Neural Screenomics:

Decoding Motivational States from Individuals' Digital Trajectories

Rinseo Park[1], Yung-Ju (Stanley) Chang[2], Byron Reeves[1], & Nilam Ram[1]

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ICA 2024 Mobile Communication
HIGH DENSITY: Navigating Ubiquitous Connectivity
6/21/2024 Fri 12:00 – 1:15 PM

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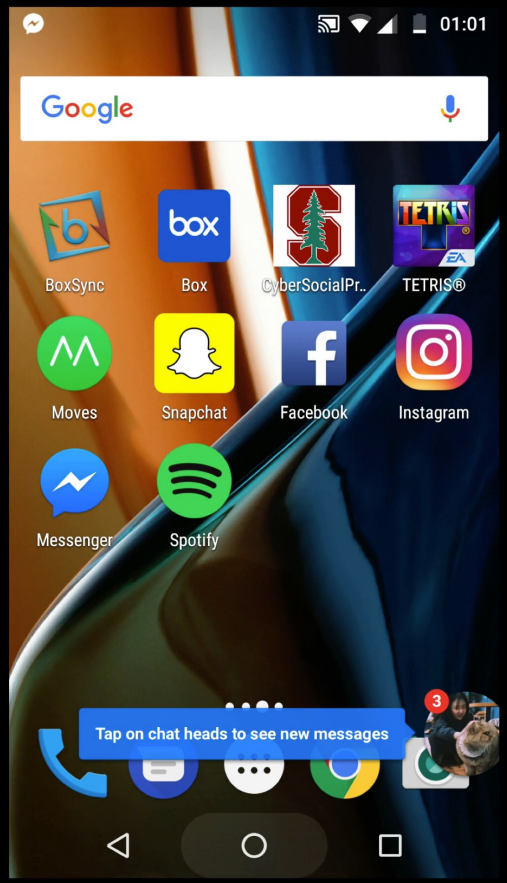
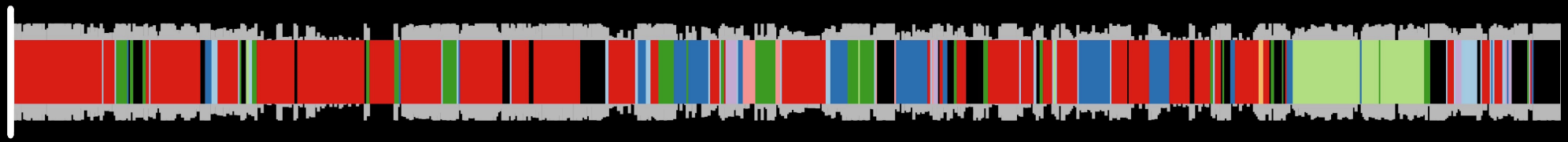
SCREENOME

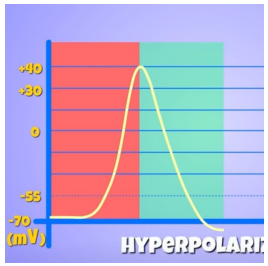
Fragments of Media Use





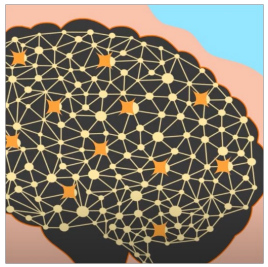
Reeves, Robinson, & Ram, 2020

Neural Screenomics: New Way of Defining Motivations



Continuous

- Higher ***frequency*** (vs. UG) and longer study ***duration*** (vs. MC)
- Pushing further task-switching research by studying **moment-to-moment** (vs. UG) changes **over time** (vs. MC)



Multiple "screen" neurons

- A scalable way of defining motivational dimensions
- Reconciling **explanatory (MC, 2 fixed)** and **exploratory (UG, 7 optimal)** frameworks to examine high-dimensional screen behavior

Context-specific

- Can identify and describe *when* and *how strongly* each motivational state is activated under certain contexts
- Revealing **when, how, and why** people are switching apps so quickly

Photo Credit: ScienceABC (2023)

Motivations for Media Task Switching

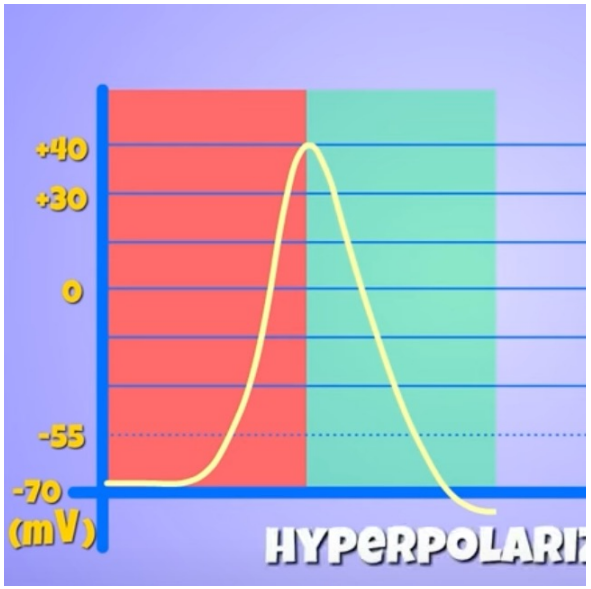
Theory of Motivated Cognition (MC)

- Focusing on **external factors**
- How do media activate motivational (appetitive/aversive) systems?
- *Lang (2006); Yeykelis et al. (2018)*

Uses & Gratifications Theory (UG)

- Focusing on **internal factors**
- How do users select media to fulfill their needs or dispositional motives?
- *Katz et al. (1973); Wang & Tchernev (2012)*

New Way of Defining Motivations



Continuous

Multiple "screen" neurons

Context-specific

Photo Credit: ScienceABC (2023)

Highlighting the Role of Timescale

Table 1. *Timescales of assessment in task switching research.*

Theory	Example	Timescale of Assessment	
		Frequency	Duration
Motivated Cognition	Screen shots every 5 seconds for 4 days (Yeykelis, Cummings, & Reeves, 2018)	**High** (e.g., 5 seconds)	Low (e.g., 4 days)
Uses and Gratifications	Self-reports 3 times per day for 4 weeks (Wang & Tchernev, 2012)	Low (e.g., 8 hours)	**High** (e.g., 4 weeks)

Note: Levels of assessment frequency/duration labeled as "**High**" or "Low."

Wrzus & Mehl (2015)

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Note: Levels of assessment frequency/duration labeled as "**High**" or "Low."

***RQ*: How to decode *motivational states* from fast-changing screen use over time?**

Wrzus & Mehl (2015)

Data: *Screenomics*

- **Every 5 seconds for 14 days, 36 participants** were instructed to submit smartphone screenshots.
- Each screenshot was auto-annotated with respect to **17+ app categories** and self-annotated with respect to **2 motivational states: (1) killing time, (2) available for viewing notifications.**

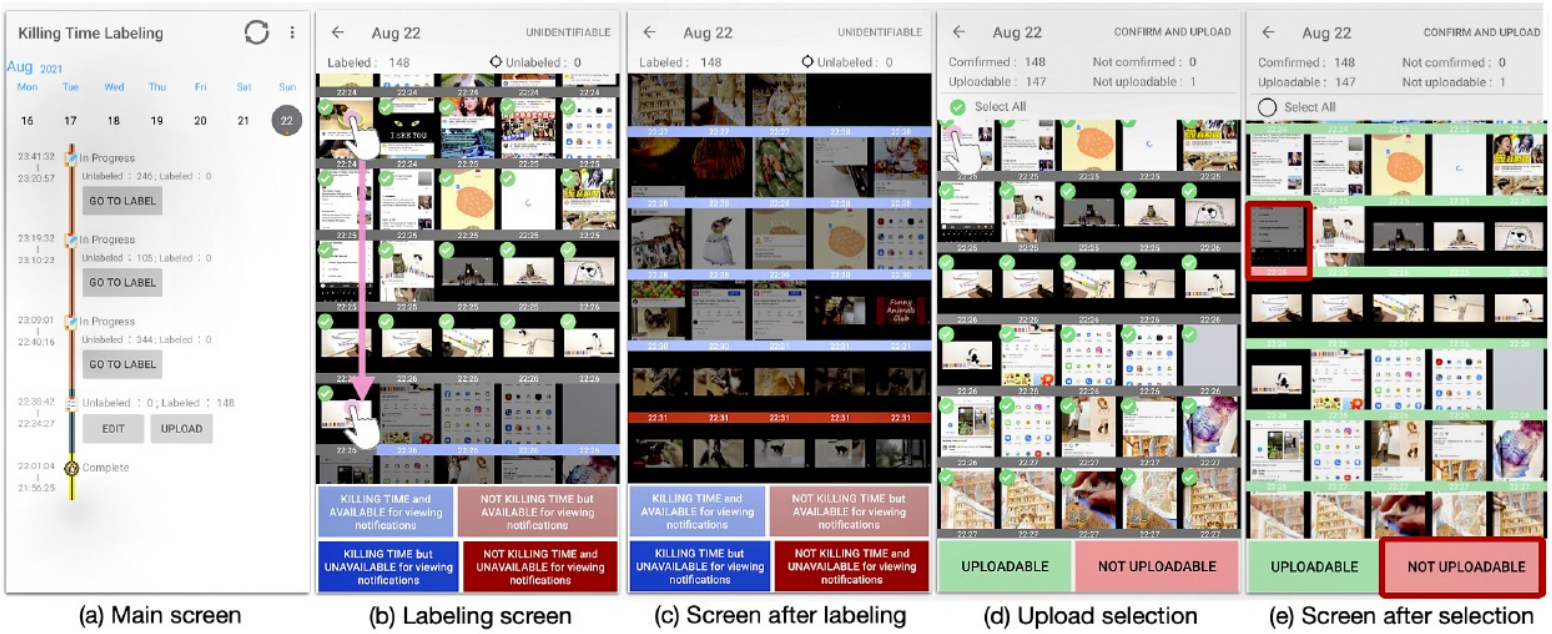
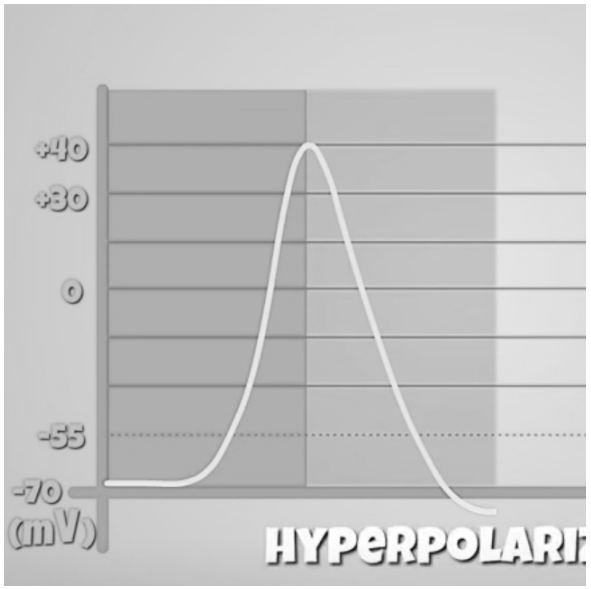


Figure 1: User interfaces for the main functions of the Killing Time Labeling application

Chen et al. (2023)

New Way of Defining Motivations



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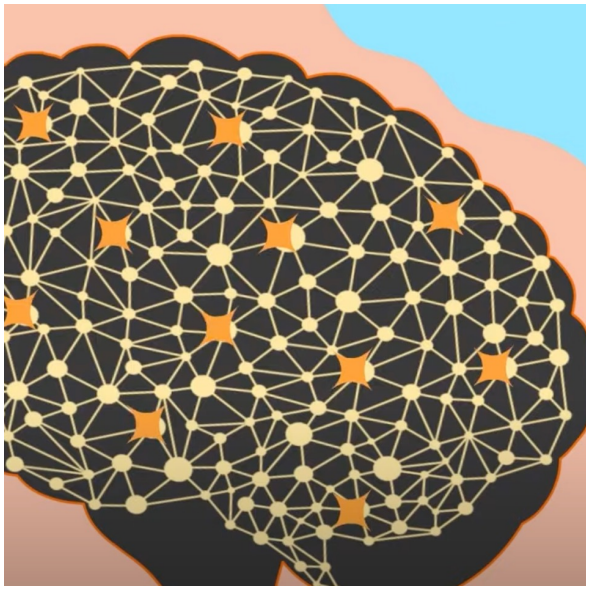


Multiple "screen" neurons

Context-specific

Photo Credit: ScienceABC (2023)

Parallels with Neuroscience: *Neuron*

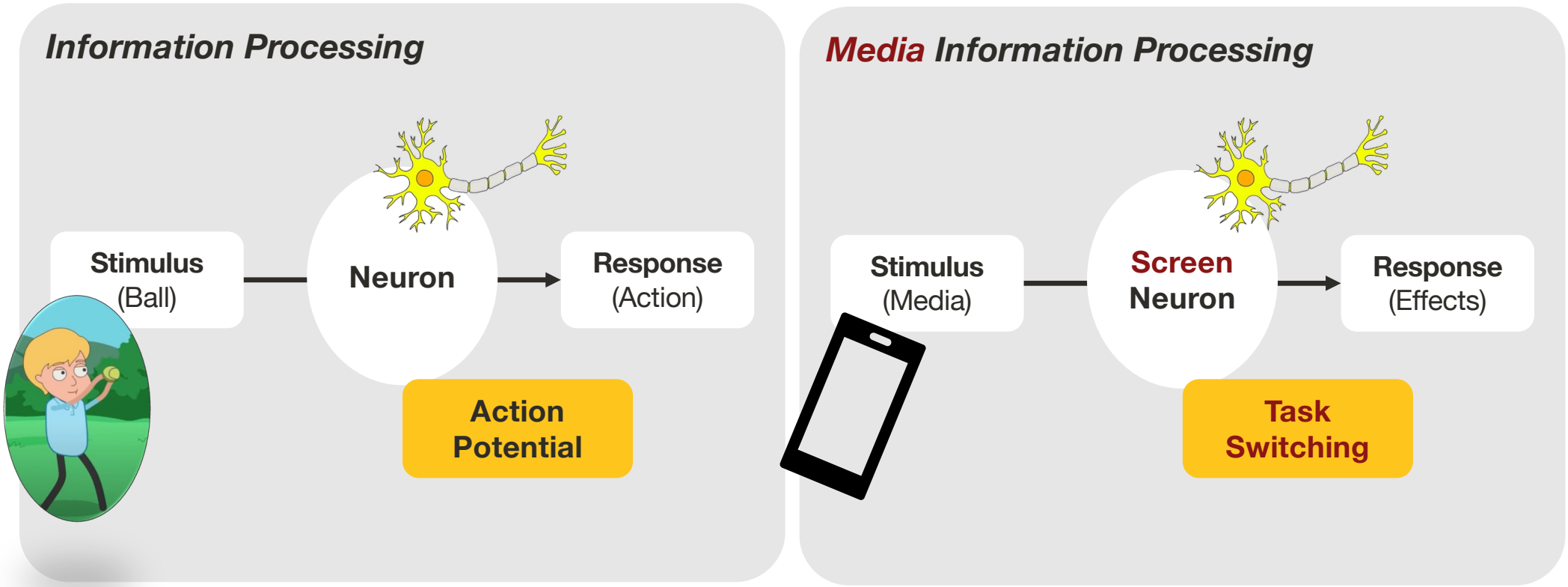
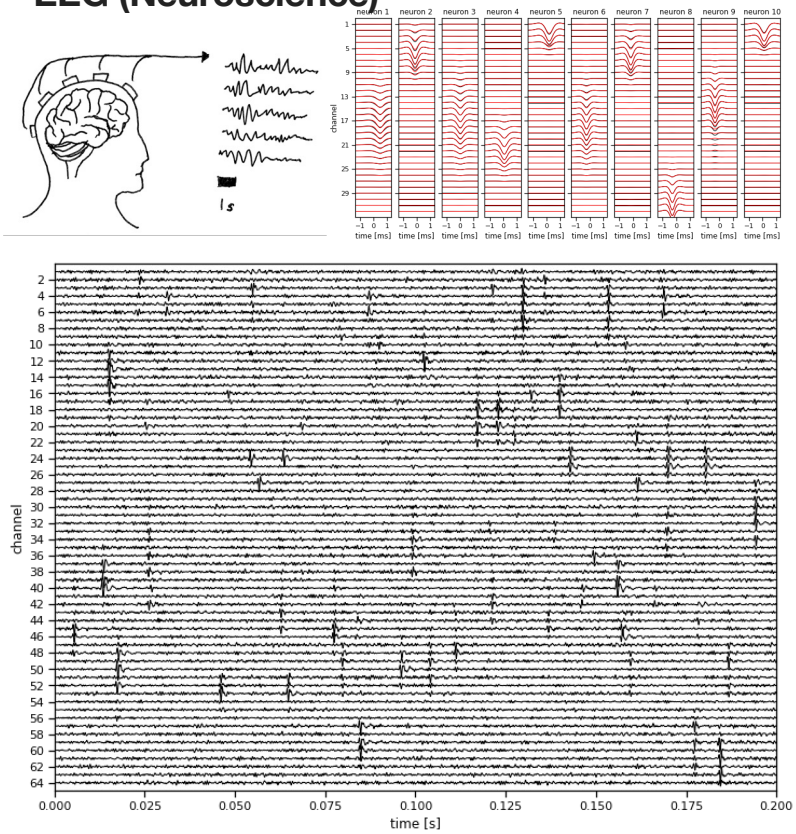


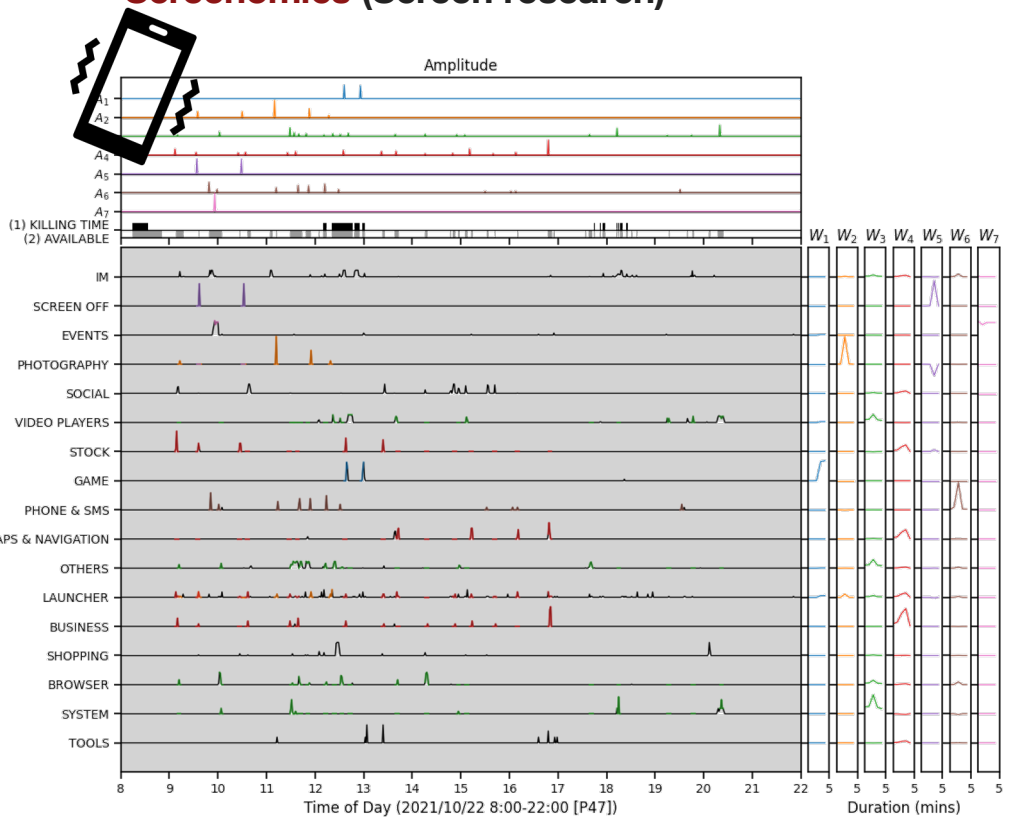
Photo Credit: ScienceABC (2023)

Parallels with Neuroscience: *Neural Signals*

***EEG (Neuroscience)**



Screenomics (Screen research)



**EEG (electroencephalogram)*

Parallels with Neuroscience*: Spike Sorting*

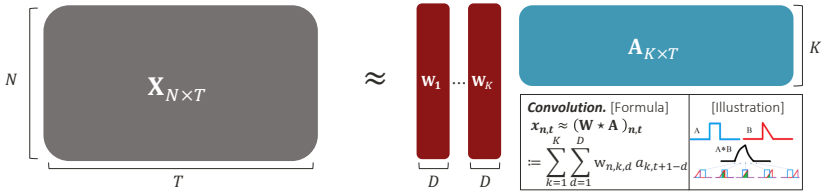
- **Spike sorting with *EEG***
  - Widely used to identify spikes (action potentials) and the underlying neurons from multi-channel neural recordings.

  1) Discover how ***neural activity*** occurs across different brain regions.
  2) Discover how ***latent states of neural activity*** change over time.

- **Spike sorting with *Screenomics***
  - Screenomics show how individuals having different motivations use and engage with different apps.
  - Thus, we aim to identify these **(1) behavioral spikes** and **(2) underlying screen neurons as motivations**.

***Kilosort* (Pachitariu et al., 2016)**

- Convolutional Non-negative Matrix Factorization (Conv-NMF)
- Data $\mathbf{X}_{N\times T} \approx$ Feature matrix $\mathbf{W}_{N\times K\times D} \star$ Coefficient matrix $\mathbf{A}_{K\times T}$

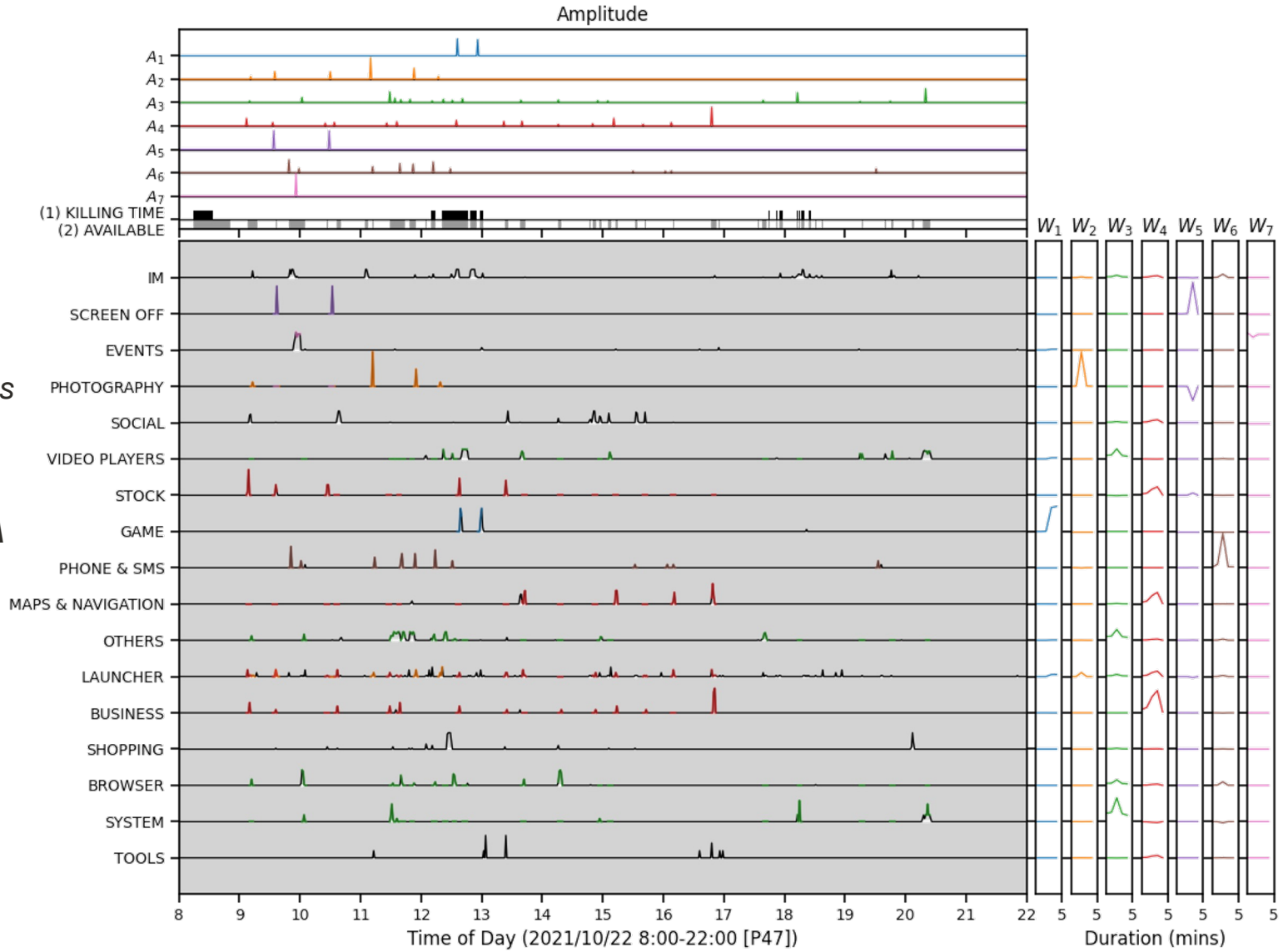


Smaragdis (2004)

Results

1-person, 1-day
***Seven neurons* (R^2 = .48)**

- ***The right panel*** *showcases the* ***spatial waveforms W*** *of these neurons, given that the duration of motivational states is under 10 minutes (D = 10)*
- ***The top panel*** *showcases their* ***temporal amplitudes A*** *that are associated with contexts of media use.*
- *Each color corresponds to a neuron, overlaid when the neuron's spatial wavelets are significantly higher than zero (using top 95th percentile).*



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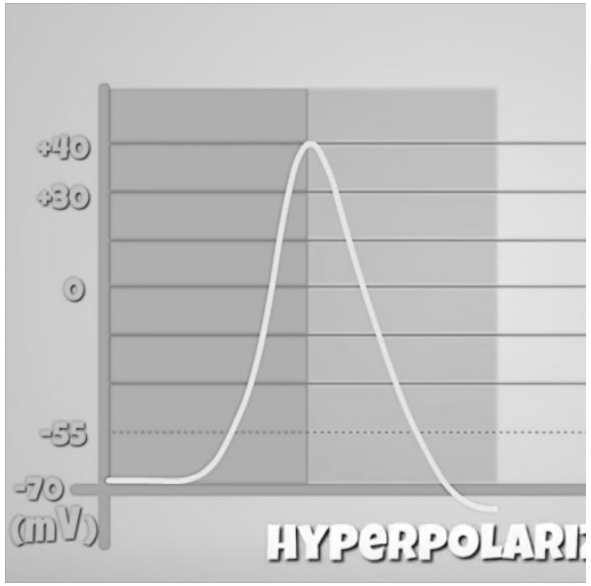
New Way of Defining Motivations



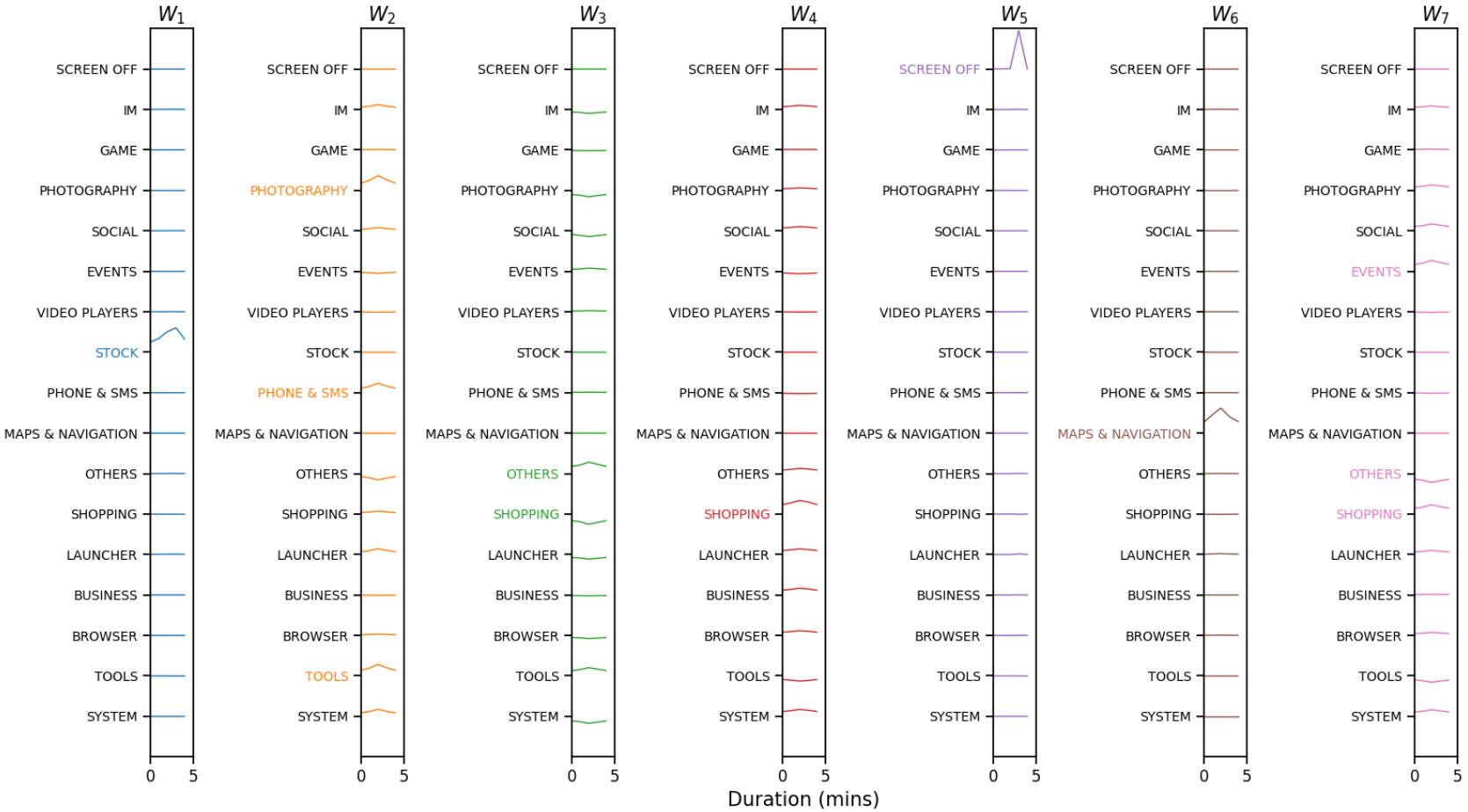
Continuous

Multiple "screen" neurons

Context-specific

Photo Credit: ScienceABC (2023)

Screen Neurons as Context-specific Motivations



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36-persons, 93-days
Seven neurons (R^2 = .34)

Statistical Relationships with Self-reported Motivations

Table 2. *Comparison of inferred and observed motivational states.*

Motivation state		Number of firing times	Regression coefficients			
			(1) Killing time		(2) Available	
			FE	RE	FE	RE
Intercept			-2.06*** (0.10)	0.61	-1.841*** (0.08)	0.50
Neuron 1	(Stock)	348	0.24** (0.09)	0.25	0.241*** (0.07)	0.17
Neuron 2	(Messenger)	6915	0.58*** (0.08)	0.44	0.891*** (0.12)	0.67
Neuron 3	(Others)	5428	-0.43*** (0.09)	0.49	-0.381*** (0.11)	0.61
Neuron 4	(Shopping)	9263	0.96*** (0.10)	0.58	1.281*** (0.12)	0.70
Neuron 5	(Screen off)	587	0.09*** (0.01)	0.04	0.121*** (0.01)	0.03
Neuron 6	(Maps & Navigation)	878	0.14*** (0.02)	0.07	0.311*** (0.04)	0.16
Neuron 7	(Events)	7776	1.62*** (0.15)	0.88	1.871*** (0.18)	1.09
AIC			525655		581928	
BIC			525839		582111	

36-persons, 93-days
Seven neurons (R^2 = .34)

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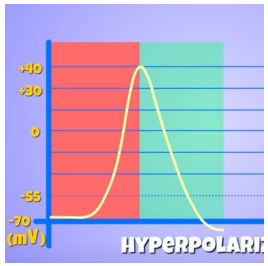

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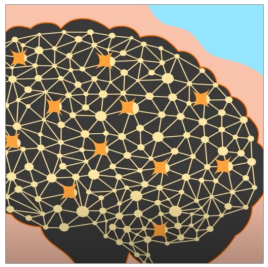

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Acknowledgement

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- **The Change Lab**[1] (Lavender Chen, Yikun Chi, Tanner Christensen, Julia Fischer, Zhenchao Hu, Christopher Kelly, Michelle Ng, Wee Qin Ng, Sam Serrano, Charles Shi, Emma Talley, A Garron Torres, & Nilam Ram)
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- **Mobile and Ubiquitous Interaction Lab**[2] NATIONAL YANG MING CHIAO TUNG UNIVERSITY
- **Korea Foundation for Advanced Studies** KFAS

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The Change Lab (thechangelab.stanford.edu)

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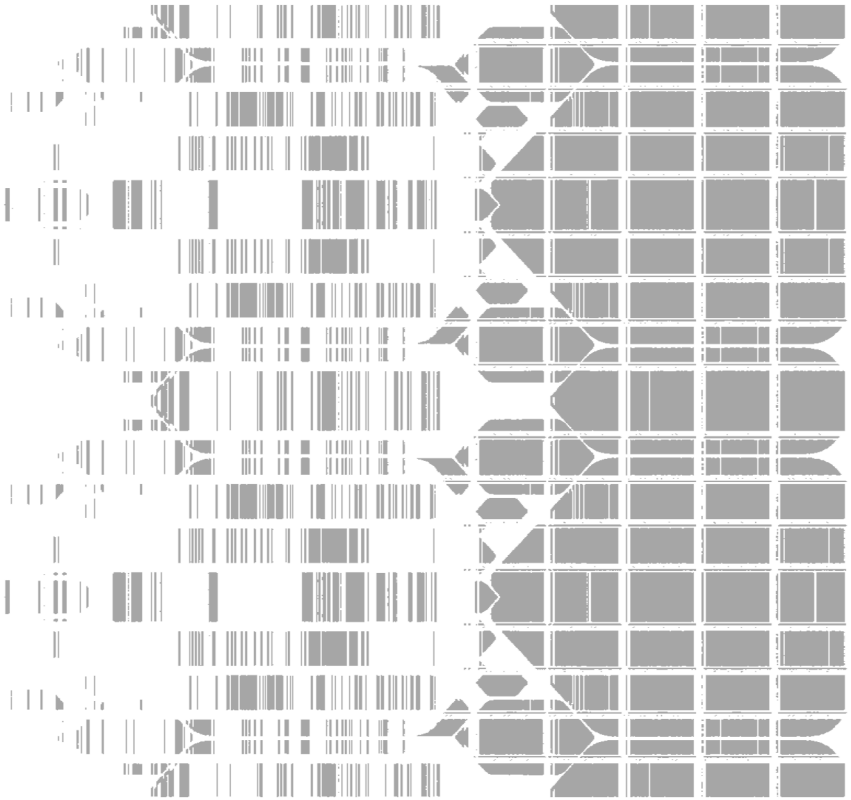

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Measures: KTL study

Table 1: Summary of data collection

Labels	Uploaded	Not uploaded	Total
Killing time and available for viewing notifications	606,760 (51.1%)	29,160 (2.5%)	635,920 (53.6%)
Killing time but unavailable for viewing notifications	135,380 (11.4%)	2,101 (0.2%)	137,481 (11.6%)
Not killing time but available for viewing notifications	202,327 (17.1%)	17,081 (1.4%)	219,408 (18.5%)
Not killing time and unavailable for viewing notifications	118,313 (10.0%)	9,071 (0.8%)	127,384 (10.7%)
Unidentifiable	0 (0.0%)	66,152 (5.6%)	66,152 (5.6%)
Total	1,062,780 (89.6%)	123,565 (10.4%)	1,186,345 (100.0%)

Table 2: The sensor features used in the study

Phone Context	Current Characteristics	Current session characteristics (accumulated up to the current screenshot record)
Transportation Mode	Physical activity (i.e., not moving, on foot, in vehicle, or on bicycle)	Cumulative time of {not moving, on foot, in vehicle, on bicycle}
	Was moving (i.e., on foot, in vehicle, or on bicycle)	Majority of physical activity
Type of Day	Day of the week (0-6)	
	Was weekend (i.e., Saturday, Sunday)	
Time of a Day	Hour of the day in 24-hour notation (0-23)	
	Was meal time (11:00 a.m.-12:59 p.m., 5:00 p.m.-6:59 p.m.)	
Battery Status	Phone battery level	{AVG, STD, MIN, MAX, MED} Phone-battery level
	Phone was charging / not charging	Charging count
	If charging over AC or USB	Cumulative charging time
Screen Time		{AVG, STD, MIN, MAX, MED, SUM} Screen time
Screen Orientation	Portrait / landscape mode	
Foreground App	Name of the app in the foreground	Count and frequency of app switches
	Package name of the app in the foreground	Count of used apps
	Category of the app in the foreground	Cumulative usage time of the 15 most frequently used app categories and all remaining app categories combined into one category group.

When

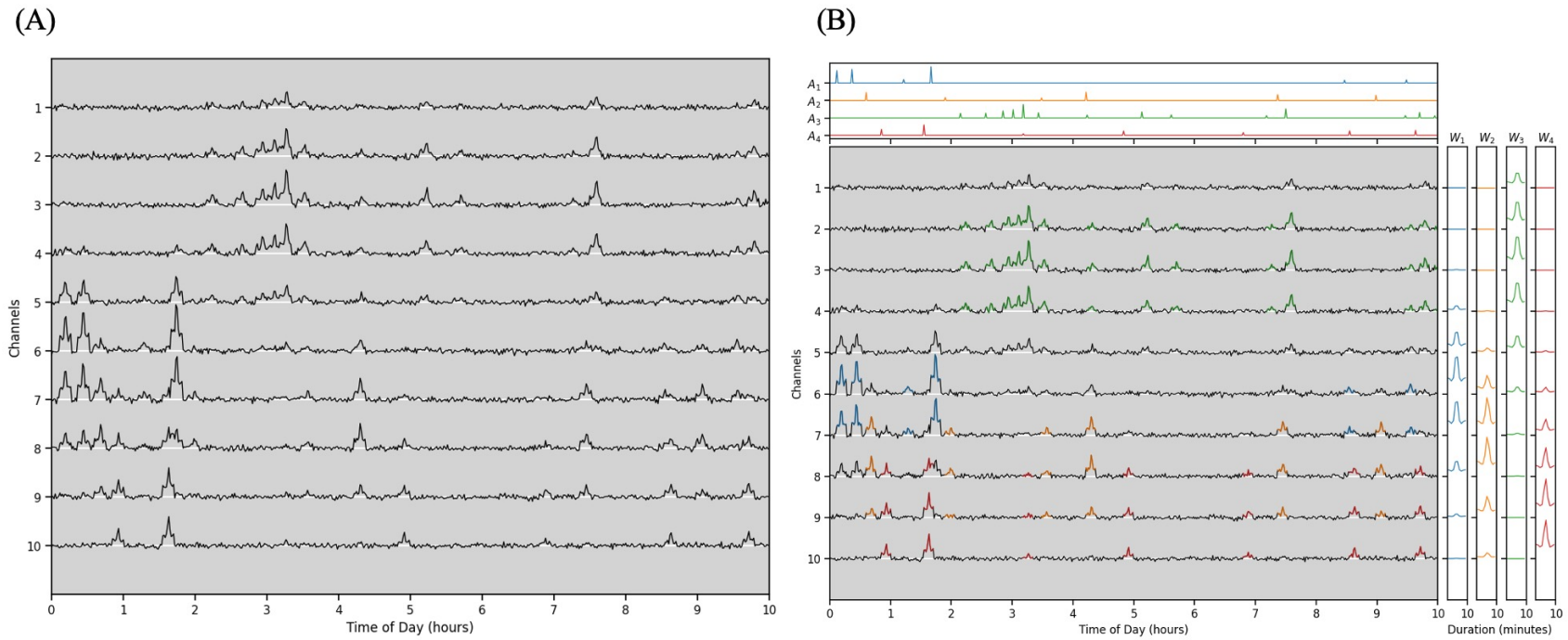
What

Measure: Foreground time spent on each of (16+1) app categories

Chen et al. (2023)

Figure 1: Synthetic dataset

Figure 1. *An illustrative example of spike sorting applied to smartphone sensing data.*



Note: **Panel A** depicts the observed multi-channel time-series data, capturing screen time across 10 applications. **Panel B** depicts the overlay of 4 ground-truth neurons that were used to generate the data. The right panel showcases the spatial waveforms **W** of these neurons, assuming that the duration of motivation states is under 10 minutes. The top panel showcases their temporal amplitudes **A** that are associated with contexts of media use. Each color corresponds to a neuron, overlaid when the neuron's spatial wavelets are significantly higher than zero (using top 95th percentile).

Figure 2A: Synthetic dataset with 4 neurons
(R^2 = .75)

In the **Uses & Gratifications** framework,

Wang & Tchernev (2012) used

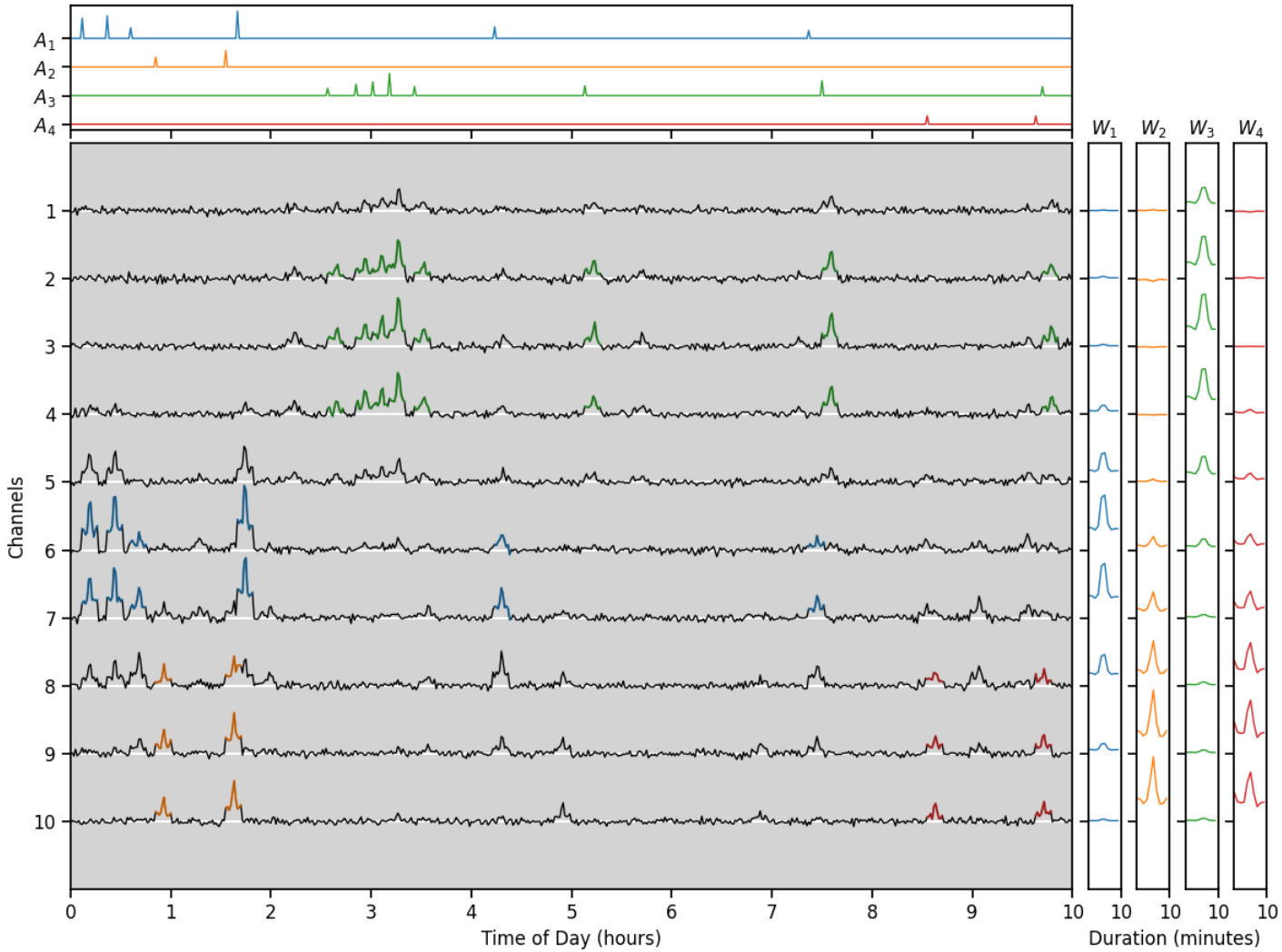
4 categories (of uses & gratifications):

(1) emotional
- fun/entertainment
- to relax/kill time

(2) cognitive
- information
- study/work

(3) social
- personal
- professional

(4) habitual
- habits/background noise



Wang & Tchernev (2012)

Figure 2B: Synthetic dataset with 2 neurons
(R^2 = .44)

In the **Motivated Cognition** framework,

Yeykelis and colleagues (2019) used

2 motivational systems:

(1) appetitive motivational system
(2) aversive motivational system

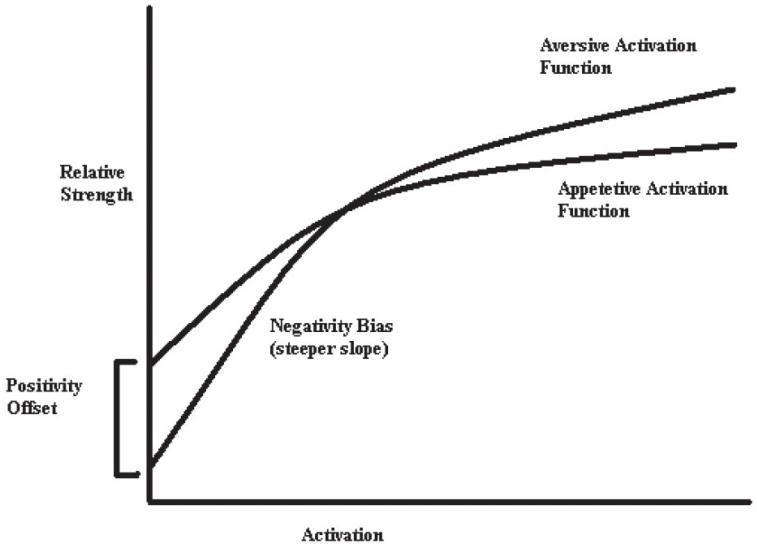
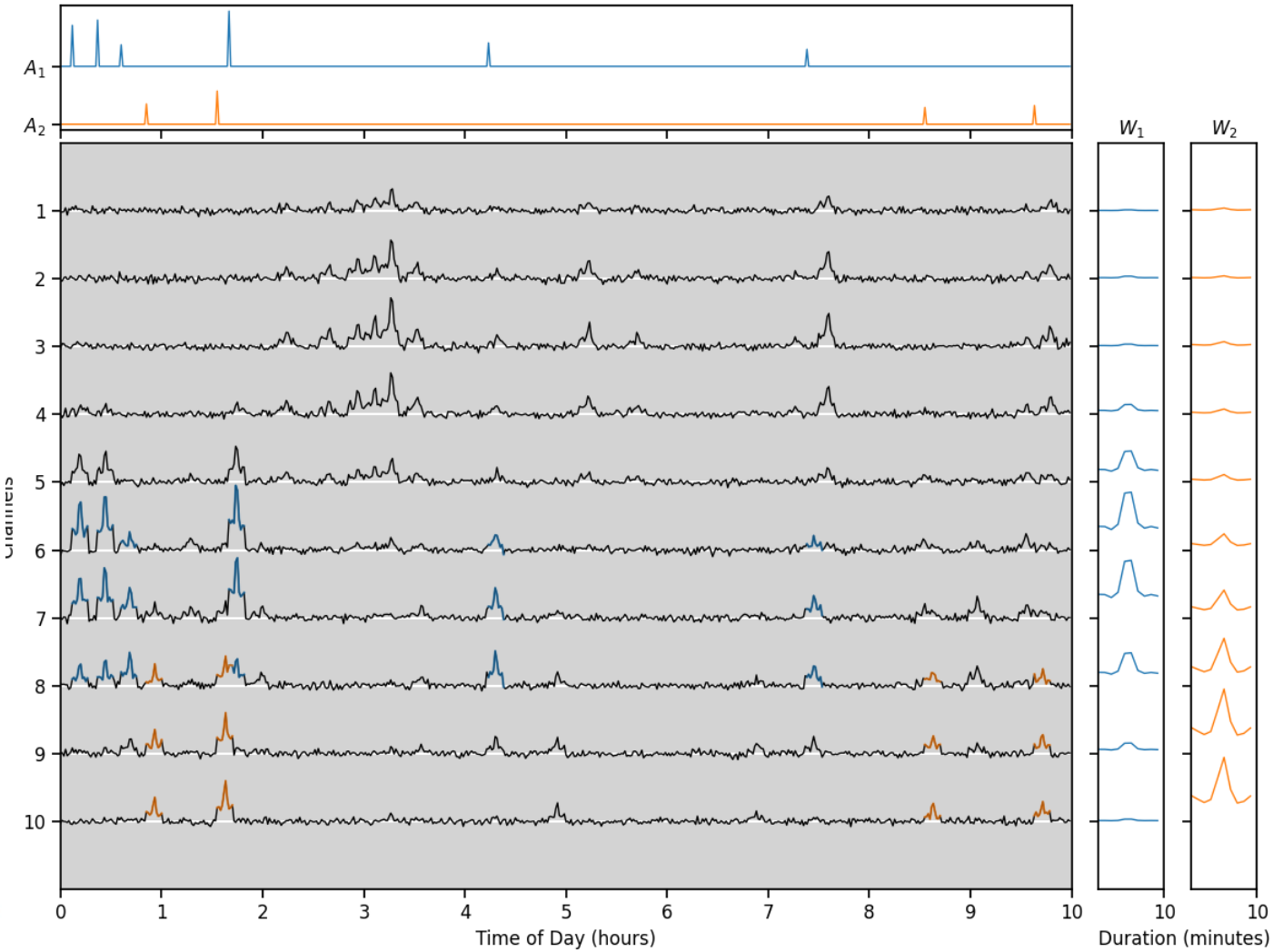


FIGURE 1 Proposed activation functions for the appetitive and aversive motivational systems.



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Lang, Shin, & Lee (2005)

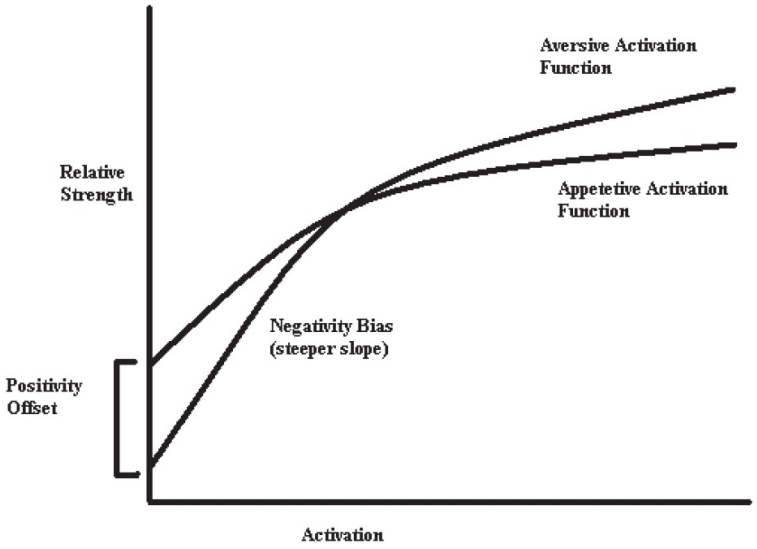
Figure 2C: Another synthetic dataset with 2 neurons **w/ Constraints**
(R^2 = .77)

In the **Motivated Cognition** framework,

Yeykelis and colleagues (2019) used

2 motivational systems:

(1) appetitive motivational system
(2) aversive motivational system



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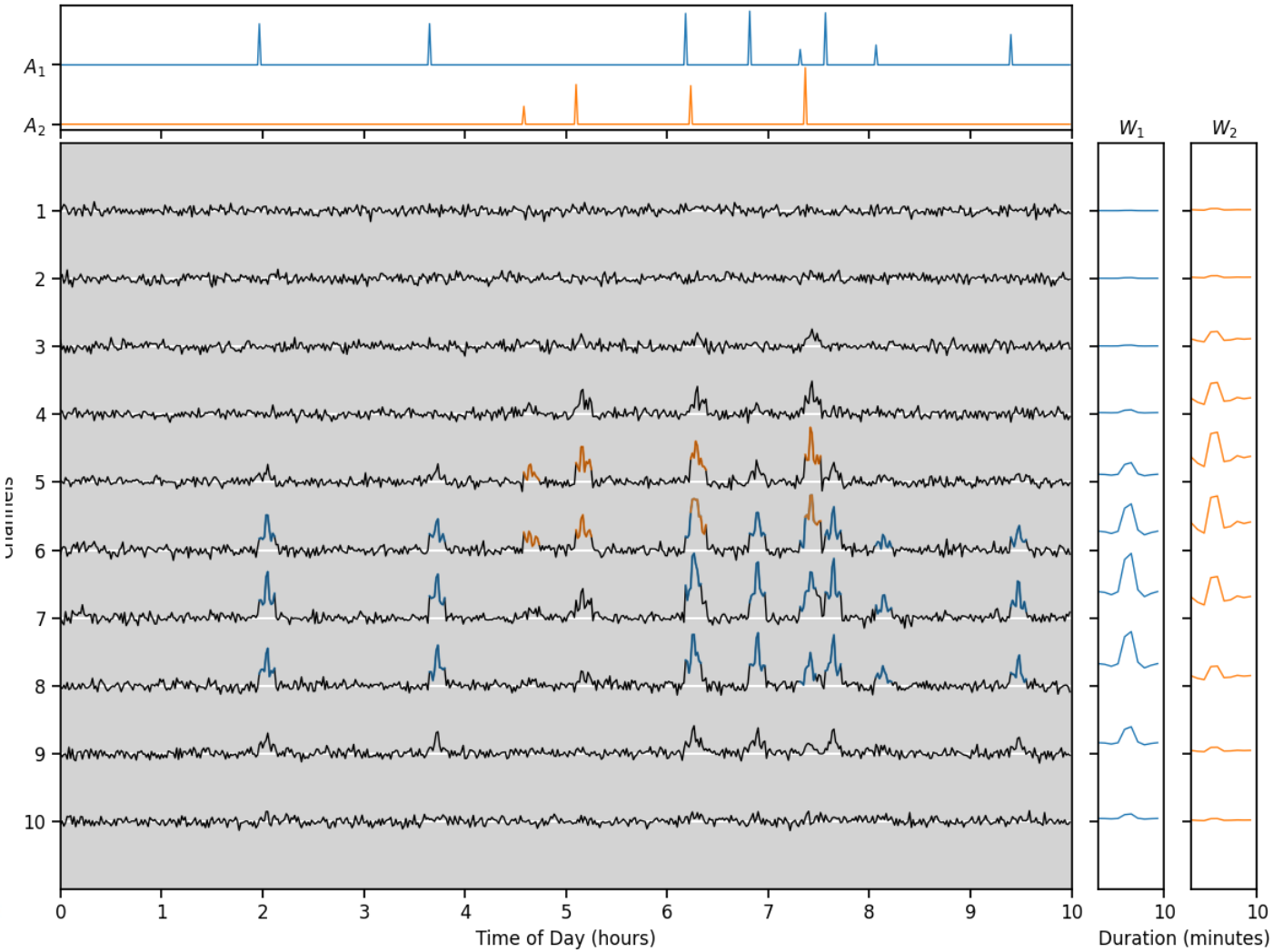

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Lang, Shin, & Lee (2005)

Figure 3: KTL dataset (1-person, 1-day) with 7 neurons
(R^2 = .48)

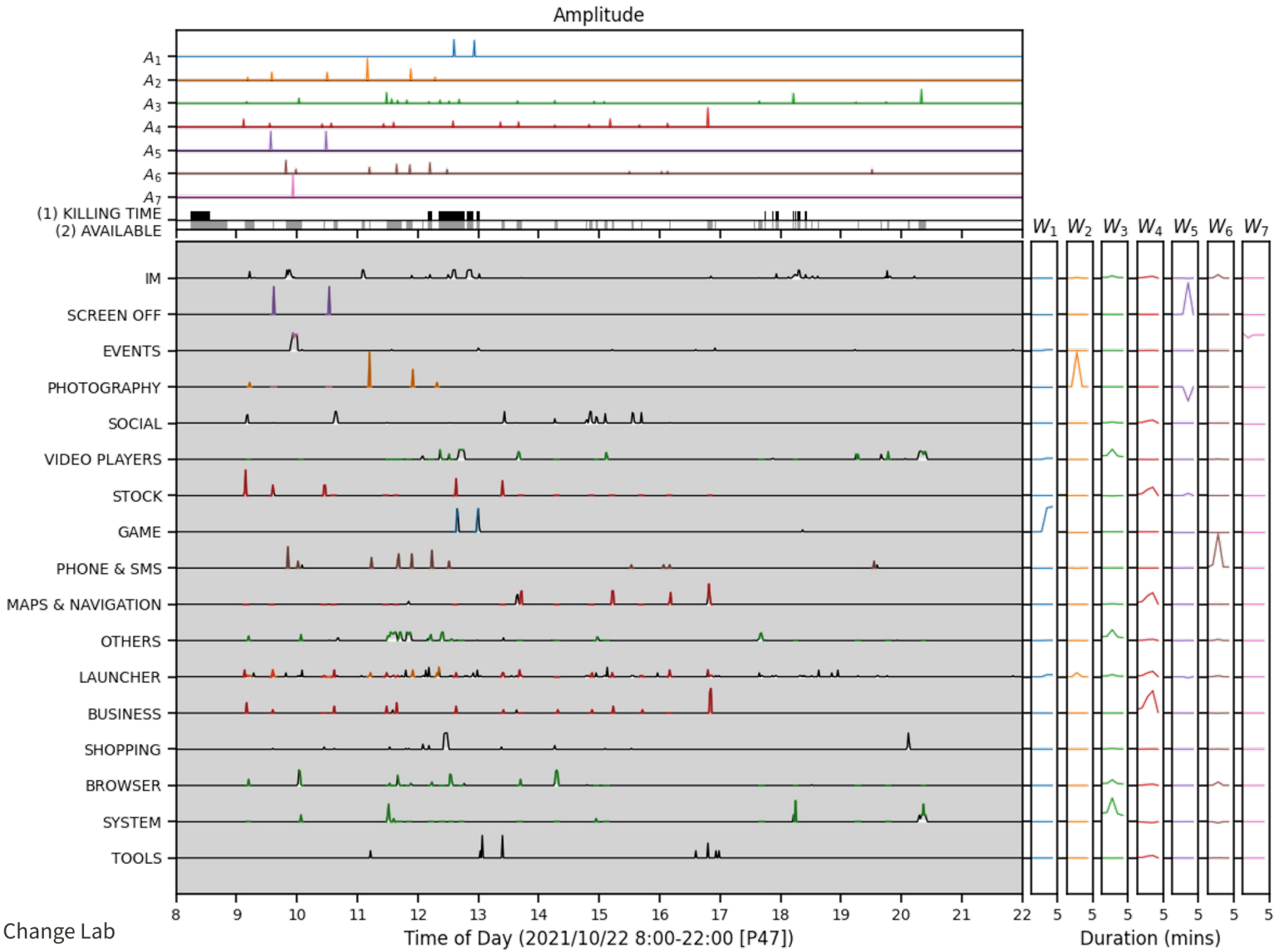

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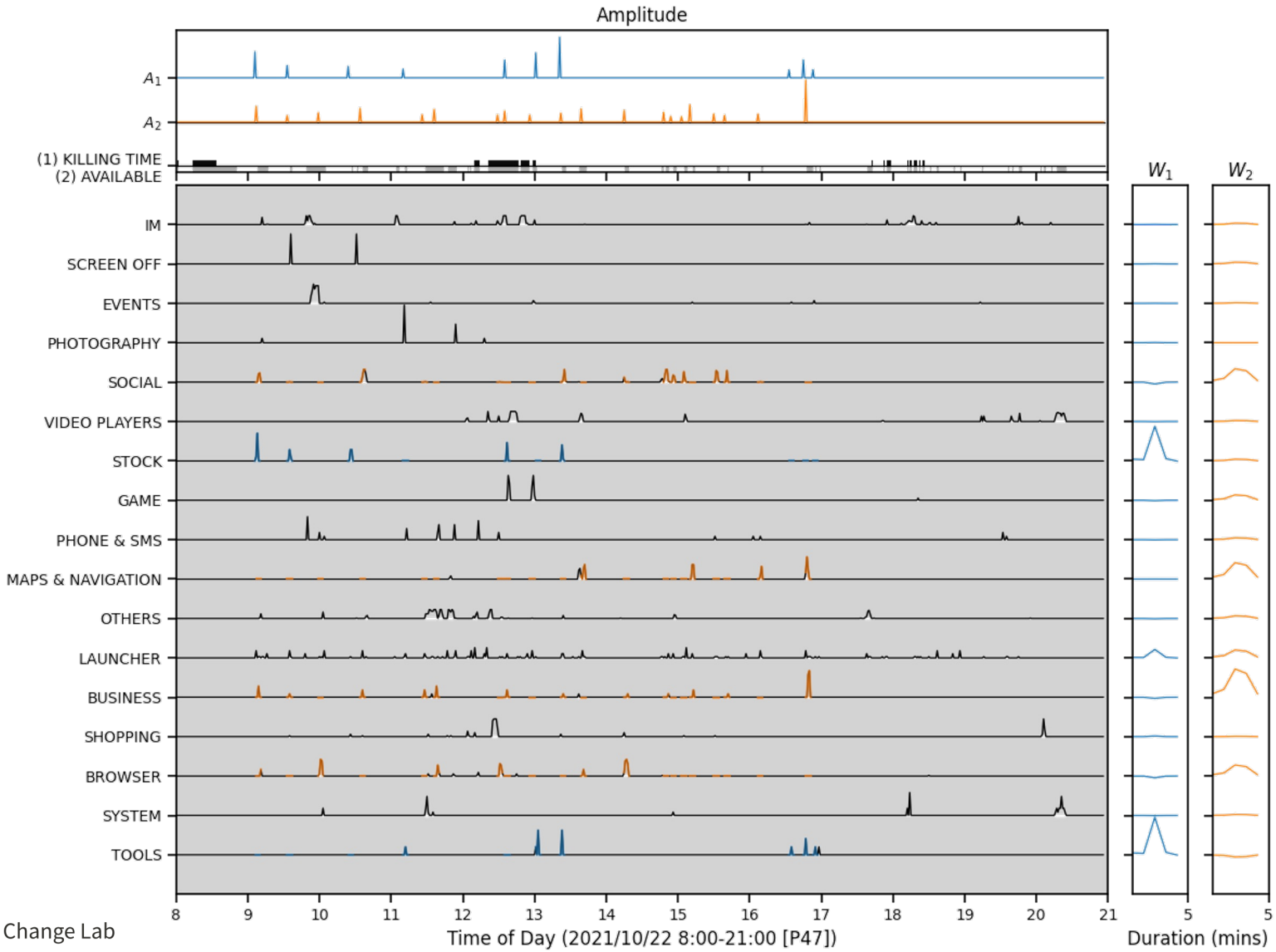
Figure 3: KTL dataset (1-person, 1-day) with 2 neurons
(R^2 = .17)



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