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Supplemental Information

Optomotor Swimming in Larval Zebrafish Is Driven by Global Whole-Field Visual Motion and Local Light-Dark Transitions

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Supplementary figures

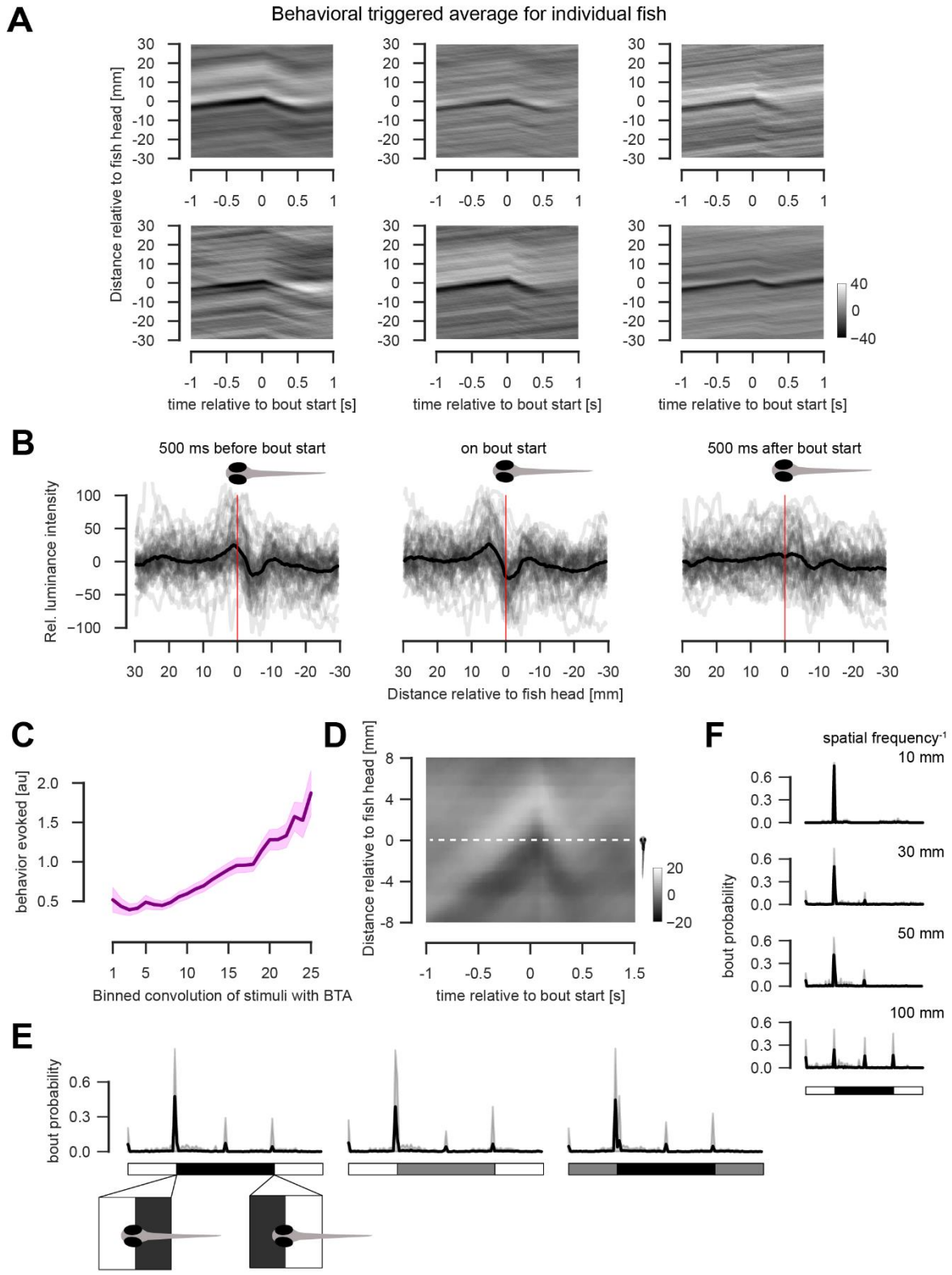

Figure S1. Related to Figure 2. Behavioral triggered average is stereotypical across individuals.
A) Behavioral triggered average (BTA) aligned to bout starts for different individual fish. The same light-dark transition trend is apparent across fish. In individual fish is more noise apparent than in the total average of 52 fish. Heatmaps indicate relative luminance intensity. **B)** Luminance profiles at different times related to bout onset. Average trace across fish in black, individual fish averages in light gray. **C)** Computed non-linearity for BTA with

stimulus (see Methods) **D)** Local filter across twelve fish. Compare to panel C) in Figure 2. A representative fish is shown right next to the filter for a size comparison. **E)** Bout probability for a binary stimulus consisting of white/black, white/gray, and gray/black bars of different spatial frequencies. Bouts were aligned depending on the correlation of the local visual environment with a reference stimulus (bars below the traces). Traces indicate mean across fish and spatial frequencies (N=25), shaded area represents 5% to 95% confidence interval. **F)** Same protocol as in E). Traces indicate the white/black bars condition for each spatial frequency tested. Shaded area indicates 5% to 95% confidence interval (N=25).

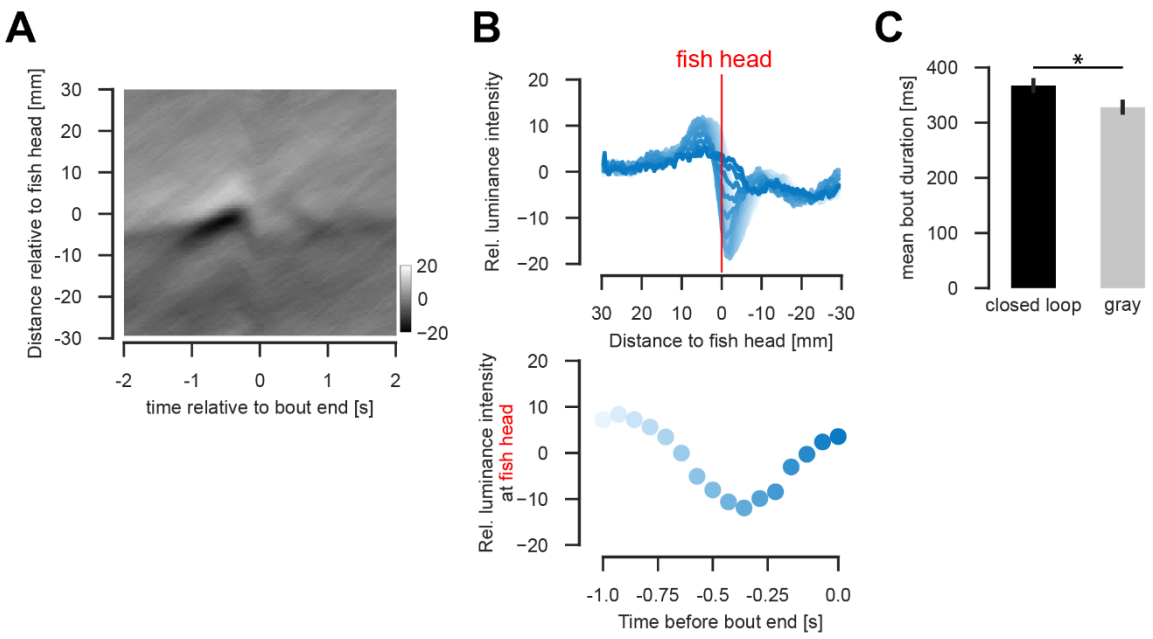

Figure S2. Related to Figure 2. Bout end triggered average shows no filter response. A) Bout end triggered average across fish, grating speeds and bar sizes. The bout inducing filter is still apparent. Heatmap shows relative luminance levels **B)** Relative luminance profile for visual scene (upper panel) and at fish head (indicated by red line), color coded in time (one second before bout end to bout end depicted in increasing blue saturations). The mean luminance profile approaches an average even luminance across the visual field. Around 400 ms before bout end (the average bout duration of a fish, as seen in C)), the luminance at fish head is minimal, and during swimming the luminance increases again. **C)** Mean bout duration of fish when provided normal closed-loop reafference or only even gray that relates to the grating with 0% contrast by overall constant luminosity. With this neutral stimulus, swim significantly less (Student's t-test, *: $p<0.05$), but still close to normal closed-loop bouts. Error bars indicate S.E.M., N=15.

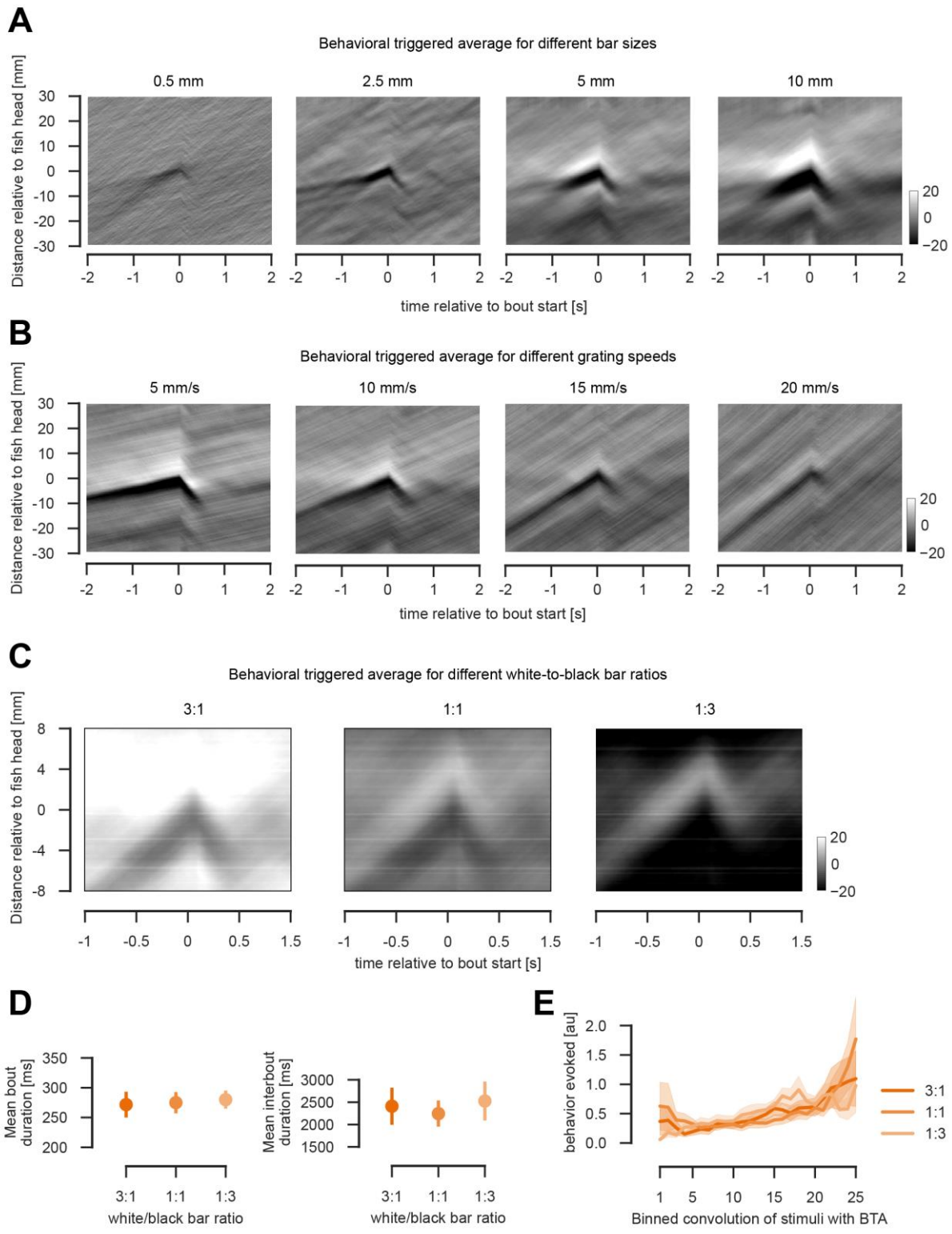

Figure S3. Related to Figure 3. The quality aspects of the behavioral triggered average are independent of grating properties. A) Behavioral triggered average for different bar sizes. **B)** Behavioral triggered average for different grating speeds, **C)** behavioral triggered average for different white-to-black-bar ratios. **D)** Mean bout and mean interbout duration for different white-to-black-bar ratios. Error bars indicate S.E.M. **E)** Nonlinearities for different white-to-black bar ratios. Shaded error shows S.E.M.

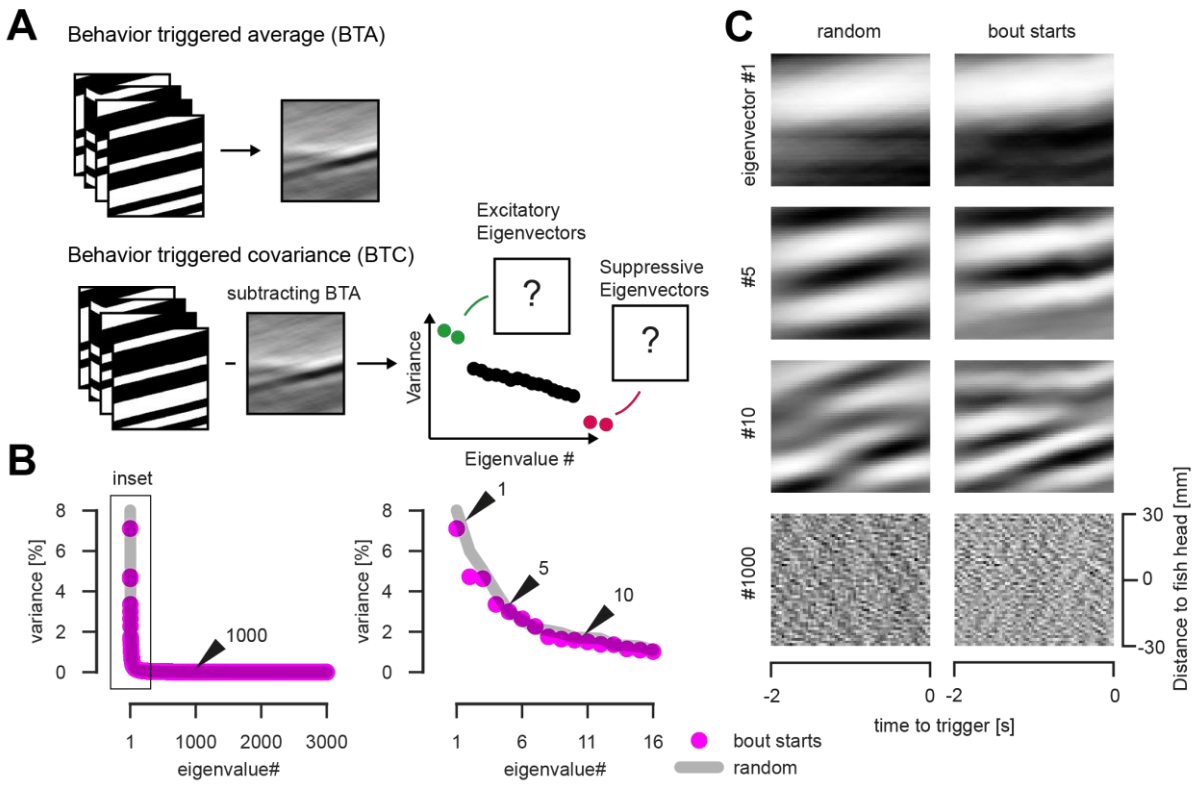

Figure S4. Related to Figure 1 and 2. Behavior triggered covariance analysis did not reveal further feature subspace. A) We determined the first filter by performing behavioral triggered average (BTA) to determine if more filters contribute to the OMR. **B)** Eigenvalues gained from singular-value decomposition of the covariance matrix of bout starts (magenta circles). The gray shade indicates the eigenvalues gained from a singular-value decomposition of the covariance matrix of shuffled bout starts. Example eigenvectors shown in C) are labeled with a black arrowhead and the respective eigenvalue number. **C)** Example eigenvectors for random and bout-triggered instances as derived from B).

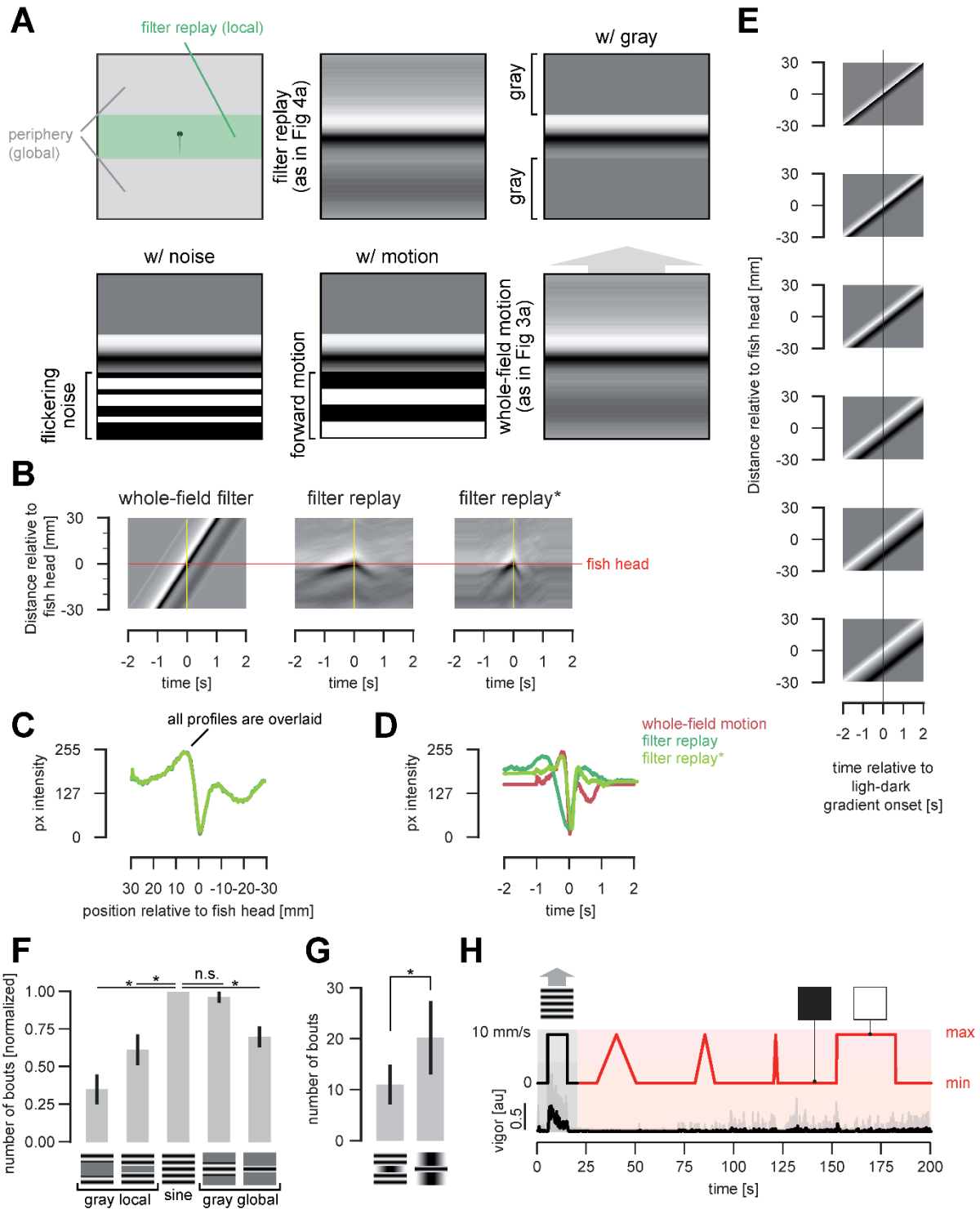

Figure S5. Related to Figure 4 and 5. Light-dark transitions and whole-field motion stimuli combinations. **A)** Visual stimuli that are presented in two zones: zone 1 either part of the filter replay, i.e. morphing of the filter, it is replaced with uniform gray, random flickering bars that induce peripheral noise, or forward moving bars. Zone 2 stays constant as being the filter replay. As a control, we are using the whole-field moving filter. How the filter is temporarily presented to the fish is shown in B). **B)** Stimuli presented across time. Note the squished version of the filter replay (indicated with an asterisks). **C)** The luminance distribution in the visual scene is constant on predicted bout onset, while **D)** the luminance on the fish head over time is different. We modified the filter replay stimulus as such to gain the same light-dark gradient as observed in the whole-field motion filter. **E)** Different visual stimuli that are tuned to different light-dark transition gradients. Visual stimuli are aligned to luminance decay onset. **F)** Average number of bouts normalized to whole-field sine gratings. Two different windows sizes

were probed, ± 5 mm and ± 10 mm, with either gray or sine gratings. In the periphery, there were either sine gratings or even gray (see icons). Error bars represent S.E.M., N=15. Significance was tested using pair-wise comparison t-tests with Bonferroni correction (*: $p < 0.0024$). **G)** Average number of bouts with local light-dark luminance changes and peripheral motion (left) or peripheral light-dark luminance changes with local motion (including light-dark transitions, right, see Methods). Error bars represent S.E.M., N=10. Significance was tested using Student's t-test (*: $p < 0.05$). **H)** Average vigor (see Methods) across fish (N=14). Fish were presented with forward, i.e. caudal to rostral, moving sine gratings at 10 mm/s in open loop condition (gray box) and whole-field luminance changes with different transition profiles (linear and steps, red box). Shaded error represents the 5% to 95% confidence interval across fish.

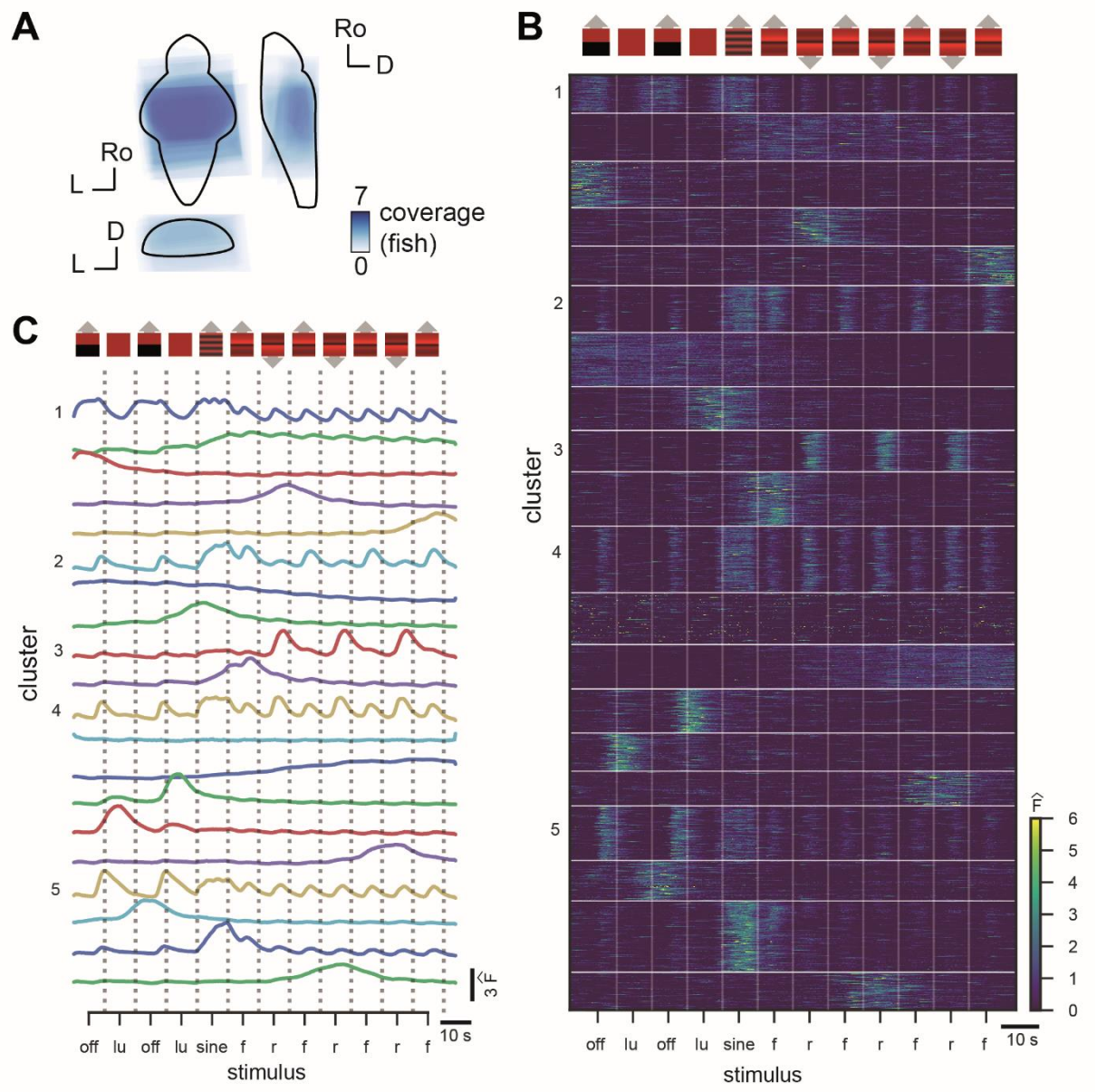

Figure S6. Relative to Figure 6. Grouping of distinct responses reveal five clusters tuned to the whole-field moving filter. A) Sampling coverage of functional imaging experiments. Colormaps indicate the number of fish sampled. **B)** Heatmap of all ROIs with z-scored fluorescence. Stimuli are indicated by off for off edge, lu for luminance transition, sine for a forward moving sine grating and f for the forward filter and r for the reverse filter (see Methods and Figure 4A). X-ticks indicate when stimuli are on the fish head, different stimuli are separated by light gray lines. **C)** Average activity profile of each cluster with same stimuli presented as in A).

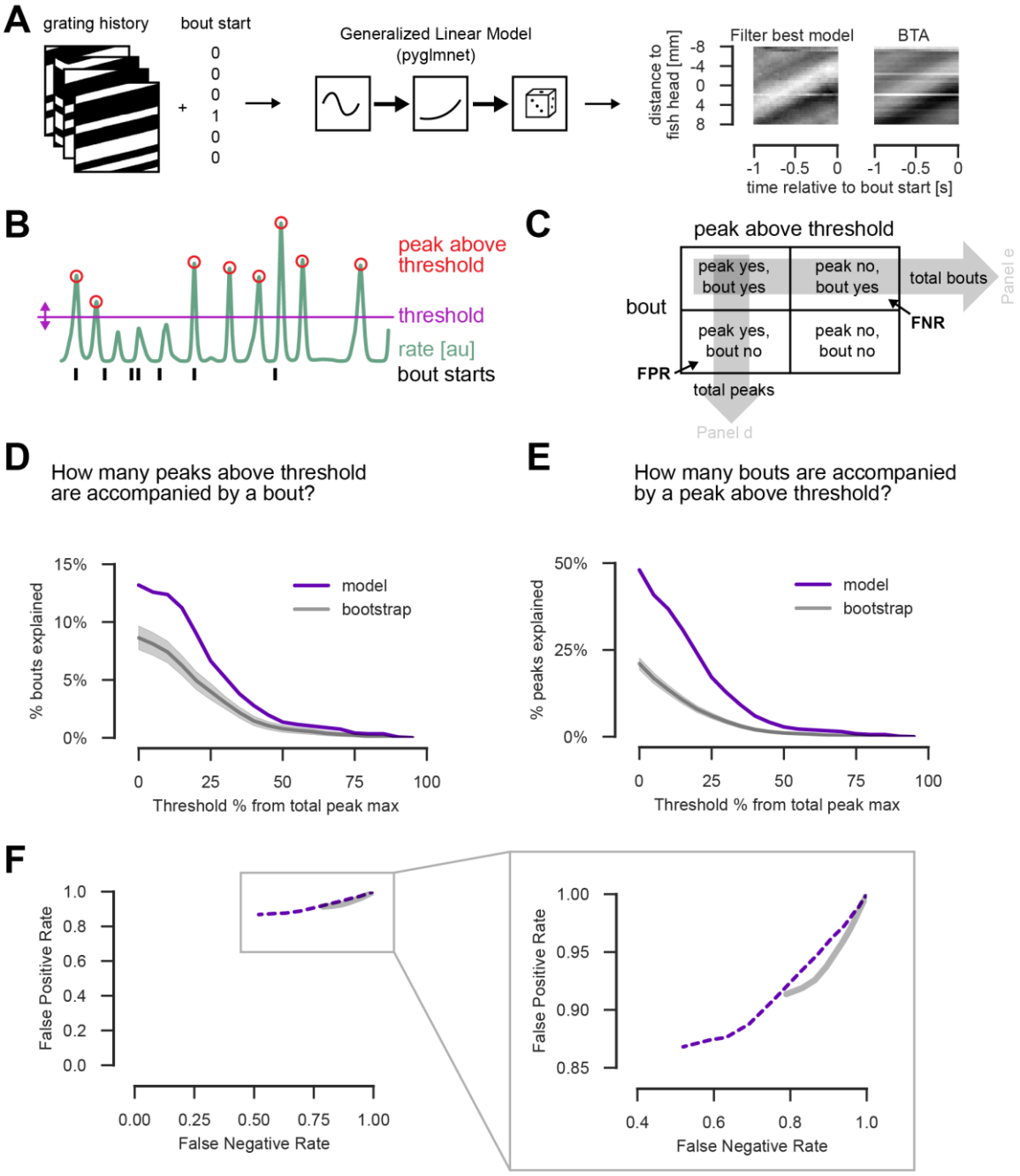

Figure S7. Related to Figure 1. A Generalized Linearized Model performs better than bootstrap control. **A)** Using the grating history as features and bout start (binary, yes and no) as labels, we fitted a generalized linear model (GLM) using pyglmnet (see Methods). The filter gained by the fitting is shown next to the behavioral triggered average of the training data. **B)** The GLM returns probability rates of a fish to swim. We used a variable threshold to determine which peaks above threshold are accompanied by a bout in a given window. **C)** Matrix indicating the four conditions. False positive and false negative rates (FPR and FNR, respectively) are indicated. **D)** Peaks above threshold accompanied by a bout (positive predictive value). Model in magenta, bootstrap (100 iterations) in gray with shaded error (standard deviation). **E)** Bout accompanied by a peak above threshold (True positive rate). Same color scheme as in D). **F)** False negative rate versus false positive rate. Color scheme as in D). To highlight that the bootstrap control does not achieve lower FPR and FNR rates we changed the line-style of the model.