Unsupervised Clustering Uncovers Two Distinct Types of Fixational Eye-Movements in Dynamic Environments

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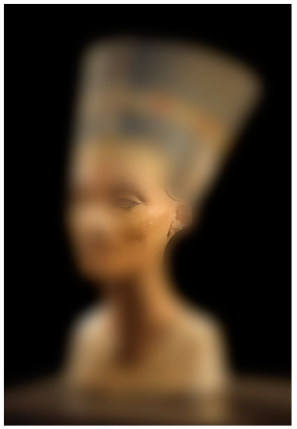
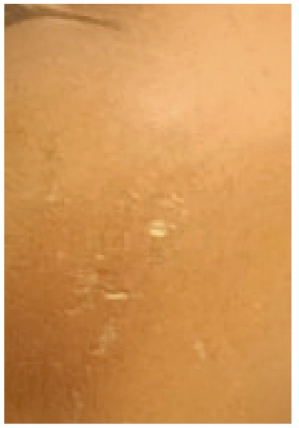
Why Study Eye Movements in Dynamic Tasks?

- Gaze isn‘t random – it reflects planning, monitoring, and adaptation

- Eye movements reveal **action strategies** in real-time

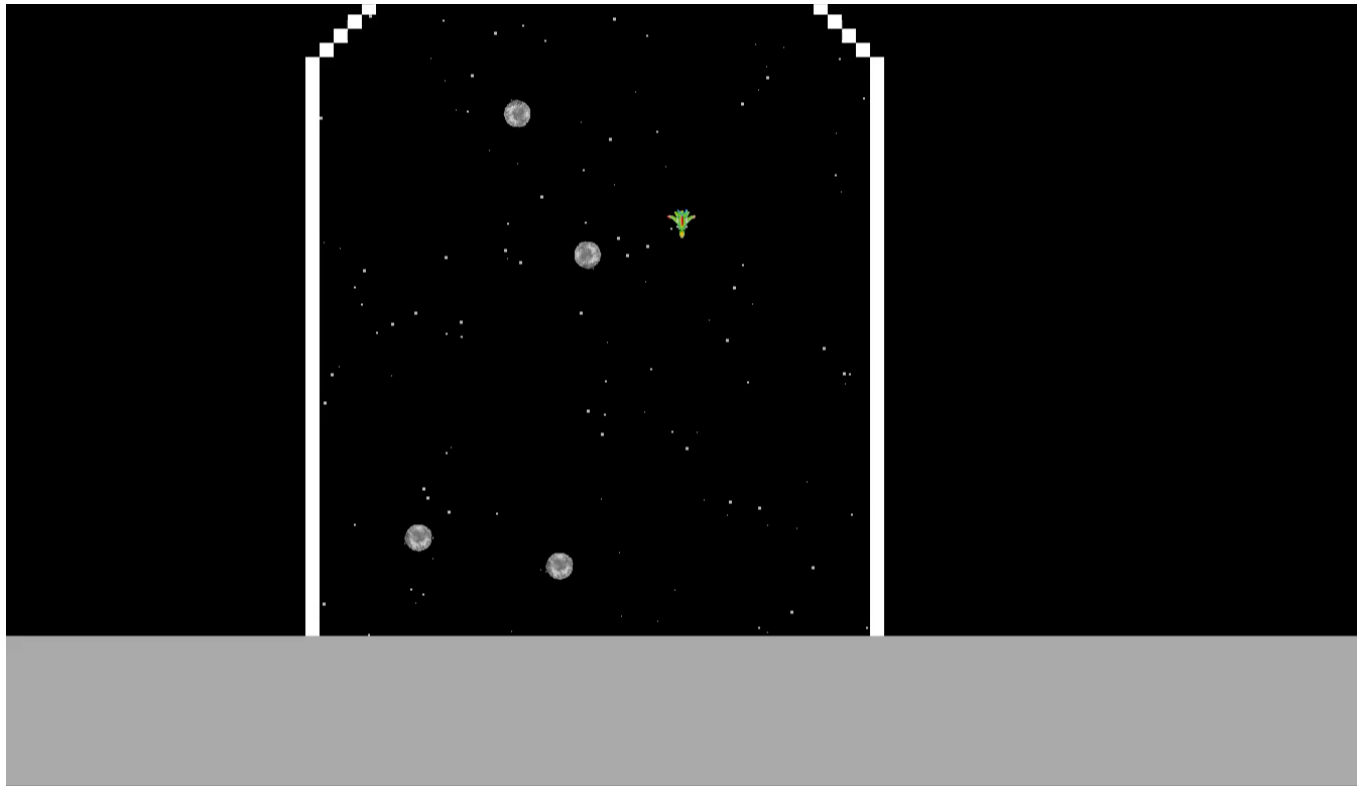




- In **dynamic environments**, we constantly switch between different visual roles

- Understanding these patterns has implications for both sensorimotor theory and psychopathological research

The Dodge Asteroids Task



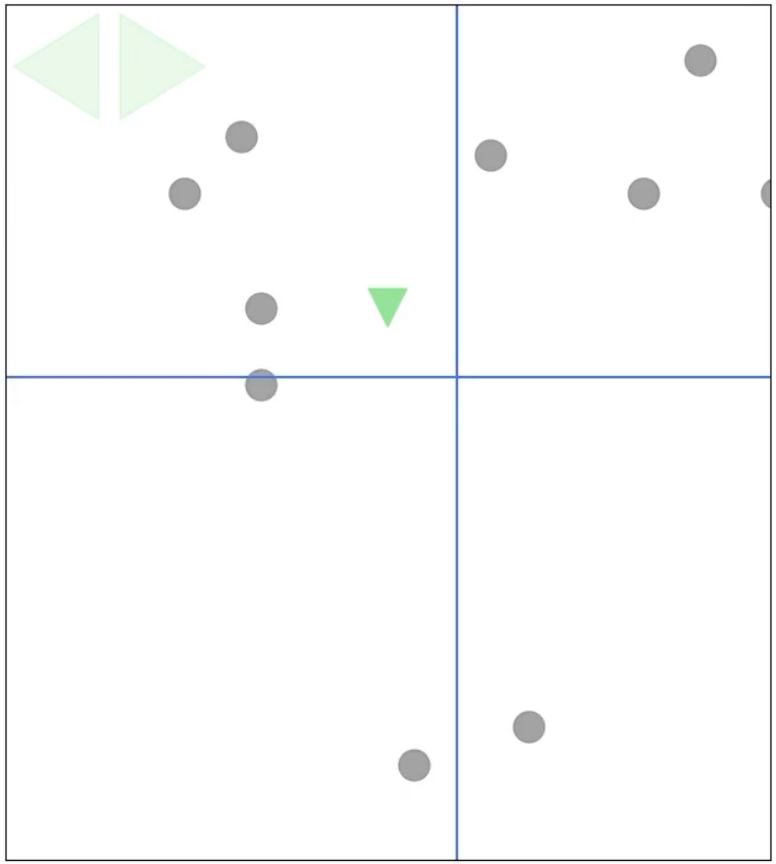
Key Manipulation

Input Noise (5 levels)
SD: 0, 0.5, 1.0, 1.5, 2.0

Increasing uncertainty in motor control

Forces adaptive gaze strategies

Eye-Movement Recording



Technical Setup

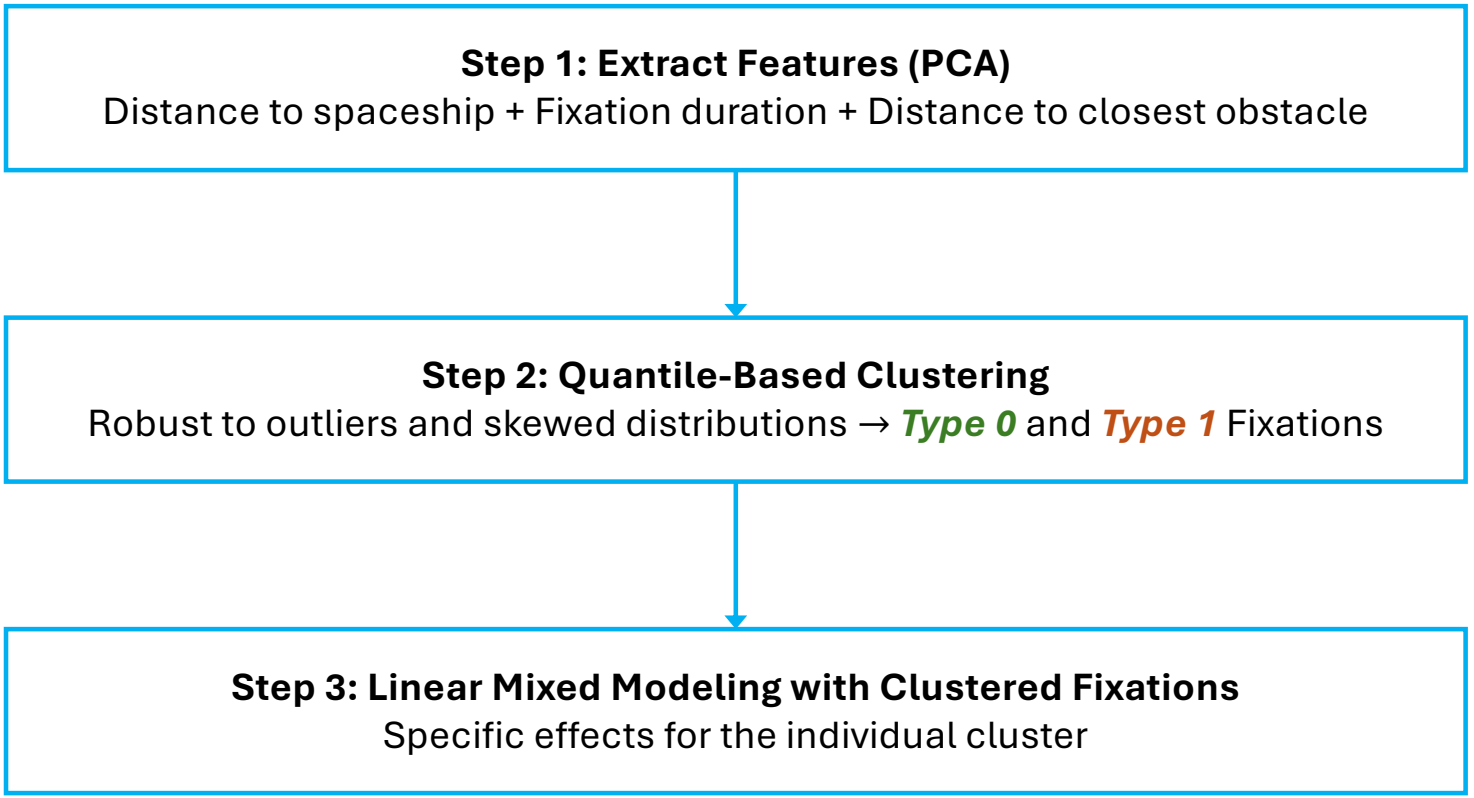
- ViewPixx TRACKPixx 3 Eye-tracker
  - 2000 Hz sampling rate
  - Binocular tracking
- Chin rest 80cm from screen
- 1920x1080, 60Hz

Fixation Algorithm

- Velocity–based saccade detection[1,2]
  - $\lambda = 6, threshold \geq 0.5°$
- Fixations as intervalls between saccades
- 31,505 Fixations

[1]: Engbert & Kliegl, 2003; [2]: Engbert & Mergenthaler, 2006

Our Approach: Data Driven Clustering

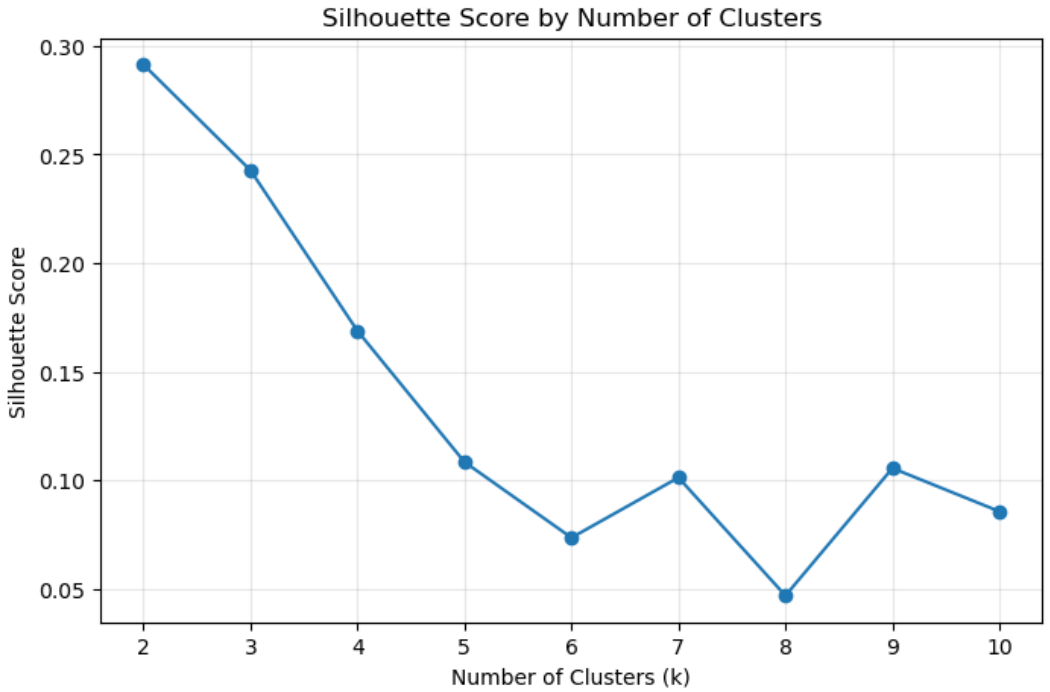


Our Approach: Data Driven Clustering

Step 1: Extract Features (PCA)
Distance to spaceship + Fixation duration + Distance to closest obstacle

Step 2: Quantile-Based Clustering
Robust to outliers and skewed distributions → ***Type 0*** and ***Type 1*** Fixations

Step 3: Linear Mixed Modeling with Clustered Fixations
Specific effects for the individual cluster



https://github.com/nilsheinrich/IEEE-SPMB2025.git

Why Quantile-Based Clustering?

Challenges

Eye-movement data features:

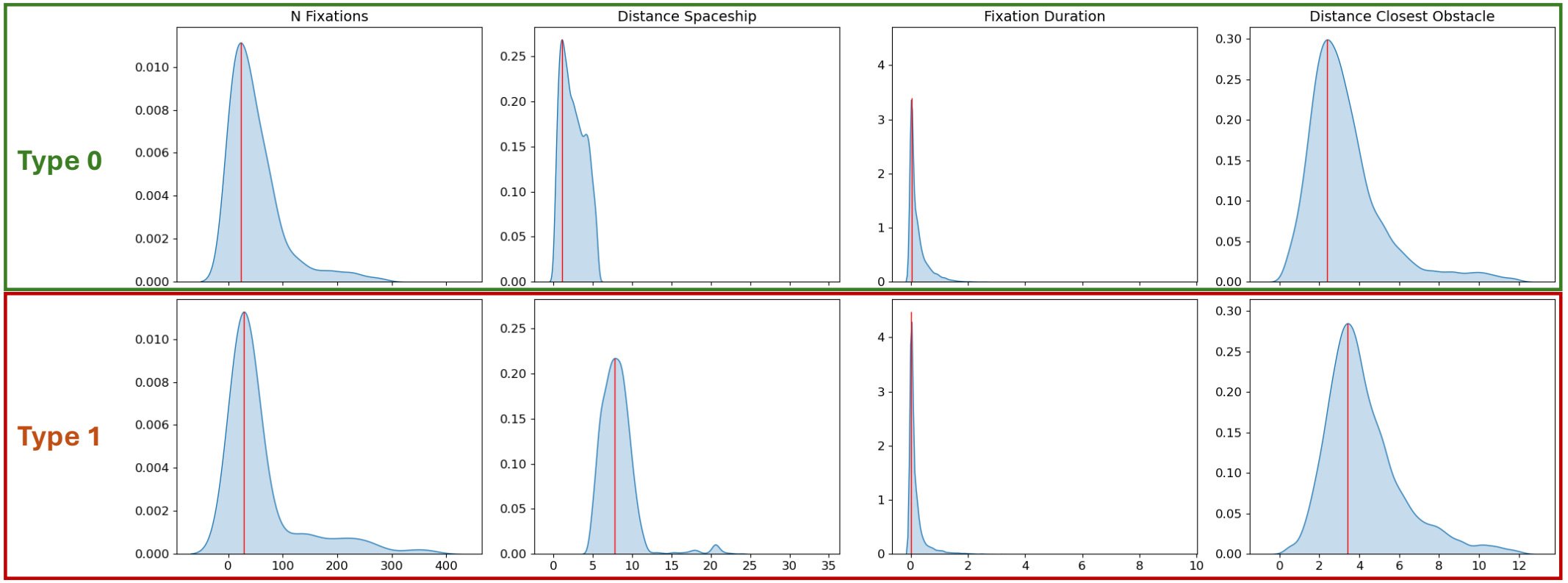
- Non-Gaussian features & Heavy-tailed distributions
- Outliers (fast saccades, long fixations)
- Strong interdependencies

Advantages

- **Robust to outliers**
- Handles skewed distributions naturally
  - No assumptions about distribution shape
- Variable-wise normalization

Think ot it as: „Let the data tell us what groups exist, rather than imposing theoretical categories“

Two Distinct Types of Fixational Eye-Movements



Linear Mixed Modeling:
How Do Fixations Adapt to Input Noise?

Type 0

- ⬇ **Frequency** (N_0): fewer
- ⬇ **Duration**: shorter
- ⬇ **Distance to spaceship**: closer
- ➡ **Distance to obstacle**: unchanged

Type 1

- ⬇ **Frequency** (N_1): fewer
- ⬆ **Duration**: longer
- ➡ **Distance to spaceship**: unchanged
- ⬆ **Distance to obstacle**: farther

Linear Mixed Modeling:
How Do Fixations Adapt to Input Noise?

Type 0

Fixating the spaceship

...more focused: tighter monitoring when control is compromised
(closer distances to spaceship)

Type 1

Fixating future locations (smooth pursuits?)

...more cautious: risk-reducing strategy
(farther distances to obstacles)

Why This Matters Clinically

- Eye movements are disrupted in multiple psychiatric and neurological conditions
- **Type 0** and **Type 1** fixations reflect distinct modes of self-environment coupling
- These coupling mechanisms are often impaired in *clinical populations*

Clinical Populations

Borderline Personality Disorder[1,2]

- Impaired visual **fixation** stability
- Hypervigilance toward threat-relevant stimuli
- Deficits in task set preparation (antisaccade tasks)
- Failure to adapt fixation patterns to context

[1]: Seitz, Leitenstorfer, Krauch, Hillmann, Boll, Ueltzhoeffer, Neukel, Kleindienst, Herpertz & Bertsch, 2021
[2]: Bortolla, Spada, Lazzarino & Maffei, 2020

Schizophrenia[3,4]

- **Smooth pursuit** impairments (eyes lag behind moving target)
- Frequent catch-up saccades during tracking
- Disrupted corrollary discharge (prediction signals)

[3]: Thaker, Avila, Hong, Medoff, Ross, & Adami, 2003
[4]: Thakkar & Rolfs, 2019

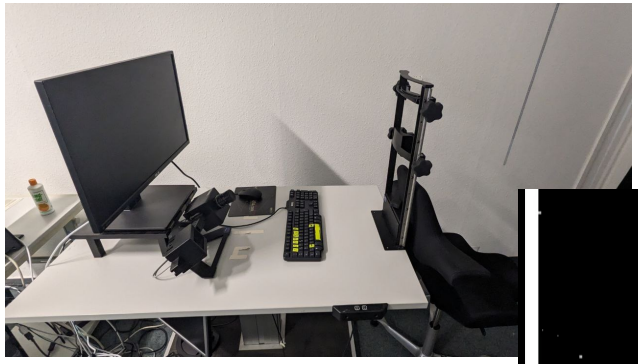
Hypothesis: Clinical populations may show an unbalance between anchoring (Type 0) and predictive-tracking (Type 1) fixations

Key Takeaways

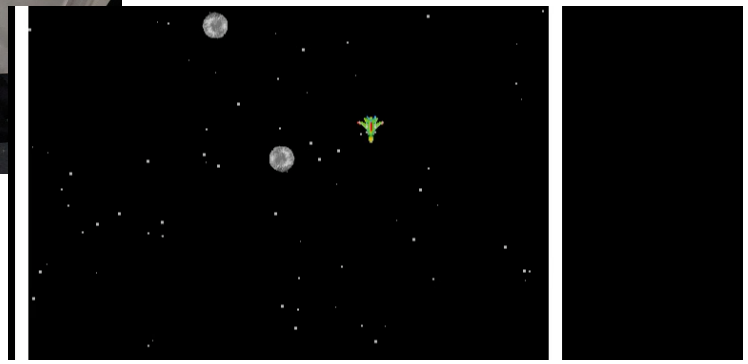
- Methodical Innovation:
  Data-driven clustering reveals fixation types that go beyond simple foveal/peripheral categorization
- Two Functional Roles:
  Type 0 (anchoring) and Type 1 (tracking) serve distinct purposes and adapt differently to uncertainty
- Clinical Potential:
  Framework may reveal how psychiatric conditions disrupt self-environment coupling in naturalistic action control

Future Directions

- Validate **Type 1** fixations as smooth pursuit movements (velocity analysis)
- Move on to testing clinical populations
- Develop computational models of adaptive gaze allocation



Thank You



Questions?

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