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pypillometry: A Python package for pupillometric analyses

Matthias Mittner[1]

1 Institute for Psychology, UiT The Arctic University of Norway, Norway

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Summary

The size of the human pupil is controlled by pairs of constrictor and dilator muscles that allow its opening (dilation) and closing (constriction) in response to varying lighting conditions (Mathôt, 2018). Importantly, it has long been known that the pupil also reacts to psychological important stimuli (Hess & Polt, 1960) and has been a firmly established tool for studying "mental effort" in the research kit of psychologists for many decades (Laeng, Sirois, & Gredebäck, 2012). More recently, pupil-size has been linked to the norepinephrinergic (NE) system originating from area *locus coeruleus* (LC) in the brainstem (Aston-Jones & Cohen, 2005), a link that has been substantiated experimentally by direct recordings in the brainstem of monkeys (Joshi, Li, Kalwani, & Gold, 2016). This finding of a correlation between NE activity in the brainstem and pupil-dilation has opened the way for researchers investigating the relationship between the LC-NE system and many cognitive functions, such as cognitive control (Gilzenrat, Nieuwenhuis, Jepma, & Cohen, 2010) and mind wandering (Mittner, Hawkins, Boekel, & Forstmann, 2016). Advancing this emerging field requires the decomposition of the pupillometric signal into tonic (baseline) and phasic (response) components that relate to different processing regimes of the LC-NE system.

The Python package `pypillometry` is a comprehensive library implementing preprocessing, plotting and advanced analysis tools in a coherent and extensible, object-oriented framework. It is oriented towards researchers in psychology and neuroscience that wish to analyze data from pupillometric experiments. `pypillometry` implements an intuitive, pipeline-based processing strategy where an analysis pipeline can be dynamically chained together. All operations and parameters applied to a dataset are stored in its history. This allows (1) a transparent and comprehensive logging of the operations applied for an analysis which is valuable for reproducible analyses, (2) the ability to "roll-back" any changes made to any point in the history of the dataset and (3) to easily generalize a processing pipeline to multiple datasets. The package contains pre-processing facilities implementing algorithms for blink detection and interpolation, filtering and resampling. All parameters are clearly documented, accessible and set to sensible default-parameters. A focus of the package is to provide extensive visualization features in order to facilitate dynamic exploration of the data as well as iterative adjustment of the pre-processing parameters. As the time-series of pupillometric data can be quite long, this requires separation into several plots or dynamically adjustable plot-axes. Both strategies are implemented in this package by allowing interactive plots if run from a Jupyter-Notebook (Kluyver et al., 2016) or storing a multi-page PDF document, allowing both interactive and scripted use. The `pypillometry` package also implements functions for event-related pupil-dilation (ERPD) analyses both at the individual and the group-level. Finally, the package implements novel algorithms for decomposing the pupillometric signal into tonic and phasic components. This approach allows to simultaneously quantify dynamic changes of both baseline and response-strength that can be related to the tonic and phasic processing regimes of the LC-NE system.

`Pypillometry` was already used for the analyses of several pupillometric datasets in our department. Several software packages with similar goals are available in R (e.g., Geller, Winn, Mahr, & Mirman, 2020; Forbes, 2020). However, to date, no comprehensive Python-based solution besides `pypillometry` exists. None of the other packages provides facilities to estimate tonic and phasic components of the pupillometric signal.

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