Using Wearables and Virtual Reality to monitor cognitive
Toward an early detection in Alzheimer’s disease from onset to late stages

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www.bcm.edu/icamp
Intelligent Wearable Technology & Game-Based Therapies
- $5.7M+ (12+ active grants) in direct extramural grant support
- $10M+ pending grants
- 18 approved clinical protocols
- 5+ filed patents

Team of Teams: ICAMP @2016
Interdisciplinary Consortium on Advanced Motion Performance

iCAMP Surgical Simulation
iCAMP Gait
iCAMP Exergaming

SmartSox
Home telemonitoring
iCAMP Frailty Meter
Automatic Fall Detector
Global Economic Impact of Dementia

The world is facing an epidemic of dementia that will affect millions of people worldwide. In 2015, there were 46.9 million people with dementia, and this number is expected to increase to 131.5 million by 2050. This is an increase of 68% over 35 years.

The worldwide cost of dementia in 2015 was estimated at US$ 818 billion, and by 2030, this cost is projected to reach US$ 2 trillion.

If dementia were a country, it would be the 18th largest economy in the world, surpassing the market value of companies such as Apple and Google.

The map shows the estimated number of people living with dementia in each world region in 2015. This is crucial for global action on dementia.

“We can’t manage what we can’t measure”

- Early diagnosis = personalized interventions in early stages

- Early diagnosis = delay further deteriorative progression and/or limit the consequences of motor-cognitive impairment, such as increasing risk of falling, decreasing mobility, and loss of independency

2. Amariglio, R.E., et al., 2015, JAMA Neurol
How to predict trajectory toward dementia?

How to early detect trajectory toward dementia/AD?

Which factors may accelerate cognitive decline?

The continuum of Alzheimer’s disease

Cognitive function

Years

Aging

Asymptomatic

Early symptomatic

Preclinical

MCI

AD Dementia

Sperling et al Alzheimer & Dementia 2011
NIA-AA Preclinical Workgroup

Graphical Representation of Accelerated Cognitive Ageing

Cognitive reserve

First hit

Second hit

Medication
Depression
Surgery
Chronic disease

Cognitive ageing with no pathology

Age
Motor Abnormality is a Predictor of Dementia

Gait is often represented by walking speed and is an indicator of motor performance in Human.

International Consensus Group on ‘Cognitive Frailty’

Cognitive-frailty can determine trajectory to dementia and its early detection is essential for an effective intervention.

International Consensus Group on ‘Cognitive Frailty’ organized by the international academy on nutrition and aging (i.a.n.a) and the international association of Gerontology and Geriatrics (i.a.G.G)

Kelaiditi et al, (2013), The Journal of Nutrition, Health &Aging
Ruan et al, (2015), Ageing Research Reviews
How to measure Cognitive-Frailty?

Motor Decline + Cognitive Decline = Cognitive-Frailty

Physical Frailty

Cognitive Impairment
Conventional methods for assessing cognitive function

Limitations
- Subjective
- Sensitive to examiner’s skill and experience
- Sensitive to patient education level, culture, and speaking language
- Do not consider physical frailty
- Time consuming (~15min)
Conventional Method for assessing Frailty

Frailty phenotypes
- Slowness
- Weakness
- Exhaustion
- Inactivity
- Weight loss

Limitations
- Time consuming (~15-30min)
- Impractical in busy clinics, homes, and those with mobility limitation
- Not sensitive to change (unable to detect decline over short period of time)
- Do not consider cognitive function
Our Solution:
A hybrid system to assess both motor and cognitive performance

- Instrumented Trail-Making Task (iTMT)
- Wearable Sensors & Virtual reality
- Traditional working-memory Test
- Technology
- Cognitive-Frailty Test

iTMT

less than 1 min!
Instrumented Trail-making Task (iTMT)

- Accelerometer
- Gyroscope
- Bluetooth data transmission
iTMT measurable metrics

iTMT time $\rightarrow$ Cognitive function
- working memory and executive function performance
- Duration needed to complete all reaching tasks in correct order

Motor-Planning Error $\rightarrow$ cognitive-motor performance
- Ability to predict the distance to the target

Ankle Velocity $\rightarrow$ Physical Frailty
- Slowness
- Weakness
- Exhaustion
iTMT measurable metrics indicator of cognitive-frailty

- iTMT Ankle Velocity (slowness)
- iTMT Ankle Moment/Power (weakness)
- iTMT Velocity Reduction (exhaustion)
- iTMT Motor Planning Error
- iTMT time

Physical Frailty

Cognitive Function

Zhou et al., 2018, Sensors
### Study #1: Measuring cognition function

<table>
<thead>
<tr>
<th>Variable (mean±SD)</th>
<th>Healthy (n = 11)</th>
<th>aMCI (n = 10)</th>
<th>AD (n = 9)</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, years</td>
<td>80.5±6.3</td>
<td>85.2±4.6</td>
<td>80.8±6.6</td>
<td>0.152</td>
</tr>
<tr>
<td>Female, n (% )</td>
<td>6.0 (54.5)</td>
<td>5.0 (50.0)</td>
<td>2.0 (22.2)</td>
<td>0.305</td>
</tr>
<tr>
<td>BMI, kg/m²</td>
<td>23.5±3.4</td>
<td>26.3±3.7</td>
<td>27.7±6.4</td>
<td>0.130</td>
</tr>
<tr>
<td>Education level, years</td>
<td>15.2±3.0</td>
<td>13.8±2.3</td>
<td>14.6±1.8</td>
<td>0.451</td>
</tr>
<tr>
<td>MoCA score, 0-30</td>
<td>27.7±1.8</td>
<td>23.3±2.9</td>
<td>16.6±4.5</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>TMT B, s</td>
<td>77.7±32.9</td>
<td>164.3±70.2</td>
<td>278.0±157.5</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>

Zhou et al, (2016), Gerontology
iTMT duration is Sensitive to distinguish MCI/AD

Difference Between

- Healthy--aMCI: 61%
  \[ p = 0.189, \text{Cohen’s } d \text{ effect size} = 1.047 \]
- Healthy--AD: 176%
  \[ p = 0.001, \text{Cohen’s } d \text{ effect size} = 1.625 \]
- aMCI--AD: 72%
  \[ p = 0.028, \text{Cohen’s } d \text{ effect size} = 1.035 \]

\( \textit{Zhou et al, (2016), Gerontology} \)
Motor Planning Error & Cognitive Impairment

- MoCA (cut-off ≤ 25):
  - Cognitive Intact
  - Cognitive Impaired

- iTMT Motor Planning Error: 52% difference
  - $p < 0.001$
  - *Cohen’s d effect size = 2.651*

* denotes $p < 0.050$

Zhou et al, (2016), Gerontology
Zhou et al, (2018), Sensors
iTMT vs. Traditional Cognitive Assessments

iTMT has strong correlation with MoCA and conventional TMT B

Zhou et al, (2016), Gerontology
### Study #2: Measuring physical frailty

<table>
<thead>
<tr>
<th>Variable (mean±SD)</th>
<th>Elderly Non-frail (n = 21)</th>
<th>Elderly Pre-frail (n = 24)</th>
<th>Elderly Frail (n = 6)</th>
<th>p-value (between elderly)</th>
<th>Young-healthy (n = 17)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, years (range)</td>
<td>69.0±8.0 (60-89)</td>
<td>75.8±10.2 (62-91)</td>
<td>78.0±13.7 (65-93)</td>
<td>0.038</td>
<td>29.0±7.2 (20-35)</td>
</tr>
<tr>
<td>Female, n (%)</td>
<td>9 (43)</td>
<td>11 (46)</td>
<td>3 (50)</td>
<td>0.948</td>
<td>6 (35)</td>
</tr>
<tr>
<td>BMI, kg/m²</td>
<td>27.4±5.9</td>
<td>27.1±4.1</td>
<td>29.4±7.7</td>
<td>0.635</td>
<td>26.2±4.6</td>
</tr>
<tr>
<td>Fall history, n (%)</td>
<td>5 (24)</td>
<td>6 (25)</td>
<td>2 (33)</td>
<td>0.892</td>
<td>-</td>
</tr>
<tr>
<td>Walking Stride Velocity, m/s</td>
<td>1.0±0.2</td>
<td>0.9±0.2</td>
<td>0.8±0.2</td>
<td>0.030</td>
<td>1.2±0.2</td>
</tr>
</tbody>
</table>

Zhou et al, (2018), Sensors
Large Effect Size was Observed for pre-frailty and frailty Identification using iTMT

* denotes $p < 0.050$
iTMT velocity had high correlation with conventional walking stride velocity

\[ r = 0.614, \ p < 0.001 \]
Conclusion

anytime        anywhere
practical in small and busy setting
Potential to determine trajectory toward dementia
Thank you!

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The World in 2050

The next four decades will see dramatic changes in the age structure of the global population. How big those changes will be, when they happen and where they will be most felt are subjects of much concern. We take a look at some of the projections.

In general, developed countries will have older populations... ...but most people aged 60+ will still live in the developing world

Map shows the percentage of each area’s total population that will be aged 60+ in 2050. It is divided by region, not country.
• MoCA (cut-off = 25):
  • Cognitive Intact
  • Cognitive Impaired

• 93% difference:
  • $p = 0.015$
  • Cohen’s $d$ effect size = 1.11

Zhou et al, (2016), Gerontology
Conventional Frailty assessments

Current frailty phenotype assessment tools are often required walking assessment. However, these are impractical for inpatient geriatricians or mobility-impaired patients.

**Current Tools**

**In-Hospital Reality**

**Our Solution**

iTMT without the need of walking test
Dementia Wave is Growing

Prevalence of Dementia in Different Age Groups

Projected Number of Americans Aged 65 and Older with Alzheimer’s Disease