MOBILE MANIFESTATIONS OF ALERTNESS:

Connecting biological rhythms with patterns of smartphone app use

Elizabeth Murnane, Saeed Abdullah, Mark Matthews, Matthew Kay, Julie Kientz, Tanzeem Choudhury, Geri Gay, Dan Cosley
Research Goals

• **Describing** phone use
  (E.g., Böhmer et al., 2011; Brown et al., 2014; Falaki et al., 2010; Ferreira et al., 2014; Hang et al., 2013; Jones et al., 2015; Shin et al., 2012; Xu et al., 2013; Yan et al., 2012)

• **Deriving signals for modeling** latent traits or phenomena
  (E.g., Bai et al., 2012; Huang et al., 2015; Mark et al., 2014; Min et al., 2014; Oulasvirta et al., 2012; Pielot et al., 2014; Pielot et al., 2015)

• **Interpreting** usage patterns
  (E.g., Do et al., 2011; Lee et al., 2011; Rahmati et al., 2012)
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* from a biological perspective *
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• **Interpreting** usage patterns from a biological perspective

• Identify signals informative for passive alertness sensing

• Enable the design of novel circadian-aware technologies
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• Interpreting usage patterns from a biological perspective

• Identify signals informative for passive alertness sensing

• Enable the design of novel circadian-aware technologies
Circadian Rhythms: biological processes following a roughly 24-hour period
Almost every neurobehavioral process displays circadian rhythms.
Circadian Rhythms: biological processes following a roughly 24-hour period

Almost every neurobehavorial process displays circadian rhythms
Motivation

Method

Findings
Chronotype
Chronotype:
A reflection of a person’s underlying circadian rhythms, quantified using a measure of sleep-midpoint
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Method
Study

- 20 participants
- 40 days

Data
- Phone usage logs
- Alertness assessment EMA
- Daily sleep diary
- Interviews
Alertness Assessment

• Median response time from a PVT session

• Establish individual baseline across all session

• Alertness is departure from baseline
App Logging

- AWARE (http://www.awareframework.com/)

<table>
<thead>
<tr>
<th>Category</th>
<th>Example Apps</th>
</tr>
</thead>
<tbody>
<tr>
<td>Browser</td>
<td>Chrome, Firefox</td>
</tr>
<tr>
<td>Communication</td>
<td>Facebook Messenger, GroupMe, Phone, SMS</td>
</tr>
<tr>
<td>Email</td>
<td>Gmail, Inbox</td>
</tr>
<tr>
<td>Entertainment</td>
<td>Clash of Clans, Ebay, Netflix, YouTube</td>
</tr>
<tr>
<td>Productivity</td>
<td>Evernote, OfficeSuite, To Do Reminder, Piazza</td>
</tr>
<tr>
<td>Social Media</td>
<td>Facebook, Twitter, Yik Yak</td>
</tr>
<tr>
<td>Time &amp; Weather</td>
<td>Clock, Timely, Weather Channel</td>
</tr>
</tbody>
</table>
RESULTS
Findings

• **Daily patterns** in app use replicate prior findings

• App use also shows **weekly patterns**

• Different **chronotypes** have different usage patterns

• App use patterns correlate with **alertness patterns**

• App use features can distinguish periods of **low vs. high alertness**

• App use reflects **sleep** duration, interruptions, and subsequent fatigue
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Daily Rhythms in App Use

Motivation

Method

Results
Daily Rhythms in App Use

![Graph showing application usage events over time for various categories such as Productivity, Entertainment, Communication, Social Media, Email, Browsing, Time & Weather. The x-axis represents time (0-23 hours), and the y-axis represents application usage events (0-2500).]
Daily Rhythms in App Use

Motivation

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Daily Rhythms in App Use
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Usage Differences by Chronotype

- Early-Late Usage Change (%)

- Morning (6AM-12PM)
- Afternoon (12PM-6PM)
- Evening (6PM-12AM)
- Night (12AM-6AM)

- Green: Productivity
- Orange: Entertainment
Usage Differences by Chronotype

- **Morning (6AM-12PM)**: Productivity usage change about 20%
- **Afternoon (12PM-6PM)**: Productivity usage change about 0%
- **Evening (6PM-12AM)**: Productivity usage change about -40%
- **Night (12AM-6AM)**: Productivity usage change about -20%

- **Productivity**
- **Entertainment**

**Results**
Usage Differences by Chronotype

- **Morning (6AM-12PM):** 25% increase in Productivity
- **Afternoon (12PM-6PM):** 20% increase in Entertainment
- **Evening (6PM-12AM):** 40% decrease in Productivity, 60% increase in Entertainment
- **Night (12AM-6AM):** 10% increase in Productivity, 10% decrease in Entertainment
Usage Differences by Chronotype

- Early-Late Usage Change (%)
  - Morning (6AM-12PM)
  - Afternoon (12PM-6PM)
  - Evening (6PM-12AM)
  - Night (12AM-6AM)

- Productivity
- Entertainment

- Motivation
- Method
- Results
Usage Differences by Chronotype

![Bar chart showing usage differences by chronotype. The X-axis represents different time periods: Morning (6AM-12PM), Afternoon (12PM-6PM), Evening (6PM-12AM), and Night (12AM-6AM). The Y-axis represents Early-Late Usage Change (%). The chart indicates a 19% difference in activity levels between early and late periods.]

- **Morning (6AM-12PM)**: Productivity and Entertainment levels are relatively low.
- **Afternoon (12PM-6PM)**: Productivity levels are slightly higher than Entertainment.
- **Evening (6PM-12AM)**: A significant increase in both Productivity and Entertainment, with Entertainment being more pronounced.
- **Night (12AM-6AM)**: A slight decrease in Productivity, while Entertainment shows a moderate increase.

**Results**

- **Entertainment** shows a notable increase in the evening, indicating a peak in usage.
- **Productivity** experiences a peak in the evening as well, suggesting a balance between work and leisure activities.

**Motivation**

- Understanding personal chronotype can help in optimizing daily routines and managing activities accordingly.

**Method**

- The study involves tracking usage patterns across different times of the day to analyze the peak usage times for both productivity and entertainment activities.
Usage Differences by Chronotype

<table>
<thead>
<tr>
<th>Time Period</th>
<th>Productivity Change</th>
<th>Entertainment Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>Morning (6AM-12PM)</td>
<td>-19%</td>
<td>29%</td>
</tr>
<tr>
<td>Afternoon (12PM-6PM)</td>
<td>-20%</td>
<td>29%</td>
</tr>
<tr>
<td>Evening (6PM-12AM)</td>
<td>-80%</td>
<td>70%</td>
</tr>
<tr>
<td>Night (12AM-6AM)</td>
<td>-20%</td>
<td>20%</td>
</tr>
</tbody>
</table>
Usage Differences by Chronotype

![Bar chart showing usage differences by chronotype]

- Productivity
- Entertainment

- Morning (6AM-12PM): 19%
- Afternoon (12PM-6PM): 29%
- Evening (6PM-12AM):
- Night (12AM-6AM):

Motivation
Method
Results
Usage Differences by Chronotype

Early-Late Usage Change (%)

Morning (6AM-12PM) Afternoon (12PM-6PM) Evening (6PM-12AM) Night (12AM-6AM)

Productivity

Entertainment

Motivation Method Results
Usage Differences by Chronotype

<table>
<thead>
<tr>
<th>Time Slot</th>
<th>Productivity</th>
<th>Entertainment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Morning (6AM-12PM)</td>
<td>-20%</td>
<td>-15%</td>
</tr>
<tr>
<td>Afternoon (12PM-6PM)</td>
<td>20%</td>
<td>15%</td>
</tr>
<tr>
<td>Evening (6PM-12AM)</td>
<td>-40%</td>
<td>80%</td>
</tr>
<tr>
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<td>10%</td>
<td>20%</td>
</tr>
</tbody>
</table>

**Motivation**

**Method**

**Results**
Usage Differences by Chronotype

![Bar chart showing usage differences by chronotype]

- **Early-Late Usage Change (%)**
  - **Morning (6AM-12PM)**: 15%
  - **Afternoon (12PM-6PM)**: 50%
  - **Evening (6PM-12AM)**: 15%
  - **Night (12AM-6AM)**: 50%

**Legend:**
- Green: Productivity
- Orange: Entertainment

---

**Motivation**

**Method**

**Results**
Usage Differences by Chronotype

![Bar chart showing usage differences by chronotype. The chart compares productivity and entertainment usage across different time periods: Morning (6AM-12PM), Afternoon (12PM-6PM), Evening (6PM-12AM), and Night (12AM-6AM). The chart highlights an increase in entertainment usage in the Evening and Night periods, with a decrease in the Morning and Afternoon periods.]

- **Morning (6AM-12PM)**: Productivity increase of 15%, Entertainment decrease of 5%
- **Afternoon (12PM-6PM)**: Productivity increase of 50%, Entertainment decrease of 20%
- **Evening (6PM-12AM)**: Productivity increase of 15%, Entertainment increase of 50%
- **Night (12AM-6AM)**: Productivity decrease of 20%, Entertainment increase of 30%

**Motivation**

**Method**

**Results**
Usage Differences by Chronotype

- **Morning (6AM-12PM)**: 0%
- **Afternoon (12PM-6PM)**: -20%
- **Evening (6PM-12AM)**: 22%
- **Night (12AM-6AM)**: 10%

**Categories:**
- Productivity
- Entertainment
## Usage Differences by Chronotype

<table>
<thead>
<tr>
<th>Time Period</th>
<th>Productivity</th>
<th>Entertainment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Morning (6AM-12PM)</td>
<td>68%</td>
<td>22%</td>
</tr>
<tr>
<td>Afternoon (12PM-6PM)</td>
<td>22%</td>
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<td>22%</td>
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### Motivation

- **Early-Late Usage Change (%):**
  - Morning: 68%
  - Afternoon: 22%
  - Evening: 68%
  - Night: 22%

### Method

- **Motivation:**
- **Method:**
- **Results:**
Usage Differences by Chronotype

- Morning (6AM-12PM): Productivity -20%, Entertainment 22%
- Afternoon (12PM-6PM): Productivity -20%, Entertainment 0%
- Evening (6PM-12AM): Productivity 0%, Entertainment 68%
- Night (12AM-6AM): Productivity -20%, Entertainment 22%

Motivation
Method
Results
Findings

• Daily patterns in app use replicate prior findings

• App use also shows weekly patterns

**Different chronotypes have different usage patterns**

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External Time

- “Local time”, “clock time”
- Hours since midnight
- I.e., the midpoint of night time
**External Time**

- “Local time”, “clock time”
- Hours since midnight
- I.e., the midpoint of night time

**Internal Time**

- “Biological time”, “body clock time”
- Hours since sleep midpoint
- I.e., midpoint of “biological night”
External Time

- “Local time”, “clock time”
- Hours since midnight
- I.e., the midpoint of night time

Internal Time

- “Biological time”, “body clock time”
- Hours since sleep midpoint
- I.e., midpoint of “biological night”

Internal Time = External Time – Chronotype
Application Usage Events

- Productivity
- Entertainment
- Communication
- Social Media
- Email
- Browsing
- Time & Weather

External Time (ExT)

Application Usage Events
Biological...
Morning
Mid-Day
Night
The graph shows the usage of three different applications: Alertness, Productivity, and Entertainment, across different times of the day. The x-axis represents the Internal Time (InT), ranging from 0 to 23, and the y-axis represents the Usage. The graph is color-coded to represent different biological times: Morning, Mid-Day, and Night. The usage peaks at different times for each application, indicating the optimal times for usage according to the biological rhythms.
Productivity Apps ~ Higher Alertness

\[ r = 0.52, \ p < .001 \]
Entertainment Apps ~ Lower Alertness

$r = -0.31, p<.05$
Manifestations of Biological Phenomena

**Graph Description:**
- The graph depicts the usage and performance over internal time (InT) with internal time ranging from 0 to 23.
- Usage is shown on the y-axis ranging from 0 to 1, and performance is shown on the y-axis ranging from -8 to 6.
- Three categories are plotted:
  - **Alertness** represented by blue stars.
  - **Productivity** represented by green circles.
  - **Entertainment** represented by orange squares.
- The graph illustrates the peaks and troughs of these categories throughout the day.

**Biological Phenomena:**
- Internal Time (InT) is divided into three segments:
  - **Morning:** 0 to 8
  - **Mid-Day:** 8 to 16
  - **Night:** 16 to 24

**Legend:**
- Blue star: Alertness
- Green circle: Productivity
- Orange square: Entertainment
Sleep Inertia

![Graph showing usage and performance over Internal Time (InT). The graph includes data for Alertness, Productivity, and Entertainment. The graph is color-coded with blue for Alertness, green for Productivity, and orange for Entertainment. The x-axis represents Internal Time (InT) ranging from 0 to 23, and the y-axis represents Usage and Performance. The graph highlights various time periods such as Biological, Morning, Mid-Day, and Night.](image-url)
Sleep Inertia

Performance

Usage

Internal Time (InT)

Alertness
Productivity
Entertainment

Biological… Morning

Mid-Day

Night

Motivation

Method

Results
Sleep Inertia

“I’ll stay on the phone longer, browsing YouTube, etc, if I’m more tired.”
Late Morning Performance Peak

- **Motivation**
- **Method**
- **Results**
Mid-Day Dip & Evening Rebound

- Alertness
- Productivity
- Entertainment

Internal Time (InT)

- Biological
- Morning
- Mid-Day
- Night

Usage

Performance
Late Night Lull

![Graph showing usage and performance over Internal Time (InT)]

- **Alertness**
- **Productivity**
- **Entertainment**

**Biological Time**
- Morning
- Mid-Day
- Night

**Usage**
- 0
- 0.1
- 0.2
- 0.3
- 0.4
- 0.5
- 0.6
- 0.7
- 0.8
- 0.9
- 1

**Performance**
- -8
- -7
- -6
- -5
- -4
- -3
- -2
- -1
- 0
- 1
- 2
- 3
- 4
- 5
- 6

**Internal Time (InT)**
- 0
- 1
- 2
- 3
- 4
- 5
- 6
- 7
- 8
- 9
- 10
- 11
- 12
- 13
- 14
- 15
- 16
- 17
- 18
- 19
- 20
- 21
- 22
- 23
Late Night Lull

"Every time before I go to bed, I play a card game until I feel sleepy."
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Opportunities
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• **Predicting** alertness from phone data

• Cognitive Rhythms: Unobtrusive and Continuous Sensing of Alertness Using a Mobile Phone (UbiComp 2016)
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• Circadian-aware **designs** for productivity technology

  • Scheduling, education, interruption, personal awareness
Ambient awareness of personal alertness levels
<table>
<thead>
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<tbody>
<tr>
<td>Ambient awareness of personal alertness levels</td>
<td>Scheduling recommendation</td>
</tr>
</tbody>
</table>
**Ambient awareness of personal alertness levels**

Diagram showing a day's schedule:
- 7am: Exercise
- 8am: Group Meeting
- 9am: Group Meeting
- 10am: Lab
- 11am: Dental appointment
- 12pm: Lunch
- 1pm: Lab
- 2pm: Laundry

**Scheduling recommendation**
Ambient awareness of personal alertness levels

Scheduling recommendation
Ambient awareness of personal alertness levels

Scheduling recommendation
Ambient awareness of personal alertness levels

Scheduling recommendation
Ambient awareness of personal alertness levels

Scheduling recommendation
Summary

• Using biology to interpret mobile usage behaviors

• Associations between biological factors (alertness, chronotype, sleep) and mobile use (especially productivity & entertainment apps)

• Opportunities for predicting alertness and creating alertness-aware technology
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Thank You! Questions?

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