Feature Extraction based on Touch Interaction Data in Virtual Reality-based IADL for Characterization of Mild Cognitive Impairment

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Abstract: The aim of this study was to explore the feature pattern of Mild Cognitive Impairment (MCI) in Virtual Reality based Instrumental Activities of Daily Living (VR-IADL) which runs on a tablet PC as well as requires participants a touch interaction to complete the task. Twelve participants (MCI: 4, history of MCI: 2, healthy elderly: 6) were recruited from the region of Philadelphia in USA to perform a VR-IADL task. We found that Non Touch Time (NTT) which is time interval during not touching screen on tablet was longer than that of MCI patients as well as healthy older adults with having history of MCI. Several types of feature patterns were extracted from the NTT such as … Based on the feature pattern, Support Vector Machine (SVM) was performed to calculate the accuracy of the feature patter for characterization of MCI. As the result, the identification rate was 75%.

1 INTRODUCTION

The population of older adults is increasing, placing a burden on health care resources. According to World Alzheimer's Report (2016), the world's dementia population included approximately 47 million in 2016 and is expected to increase to 131 million by 2050. Dementia is an irreversible condition that includes symptoms that disturb daily living due to degeneration of the brain and impaired cognitive abilities. Mild Cognitive Impairment (MCI) is the prodromal stage of dementia that is associated with mild cognitive and functional difficulties. MCI may be reversible; therefore, screening for MCI may promote prevention of Alzheimer's disease through early intervention. Recent research has turned to the characterization of early behavioral dysfunction in MCI and cognitive aging (Seligman et al., 2013). People with MCI have been shown to perform more inefficiently than healthy older adults on performance-based tests of instrumental activities of daily living (IADL; i.e., learned, sequential, object-oriented behaviour in the service of everyday goals like meal preparation) (Schmitter-Edgecomb et al., 2012). In several studies, neuropsychologists view video recordings of the everyday action performance of participants and code behaviour according to an error taxonomy that includes micro-error and overt error subtypes, such as omission error and various types of commission (Giovannetti et al., 2008). The method has been used with the Naturalistic Action Test (NAT), a performance-based test of IADL. IADL performance analysis of MCI participants must include indicators of subtle errors or inefficient behaviour. Some investigators have shown that time to complete IADL tasks distinguish people with MCI from healthy older adults (Wadley et al., 2008). Long completion times in people with MCI may be the result of slowed thinking and/or slowed movements; however, to date investigators have not evaluated motor vs. cognitive IADL speed in MCI. Virtual Reality (VR)-based technology has been introduced for environmental assistive technology and to assist in diagnostic decision making. Yamaguchi et al. developed the Virtual Kitchen application with VR-based technology for assessment Alzheimer's disease

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(Yamaguchi et al., 2012, Allain et al., 2015). The Virutal Kitchen includes VR-based IADL tasks (VR-IADL) to assess functional ability of people with Alzheimer's disease by comparing frequency of omission error and commission error. Martono et al. classified the error pattern based on the acceleration changes of finger movement in a touch-screen version of the Virtual Kitchen (Martono et al., 2016). However, effective feature patterns that could clearly classify MCI vs. healthy elderly remain elusive. The aim of this study was to investigate the feature pattern of MCI with behavioral data such as touching interaction data in VR-IADL task. Because previous studies have shown that people with MCI demonstrate longer decision making times and slower cognitive processing speed, we hypothesized that MCI participants would show greater cognitive slowing than older adults on IADL. By contrast, we expected motor speed would be relatively spared. Thus, we predicted that MCI participants would spend more time not touching the screen (i.e., Non-Touch Time; NTT) than healthy elderly.

2 EXPERIMENT AND METHOD

2.1 Participants

Table 1: Neuropsychological test.

Domain	Test
Language	Category fluency; Boston Naming Test
Executive function	WAIS-R digit span backward; Trail Making Test version B
Memory-Immediate	Rey Figure in recall; WMS-R: logical memory Ⅱ Story A
Episodic Memory ability	Rey Figure copy; WAIS-R: picture completion
Attention	TMT part A, WAIS-R: digit span forward
Processing speed	TMT part A, crossing-off test

The participants aged 60 years and older were recruited from the region of Philadelphia in the USA. Participants included 6 healthy elderly, 4 elderly with MCI, and 2 elderly with a history of MCI but who no longer met MCI diagnostic criteria at the time of testing. Participants were classified with several test such as MMSE (score > 24), GDS: (Geriatric Depression Scale < 10) and neuropsychological tests of specific abilities (Seelye, 2015) as shown in Table 1 (Kaye, 2011).

2.2 Apparatus

2.2.1 Experimental Setup

Figure 1: The experimental setup for the VR-IADL task.

Figure 1 shows the experimental setup for the task. It included one tablet device, web camera for video recording during the task, and the Virtual Kitchen Challenge application, which is VR-IADL assessment tool. Participants were seated in front of the tablet device, which was placed on the table. They were asked to use their finger to complete the task. The finger enabled them to move virtual objects by touching on the object with their finger and then dragging the object to the desired position in the plane.

In this study, we used the Virtual Kitchen Challenge (VKC), which is visually developed 3D environment in order to improve reality. VKC could record several types of data such as the objects the participant touched and dragged in time series. Firure 2 shows an example of the structure of each task. This application consists of two IADL tasks: (1) Toast and coffee task, (2) Lunch box task. Each task has two or three main tasks, and main task has several sub task which is action to complete main task. For example, Toast and coffee task has 2 main task: (1) Toast task, (2) Coffee task. Toast task has 8 sub task, and coffee task has 8 sub task, too.

Before performing the task, we introduced the goal of task, and operation of VK and we were sure that participants understood (Giovannetti, 2008).

2.2.2 Toast and Coffee Task

The toast and coffee task included 14 objects, 10 target objects and 4 distractor objects. Two of the distractors were related (salt shaker, ice-cream scoop) to the target objects and the other two distractors were unrelated to the targets (paintbrush, ash tray). The placement of the distractors was evenly distributed within right/left and proximal/distal positions on the screen. Figure 3 shows the screen shot of toast and coffee task.

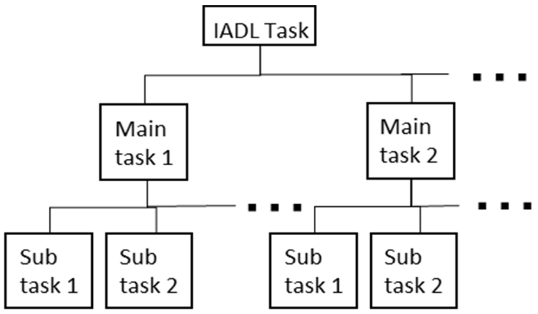

Figure 2: The example of the task structure.

Figure 3: Screen shot of the Toast and Coffee Task.

Participants were required to perfom 13 steps to make toast with butter and jelly and instant coffee with cream and sugar. The steps included: (1) place a slice of bread into the toaster; (2) turn on the switch to toast; (3) remove toast and place on the plate; (4) take butter; (5) spread butter on the toast; (6) open the jelly jar; (7) place jelly on the toast with knife; (8) open the coffee jar; (9) take a spoonful of coffee powder with spoon and into the cup; (10) open the suger pot jar;(11) place suger into cup with spoon; (12) pour milk into the cup; (13) stir cup of coffee with spoon.

2.2.3 Lunch Box Task

Lunch box task included 13 objects, 9 target objects and 4 distractor objects. Two of the distractors were related (fork, cup) to the target objects and the other two distractors were unrelated to the targets (razor, spray bottle). The placement of the distractors was evenly distributed within right/left and proximal/distal positions on the screen. Figure 4 shows the screen shot of the lunch task. The lunch task required participants to make, wrap and pack a peanut butter and jelly sandwich, prepare a thermos, and wrap and pack cookies. The task included 16 steps: (1) take bread; (2) open the jelly jar; (3) place jelly on the bread with knife; (4) open the peanut butter jar; (5) place peanut butter on bread with knife; (6) take another piece of bread to close sandwich; (7) take a sheet of foil to wrap the sandwich; (8) pack the wrapped sandwich into the lunchbox; (9) take cookies (one by one); (10) take a sheet of foil then wrap the cookies; (11) pack the wrapped cookies into the lunchbox; (12) pour the juice into the themos; (13) seal the thermos with lid; (14) seal the thermos with cap; (15) pack thermos into the lunch box; (16) close the lunch box (Martono, 2016).

Figure 4: Screen shot of the Lunch Box Task.

3 DATA AND METHODS

3.1 Movie Analysis

Video recordings of performances were reviewed for error coding. As a result, we realized difference between the Touch Time (TT) and Non Touch Time (NTT). Figure 5 shows the flow of acquire several data and definition of dragging time and not dragging time.

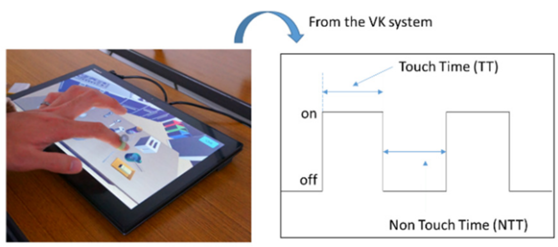

Figure 5: Classification of behaviour.

In this study, we defined TT as the time participants had contact with the screen. NTT was the time when participants were not touching the screen; see Figure 5. TT and NTT behaviour could be classified as shown in Figure 6. When participants touched the screen, they make two types of actions: (1) move object appropriately to complete task (2) move object inappropriately (i.e., error). NTT included three types of action: (1) no movement (possibly resting or thinking), (2) movements above tablet (possibly scanning and searching for object), (3) reaching error.

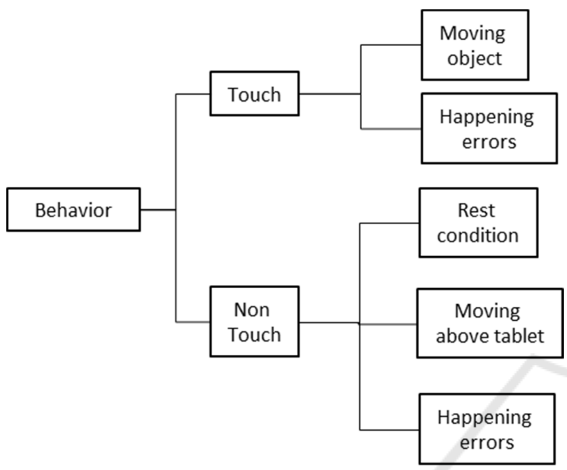

Figure 6: Classification of behaviour.

We hypothesized that MCI participants would show larger NTT times than healthy elderly, because we hypothesized that people with MCI demonstrate longer decision making times and slower processing speed.

3.2 Touch Time Data

We hypothesized that the rate of touching time ($RTT \in \mathbb{R}_{\geq 0}$) would be higher in healthy elderly people compared to people with MCI, including those with a history of MCI. We calculated RTT, using the following mathematical formula (1).

$$RTT = \frac{\sum_{n=1}^{N} TT_n}{\sum_{n=1}^{N} TT_n + \sum_{m=1}^{M} NTT_m} \tag{1}$$

RTT was calculated with $TT \in \mathbb{R}_{\geq 0} \backslash$ and $NTT \in \mathbb{R}_{\geq 0}$. The Rate of Not Touching Time ($RNTT \in \mathbb{R}_{\geq 0}$) was calculated with the following mathematical formula (2).

$$RNTT = 1 - RTT \tag{2}$$

4 RESULT AND DISCUSSION

4.1 VR-IADL Analysis

The number of times the participant touched the screen, the sum of TT and NTT, mean and variance of TT and NTT, RTT and RNTT, which is showed formula (1) and (2), were calculated for both IADL tasks for the healthy elderly group and MCI groups (i.e, MCI + history of MCI). Mann-Whitney tests for the toast and coffee task showed significant differences between the healthy and MCI participants for variance of NTT ($p < 0.05$), mean of NTT ($p < 0.1$), the sum of NTT ($p < 0.05$), and RNTT and RTT ($p < 0.05$). Also in lunch box task, there were significant differences on two types of variance of NTT ($p < 0.05$), the sum of NTT ($p < 0.05$) and RNTT and RDT ($p < 0.05$).The mean NTT in the toast and coffee task was longer for MCI participants than the healthy group. Also, the sum of NTT and RNTT of MCI group in both tasks is larger than that of healthy group.

The results suggest that NTT could reflect slowed cognitive speed and may be a behavioural feature that reliably distinguishes MCI from healthy elders. The variance of NTT was larger for the MCI group; therefore, it is possible that the MCI group may be experiencing more cognitive slowing at specific points in the IADL (i.e., main task vs. subtask). In next section, we analysed NTT and TT in different IADL task segments.

4.2 Main Task Analysis

The lunch box task consists of three main tasks: sandwich, snack, and juice. The toast and coffee task consists of two main tasks: toast and coffee. We observed how these main tasks were conducted by analysing timing of subtasks in these main tasks. Figure 7 shows the sequence in which the main tasks were conducted. The timing of the sub tasks under each the main tasks is represented by a different red marker. This graph was generated automatically with participant data. The blue, yellow, and green area respectively represents the section of the main tasks (i.e. sandwich task, snack task, and juice task).

Figure 8 shows the sequence of the toast and coffee t main tasks and sub tasks under the main task. The blue, and green area respectively represents the section of the main tasks (i.e. toast task, and coffee task).

In this study, the main task was defined as a set of completion times of each subtask. The mean of NTT, variance of NTT, the sum of NTT, the number of

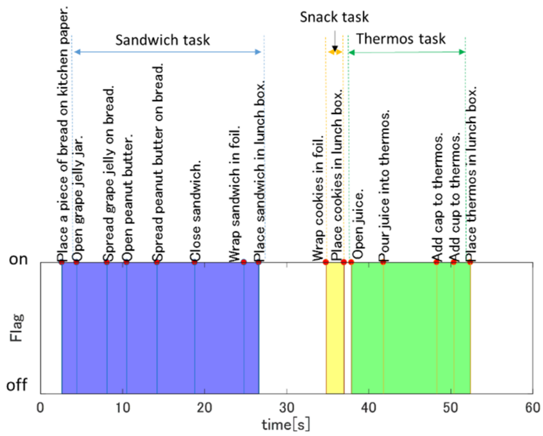

Figure 7: The sequence of the conducted main task in lunchbox task.

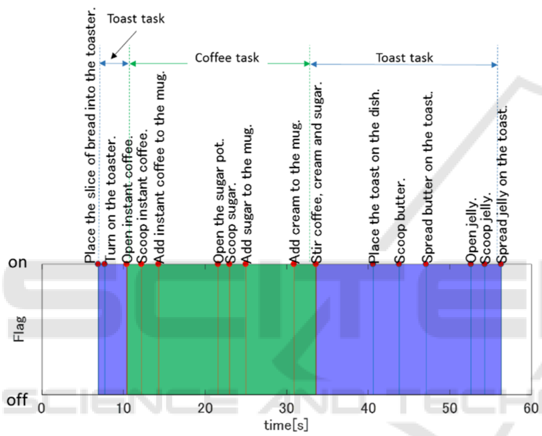

Figure 8: The sequence of the conducted main task in toast and coffee task.

touching screen, RTT and RNTT for each task. Mann-Whitney tests were performed on these parameters. In lunchbox's main task, there were significant differences for NTT variance ($p < 0.05$, sandwich and juice task), NTT mean ($p < 0.05$, only sandwich task), the sum of NTT ($p < 0.05$, sandwich task, $p < 0.1$, juice task) and RNTT ($p < 0.05$, sandwich task). In toast task and coffee task, there were significant difference for NTT variance ($p < 0.05$, both task), NTT mean ($p < 0.1$, both task), the sum of NTT ($p < 0.05$, toast task, $p < 0.1$, coffee task) and RNTT ($p < 0.05$, both task). There were no significant differences for the number of times participants touched the screen, though there were significant differences for all data in toast and coffee task.

The result indicates that NTT of MCI group is longer and more variable than that of healthy group. The sandwich and juice tasks were especially difficult for the MCI group. From the task structure point of view, the toast and coffee tasks are performed easily in parallel; therefore, the causal relationship of subtask of toast and coffee task could be more complicated to perform.

Summarizing the above, (1) Sandwich and juice task more difficult for the MCI group. (2) Task structure could make participant confused. In next section, we attempted to perform the NTT and TT analyses on smaller IADL subtasks.

4.3 Sub Task Analysis

We tried to divided main tasks into sub tasks and calculate NTT in order to find which sub task is difficult for MCI group. However, it is difficult to analyse because NTT data is small. We conclude that we should analyse with another data to explore the behaviour such as finger velocity data during VR-IADL.

4.4 Classification with SVM

In order to investigate whether the features is useful for classifying MCI, Support Vector Machine (SVM) was performed on eleven parameters: variance and mean of NTT in both tasks, RNTT in both tasks, NTT variance in sandwich task, juice task, NTT mean in sandwich task and variance of toast task and coffee task. The accuracy of MCI including history of MCI is 75%. Figure 9 showed that the result of ROC analysis, which indicate that FPT is 0.5 and FPF is 0.67 and AUC is 0.71. This result suggests that NTT and several parameters calculated with NTT can classify MCI group.

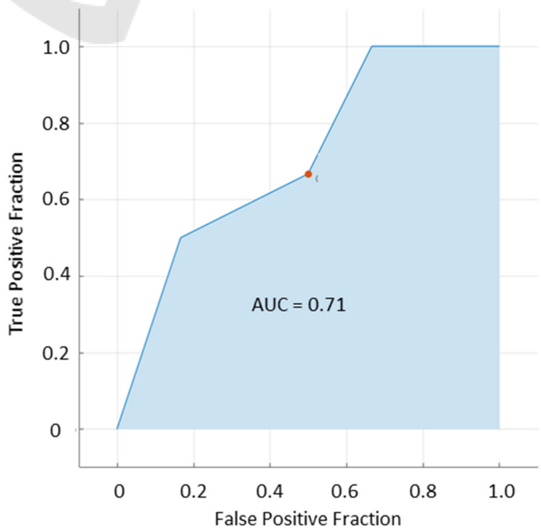

Figure 9: ROC analysis.

5 CONCLUSIONS

This study explored the features of IADL behaviours that effectively distinguish MCI from healthy older adults. The study focused on identifying cognitive processing speed and motor processing speed using time spent touching (TT) or not touching (NTT) the screen on a VR-based IADL task. We conclude that NTT was greater in participants with MCI or a history of MCI. NTT may reflect slowed cognitive processing speed; however, we were unable to identify reliable behaviours during NTT did not see a reliable relation between NTT and IADL subtask. Therefore, future work is needed to understand why NTT are longer in MCI. Future studies will include larger participant samples and analysis with other methods, including analysis of finger movements during NTT.

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