Ball Pushing Metrics Documentation

This document provides a comprehensive explanation of all metrics computed by the `BallPushingMetrics` class for analyzing fly-ball interaction behavior.

Overview

The Ball Pushing Metrics system analyzes behavioral data from experiments where flies interact with balls in controlled environments. Each metric captures different aspects of the fly's learning and motor behavior during ball manipulation tasks.

Pixel-to-millimeter conversion: All thresholds are given in both pixels and millimeters. The conversion factor is 1 pixel = 0.06 mm (based on 30 mm = 500 pixels).

Core Event Definitions

Basic Event Types

These are metrics that are used as tools to generate the summary metrics.

- **Interaction Event**: A period where the fly is in close proximity to the ball and potentially manipulating it
  - *Close proximity threshold*: ≤ 45 pixels (2.7 mm) distance between fly and ball
- **Significant Event**: An interaction event that results in significant ball displacement
  - *Threshold*: > 5 pixels (0.3 mm) ball displacement
- **First Major Event**: The first significant event that crosses a higher threshold, often considered the "aha moment"
  - *Threshold*: ≥ 20 pixels (1.2 mm) ball displacement
- **Final Event**: The last interaction event that achieves the final distance threshold before task completion
  - *Threshold*: 170 pixels (10.2 mm) for standard experiments, 100 pixels (6.0 mm) for F1 experiments
  - *Note*: This represents the last significant interaction that moves the ball toward the task goal

Temporal Metrics

These metrics capture how behavior changes over time:

Event Counts and Timing

`fly_distance_moved`

Description: Total distance traveled by fly throughout experiment **Calculation**: Sum of frame-to-frame Euclidean distances for fly position **Units**: millimeters

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Ball Pushing Metrics (current)

This README documents the metrics produced by `BallPushingMetrics` as implemented in `ballpushing_metrics.py`. It removes duplicates and reflects the current code paths, units, and configurable thresholds.

Note on configuration and gating

- Each metric is computed only if enabled via `fly.config.enabled_metrics` (None means compute all).

- Many thresholds are configurable in `fly.config` (values below are typical defaults; use your config for ground truth).
- Pixel-to-millimeter conversion uses `fly.config.pixels_per_mm` (default ≈ 16.67 px/mm → 1 px ≈ 0.06 mm).

Core event concepts (as used by the code)

- Interaction event: a contiguous contact/proximity bout between fly and ball (precomputed in `tracking_data`).
- Significant event: event with ball movement exceeding `config.significant_threshold` (in pixels) along y.
- Major event ("aha"): first event exceeding `config.major_event_threshold` (pixels).
- Final event: last event where ball distance from start reaches the threshold. Threshold is chosen per ball identity:
    - Standard: `config.final_event_threshold` (e.g., 170 px)
    - F1 test ball: `config.final_event_F1_threshold` (e.g., 100 px)

Identification fields

- fly_idx, ball_idx, ball_identity ("training", "test", or None)

Event counts and timing

- nb_events: Adjusted number of interaction events normalized by available time (float).
- nb_significant_events: Count of significant events up to the final event.
- significant_ratio: nb_significant_events / number of events considered (0–1).
- max_event / max_event_time: Index/time of event closest to maximum displacement (s).
- first_significant_event / first_significant_event_time: Index/time of first significant event (s).
- first_major_event / first_major_event_time: Index/time of first major (aha) event (s).
- final_event / final_event_time: Index/time (s) of last event reaching the final threshold.
- has_significant / has_major / has_finished: 1 if such event exists, else 0.
- exit_time / chamber_exit_time: Raw timing from tracking_data (s).

Spatial manipulation metrics

- max_distance: Max euclidean distance of ball from its start (pixels).
- distance_moved: Sum of euclidean distances across events using median start/end frames (pixels).
- distance_ratio: distance_moved / max_distance (≥ 1 indicates efficient directional movement).
- success_direction: "push", "pull", "both", or None based on movement past `config.success_direction_threshold`.

Directionality counts (significant events only)

- pushed: Number of pushing events.
- pulled: Number of pulling events.
- pulling_ratio: pulled / (pushed + pulled) in [0,1].

Interaction amount and persistence

- interaction_proportion: Fraction of session spent in interaction (0–1).
- interaction_persistence: Mean duration of interaction events (s).
- cumulated_breaks_duration: Total duration of gaps between events that overlap analyzed intervals (frames).

Velocity and trends

- normalized_velocity: Fly velocity normalized by available space (dimensionless).
- velocity_during_interactions: Mean fly speed during interactions (px/s).
- velocity_trend: Slope of velocity vs time (px/s²).
- overall_slope: Slope of ball y-position vs time (px/s).
- overall_interaction_rate: Events per second across the whole session (events/s).

Learning and curve fitting

- learning_slope / learning_slope_r2: Linear fit of ball y-position over time.
- logistic_L / logistic_k / logistic_t0 / logistic_r2: Logistic fit parameters and R^2 of ball y-position.
- event_influence: Dict with
    - avg_displacement_after_success
    - avg_displacement_after_failure
    - influence_ratio (= success/failure)

Area under curve (AUC) and binning

- auc: $\int$ distance_from_start dt using euclidean distance (pixel·seconds).
- binned_slope_[0..11]: Slope per time bin (px/s).
- interaction_rate_bin_[0..11]: Events per second per bin (events/s).
- binned_auc_[0..11]: AUC per bin (pixel·seconds).

Chamber and spatial occupancy

Ball Pushing Metrics (current)

- chamber_time: Time in chamber radius (s).
- chamber_ratio: chamber_time / total analyzed time (0–1).
- time_chamber_beginning: Time in chamber during first 25% of video (s).
- persistence_at_end: Fraction of frames at/after `config.corridor_end_threshold` (0–1).
- Pauses (medium): 5–10 s
    - nb_pauses, median_pause_duration, total_pause_duration Skeleton-derived metrics (computed only when skeleton data is available)
- fraction_not_facing_ball: Fraction of time outside chamber the fly is not facing corridor direction (angle > 30°).
- flailing: Mean motion energy of front legs during interactions (higher = more flailing).
- head_pushing_ratio: Fraction of contacts dominated by head pushing (0–1). Honors `config.exclude_hidden_legs`.

Fly movement (global)

- success_direction is particularly informative in F1 where pulling may achieve success.

- pixels_per_mm, enabled_metrics, debugging

- exclude_hidden_legs, contact_nodes, head_pushing_threshold, late_contact_window

Version **Units**: pixel·seconds

Description: Average duration of interaction events

Units: seconds

Description: Whether major breakthrough occurred in first event

Interpretation: Immediate vs. gradual task discovery

Temporal Structure Metrics

Activity Patterns

`cumulated_breaks_duration`

Ball Pushing Metrics (current)

Ball Pushing Metrics (current)

Description: Total time between interaction events

Interpretation: Rest/planning time between manipulation attempts

Description: Weighted ratio of front leg visibility during contact events

Description: When fly left experimental chamber *Note*: Exit time is also used to compute timing based metrics such as `final_event_time`

Threshold Summary

The following table summarizes all thresholds used in the metrics: **Description**: Efficiency of ball manipulation

Interpretation: 0.5 = balanced, > 0.5 = pulling more often than pushing, < 0.5 = pushing more often than pulling.

Note: This metric is particularly relevant for F1 experiments where the task can be achieved by pulling the ball as well as pushing it.

Movement and Locomotion Metrics

Velocity Analysis

velocity_during_interactions

velocity_trend

Description: Total distance traveled by fly throughout experiment

Spatial Distribution

Calculation: Duration within chamber radius during first quarter of video

Calculation: Proportion of frames where fly is at or beyond corridor end threshold distance

interaction_proportion

Description: Fraction of time spent interacting with ball **Calculation**: Total interaction duration / experiment duration **Range**: 0.0 to 1.0 **Interpretation**: Task engagement level

Freeze and Pause Behavior

number_of_pauses / **total_pause_duration**

Units: count / seconds

nb_freeze

Units: count

median_freeze_duration

Description: Median duration of locomotor pause events

Calculation: Median of all detected pause episode durations

Learning and Strategy Metrics

Learning Dynamics

Units: pixels/second / R^2

- $t0$: Midpoint time (50% achievement)

- $r2$: Model fit quality

Interpretation: Captures S-shaped learning curves typical of skill acquisition **Description**: Global behavioral trends

Calculation: Overall ball displacement rate / total interaction frequency

Units: pixels/second / events/second

Interpretation: Summary measures of performance and activity

auc

Description: Total area under ball position curve

Calculation: Integral of ball Y-position over entire experiment

Units: pixel·seconds

Interpretation: Cumulative manipulation achievement

Strategy and Persistence

interaction_persistence

Description: Average duration of interaction events

Calculation: Mean duration of all interaction episodes

Units: seconds

Interpretation: Longer values indicate sustained manipulation attempts

major_event_first

Description: Whether major breakthrough occurred in first event

Values: True/False

Calculation: Boolean indicating if first_major_event index = 0

Interpretation: Immediate vs. gradual task discovery

Temporal Structure Metrics

Activity Patterns

cumulated_breaks_duration

Description: Total time between interaction events

Calculation: Sum of all inter-event intervals

Units: seconds

Interpretation: Rest/planning time between manipulation attempts

Behavioral Strategy Metrics

These metrics analyze specific behavioral patterns and strategies used by flies during ball manipulation:

Body Orientation

fraction_not_facing_ball

Description: Fraction of time when fly is not facing the ball direction while outside chamber

Calculation: Proportion of frames where fly's body orientation deviates more than 30° from corridor direction (toward ball) when outside starting chamber

Range: 0.0 to 1.0

Interpretation: Higher values indicate distraction or lack of directional focus; lower values suggest goal-directed behavior

Motor Behavior Patterns

flailing

Description: Average motion energy of front legs during interaction events

Calculation: Motion energy computed as sum of squared velocity differences for leg keypoints during ball interactions

Units: dimensionless motion energy

Interpretation: Higher values indicate more energetic leg movement during interactions, potentially reflecting struggle or inefficient manipulation

head_pushing_ratio

Description: Proportion of contacts where head is used for pushing rather than legs

Calculation: Frame-by-frame analysis during contact events to determine whether head or legs are closer to ball

Range: 0.0 to 1.0

Interpretation: 1.0 = pure head pushing strategy, 0.0 = pure leg pushing strategy, 0.5 = mixed strategy

Contact Analysis

median_head_ball_distance

Description: Median distance between fly head and ball during contact events

Calculation: Median Euclidean distance across all contact frames

Units: pixels

Interpretation: Lower values indicate head-pushing behavior; higher values suggest leg-pushing with head maintained at distance

mean_head_ball_distance

Description: Mean distance between fly head and ball during contact events

Calculation: Average Euclidean distance across all contact frames

Units: pixels

Interpretation: Complements median distance; comparison reveals distribution shape of head-ball distances

leg_visibility_ratio

Description: Weighted ratio of front leg visibility during contact events

Calculation: Weighted score based on number of visible front legs per frame during contacts (0-2 legs visible)

Range: 0.0 to 1.0

Interpretation: Higher values indicate better leg tracking quality and potentially more leg-based manipulation

Task Completion Metrics

Achievement Status

has_finished

Description: Binary indicator of task completion

Calculation: 1 if final event exists (ball moved to completion threshold), 0 otherwise

Values: 0 or 1

Interpretation: Simple binary measure of whether fly successfully completed the ball-pushing task

has_major

Description: Binary indicator of major event achievement

Calculation: 1 if a major event was detected, 0 otherwise

Values: 0 or 1

Interpretation: Indicates whether the fly achieved a major breakthrough event during the experiment

has_significant

Description: Binary indicator of significant event achievement

Calculation: 1 if at least one significant event (ball displacement > 5 pixels / 0.3 mm) was detected, 0 otherwise

Values: 0 or 1

Interpretation: Indicates whether the fly achieved any significant ball manipulation event

Experimental Context Metrics

Timing References

`exit_time` / `chamber_exit_time`

Description: When fly left experimental chamber

Note: Exit time is also used to compute timing based metrics such as `final_event_time`

Calculation: Timestamp when fly moved beyond chamber radius

Units: seconds

Interpretation: Later exit_time can indicate struggle to exit or lack of motivation to explore.

Threshold Summary

The following table summarizes all thresholds used in the metrics:

Threshold Type	Pixels	Millimeters	Degrees	Used For
Interaction proximity	≤ 45	≤ 2.7 mm	-	Detecting when fly is close enough to ball for interaction events
Significant event	> 5	> 0.3 mm	-	Significant ball displacement; used for significant events, push/pull classification
Major event	≥ 20	≥ 1.2 mm	-	First major breakthrough ("aha moment")
Success direction	≥ 25	≥ 1.5 mm	-	Determining successful manipulation direction (push/pull/both)
Final event (standard)	170	10.2 mm	-	Task completion threshold for standard experiments
Final event (F1)	100	6.0 mm	-	Task completion threshold for F1 experiments (second part)
Body orientation	-	-	30°	Angle deviation from corridor direction for `fraction_not_facing_ball`

Statistical tests

Broad exploration approach

For broad exploration of different experiments, we realised a Mann-whitney test for each metric to compare conditions to controls as it doesn't assume normal distribution and thus can be used with our data generally. In conditions where more than two conditions were compared, we applied a FDR multiple comparisons correction.

As an alternative, especially for heavily skewed data, we also generated permutation test of the metrics tested, which is more robust to skewed data but for the mean yields similar results.