brief fixations on an object she erroneously “toyed with” and speculated that this reflected similar characteristics to FK’s eye movements during perseveration, representing a disconnect between attention-grabbing features of objects and top-down processes (Morady & Humphreys, 2011a). Together, the case studies of FK and BL suggest a shift towards a more salience-based or bottom-up approach to everyday tasks when cognition is severely compromised. Although these studies included different variables, which makes direct comparison challenging, some consistencies emerged that have broad implications for visual processing during completion of everyday tasks. They suggest a dissociation between attentional processes directed towards “global” task features that govern between-step actions and those relevant to “local” processes, such as the timing of fixations and an upcoming reach/grasp. It is suggested that the former, thought to rely on prefrontal cortical networks, is disrupted in these cases with severe naturalistic action impairment whereas the latter, dependent on more dorsal visual regions, is spared (Morady & Humphreys, 2011a).

Studies of eye movements in other clinical populations have suggested relative preservation of top-down influences during everyday tasks. In a study on eye movements during naturalistic action in schizophrenia, individuals with schizophrenia and healthy control participants completed a “familiar” sandwich-making task and an “unfamiliar” construction task (Delerue et al., 2013). The schizophrenia group completed both tasks more slowly than healthy participants, but they performed more poorly only on the unfamiliar task. The only group difference in scanning that emerged in the familiar condition was that schizophrenia patients displayed longer gaze durations on irrelevant objects than the control group, suggesting greater susceptibility to distraction even during a familiar everyday task. Group differences in scanning were primarily observed in the unfamiliar task such that the schizophrenia group made more fixations on distractors, or task-irrelevant objects. The authors concluded that this might reflect a susceptibility to object saliency in schizophrenia along with an inability to disengage from salient features to complete the task. The schizophrenia group also made fewer look-ahead fixations only in the unfamiliar task, suggesting a failure to establish an efficient planning strategy like that employed by healthy individuals only in a novel context. Finally, schizophrenia participants had to reference the display model to complete the unfamiliar task more frequently than healthy controls, indicating difficulty constructing a mental representation and then holding that representation in mind while performing the task (Delerue et al., 2013). With regards to everyday, naturalistic action, this study suggests that individuals with schizophrenia are slower but display similar visual behaviors to healthy individuals; it is only when task demands are increased by introducing a novel task for which the action plan is less familiar that susceptibility to feature salience, distractibility, inefficient planning, and working memory limitations appear to differentiate between impaired and healthy individuals.

Together, these studies suggest that individuals with significant cognitive impairment retain some similarities in their eye movements during everyday tasks to controls, namely the time locking of fixations and object use associated with local visual attention. However, they reveal several ways in which eye movements can differ from healthy individuals across disorders, including increased numbers of irrelevant fixations and differences in the number of look-ahead or orienting fixations, particularly when impairment is severe or task demands are high. A striking difference that emerged between the case studies presented was that of FK's absence of look-ahead fixations compared to that of healthy individuals, in contrast to BL's greater number of look-ahead fixations. One potential explanation for this discrepancy may be differences in the severity of injury between these two patients, with FK having sustained more widespread brain damage. Greater numbers of look-ahead fixations, as demonstrated by BL, may thus reflect attempts to compensate for impairment facilitated by some preservation of task knowledge or planning capability, which may decline as impairment progresses and additional cognitive functions are lost. If this is the case, look-ahead fixations may be expected to increase in MCI and then decrease into dementia and may therefore represent an effective target in examining visual behaviors in MCI. However, the progression of eye movement patterns may also vary by MCI subtype, which will be an important consideration for future studies.

Eye Movements in Mild Cognitive Impairment

Although informative regarding visual behavior in action dysfunction, the few existing studies of individuals with severe impairment do not address the initial phases of decline, when intervention may be most effective, and interpretations regarding MCI are entirely speculative. As indicated previously in this review, eye tracking has the potential to fill this gap by providing sensitive indicators of early functional difficulties, but to date no studies have examined eye movements in MCI during completion of everyday tasks. There is, however, a growing body of literature exploring eye movements during specific visual tasks with the goal of identifying potential early indicators of future decline. Results from these studies demonstrate the potential to obtain information from eye movements that may reflect mild or even latent cognitive dysfunction, and they provide support for the utility of eye tracking as a sensitive measure of subtle behavioral differences.

One such visual task, the visual paired comparison (VPC) task, evaluates memory function by determining whether individuals exhibit a preference for a novel as opposed to a previously presented picture; more time spent viewing the novel picture indicates intact memory of viewing the other image. No overt behavioral response to the stimuli is required; participants are simply asked to look at the stimuli on the screen as if they were "watching television." Performance on the VPC task has been shown to differentiate between healthy individuals and those with aMCI, demonstrating the sensitivity of eye movement patterns to subtle cognitive decline (Crutcher et al., 2009; Lagun, Manzanares, Zola, Buffalo, & Agichtein, 2011). Further, Zola and colleagues (2013) showed that performance on this task predicted conversion from healthy aging to aMCI and from aMCI to dementia up to three years prior to diagnosis. Thus, results obtained using the VPC task may capture the episodic memory deficits characteristic of aMCI not only in their early phases, but also prior to their manifestation on standard neuropsychological tests of cognitive functioning.

Another task that has been used to examine eye movements in MCI is the antisaccade (AS) task, in which individuals must inhibit a prepotent response towards a stimulus and voluntarily shift their eyes in the opposite direction when a stimulus is presented. The AS task has been shown to correlate most strongly with measures of executive function in combined groups of healthy older adults, MCI, and dementia participants (Hellmuth et al., 2012; Heuer et al., 2013). It has been demonstrated that performance on this task is similarly impaired in individuals with aMCI and AD compared to controls (Peltsch, Hemraj, Garcia, & Munoz, 2014). In this study, errors on the AS task were negatively correlated with performance on the Stroop task, a cognitive measure of inhibition, in both control and aMCI groups but not in the AD group, suggesting that AS performance may reflect subtle executive difficulties in the early phases of cognitive decline. Interestingly, Heuer and colleagues (2013) found that although individuals with MCI performed comparably to healthy older adults in their sample on the AS task, cortical thickness in frontoparietal regions typically associated with AD was significantly related to AS performance in the MCI group, but not the healthy older adult group. This suggests that features of eye movements in MCI may uniquely reflect disease burden associated with dementia progression, and specifically executive dysfunction, at this early stage.

Several studies have also investigated more basic visual behaviors in MCI. One study examining fixation properties in aMCI, AD, and healthy older adult groups found that individuals with both aMCI and AD differed from healthy controls in the direction of their “microsaccades,” or small, involuntary movements when instructed to fixate. Individuals with aMCI and AD did not differ from each other, but both made more oblique eye movements in comparison to the typical horizontal microsaccades of their healthy counterparts. Interestingly, global cognitive impairment as measured by the Mini-Mental State Examination (MMSE) correlated with microsaccade direction only in the aMCI group but not within the AD or healthy control groups, suggesting a specific relation between microsaccades and cognitive impairment in MCI, at least when memory impairment is present (i.e., in individuals with aMCI). Microsaccade direction was also correlated with a subjective measure of independence in activities of daily living across the groups, providing support for the relevance of visual behaviors to functional ability (Kapoula et al., 2014). In contrast, examination of prosaccades (i.e., eye movements towards a stimulus presentation) did not show differences between healthy and aMCI groups, whereas individuals with AD had longer prosaccade latencies as well as greater variability in speed and accuracy of prosaccades than both healthy older adults and those with aMCI (Yang et al., 2011; Yang, Wang, Su, Xiao, & Kapoula, 2013). Prosaccades have been described as involving rapid, automatic responding that does not require higher-order executive processing (Peltsch et al., 2014), so it may be the case that this more basic function is not yet disrupted at the level of MCI. In support of this conceptualization, a follow-up analysis by Yang and colleagues (2013) revealed that when task demands increased to require shifting of attention and decision-making, the aMCI group did show longer prosaccade latencies than healthy control participants.

In light of the current research examining visual behaviors in MCI, it seems reasonable to conclude that basic eye-tracking tasks can detect subtle cognitive deficits indicative of prodromal dementia. However, these studies predominantly addressed a single domain of cognitive dysfunction (e.g., episodic memory or executive function), most included an exclusively amnestic MCI population (i.e., aMCI), and none examined these processes during completion of everyday tasks, which are subtly compromised in MCI but have been shown to be strongly associated with conversion to dementia. With regards to naturalistic action, the cognitive resources required are much more widespread and complex, and a more nuanced description of eye movements during these tasks is crucial to our understanding of the breakdown of everyday functioning in MCI and dementia. For example, the number of look-ahead fixations made by individuals with MCI during everyday action tasks has greater potential to capture coordinated aspects of planning, memory, and task knowledge than isolated paradigms such as the VPC and AS tasks. Further, findings of deviant eye movements in MCI across several studies (Crutcher et al., 2009; Lagun et al., 2011; Peltsch et al., 2014; Yang et al., 2013; Zola et al., 2013) suggests that eye movement data may reveal marked compensation in MCI relative to healthy populations during everyday tasks. Variability in this compensation across individuals with MCI may explain the controversy surrounding whether everyday functioning is a feature of this syndrome (see Table 1). There is clearly a need for more sensitive measures of early dysfunction that can aid with both early detection as well as increased understanding of the mechanisms associated with early action disruption, and we propose that eye-tracking methods are well suited to serve this need.

Conclusion and Future Research Directions

MCI is a transitional period between normal aging and dementia during which functional difficulties are present and are associated with cognitive decline. Central to our understanding of these difficulties is the development of sensitive measures to characterize subtle functional changes and identify those at greatest risk for conversion to dementia. Examination of eye movements during completion of everyday tasks in healthy individuals and those with severe impairment has demonstrated the potential for this methodology to reveal the mechanisms underlying completion of complex daily tasks. Eye-tracking methodology has also been shown to capture subtle differences associated with cognitive changes in MCI. However, this has not yet been explored in naturalistic action, which involves more complex cognitive interactions than isolated visual tasks. Among the important initial future directions of eye-tracking research is the establishment of standardized naturalistic eye-tracking variables to promote comparison across studies. Currently, much of the literature contains qualitative descriptions of eye movements during everyday action, although early studies suggest the number and timing of look-ahead fixations and the number of fixations to non-target objects may be the most promising indicators for initial research. As the field expands, the development of quantitative norms will be important to provide a valid and meaningful assessment standard.

Many important open questions exist, including whether changes in naturalistic eye movements can help predict risk for conversion to dementia and whether eye tracking has the potential to reveal specific functional difficulties that can be targeted with intervention and prevention strategies. The sensitivity provided by eye-tracking technology may also allow for exploration of differences in functioning across MCI that can aid in characterizing cognitive and functional heterogeneity within this population. Specifically, examination of the cognitive underpinnings of eye movement features will be important in bridging our understanding of neurodegenerative changes at the level of the brain with their impact on daily life. This is particularly important given the range of cognitive functions required for naturalistic action including knowledge of task objects and goals, planning for efficient completion of everyday tasks, recollection of what has been completed previously, maintenance of broad task goals during execution of sub-goals, and facilitation of coordinated eye-hand movements in pursuit of these goals. Systematic investigation of these questions will help elucidate effective markers for early identification of those at risk for future decline. Early markers also might identify treatment targets, which could include specific cognitive processes (e.g., task knowledge) and their neural circuitry (e.g., prefrontal cortex) as well as atypical eye movements (e.g., increased saccades to irrelevant objects). Novel research suggests that manipulating eye movements may improve performance on cognitive tasks (University of Illinois at Urbana-Champaign, 2007). Thus, investigations of visual behaviors may lead to a multitude of alternative intervention approaches to preserve independence and delay the functional disability associated with dementia.

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APPENDIX

NATURALISTIC ACTION TEST PSYCHOMETRIC PROPERTIES

The Naturalistic Action Test (NAT; Schwartz et al., 2003) is a standardized and published performance-based measure of everyday action. Instructions, object placement, cuing procedures, and scoring are systematized and described in detail in the test manual, which is available online (www.mrri.org/naturalistic-action-test). The NAT involves three independent trials in which an everyday task(s) is performed with little guidance from the examiner. The trials include: 1) prepare a single slice of toast with butter and jelly and prepare a cup of instant coffee with cream and sugar; 2) wrap a gift with related distracter objects (gardening clippers, stapler, etc.) present in the array; and 3) pack a lunchbox with a sandwich, snack, and a drink and pack a schoolbag with supplies for school, while several of the necessary objects (knife, thermos lids) are stored out of view in a drawer with additional, and potentially distracting, objects (ice tongs, measuring tape, etc). The third NAT task also requires participants to ring a bell after they complete each subtask (i.e. after packing the lunchbox and after packing the schoolbag).

The NAT was validated in a study involving 75 cerebral vascular accident patients, 25 traumatic brain injury patients, and 28 healthy controls. The NAT reliably discriminates cognitively impaired individuals from age-matched controls. The NAT has good internal consistency (Cronbach's $\alpha = 0.79$) and has been shown to correlate with the Functional Impairment Measure (FIM), a measure of disability that is based on clinician ratings ($r = 0.5$). Additionally, with dementia patients, NAT performance has been shown to correlate significantly with performance of ADL/IADL in the home (accomplishment $r = 0.34$; total error score $r = 0.45$; Giovannetti et al., 2002). A recently establish subtle error category on the NAT termed “micro-errors” has been shown to be more sensitive to increasing task demands than overt errors, and micro-errors were also significant related to cognitive variables in a sample of non-demented older adults (Seligman, Giovannetti, Sestito, & Libon, 2014).

Inter-rater reliability for scoring the NAT is excellent for both accomplishment scores (median kappa = 0.98) and overall error rates (median kappa = 0.95). The test-retest reliability of the NAT for individuals suffering from acute injuries in a rehabilitation setting is moderate ($r = 0.66$). However, this finding is not surprising given that these NATs were given in a rehabilitation setting in which cognitive functioning is not stable and some functional improvements should be expected. Thus, it is reasonable that the two tests would be imperfectly correlated. With regards to micro-errors, inter-rater reliability has been shown to be strong for raters coding performance of non-dementia older adults ($r = 0.98$) with a difference in mean number of micro-errors coded of less than one (Seligman et al., 2014).

The NAT has been used to study diverse groups of cognitively impaired individuals that include people with closed head injury (CHI; Schwartz et al., 1998), stroke (Buxbaum, Schwartz, & Montgomery, 1998; Schwartz et al., 1999), dementia (Giovannetti et al., 2002), and mild cognitive impairment (Giovannetti et al., 2008; Seligman et al., 2014). Normative data are reported in the NAT manual (Schwartz et al., 2003) and in previously published studies (Schwartz, Segal, Veramonti, Ferrara, & Buxbaum, 2002; Sestito, Schmidt, Gallo, Giovannetti, & Libon, 2005). Previous studies have demonstrated that NAT variables are not affected by education, gender, or motor problems (Buxbaum et al., 1998; Giovannetti et al., 2002; Schwartz et al., 1998, 1999, 2002; Sestito et al., 2005).

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