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

Cornell CIS
COMPUTING AND INFORMATION SCIENCE

HUMAN CENTERED DESIGN & ENGINEERING
UNIVERSITY of WASHINGTON

MOTIVATION METHOD FINDINGS

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)

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)

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)

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)

*** from a biological perspective ***

Research Goals

- **Interpreting** usage patterns from a biological perspective
- Identify signals informative for passive alertness sensing
- Enable the design of novel circadian-aware technologies

Research Goals

- Interpreting usage patterns from a biological perspective
- Identify signals informative for **passive alertness sensing**
- Enable the design of novel circadian-aware technologies

Research Goals

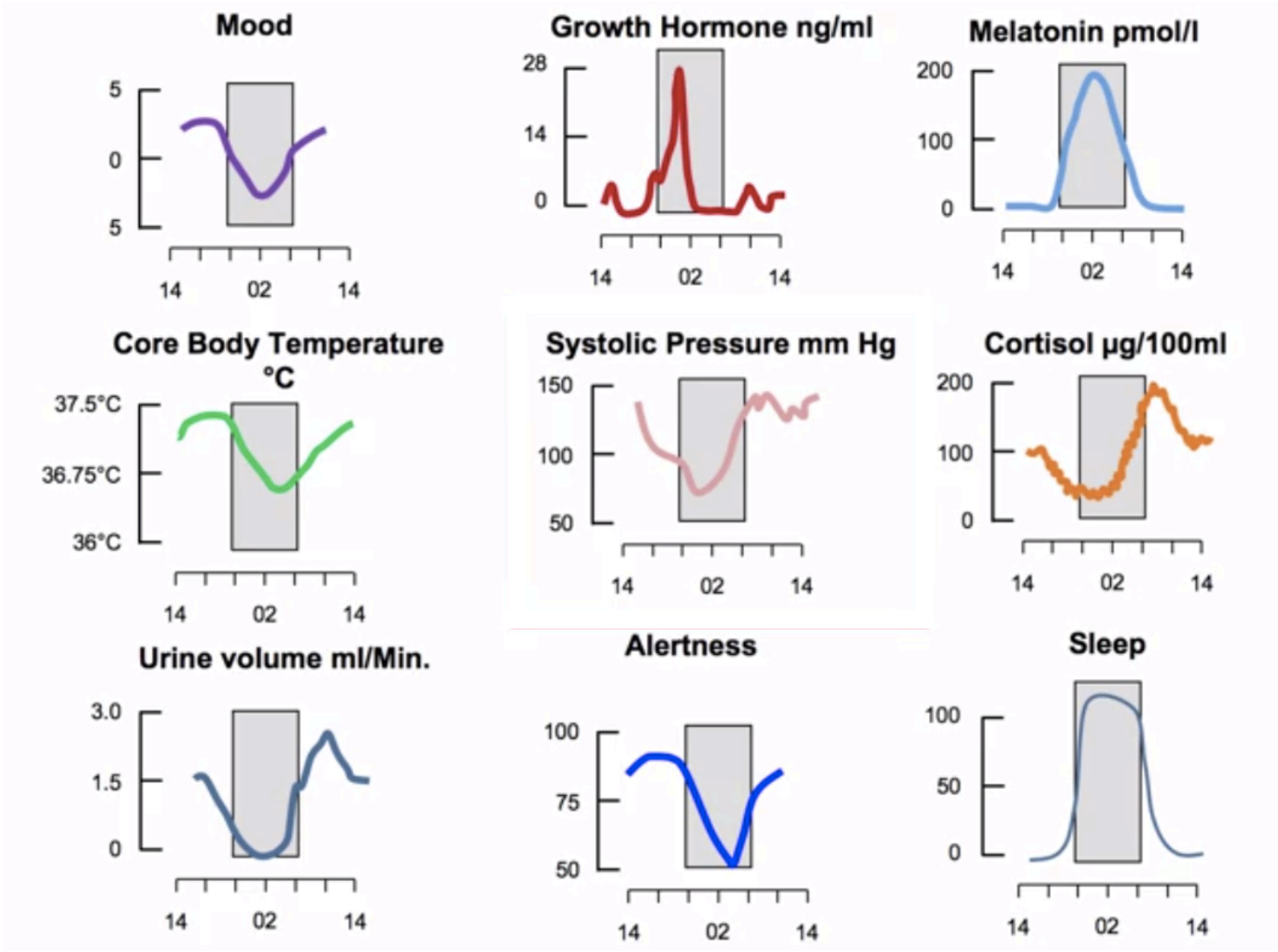
- Interpreting usage patterns from a biological perspective
- Identify signals informative for passive alertness sensing
- Enable the design of novel **circadian-aware technologies**

Circadian Rhythms:

biological processes following a roughly 24-hour period

Circadian Rhythms:

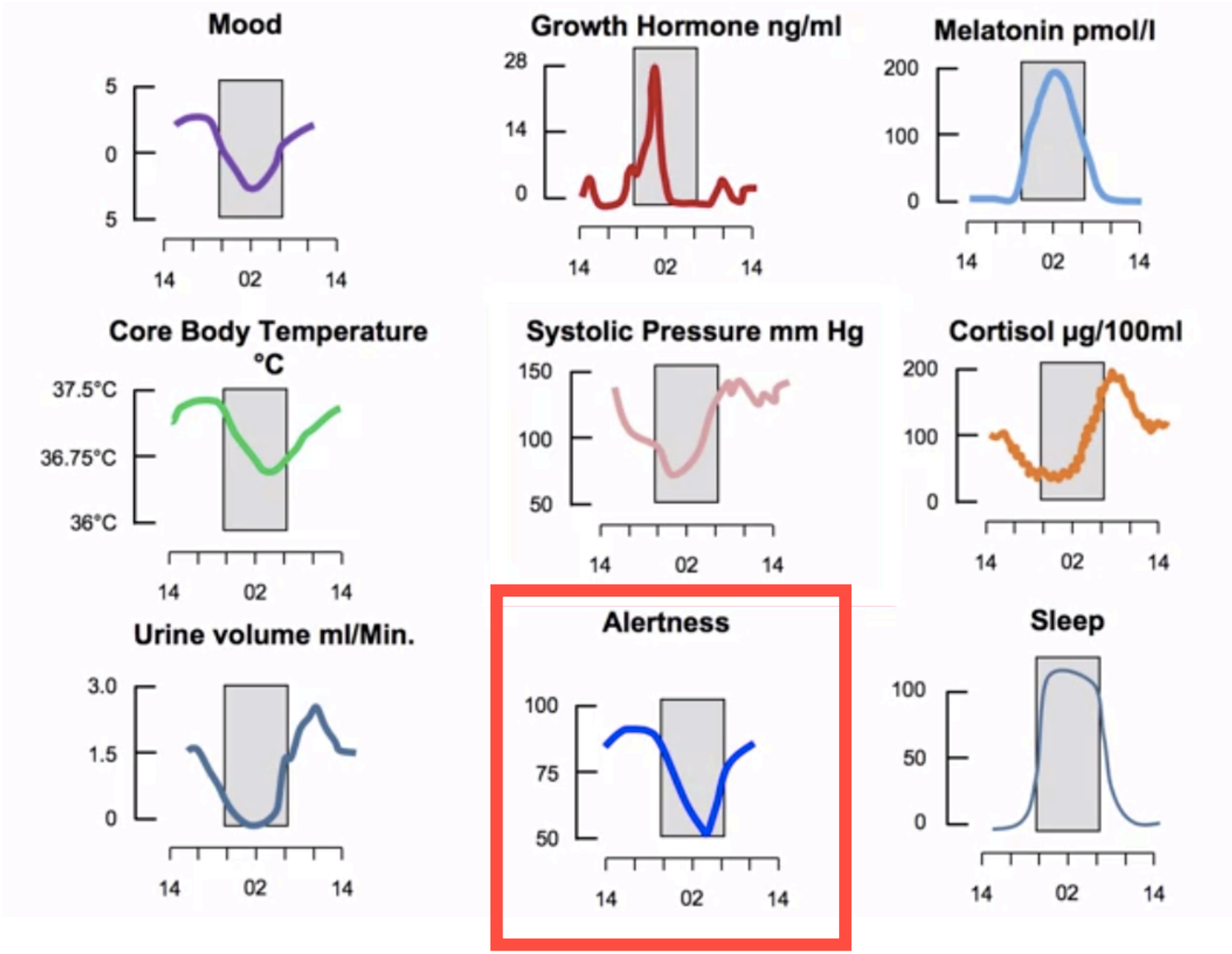
biological processes following a roughly 24-hour period



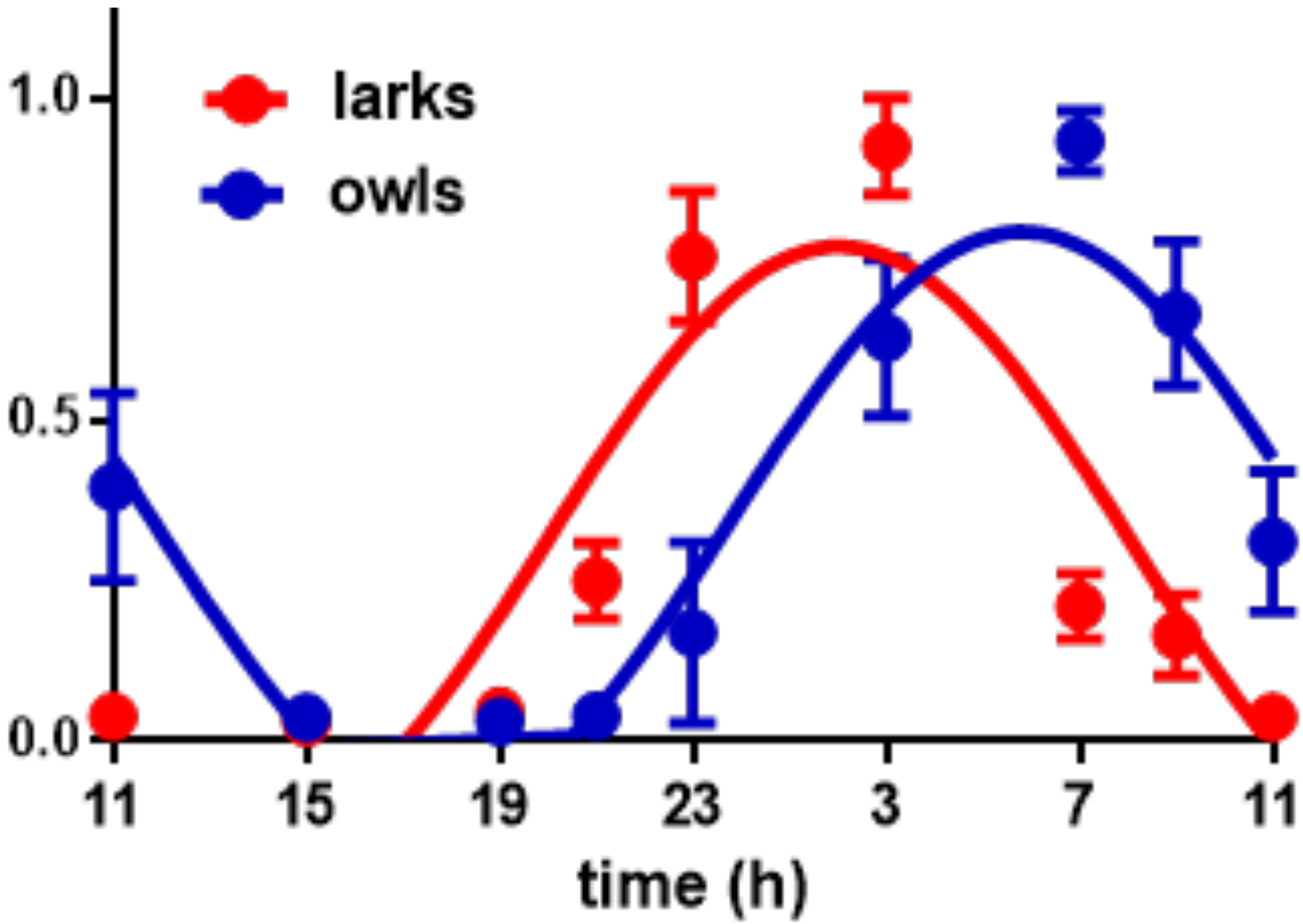
Almost **every** neurobehavioral process displays circadian rhythms

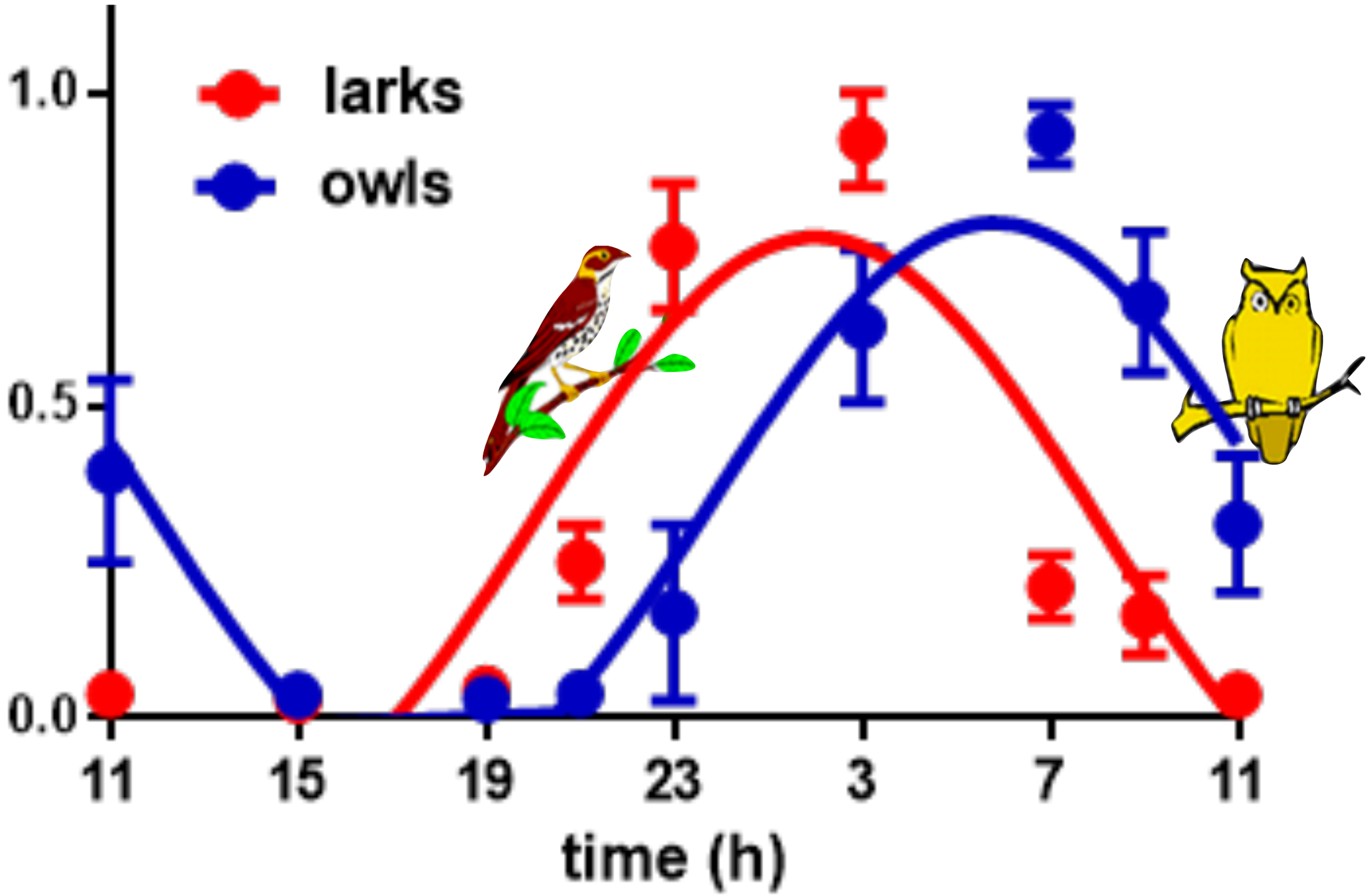
Circadian Rhythms:

biological processes following a roughly 24-hour period



Almost **every** neurobehavioral process displays circadian rhythms


1.0
0.5
0.0
larks
owls
11
15
19
23
3
7
11
time (h)


1.0
0.5
0.0
larks
owls
11
15
19
23
3
7
11
time (h)

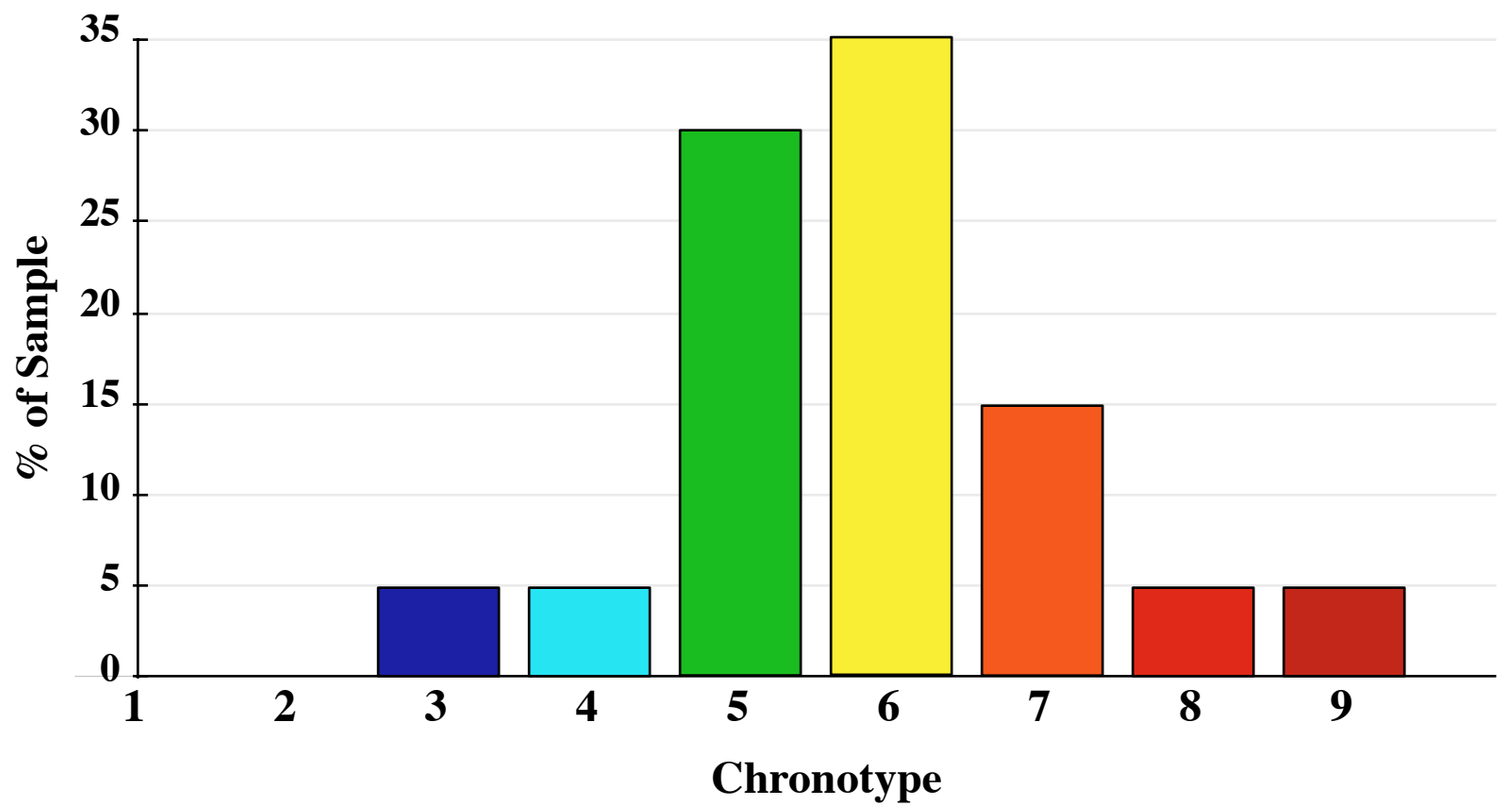
Chronotype

Chronotype:

A reflection of a person's underlying circadian rhythms, quantified using a measure of sleep-midpoint

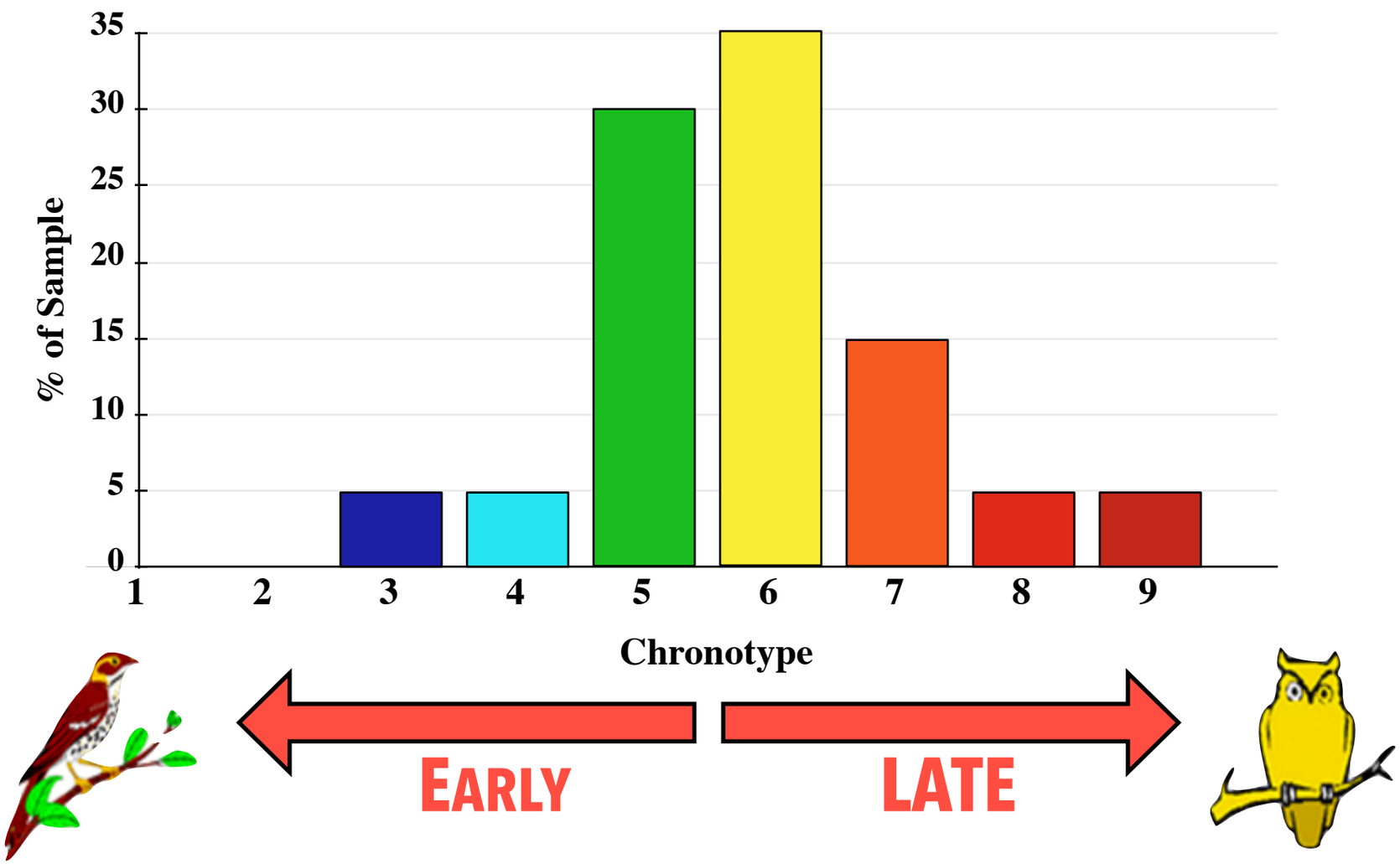
Chronotype:

A reflection of a person's underlying circadian rhythms, quantified using a measure of sleep-midpoint



Chronotype:

A reflection of a person's underlying circadian rhythms, quantified using a measure of sleep-midpoint



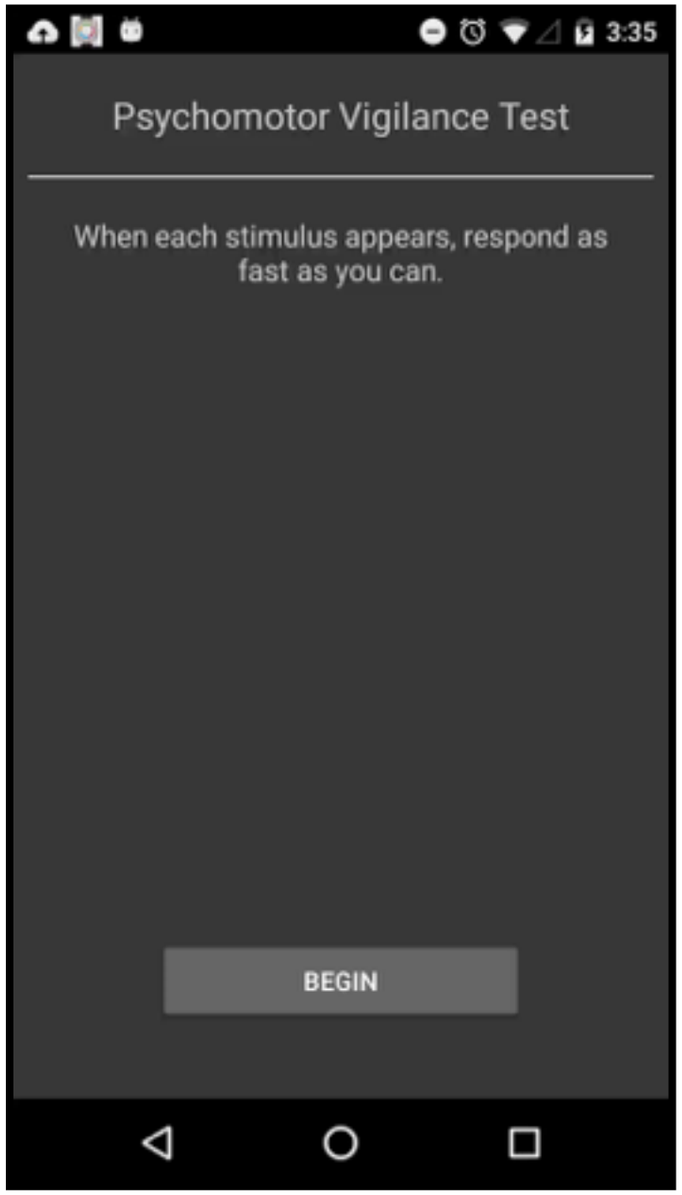
Method

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/)

Category	Example Apps
Browser	Chrome, Firefox
Communication	Facebook Messenger, GroupMe, Phone, SMS
Email	Gmail, Inbox
Entertainment	Clash of Clans, Ebay, Netflix, YouTube
Productivity	Evernote, OfficeSuite, To Do Reminder, Piazza
Social Media	Facebook, Twitter, Yik Yak
Time & Weather	Clock, Timely, Weather Channel

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

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

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

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

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

Findings

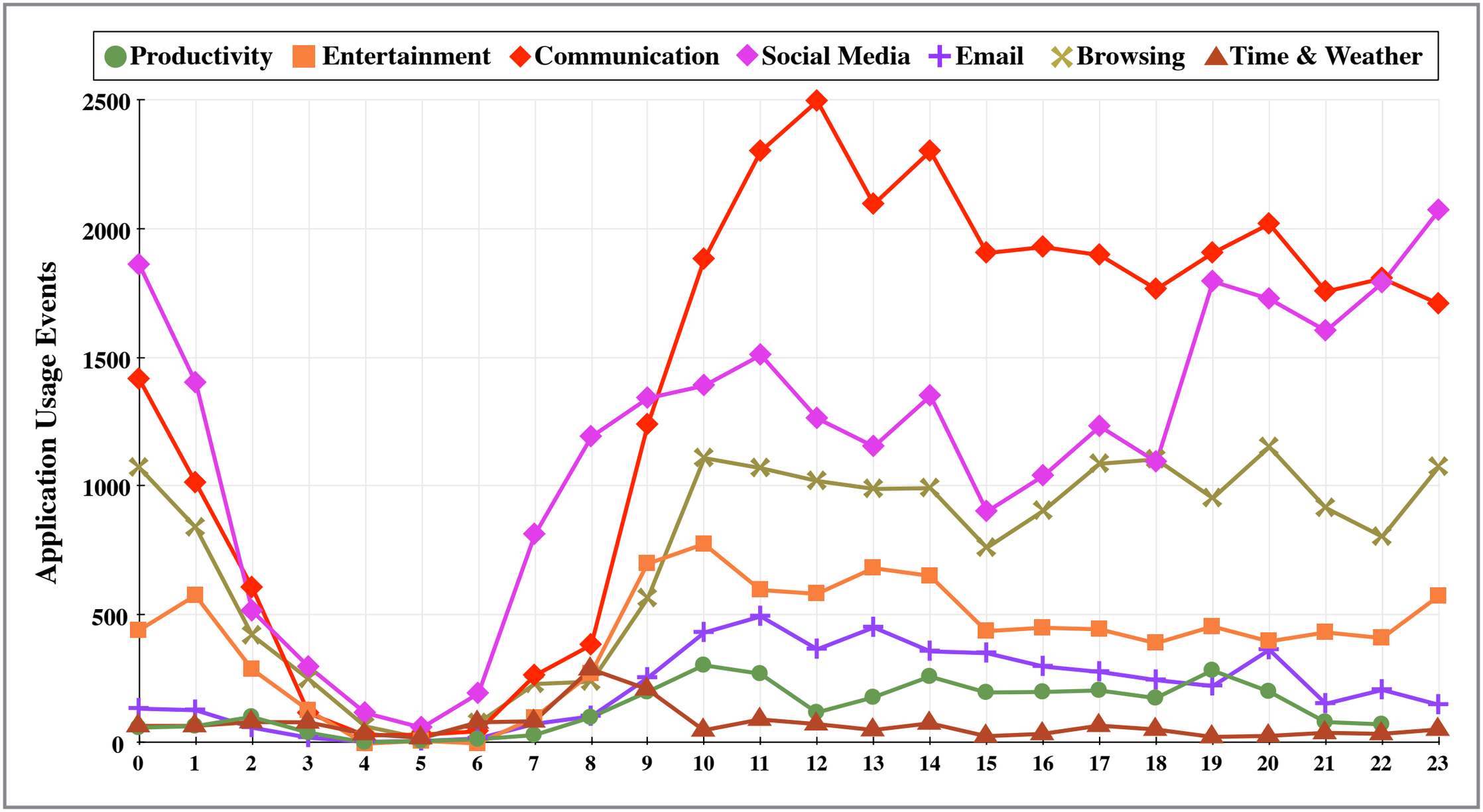
- **Daily patterns** in app use replicate prior findings
- App use also shows weekly patterns
- Different **chronotypes** have different usage patterns
- App use patterns correlate with **alertness patterns**
- App use features can distinguish periods of low vs. high alertness
- App use reflects sleep duration, interruptions, and subsequent fatigue

Findings

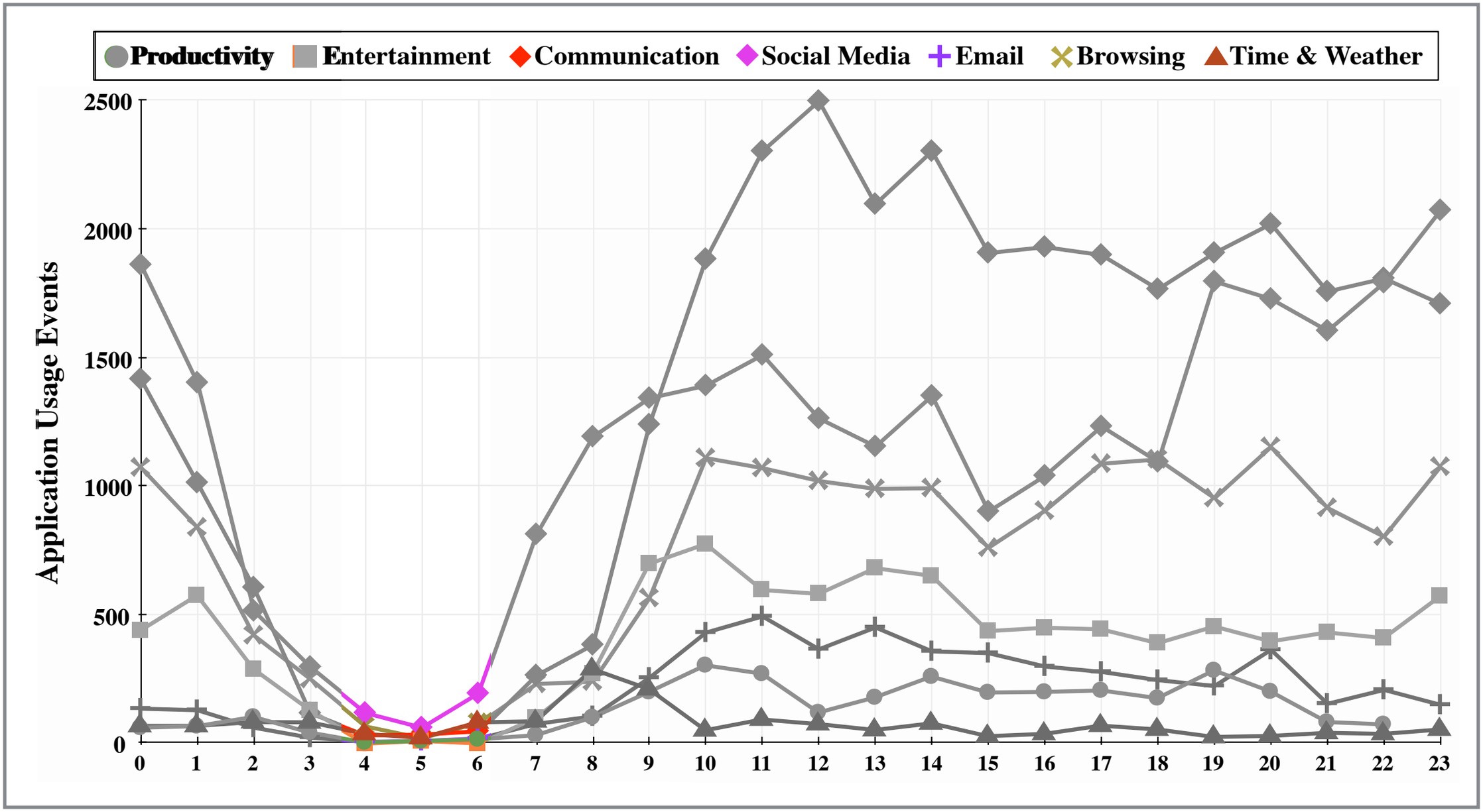
Daily patterns in app use replicate prior findings

- 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

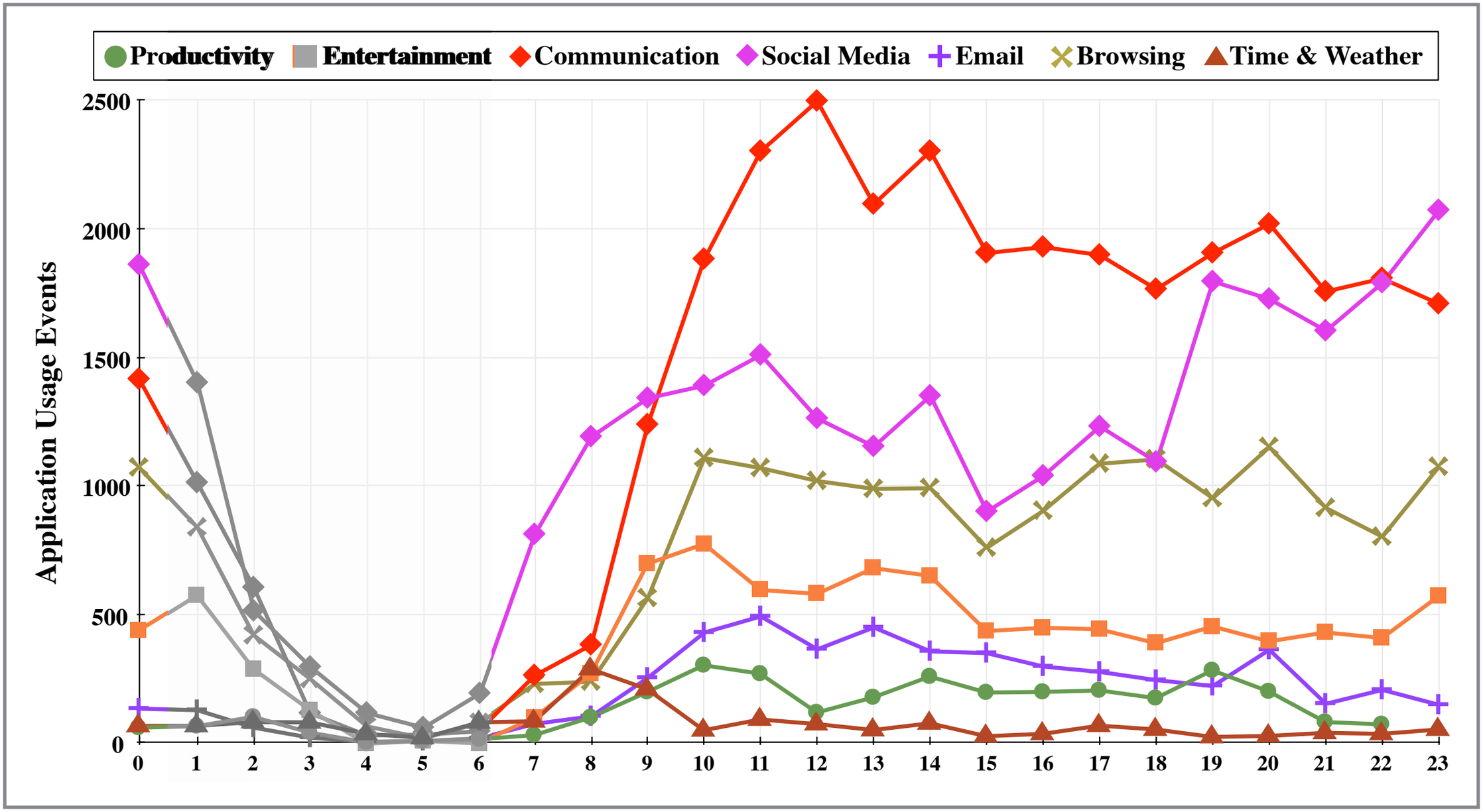
Daily Rhythms in App Use



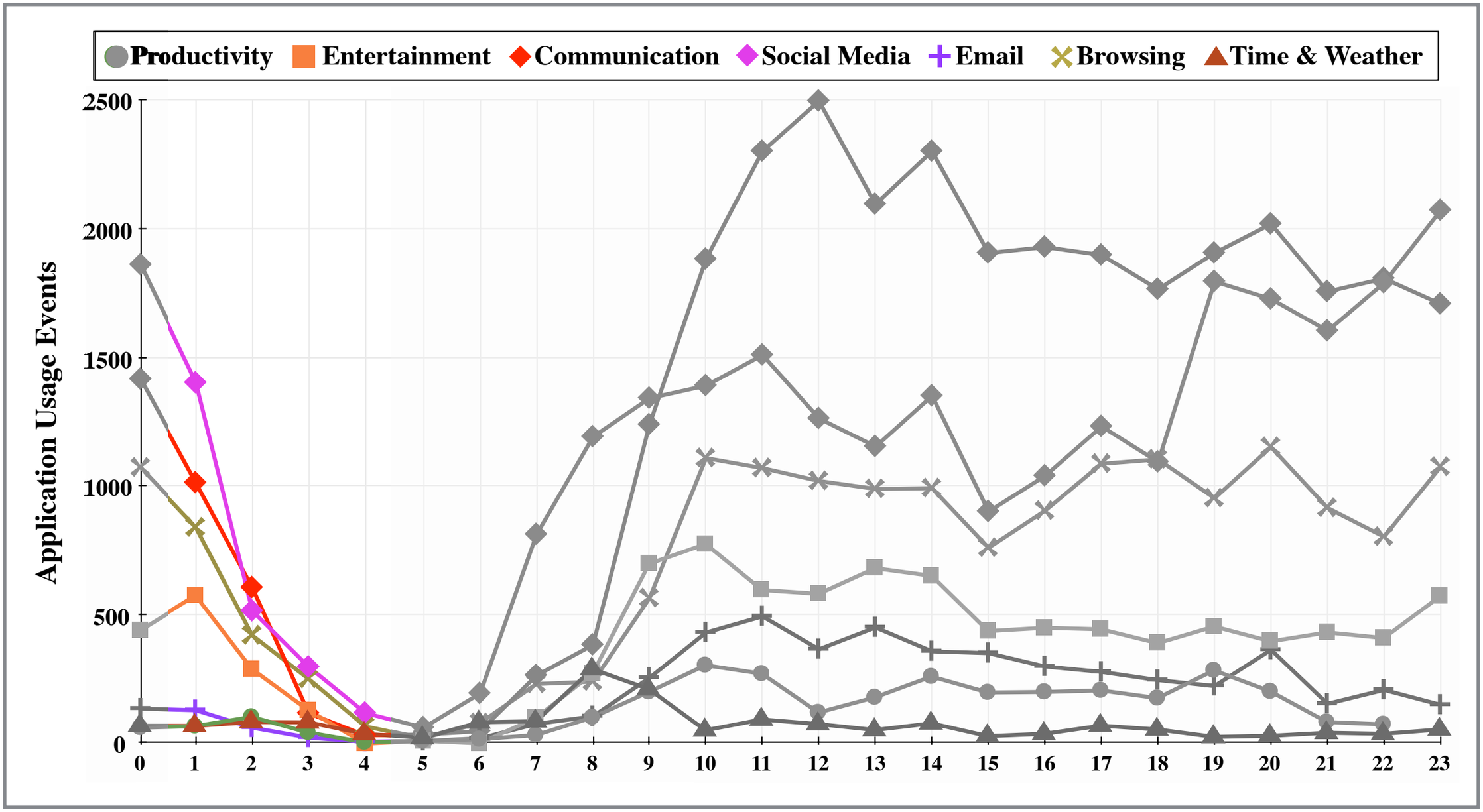
Daily Rhythms in App Use



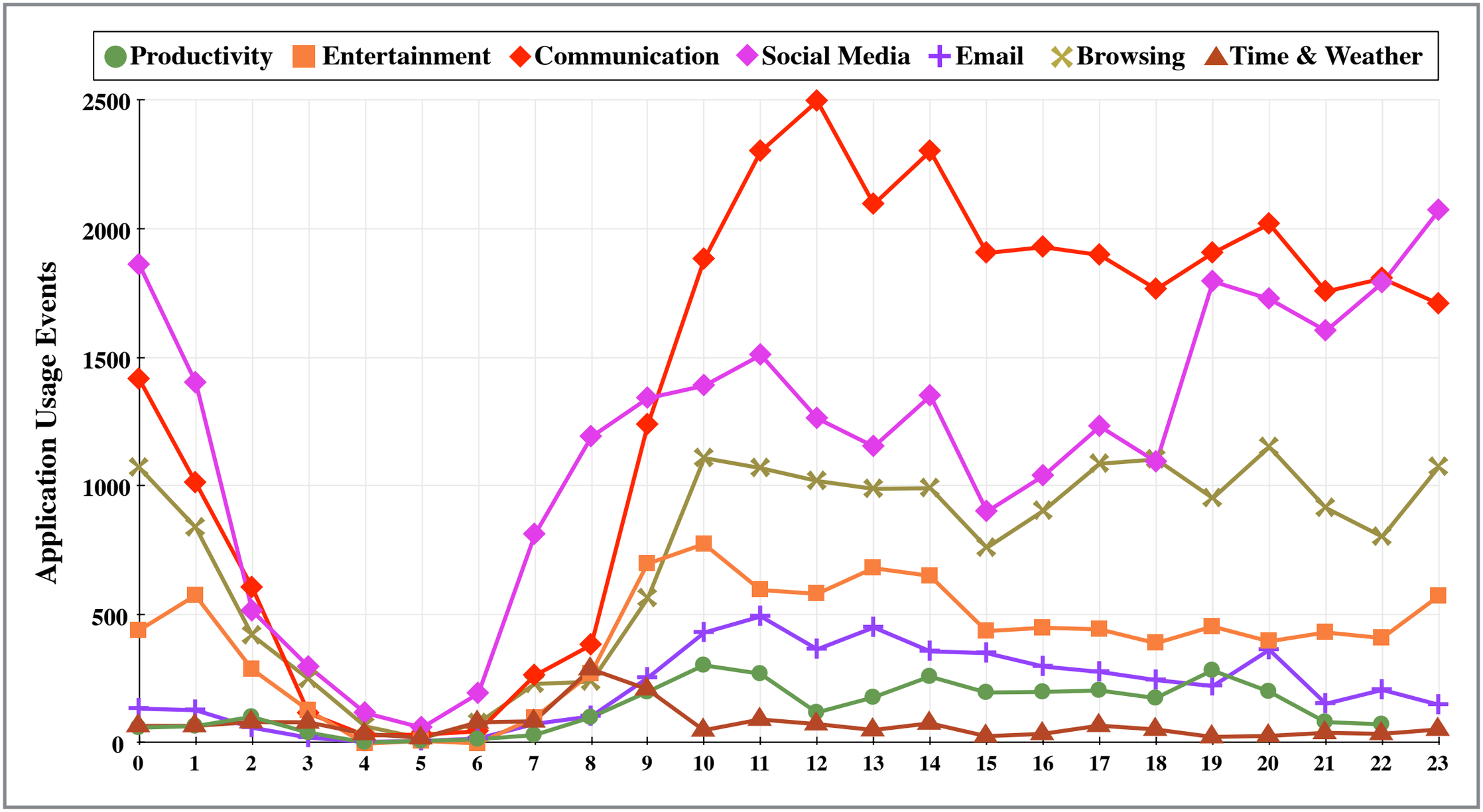
Daily Rhythms in App Use



Daily Rhythms in App Use



Daily Rhythms in App Use



Findings

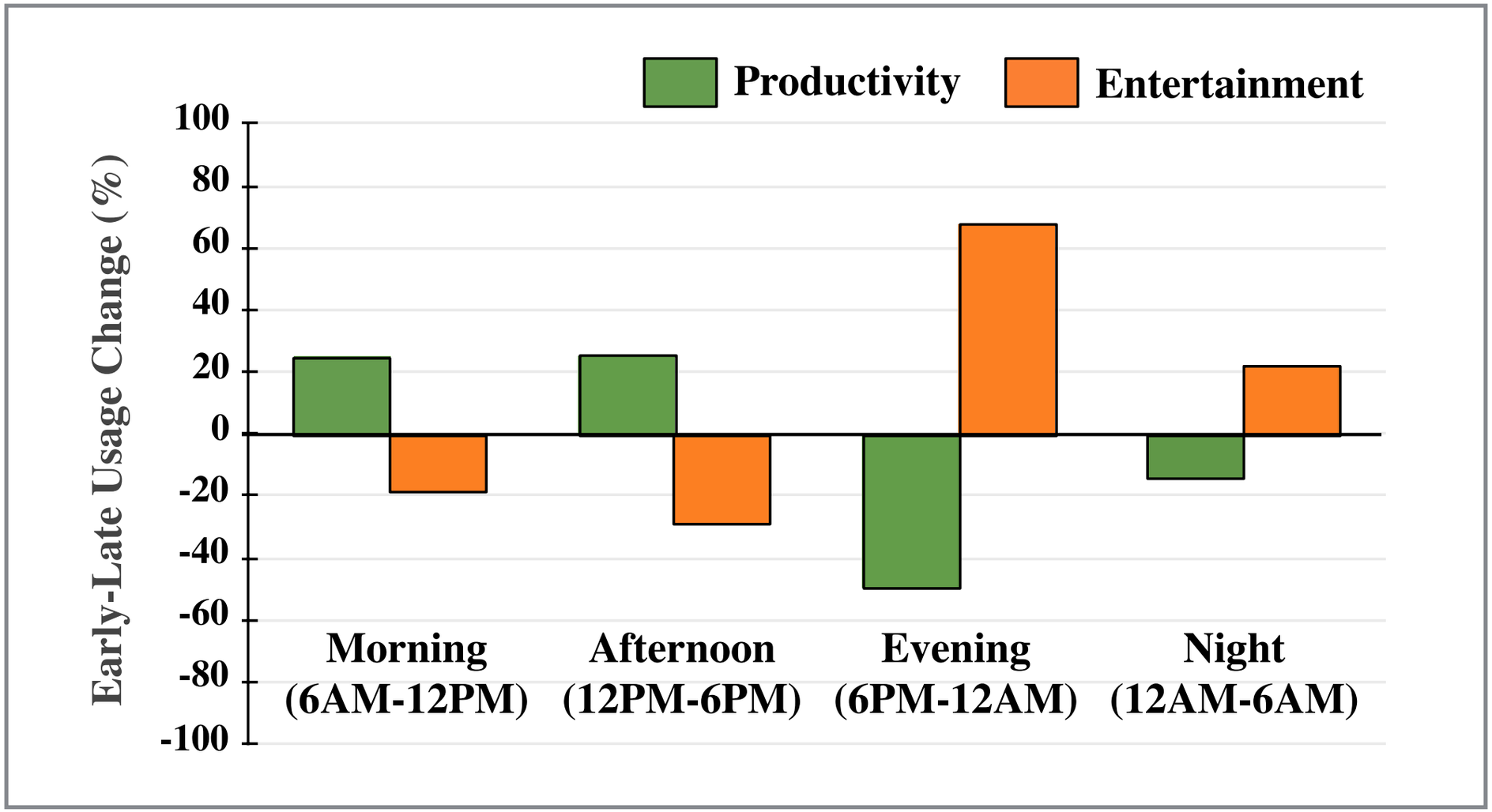
Daily patterns in app use replicate prior findings

- 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

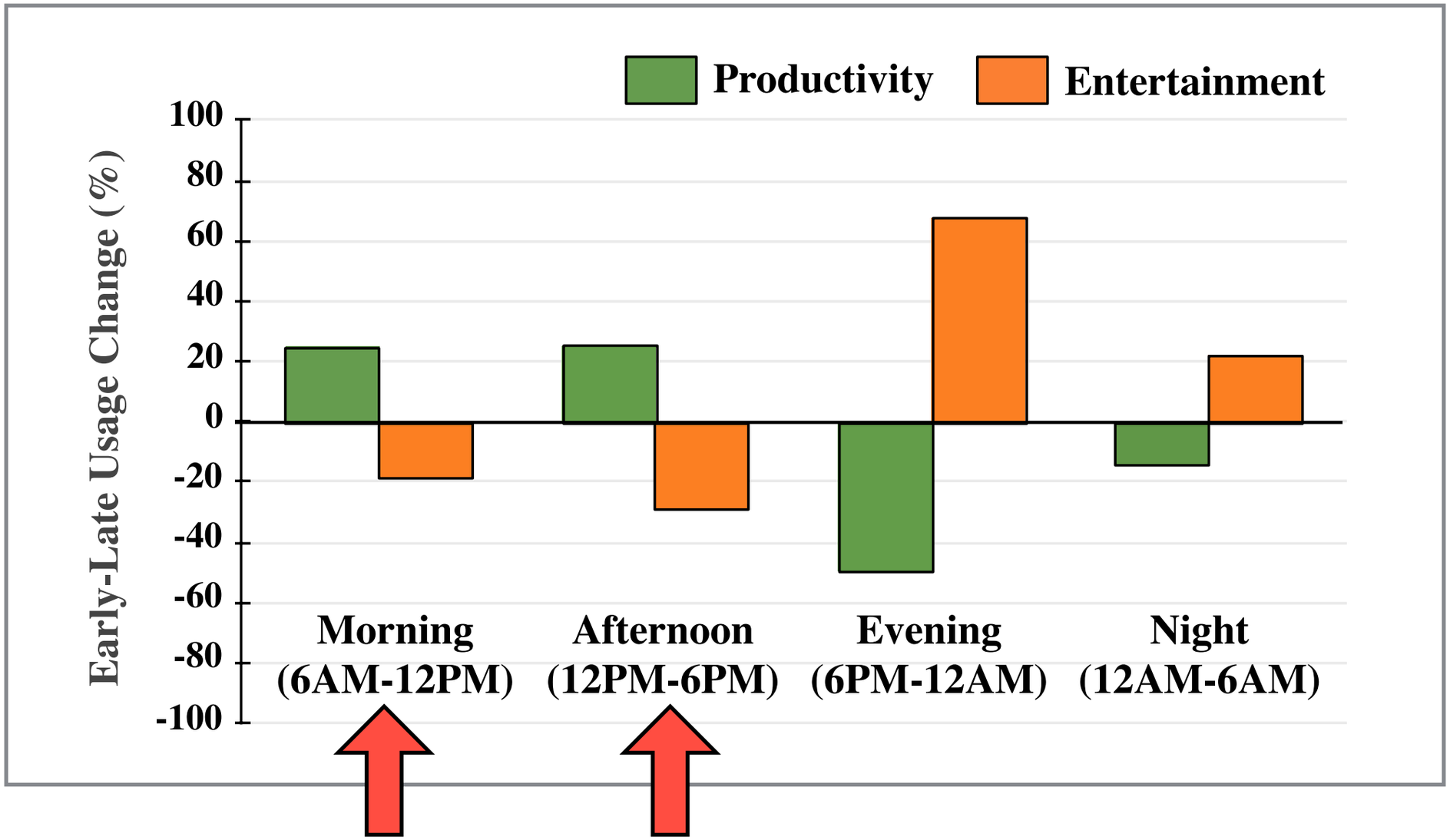
Findings

- 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

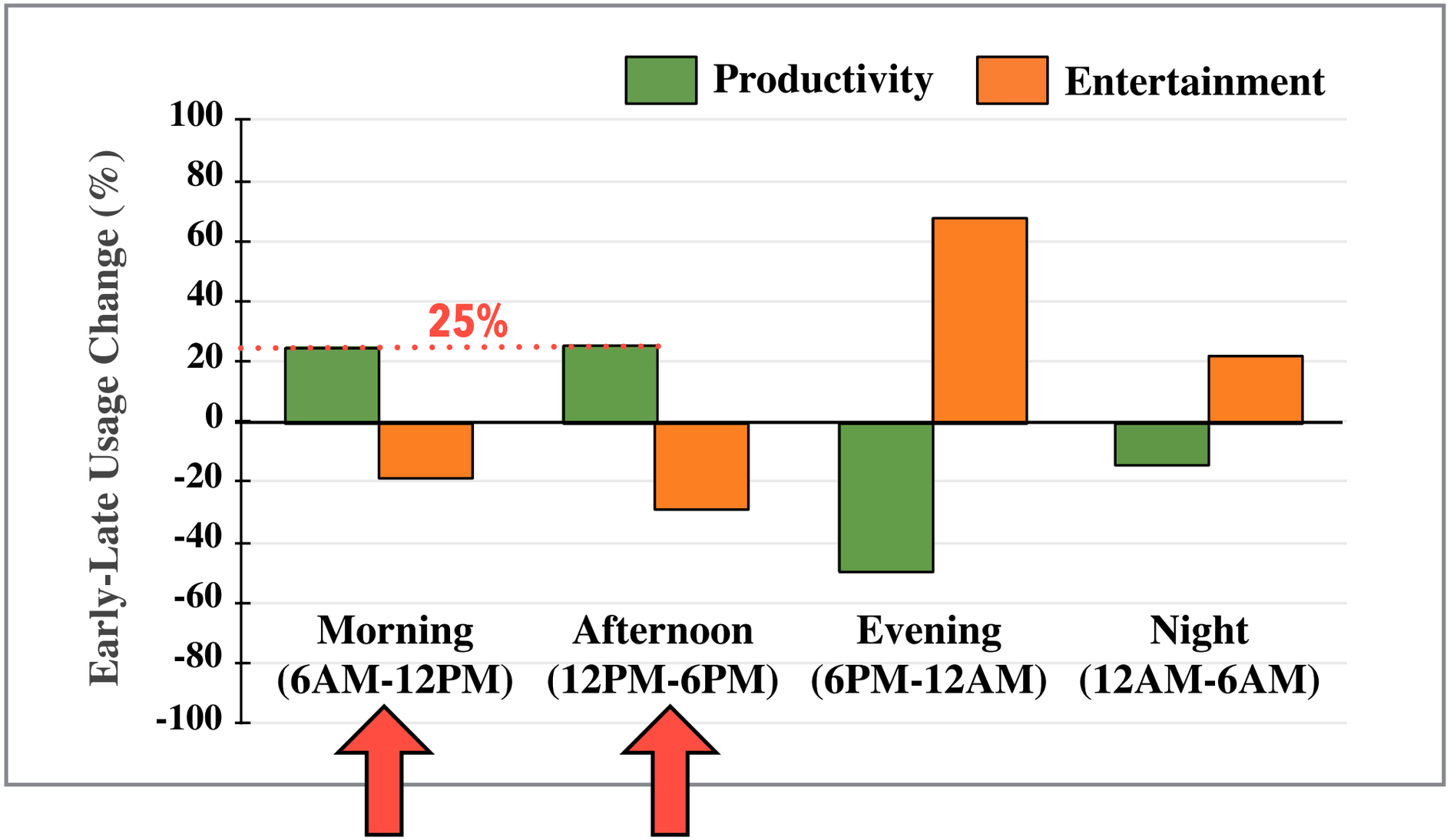
Usage Differences by Chronotype



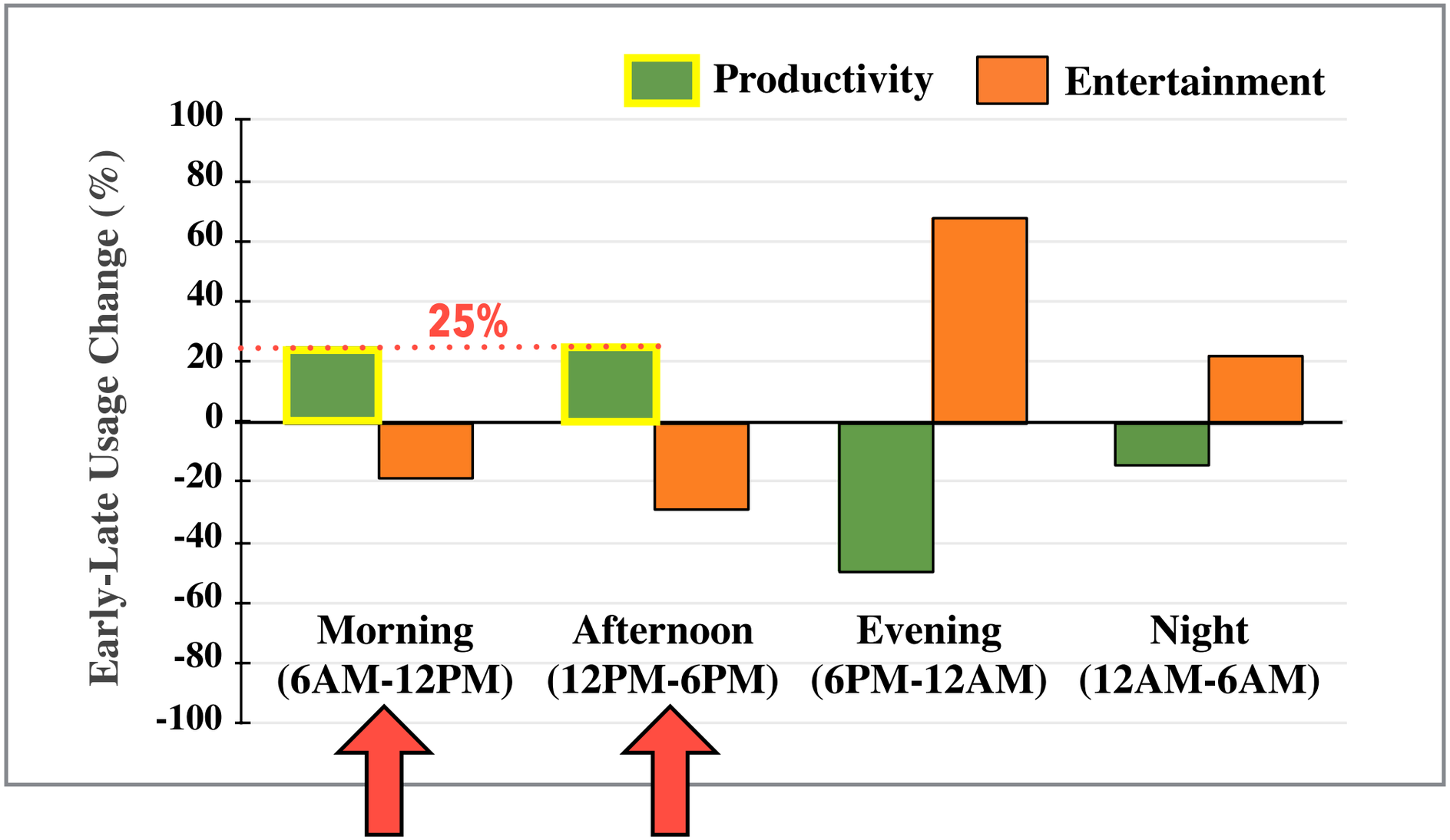
Usage Differences by Chronotype



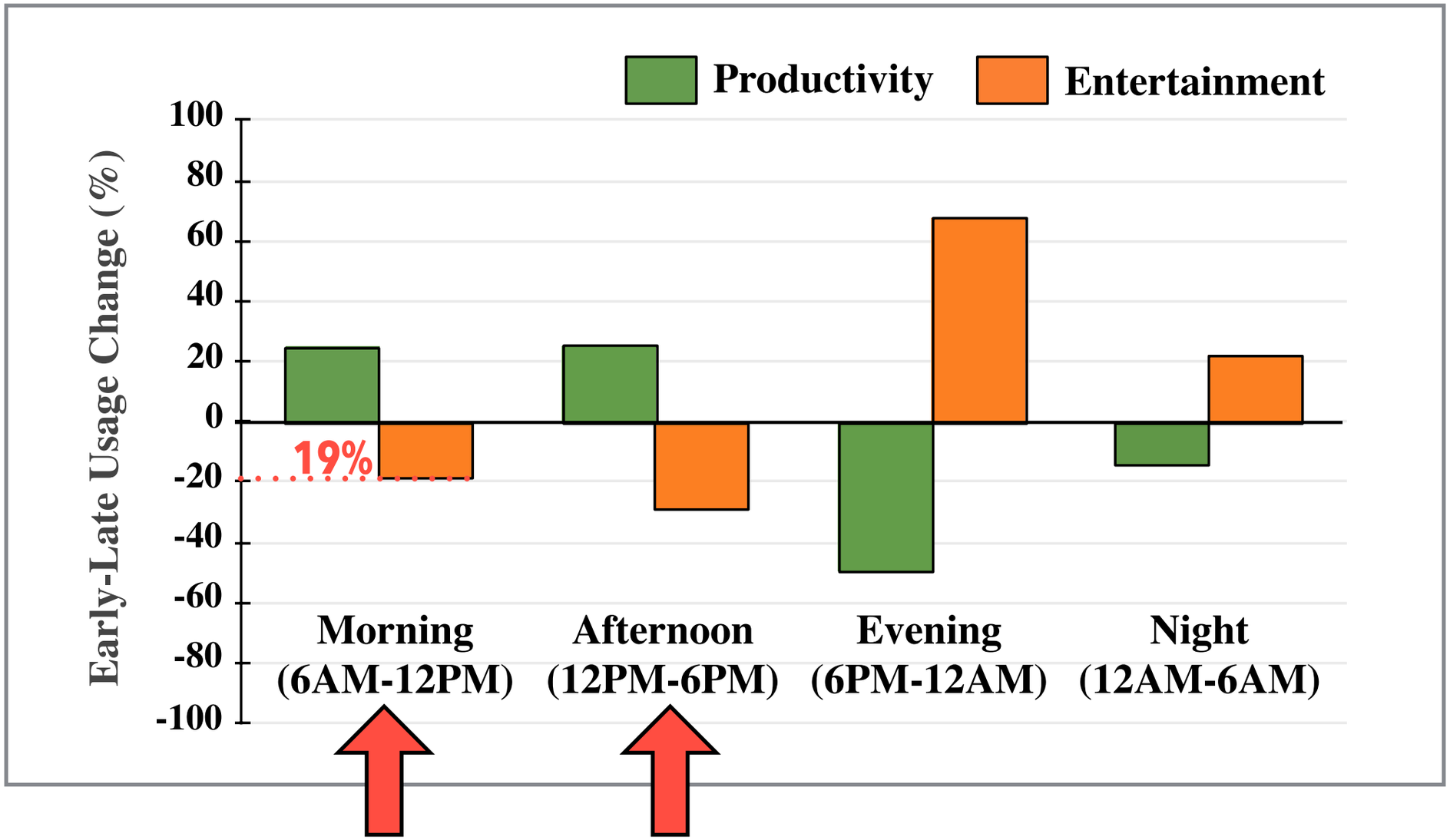
Usage Differences by Chronotype



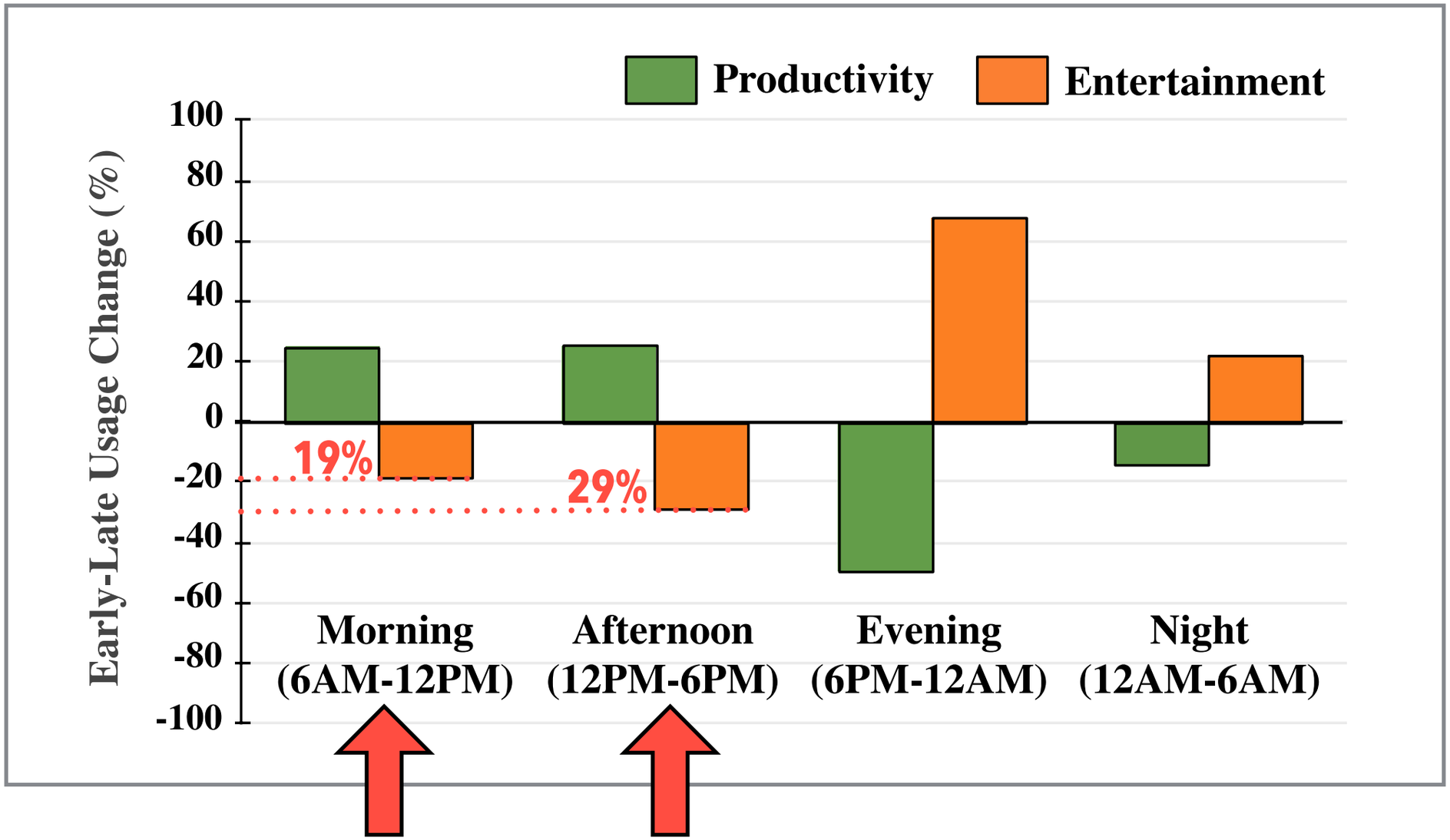
Usage Differences by Chronotype



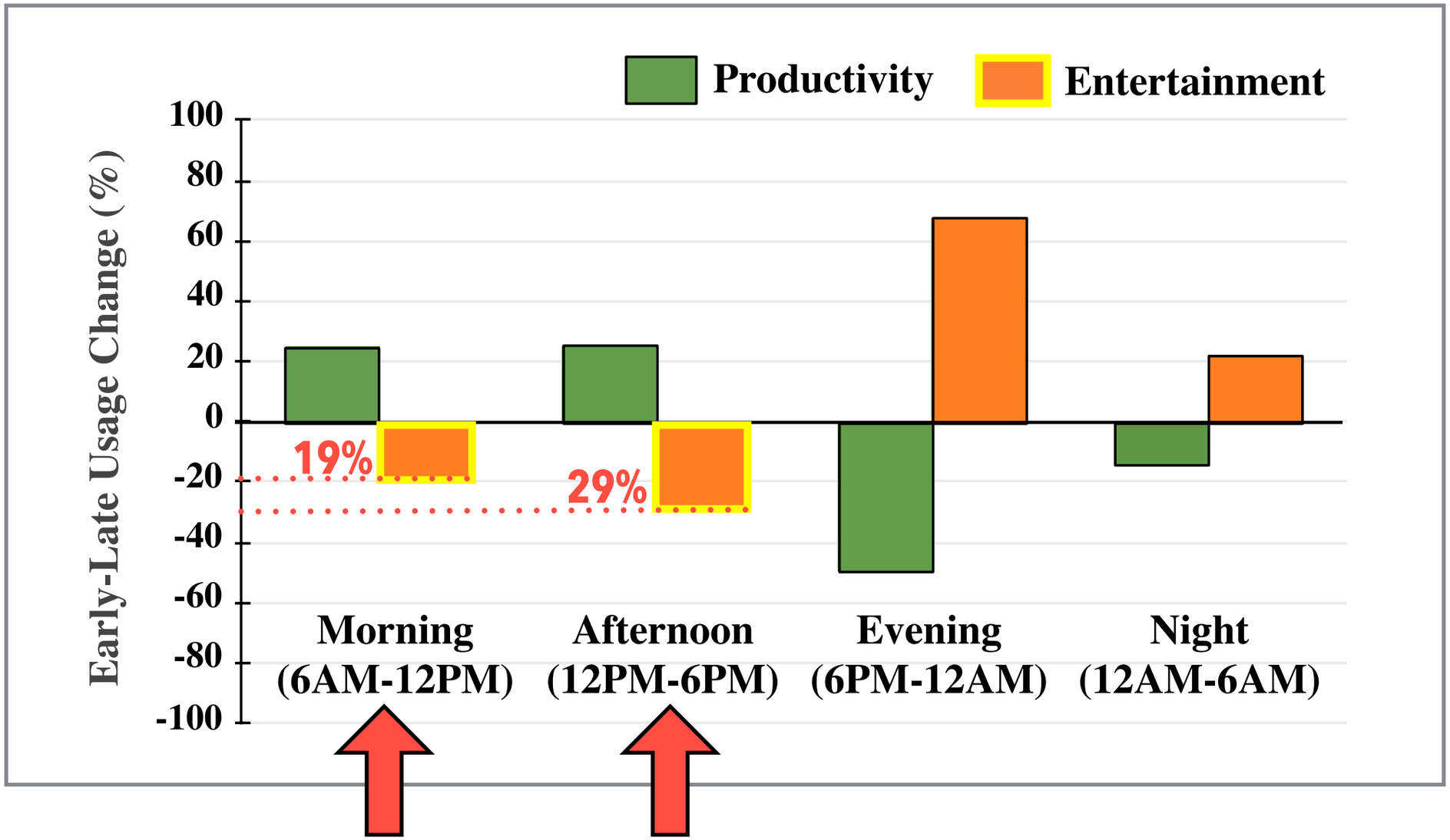
Usage Differences by Chronotype



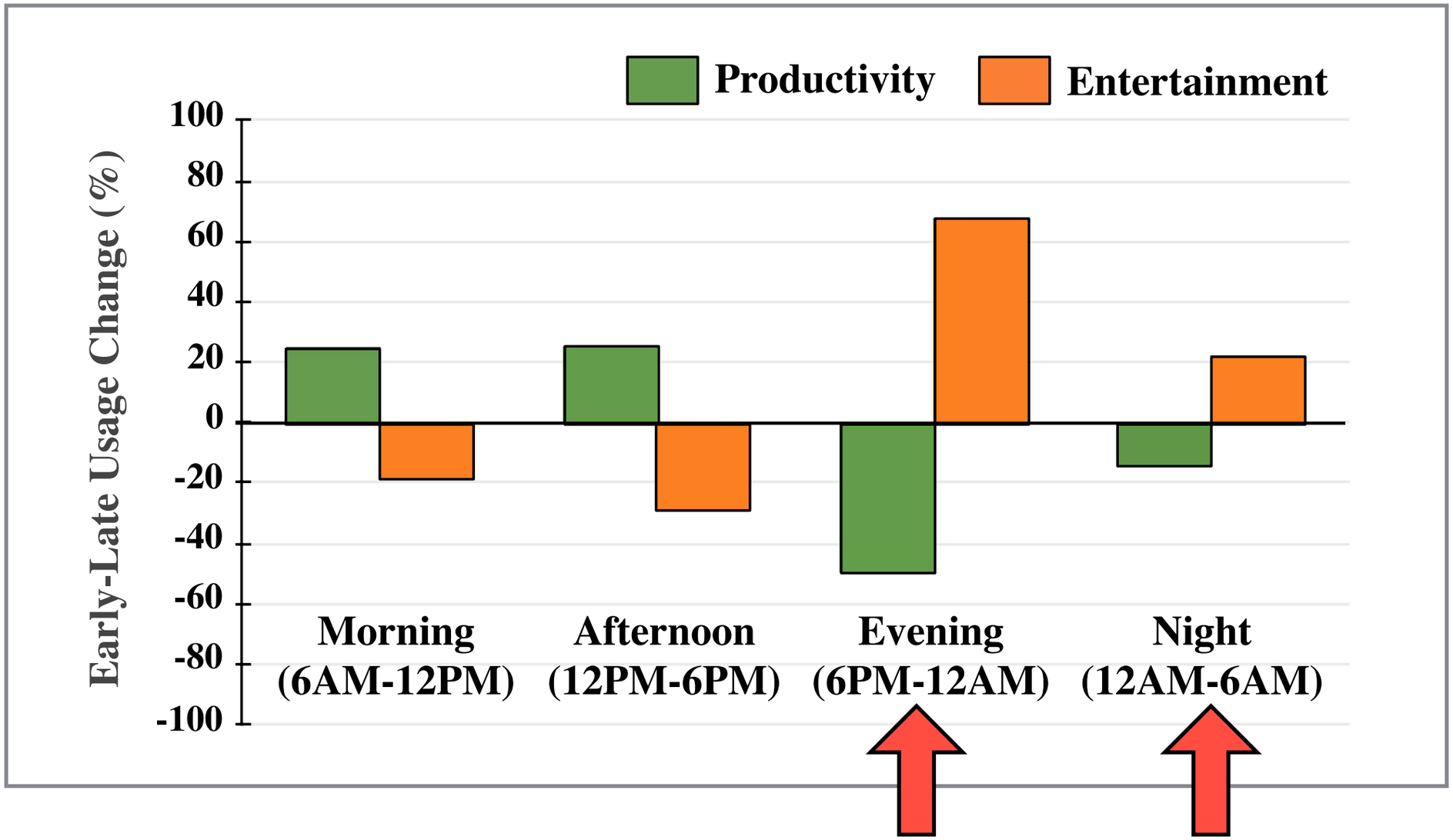
Usage Differences by Chronotype



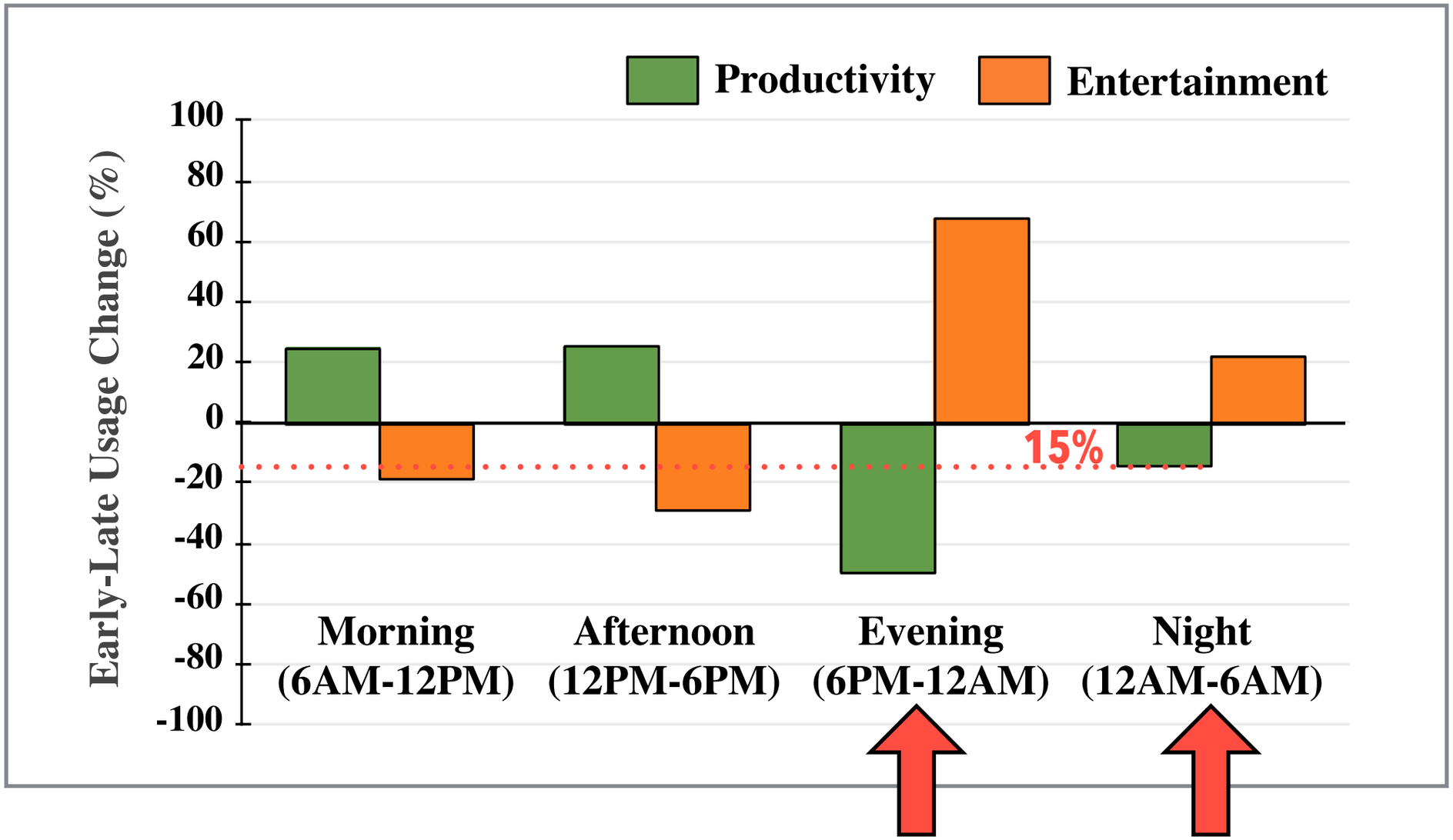
Usage Differences by Chronotype



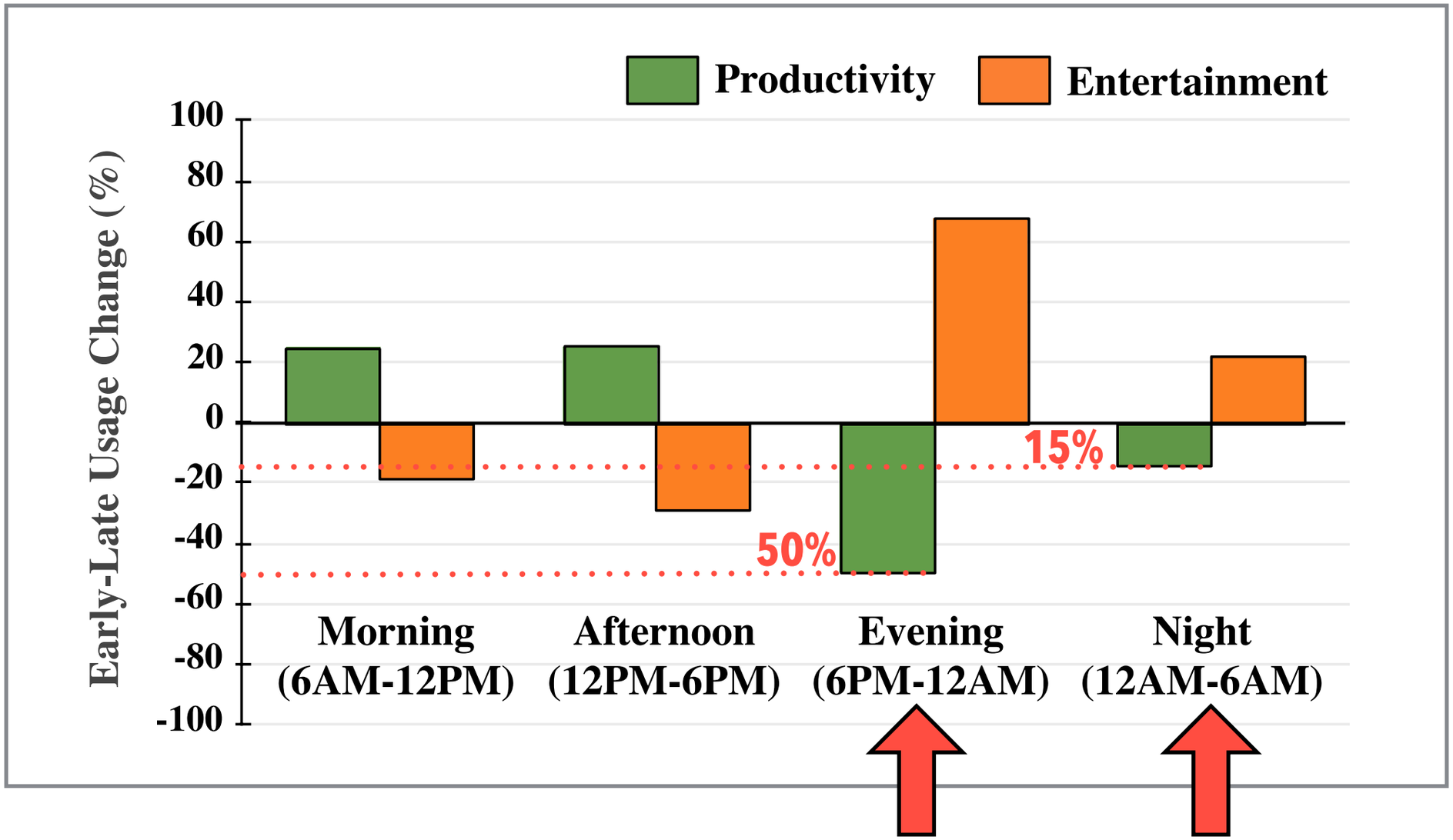
Usage Differences by Chronotype



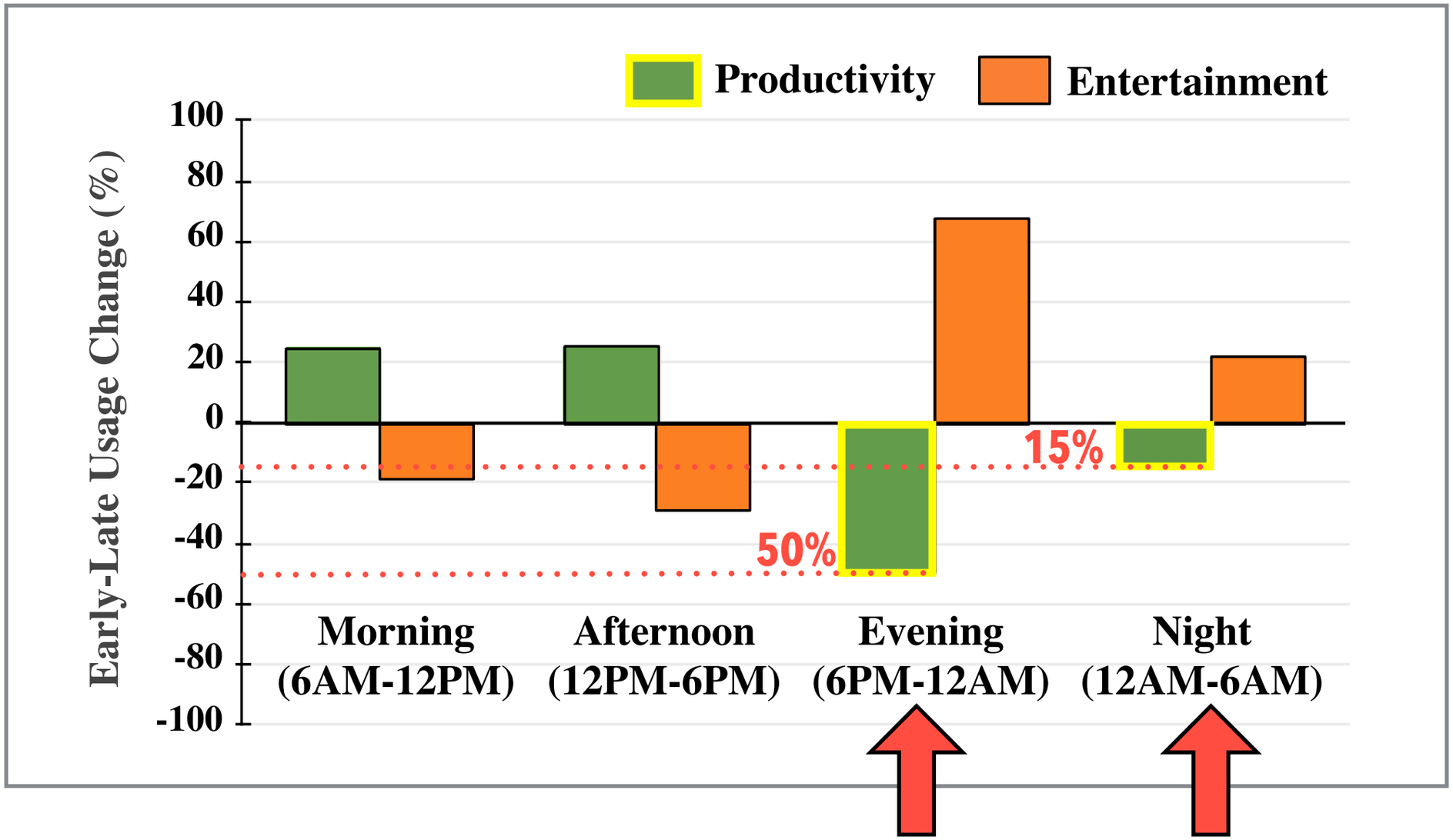
Usage Differences by Chronotype



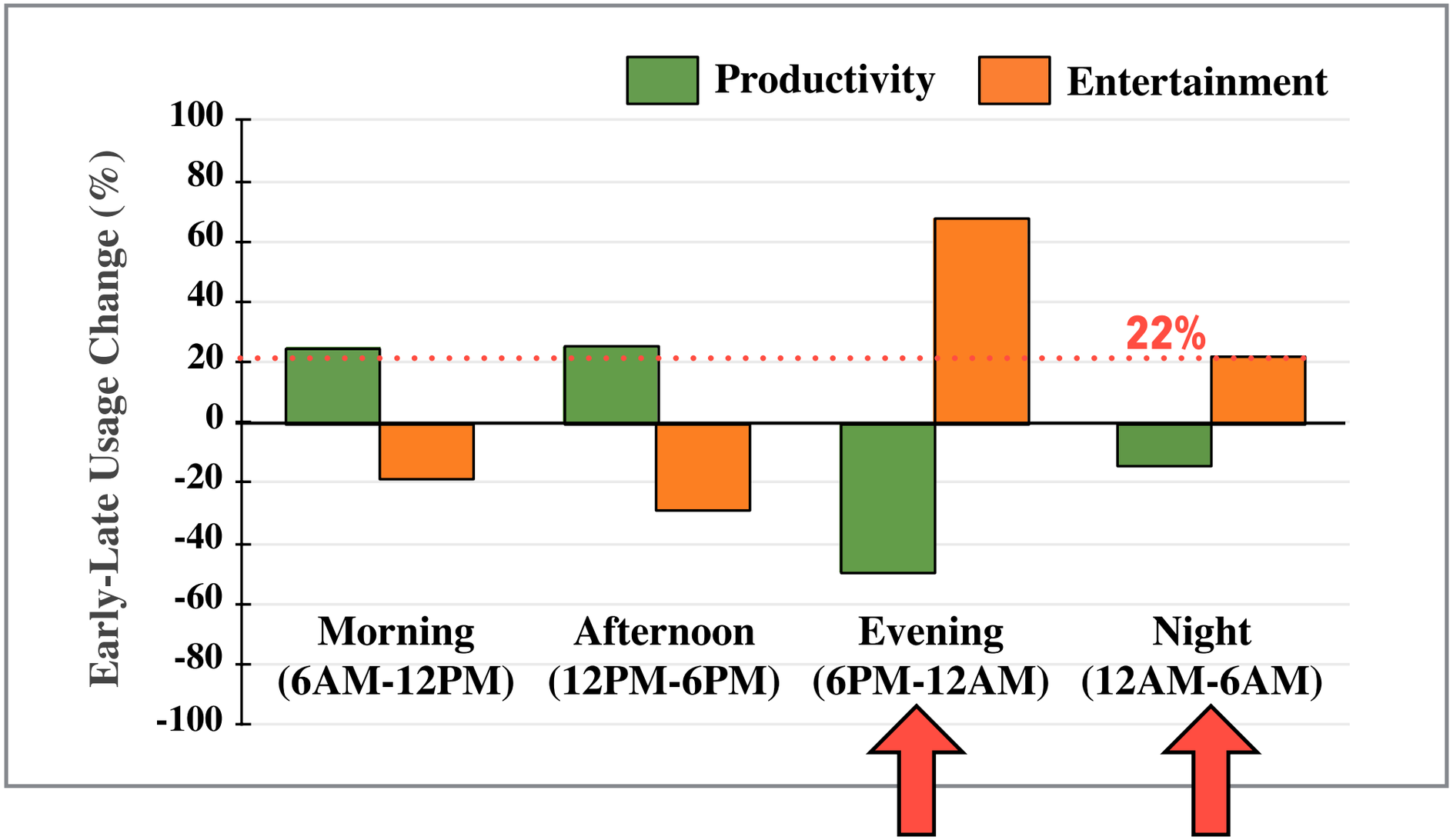
Usage Differences by Chronotype



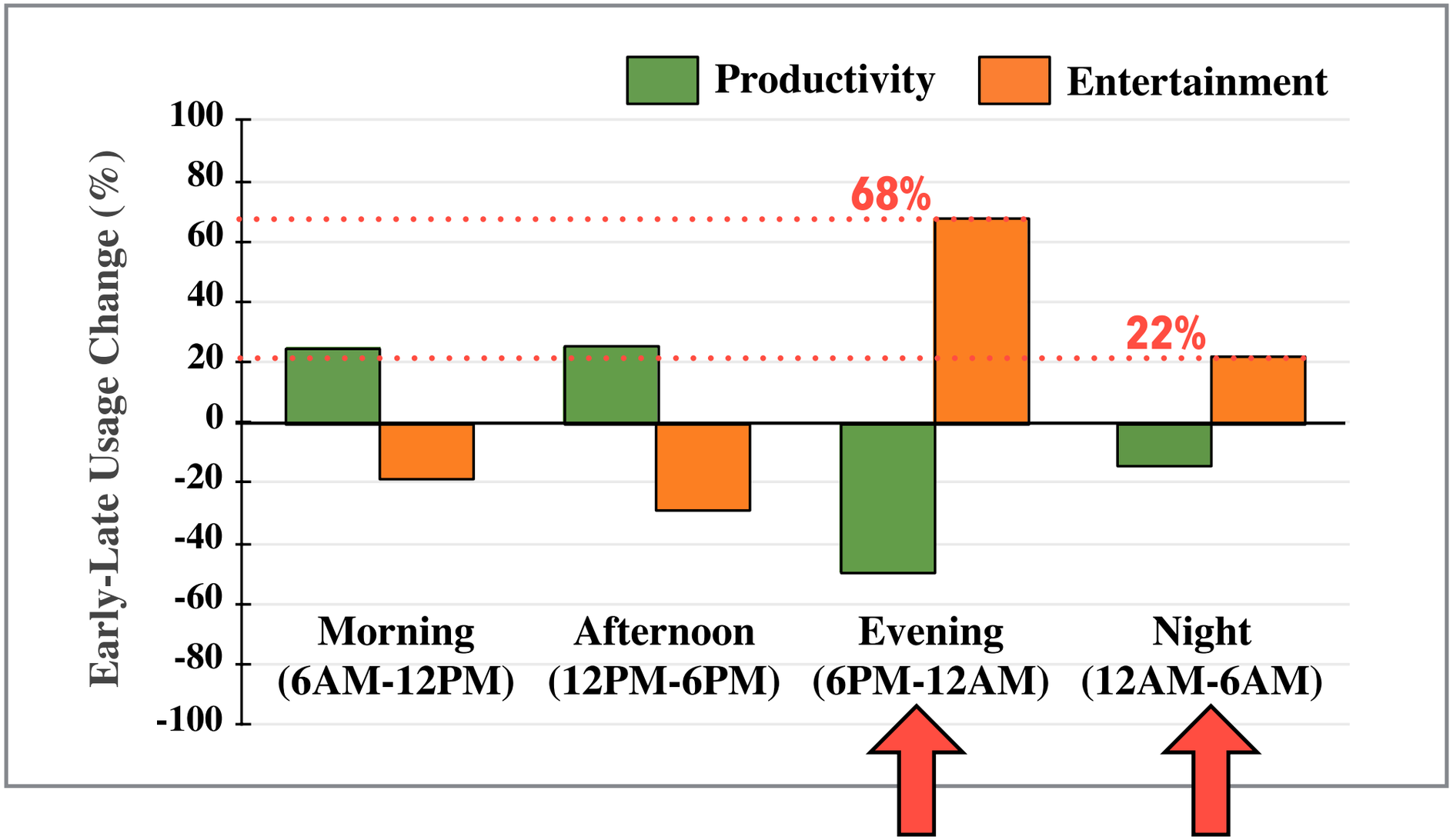
Usage Differences by Chronotype



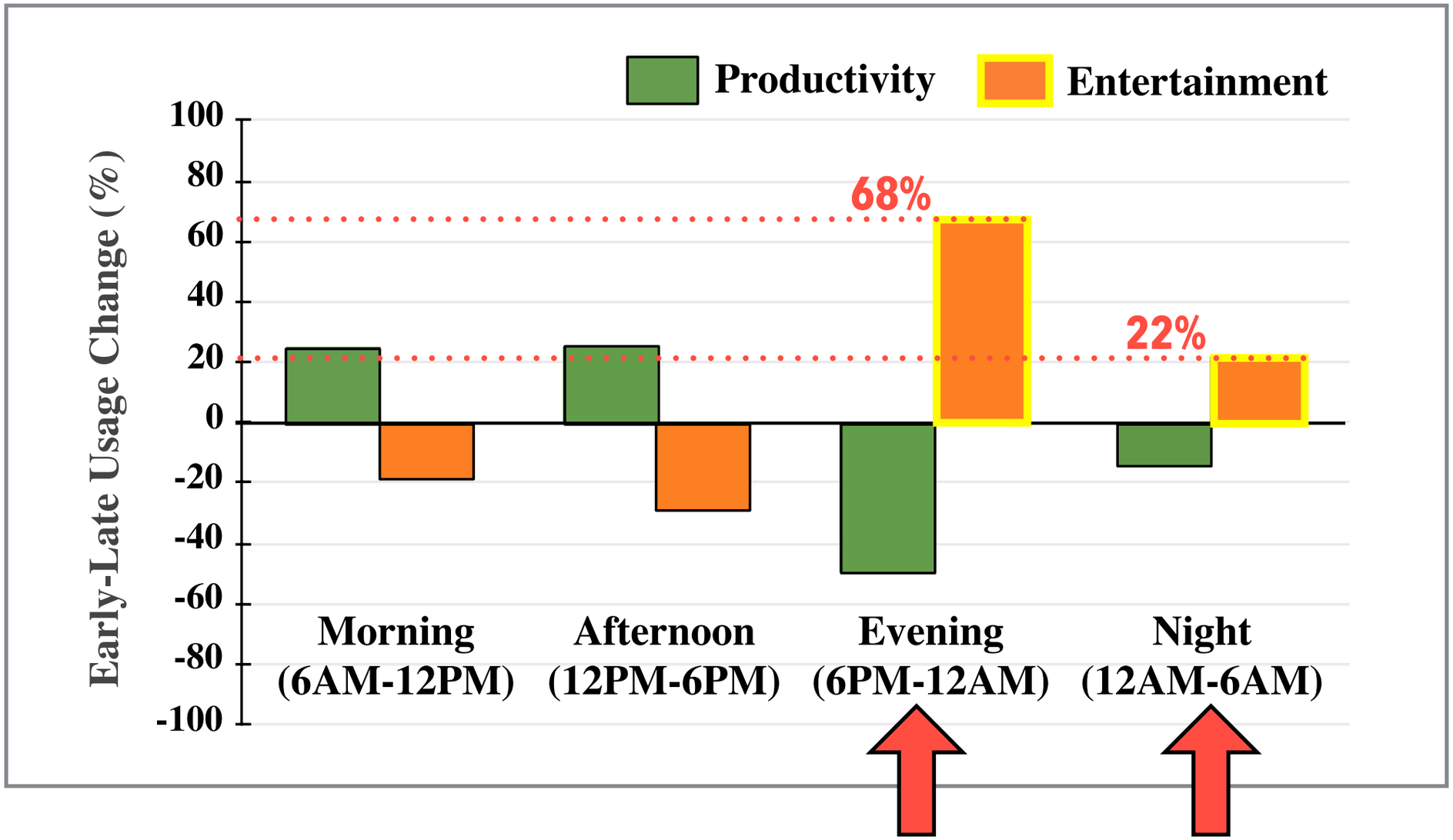
Usage Differences by Chronotype



Usage Differences by Chronotype



Usage Differences by Chronotype



Findings

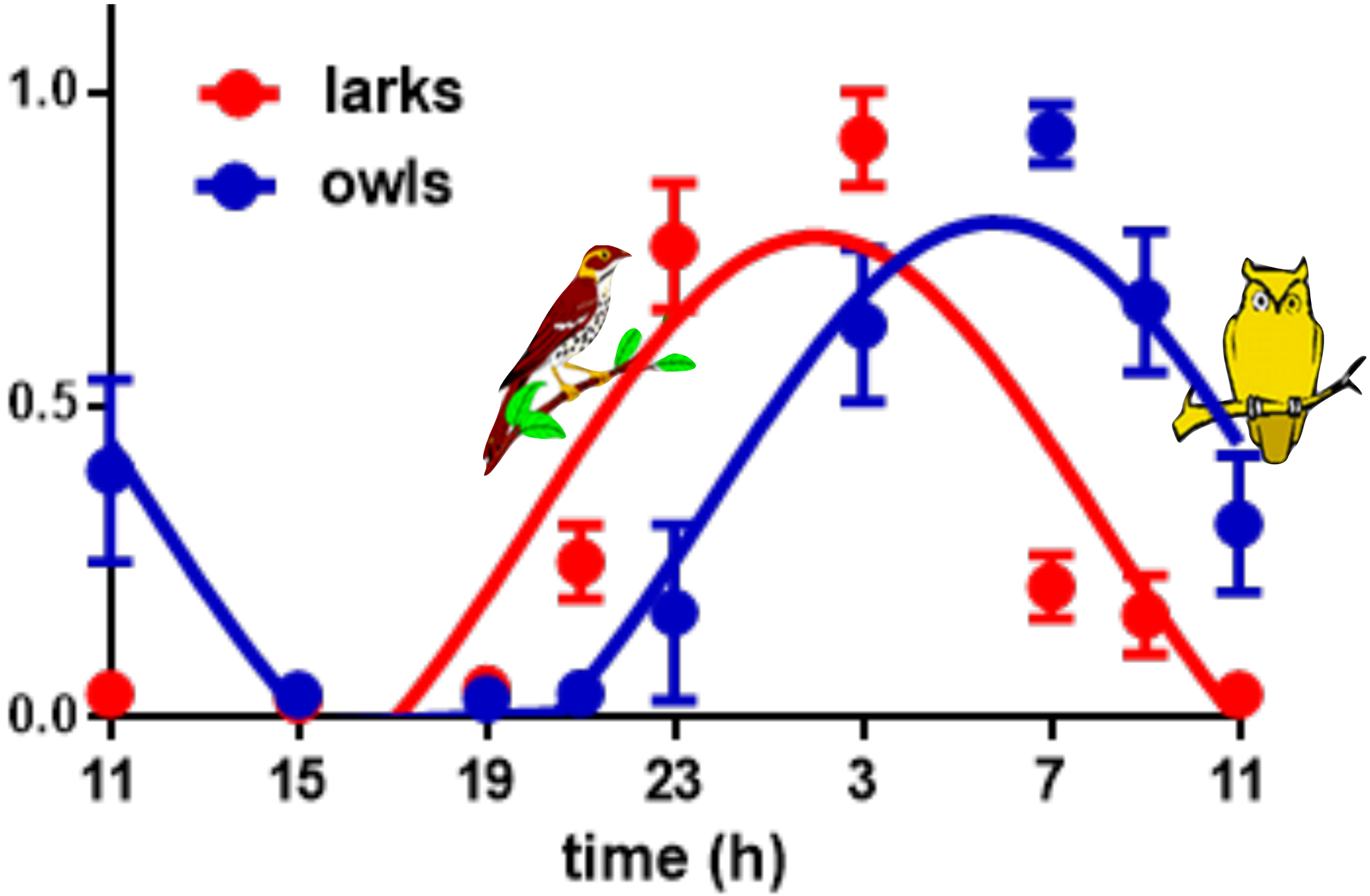
- Daily patterns in app use replicate prior findings
- App use also shows weekly patterns
- Different chronotypes have different usage patterns
- App use patterns correlate with alertness patterns
- App use features can distinguish periods of low vs. high alertness
- App use reflects sleep duration, interruptions, and subsequent fatigue

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


1.0
0.5
0.0
larks
owls
11
15
19
23
3
7
11
time (h)

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"

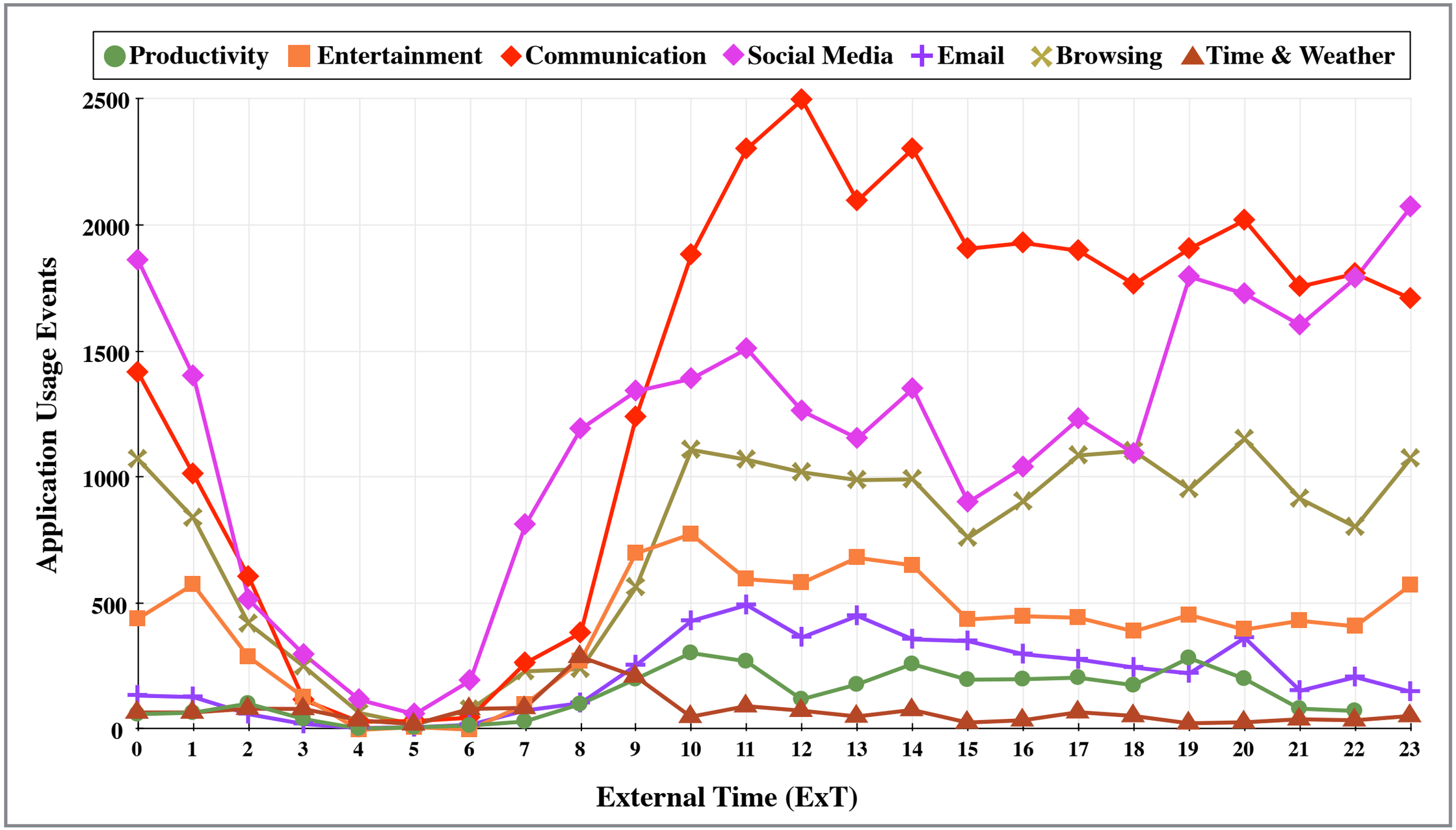
External Time

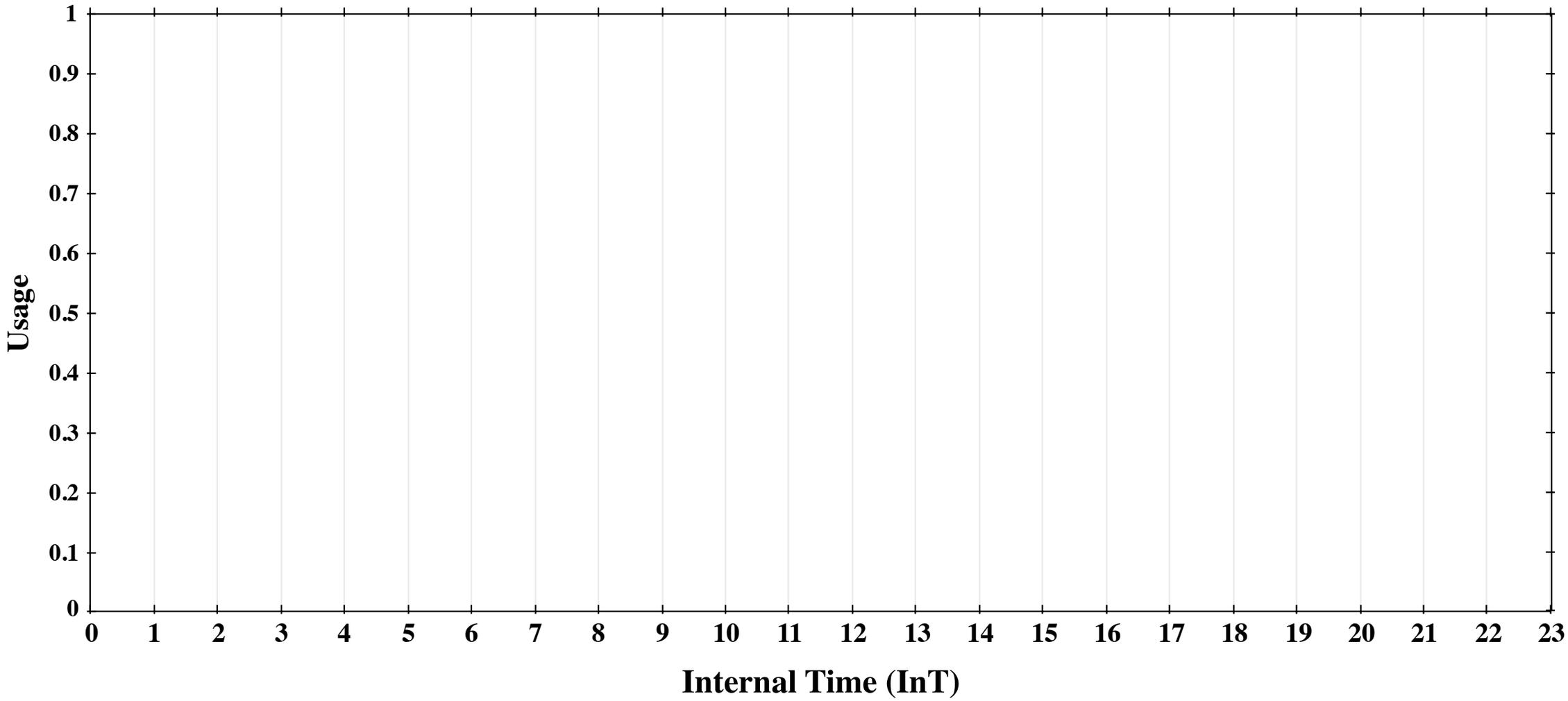
- "Local time", "clock time"
- Hours since midnight
- I.e., the midpoint of night time

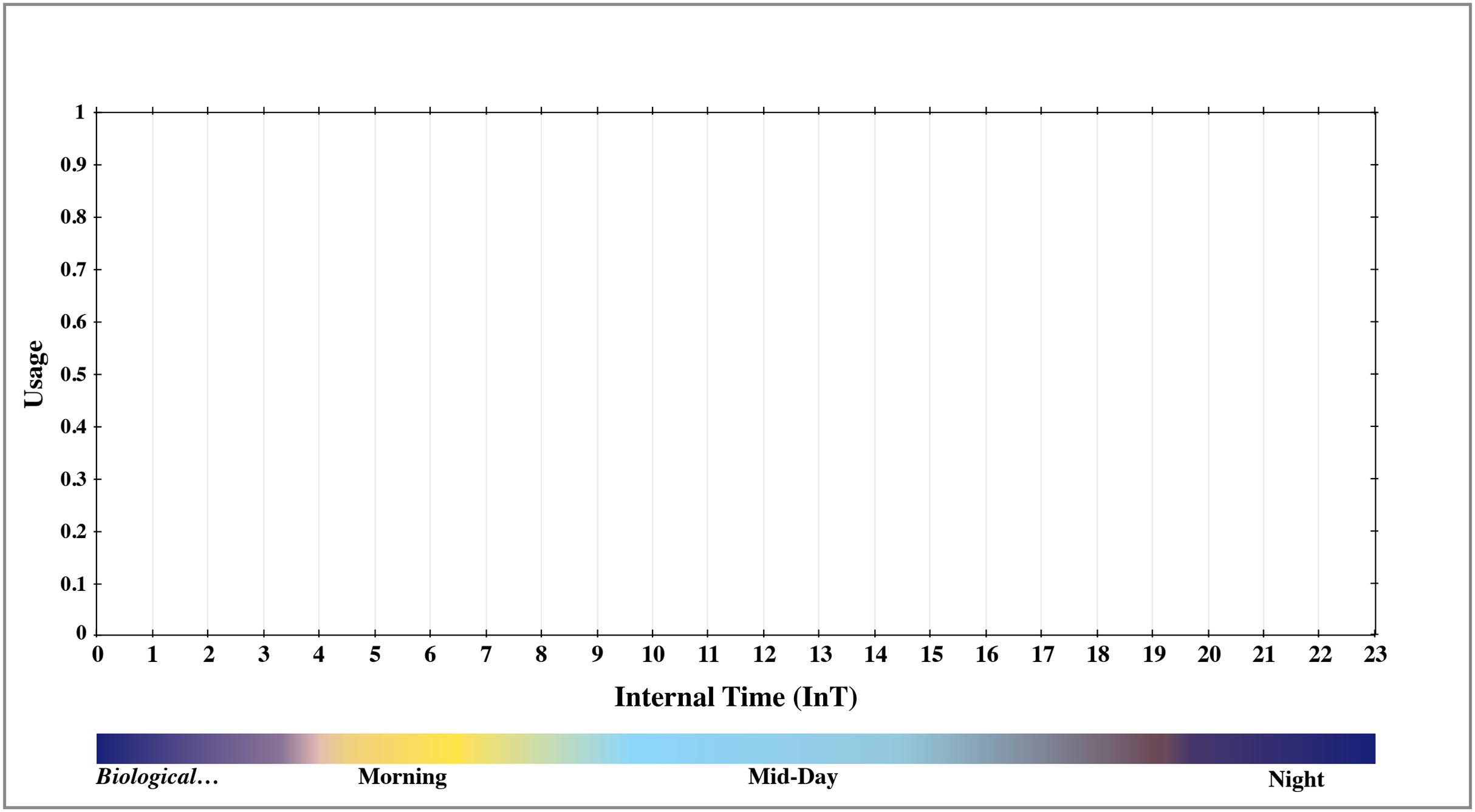
Internal Time

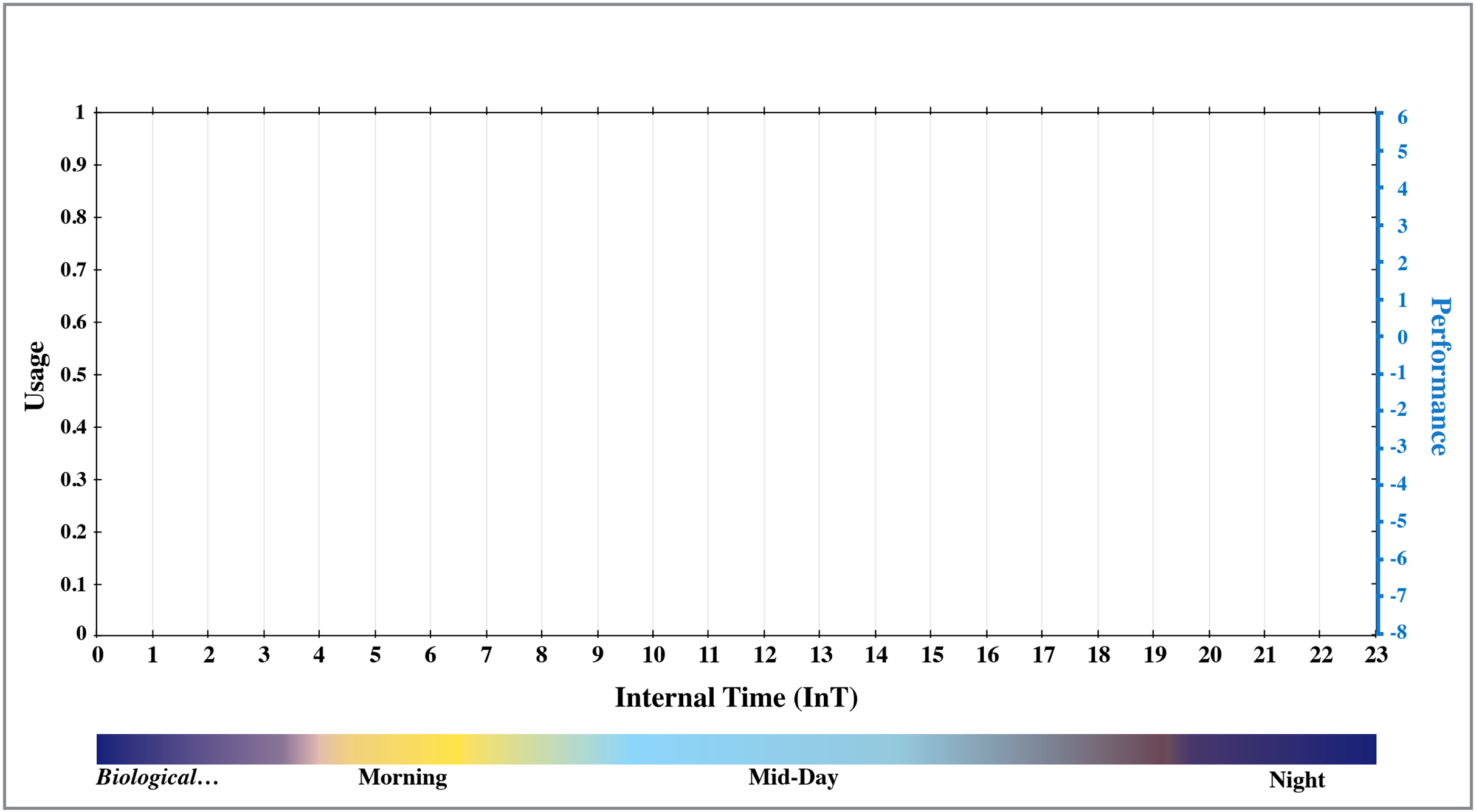
- "Biological time", "body clock time"
- Hours since sleep midpoint
- I.e., midpoint of "biological night"

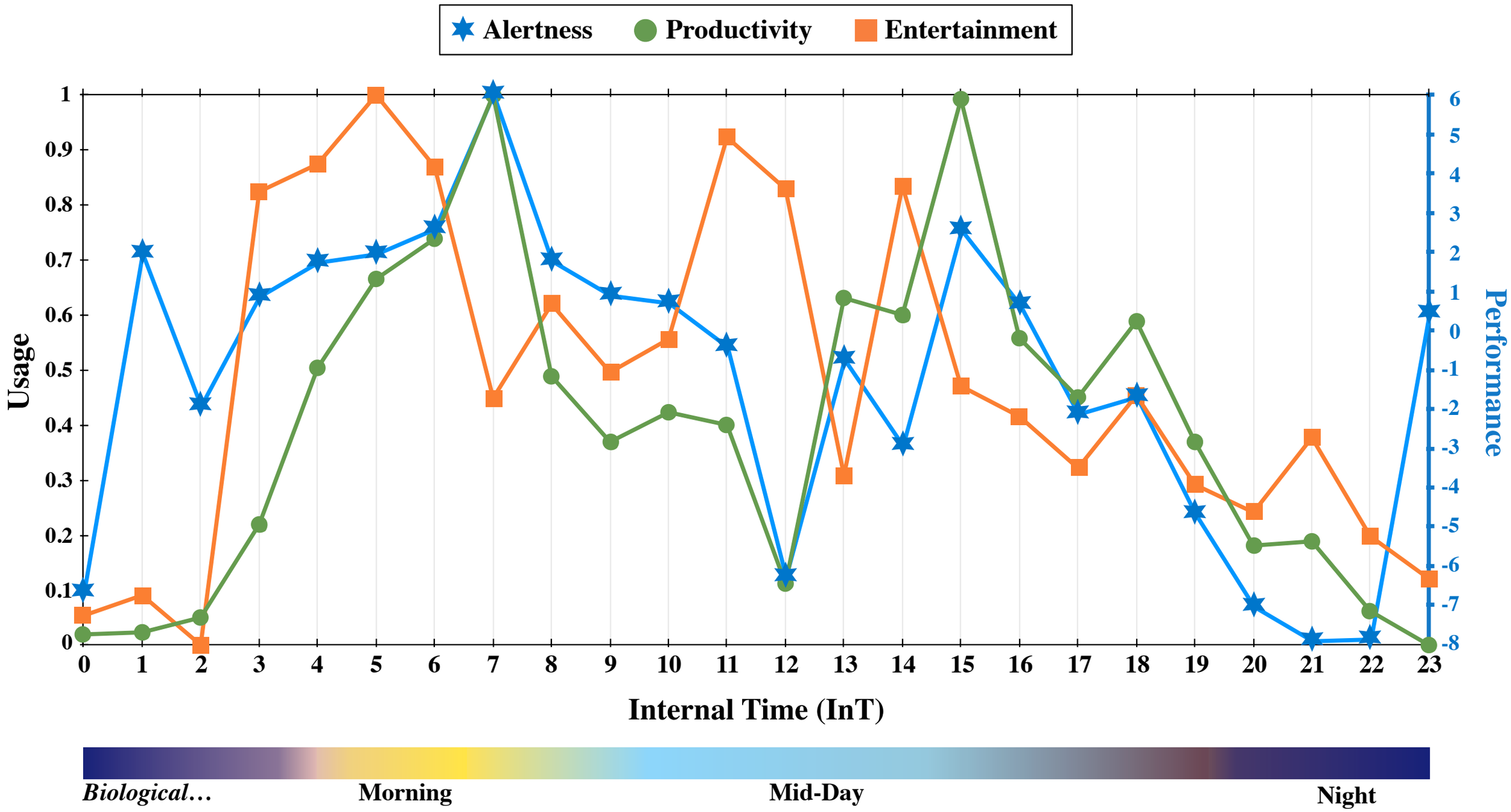
Internal Time = External Time – Chronotype


Productivity
Entertainment
Communication
Social Media
Email
Browsing
Time & Weather
Application Usage Events
2500
2000
1500
1000
500
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23
External Time (ExT)

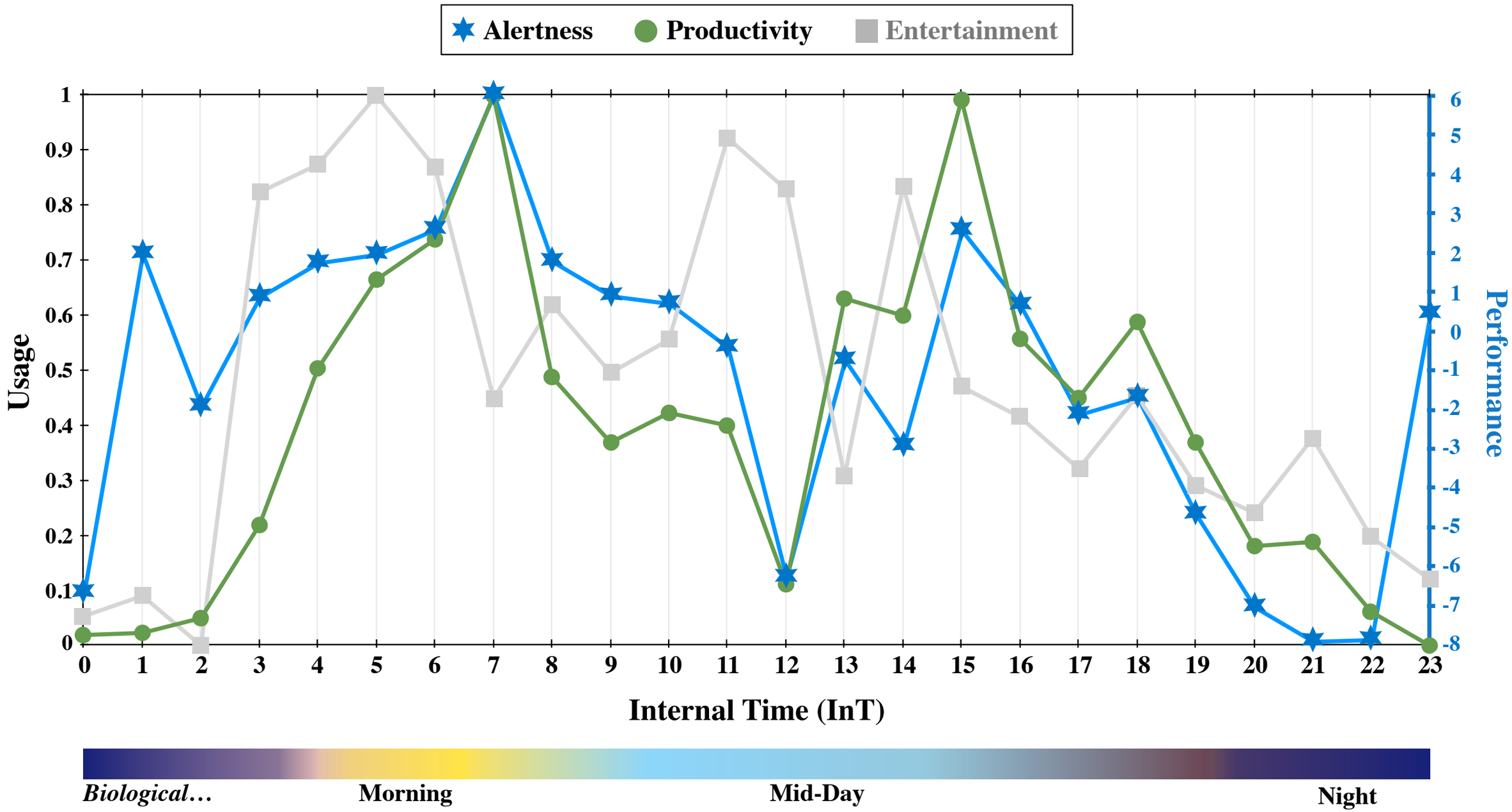

Usage
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23
Internal Time (InT)


Usage
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23
Internal Time (InT)
Biological…
Morning
Mid-Day
Night


Usage
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Performance
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
-6
-7
-8
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23
Internal Time (InT)
Biological…
Morning
Mid-Day
Night

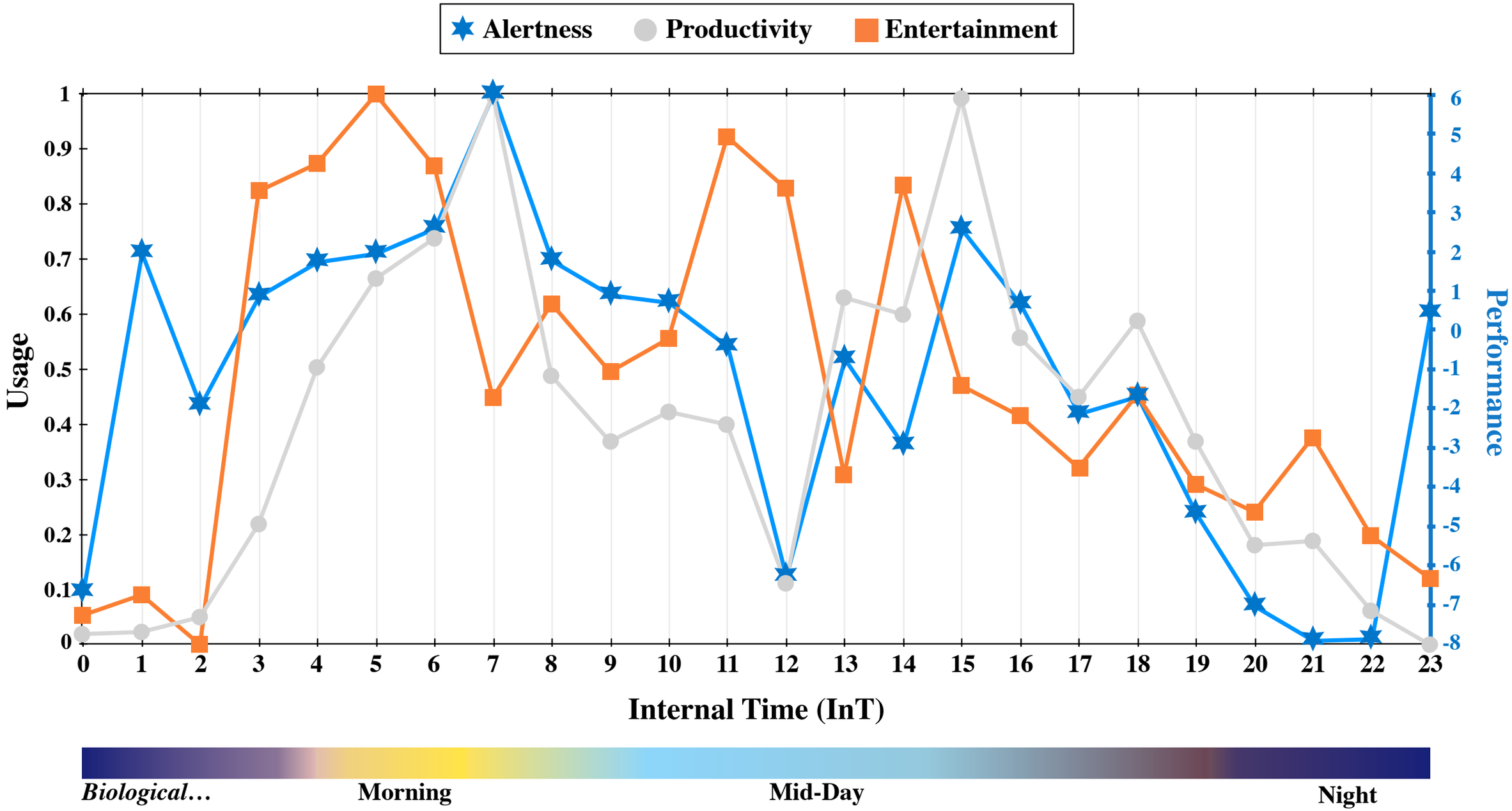

Alertness
Productivity
Entertainment
Usage
Performance
Internal Time (InT)
Biological…
Morning
Mid-Day
Night

Productivity Apps ~ Higher Alertness



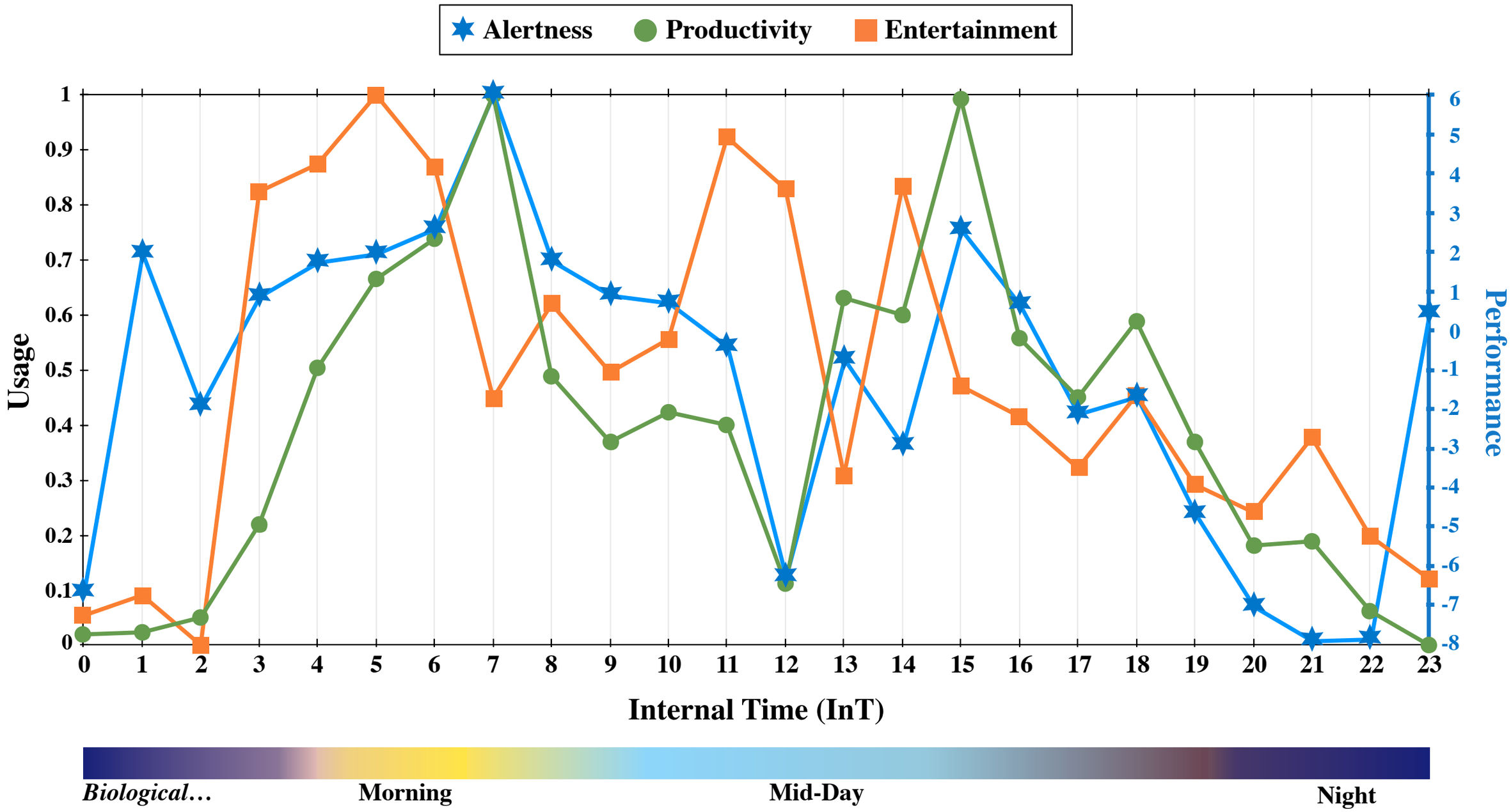
$r = 0.52$, $p < .001$

Entertainment Apps ~ Lower Alertness

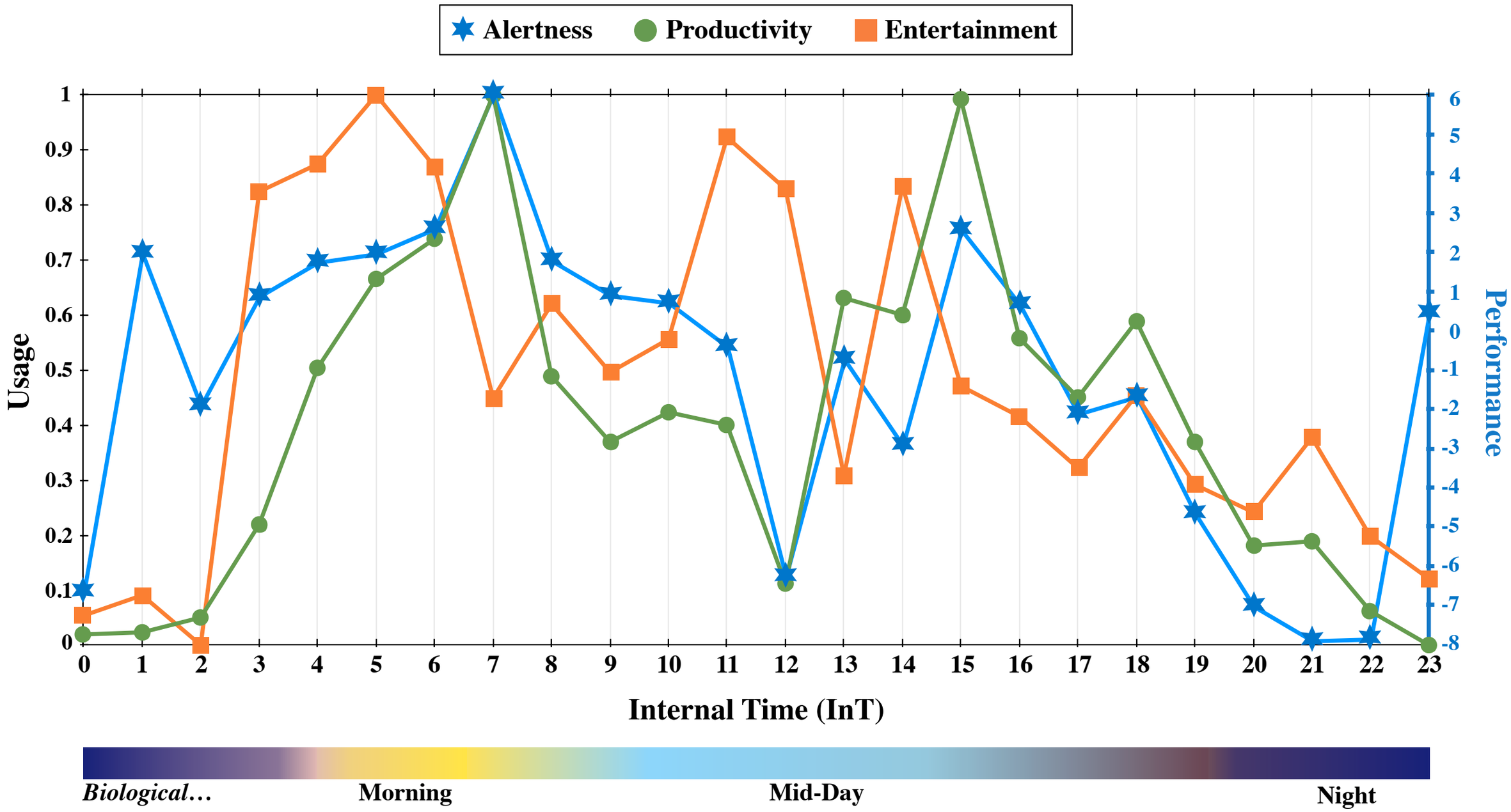


$r = -0.31$, $p < .05$

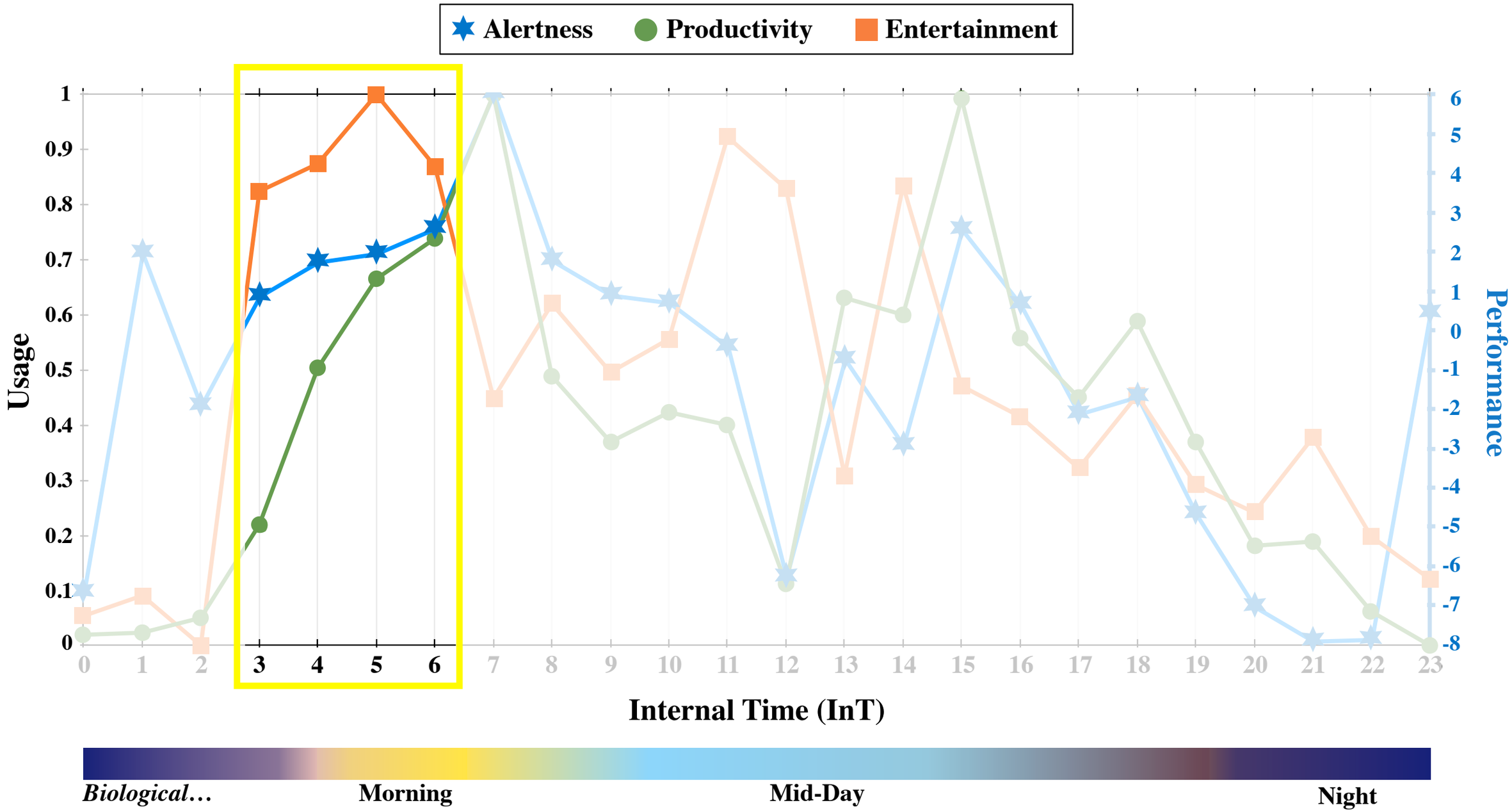
Manifestations of Biological Phenomena



Sleep Inertia

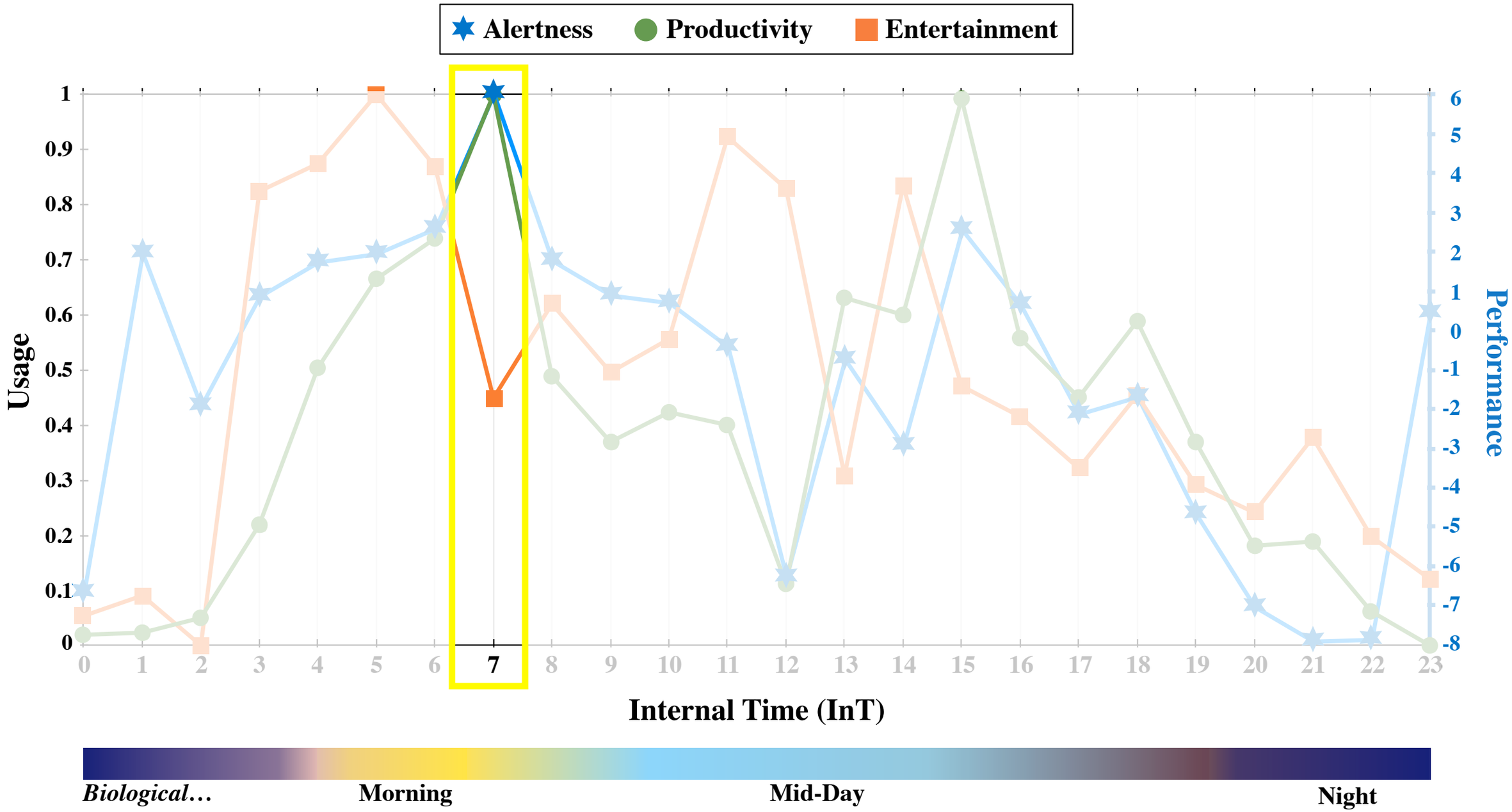


Sleep Inertia

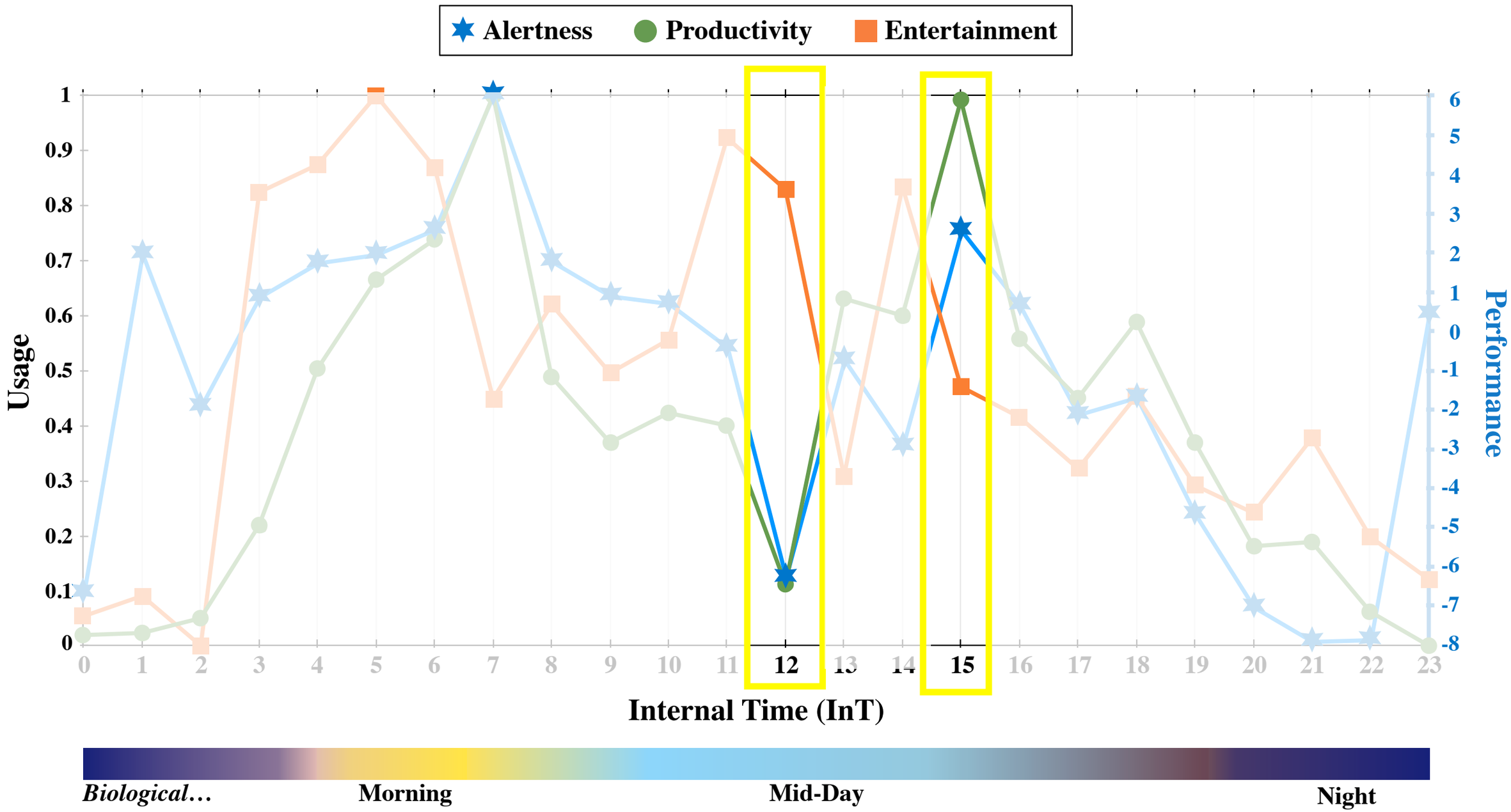


Sleep Inertia

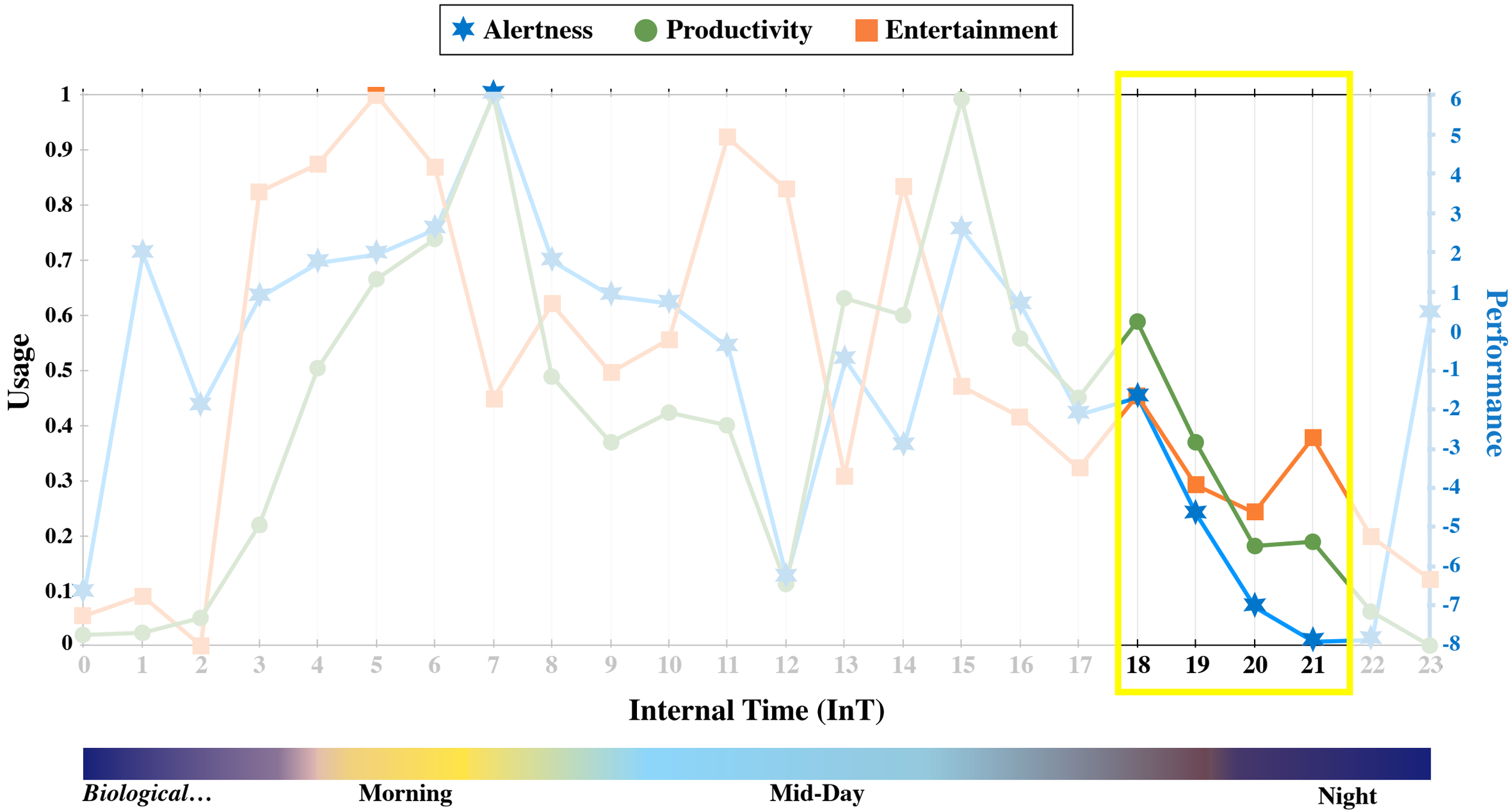
Late Morning Performance Peak



Mid-Day Dip & Evening Rebound



Late Night Lull



Late Night Lull

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

Opportunities

Opportunities

- **Predicting** alertness from phone data
  - Cognitive Rhythms: Unobtrusive and Continuous Sensing of Alertness Using a Mobile Phone (UbiComp 2016)

Opportunities

- **Predicting** alertness from phone data
  - Cognitive Rhythms: Unobtrusive and Continuous Sensing of Alertness Using a Mobile Phone (UbiComp 2016)
- Circadian-aware **designs** for productivity technology
  - Scheduling, education, interruption, personal awareness

Ambient awareness of personal alertness levels

Ambient awareness of personal alertness levels

Scheduling recommendation

Ambient awareness of personal alertness levels

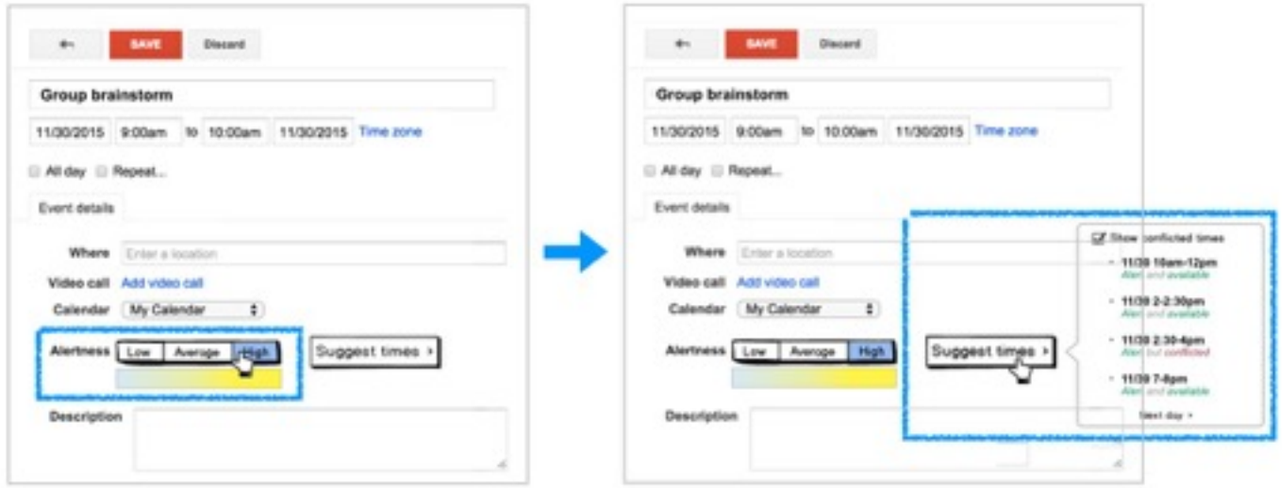
Scheduling recommendation

Ambient awareness of personal alertness levels

Scheduling recommendation

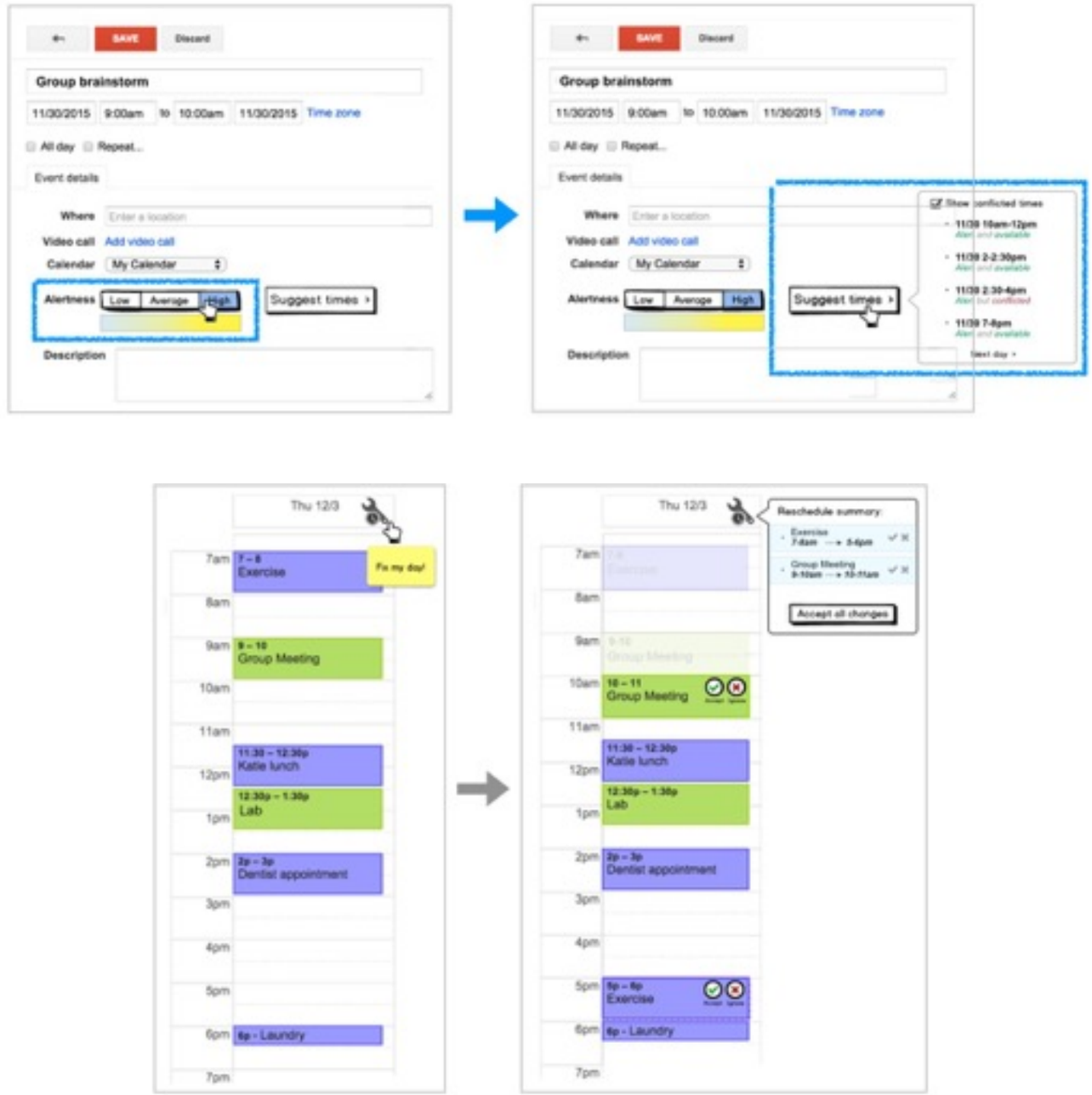
Ambient awareness of personal alertness levels

Scheduling recommendation

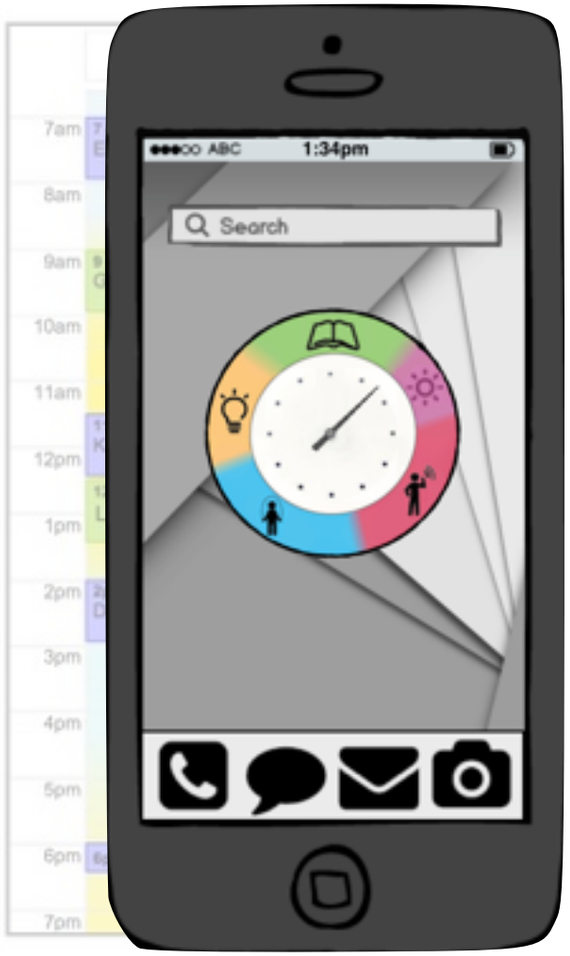


Ambient awareness of personal alertness levels

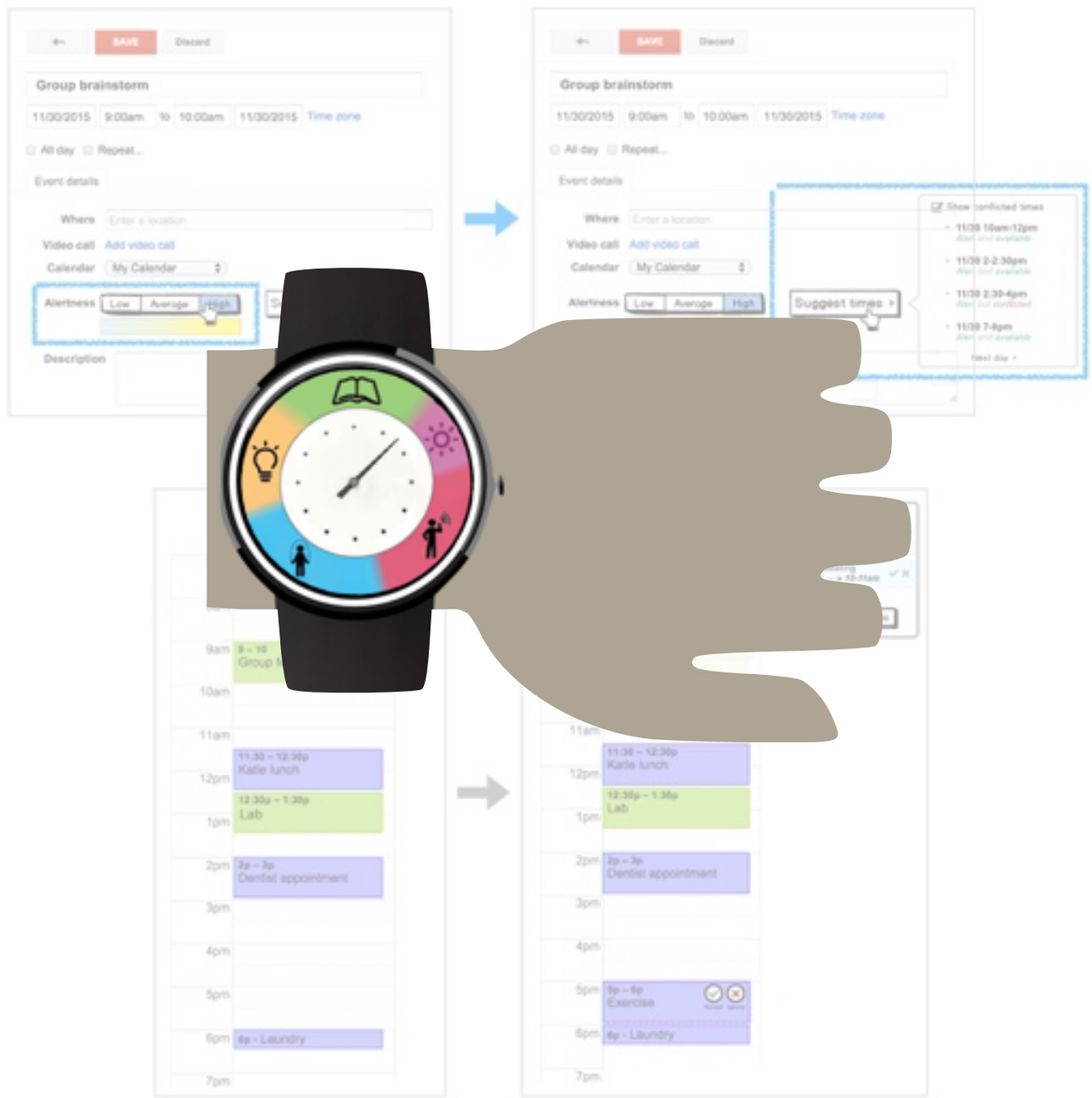
Scheduling recommendation



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**

Elizabeth Murnane
elm236@cornell.edu

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**

Elizabeth Murnane
elm236@cornell.edu

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**

Elizabeth Murnane
elm236@cornell.edu

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**

Elizabeth Murnane
elm236@cornell.edu

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**

Elizabeth Murnane
elm236@cornell.edu

Thank You! Questions?

- 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**

Elizabeth Murnane
elm236@cornell.edu