

# PERSONALIZED BRAIN STATE TARGETING VIA REINFORCEMENT LEARNING

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# MOTIVATION

Help achieve desired states of the mind  
without active effort by an individual

*Meditative state*



[npr.org](http://npr.org)

*Deep sleep state*



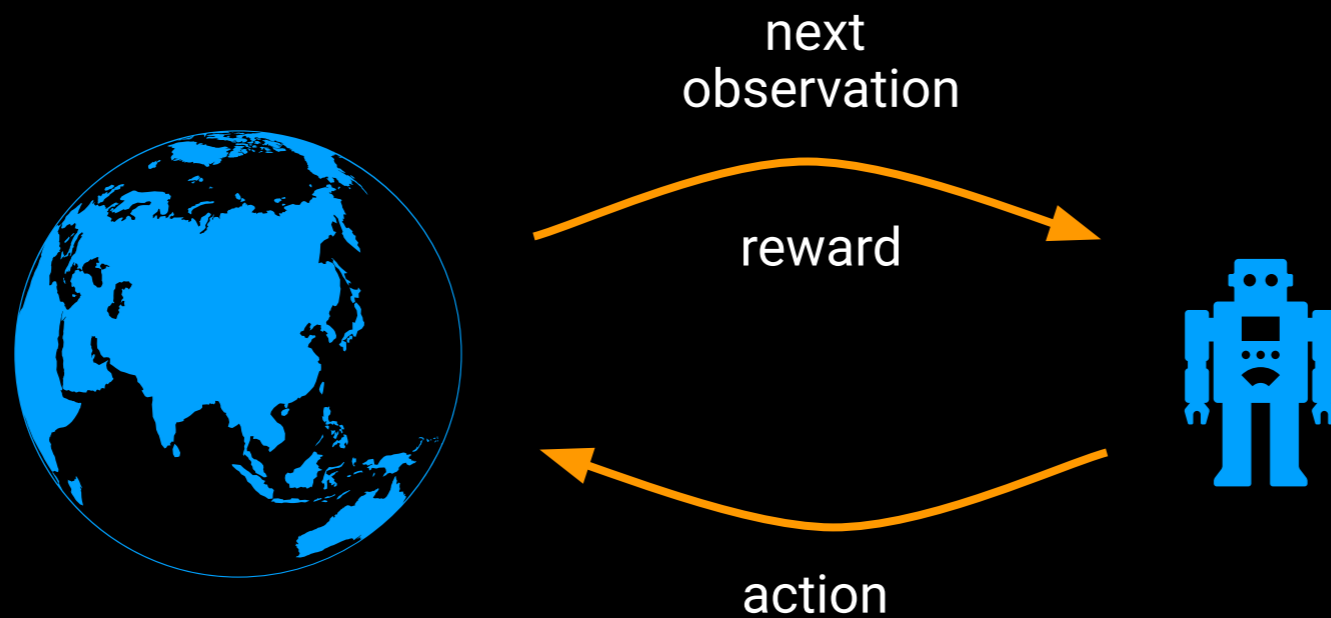
[healthcentral.com](http://healthcentral.com)

# RELATED WORK

- ▶ **Sleep-assistance systems:**
  - ▶ Open-loop: playing lullabies, soothing music, etc.
  - ▶ Closed-loop: e.g., iSleep (Zhang et al. 2015), Muse, MindAlive, Snozic
- ▶ **Goal-state existence:**
  - ▶ Transition to sleep is correlated with significant changes in  $\alpha$  and  $\theta$  activity in the midline region (e.g., Wright Jr. et al. 1995)
- ▶ **Goal-state identification:**
  - ▶ Machine learning techniques trained on large datasets used to categorize sleep stages (e.g., Malafeev et al. 2018)
- ▶ **Affecting state of the brain:**
  - ▶ Audio cues like binaural beats are effective in inducing  $\theta$  activity (e.g., Lee et al. 2019)

# METHODOLOGY

- ▶ Reinforcement learning



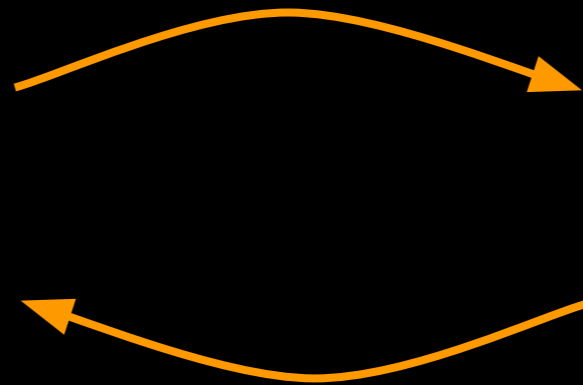
# METHODOLOGY

- ▶ Reinforcement learning



[trendhunter.com](https://www.trendhunter.com)

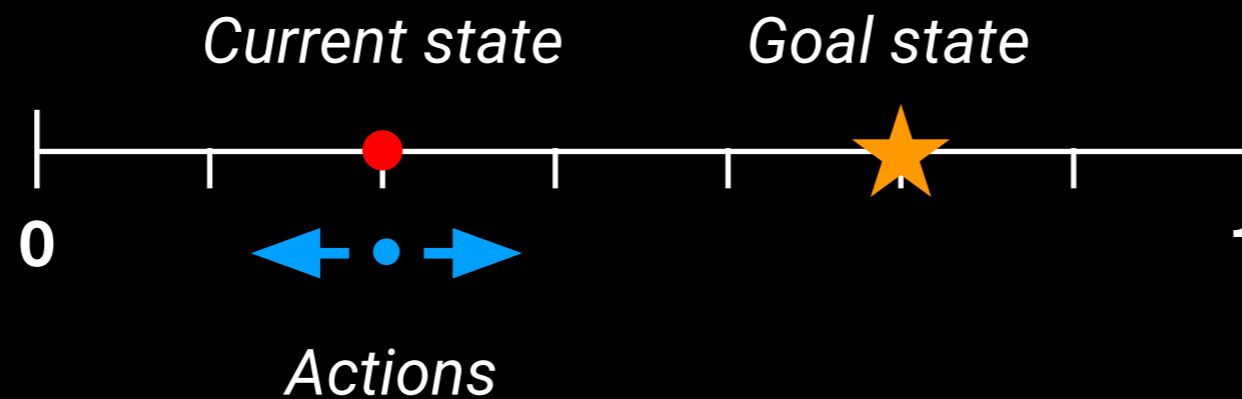
Real-time EEG data



Audio-visual cues

Reward depends on  
distance to goal state

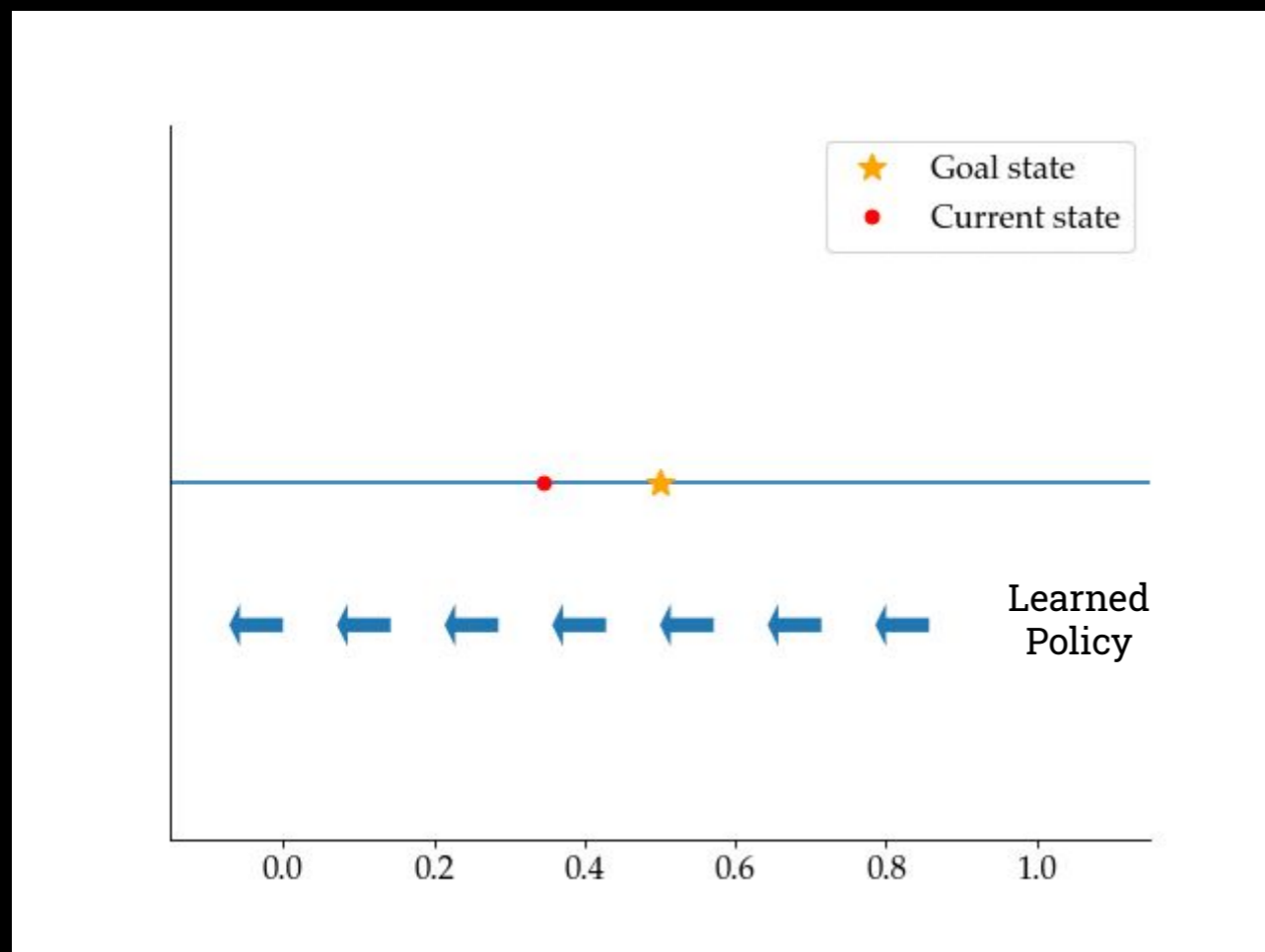
# PROOF-OF-CONCEPT



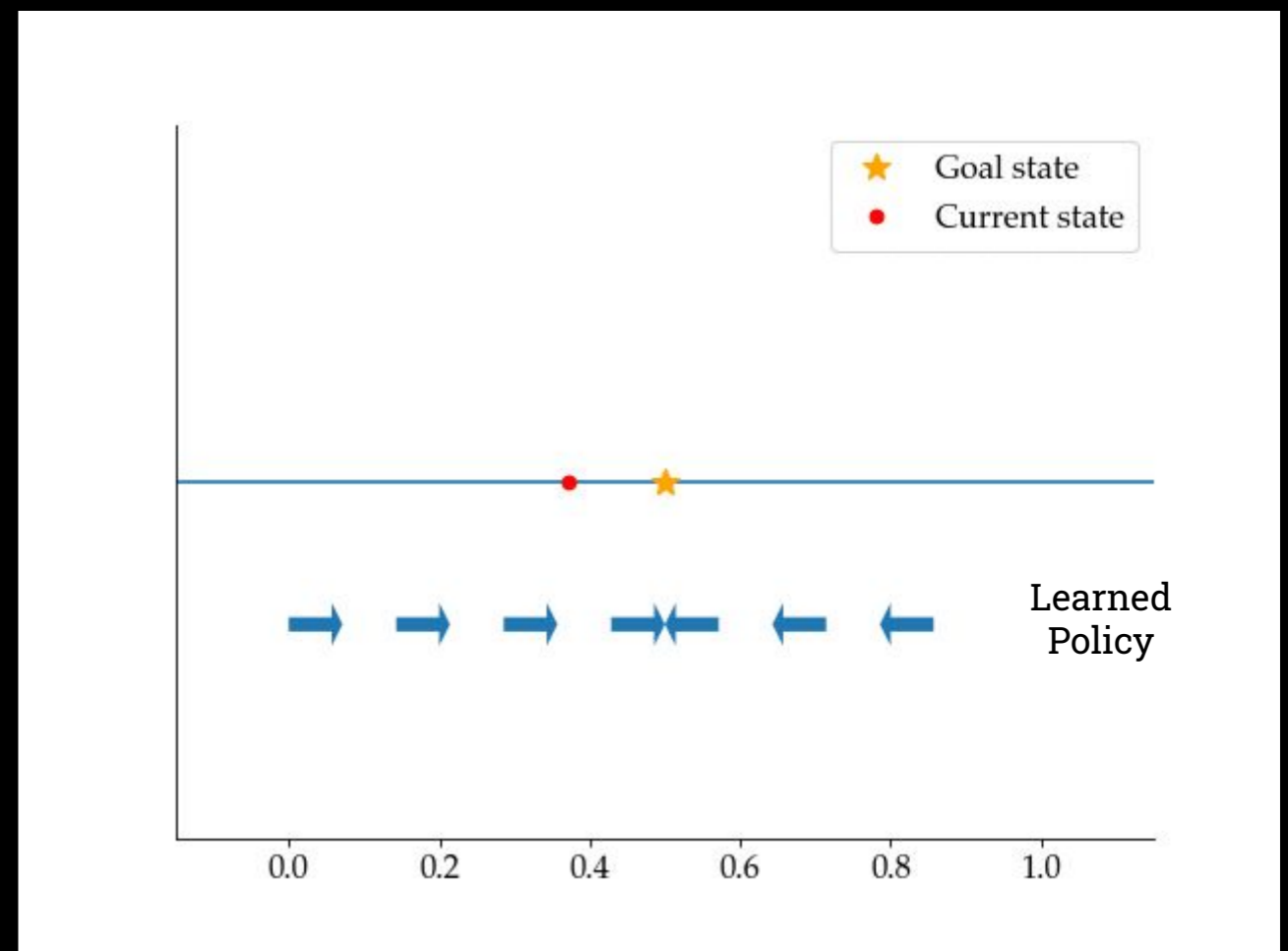
- ▶ Observations:  $o_{t+1} = \mathcal{N}(o_t, \sigma) + f(a_t)$
- ▶ Rewards: inversely proportional to the distance to the goal state

# PROOF-OF-CONCEPT

- ▶ Algorithm: Differential Q-learning (Wan, Naik, & Sutton 2020)



*Beginning of training*



*End of training*

# DISCUSSION

## From prototype to product:

- ▶ Multi-dimensional EEG data as input, along with features such as time of day, age of the individual, etc.
- ▶ Brain-state categorization using deep neural networks trained on datasets of thousands of people (e.g., Malafeev et al. 2018)
- ▶ Usage of audio and visual cues to affect the brain state

**Goal:** an active closed-loop system that learns in real-time the set of audio-visual cues best suited for every individual to lead them to a physiologically-objective goal state from any state.

- ▶ Feedback?
- ▶ Questions?



# REFERENCES

- ▶ Wright Jr, K. P., Badia, P., & Wauquier, A. (1995). Topographical and temporal patterns of brain activity during the transition from wakefulness to sleep. *Sleep*, 18(10), 880-889
- ▶ Marzano, C., Moroni, F., Gorgoni, M., Nobili, L., Ferrara, M., & De Gennaro, L. (2013). How We Fall Asleep: Regional and Temporal Differences in Electroencephalographic Synchronization at Sleep Onset. *Sleep Medicine*, 14(11), 1112-1122
- ▶ Malafeev, A., Laptev, D., Bauer, S., Omlin, X., Wierzbicka, A., Wichniak, A., ... & Achermann, P. (2018). Automatic Human Sleep Stage Scoring Using Deep Neural Networks. *Frontiers in Neuroscience*, 12:781
- ▶ Lee, M., Song, C.B., Shin, G.H., Lee, S.W. (2019). Possible Effect of Binaural Beat Combined With Autonomous Sensory Meridian Response for Inducing Sleep. *Frontiers in Human Neuroscience*, 13:425
- ▶ Wan, Y., Naik, A., & Sutton, R. S. (2020). Learning and Planning in Average-Reward Markov Decision Processes. *Under review*, arXiv preprint 2006.16318

# CHALLENGES TO SUCCESS

## From prototype to product:

- ▶ Not many physiologically-objective goal states. Research is limited in isolating brain states unique to an activity, e.g., meditation.
- ▶ Goal states might vary significantly across individuals. Might require an active categorization system based on features like heart rate.
- ▶ The audio-visual cues might have delayed consequences, making credit assignment harder.
- ▶ Might not know of cues that can achieve a given goal state even under ideal conditions.

# WHY TARGET SLEEP?

- ▶ **Insomnia is widely prevalent:**
  - ▶ Adults: ~33% (Bhaskar et al. 2016)
  - ▶ Adolescents: 4–23.8% (Ohayon et al. 2000, Roberts et al. 2008)
  - ▶ Ages 5–10: ~20% (Armstrong et al. 2014)
- ▶ Regular good sleep helps maintain focus, improve athletic performance, helps the immune system, etc.
- ▶ The 'Deep Sleep' state is a physiologically-objective state.
- ▶ Studies show some audio cues help in inducing sleep.