Supplementary Methods: Van Wassenbergh & Aerts.

“Aquatic suction feeding dynamics: insights from computational modelling” J. R. Soc. Interface

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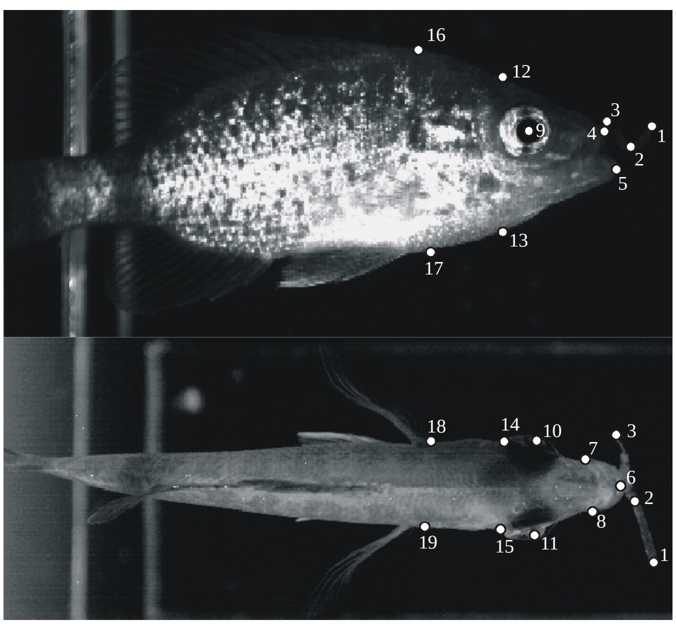
1. Kinematics of buccal expansion

The model mimics a single prey capture sequence of a *Lepomis gibbosus* of 75.7 mm in total length. This sequence was recorded with a Redlake M3 digital video camera (filming at 1000 Hz, shutter 1/2000 s, 1280 x 512 pixels) from lateral view, and a Redlake MotionPro camera (filming at 500 Hz, shutter 1/2000 s, 1280 x 1024 pixels) from dorsal view. Several kinematic events were used to synchronize both videos, and time 0 was set to the frame before the start of mouth opening. A bloodworm of approximately 17 mm in length was used as prey.

The following anatomical landmarks were digitized frame-by-frame (**Fig. A**) using Didge (Alistair Cullum, Creighton University, Omaha, U.S.A): front (1), middle (2) and back (3) of the prey; the tip of the upper (4, 6) and lower jaw (5); the left (7) and right (8) side of the base of the upper jaws; the center of the eyes (9, 10, 11), a fixed point on the dorsal (12), ventral (13), right (14) and left (15) contours of the head just posterior of the eye, and a fixed point on the dorsal (16), ventral (17), right (18) and left (19) contours at the level of the opercular spot.

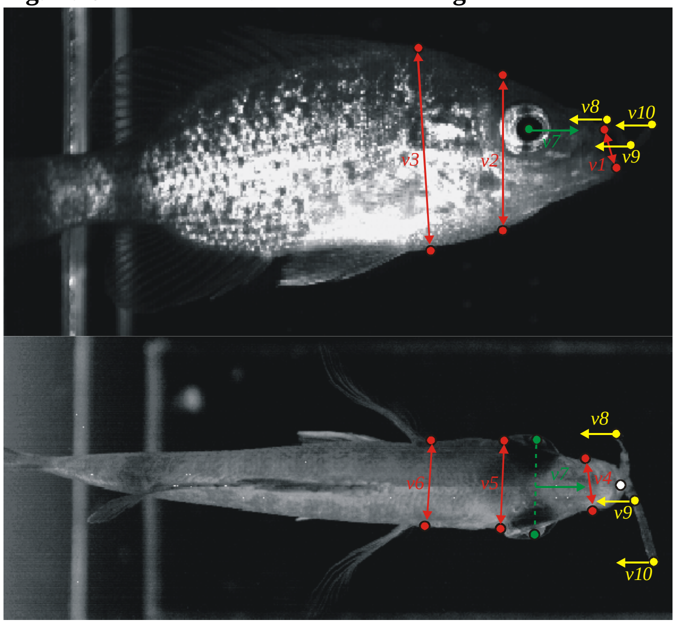
Fig. A: landmarks digitized



As shown in Fig. B, we calculated the velocity of expansion at three levels: the mouth (v1 and v4), the posterior edge of the eye (v2 and v5), and the opercula (v3 and v6). The forward velocity of the fish (v7) was calculated from the instantaneous horizontal displacement of landmarks 9, 10 and 11.

The prey velocity was calculated as the average of the velocities of the three landmarks on the prey (v9, v10 and v11).

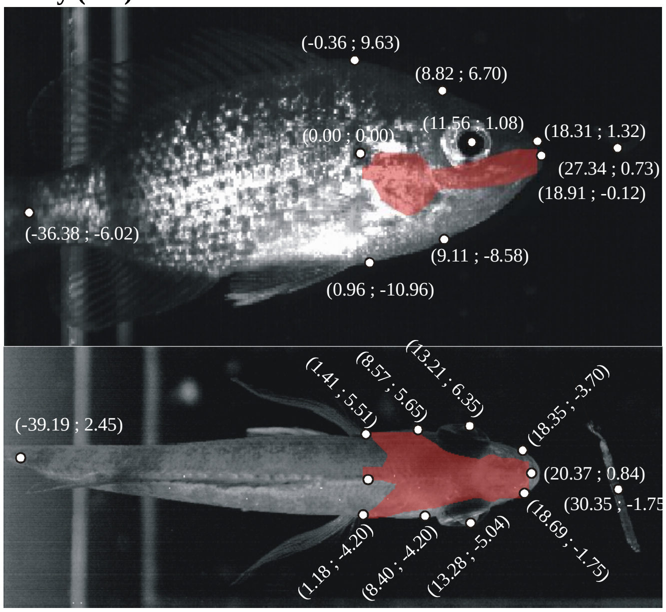
Fig. B: Velocities calculated from the digitized landmarks



2. Initial model configuration and mesh

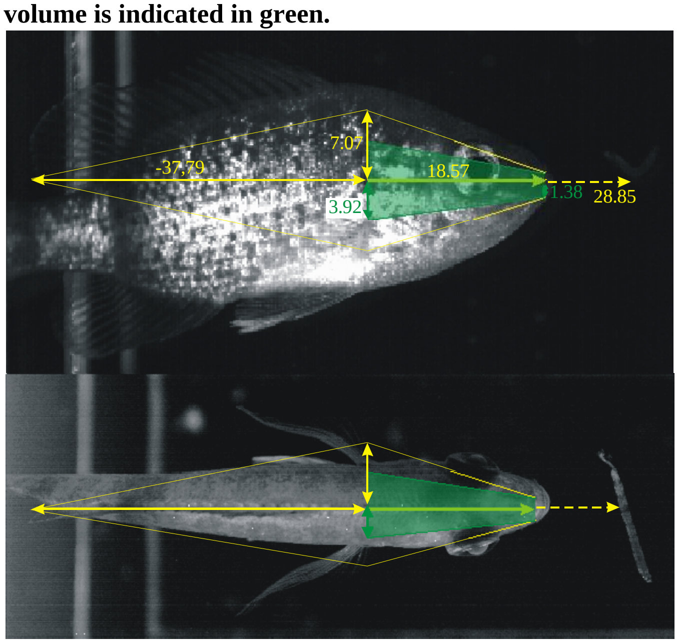
Since the CFD simulations (see further) will start at time = -0.050 s, the initial configuration of the mesh must match the *in-vivo* situation at this time. Several external coordinates were measured, as well as the dimensions of the bucco-pharyngeal cavity (Fig. C). The latter was done based on lateral and ventral view radiographs of a specimen in which the buccal cavity was injected with a Barium solution. The presence of the gills was not taken into account in the model.

Fig. C: Digitized coordinates prior to the start of feeding (white) and outlines of the internal volume of the buccal cavity (red). All values are mm.



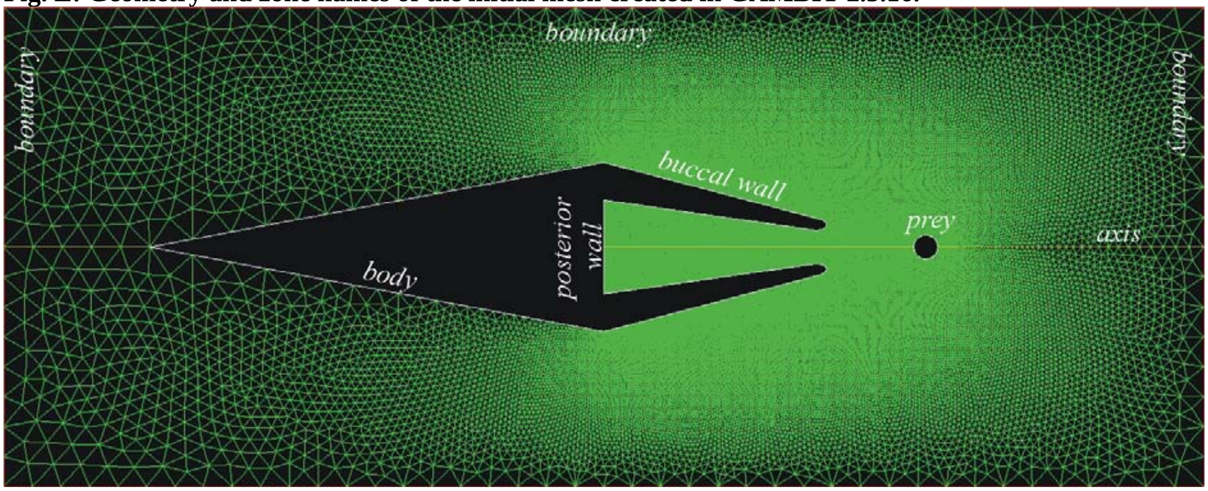
In order to obtain an axisymmetric model, the radius of the model was determined by taking the square root of the product of the corresponding lateral and dorsal radii (Fig. D). In this way, cross-sectional areas and volumes remain unaffected. The middle coordinates (at the level of the eye) were not taken into account for this initial model.

Fig. D: Cone model with dimensions in mm. Bucco-pharyngeal volume is indicated in green.



A 3D axisymmetric, unstructured tetrahedral mesh was created using GAMBIT 2.3.16 (Ansys, Lebanon, USA). In order to optimize the accuracy of the model for a given computational time, smaller distances between the nodes (0.12 mm) were chosen for the fluid zone near the prey and the head of the model, then for boundary of the domain (2.4 mm) (Fig. E).

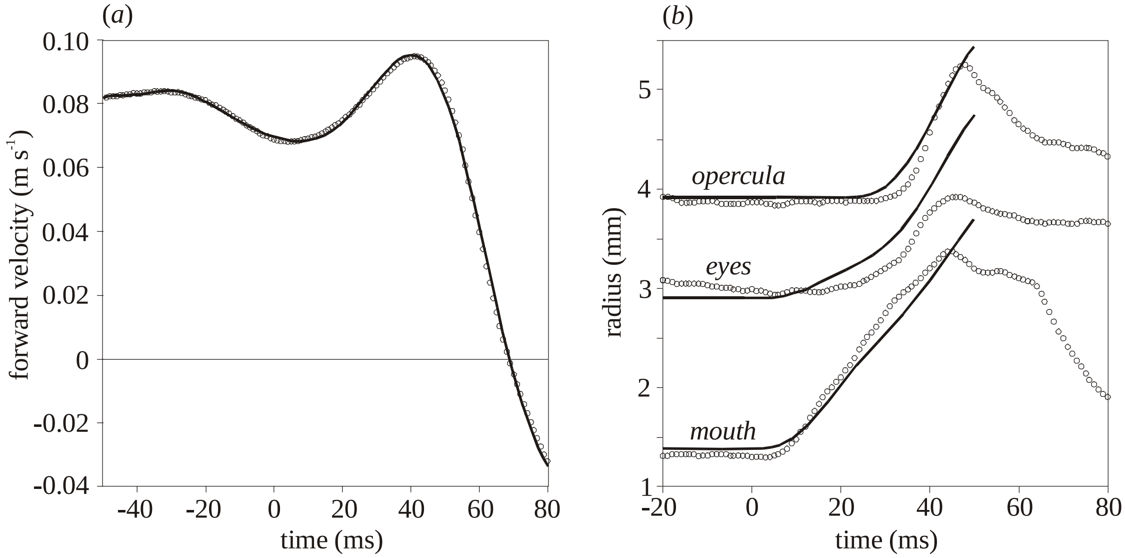
Fig. E: Geometry and zone names of the initial mesh created in GAMBIT 2.3.16.



3. *Kinematic functions defining mesh motion*

First, forward translation velocities and radial expansion velocities of the mouth cavity were fitted with high order (maximum 15th order) polynomial functions using Microsoft Excel equipped with the XLXtrFun add-in functions (Advanced Systems Design and Development, Red Lion, USA) (Fig. F).

Fig. F: Measured (circles) and polynomial fit (back curves) of the forward translation (*a*) and radial expansion (*b*) of the model.



As the CFD solver FLUENT 6.3.16 will be used to solve the Navier-Stokes equations (see further), the unsteady motion of the model was described using FLUENT user-defined functions (UDF). The forward translation of the 'body', 'posterior wall' and the 'buccal wall', as well as the abduction of the 'buccal wall' (see Fig. E) were provided to the solver via a DEFINE-CG-MOTION UDF. A forward dynamic calculation of prey motion due to the interaction with the surrounding fluid is provided via a DEFINE-GRID-MOTION UDF. The following equation of motion is included in this UDF:

$$\Delta v = \Delta t \bullet (\sum F_{pressure} + \sum F_{shear}) / M$$

, where Δv equals the change in velocity in the axial direction, Δt the time step size, $F_{pressure}$ the pressure force exerted by the water on the edges of the prey in the axial direction as calculated by Fluent from the flow solution at the previous time step, F_{shear} the viscous shear force in the axial direction as calculated by Fluent from the flow solution at the previous time step, and M the mass of the prey. The same UDF also included a procedure to displace the nodes attached to the symmetry axis in response to the forward translation of the fish and the displacement of the prey. All UDFs were compiled using Microsoft Visual Studio 2005.

Numerical algorithms of Fluent 6.3.16 can automatically update the mesh after each time step relative to the input motion. Here, two methods were combined. Firstly, the spring-based smoothing method was used, in which the edges between nodes are considered as a network of interconnecting springs. To smooth the mesh, a value of 1.0 was used for spring constant factor and 1.0 for boundary node relaxation factor, while a standard value of 0.001 was used for the convergence tolerance.

Secondly, cells that became critically small (<0.01 mm), too large (>0.05 mm) or too skewed (>0.6) by the movement of the model were automatically remeshed by Fluent.

4. CFD settings

The unsteady flow simulations were performed using FLUENT 6.3.16. The flow was assumed to be laminar (see article text for discussion on this subject). The no-slip wall condition was enforced at the moving surfaces of the fish and the prey, which is the default condition for models of viscous flow in FLUENT 6.3. The cylindrical open boundary surface of the domain (Fig. E) was modeled as a pressure-outlet where a gauge pressure of zero applies (i.e. no changes in pressure due to the fish is assumed at this boundary) and a backflow normal to the boundary.

The pressure-based solver (chosen to obtain fast-converging solutions) was used with a node-based Green-Gauss gradient treatment. The latter achieves higher accuracy in unstructured triangular grids compared to the cell-based gradient treatment. The first-order implicit unsteady formulation option was used in the simulation because moving mesh simulations (see above) currently only work with first-order time advancement. The standard pressure discretization scheme was used for the pressure calculation and a second-order upwind scheme was used for momentum equations. The pressure-velocity coupling was solved using the SIMPLE scheme. The latter is a discretization method that uses a relationship between velocity and pressure corrections to enforce mass conservation and to obtain the pressure field. A fixed time step size of 0.2 ms was used for the approaching phase (time –50 to –2 ms). The suction phase was solved using a smaller time step of 0.05 ms. A maximum of 60 iterations per time step was sufficient to reach a converged solution.

5. Calculation of power requirement

The total power required from the feeding system to realize the buccal expansion that was prescribed (see section 3 on kinematic input) was calculated by taking the product of the radial component of the pressure force and radial velocity of each of the faces (i.e. mesh surface subdivisions) of the modelled buccal cavity, and summing these powers for the entire buccal surface (interior as well as exterior). This calculation was automatically performed after each time step by including a DEFINE_EXECUTE_AT_END user-defined function in the program.