GENERATIVE PROCESSING OF ANIMATED PARTIAL DEPICTIONS FOSTERS FISH IDENTIFICATION SKILLS: EYE TRACKING EVIDENCE

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GENERATIVE PROCESSING OF ANIMATED PARTIAL DEPICTIONS FOSTERS FISH IDENTIFICATION SKILLS: EYE TRACKING EVIDENCE

AMÉLIORATION DES COMPÉTENCES D'IDENTIFICATION DE POISSONS PAR LE TRAITEMENT DE DESCRIPTIONS PARTIELLES ET ANIMÉES : MISE EN ÉVIDENCE PAR L'*EYE TRACKING*

by/par Jean-Michel Boucheix* & Richard K. Lowe* **

SUMMARY

This study addressed the issue of learning fish locomotion patterns, and was realized within an international broader collaboration: the "Fish locomotion project" which aimed at designing and testing multimedia tools for training on fish species conservation. The issue addressed professionals' skills involved in fish species surveys. They have to identify fish species from viewing videos recorded in oceans (or lakes). Fish species recognition relies on using conventional biological fish classification based on body shapes features. However, very often, when the viewing conditions become difficult (water turbidity), the conventional shape based recognition appears to be no longer effective. Another classification, based on locomotion types, was developed by biologists. This paper presents the results of a study about the internal animation generation effect. Within the theoretical framework of cognitive imagery, and mirror neurons systems in neuroscience, the present experiment investigated the effect of imagining versus viewing animations of fish locomotion. Novices (students) learned fish locomotion, from 3D animation. During a perceptual learning task, we compared 4 presentation conditions of the fish animation: depending of the group, learners could view either, the head of the fish only, the middle of the body only, the tail only or the whole fish, control condition. Eye tracking was recorded in order to assess "internal animation processing". Post test was a recognition task of the fish locomotion (versus other fish movement, such as an eel). Results indicated that learning in fish parts only conditions produced better learning gains compared to the control condition. Implication of the results for instructional design in training is discussed.

Keywords: *Eye tracking, Generation effect, Fish locomotion, Perceptual learning, Mental imagery.*

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RÉSUMÉ

Cette étude s'intéresse à l'apprentissage de la reconaissance des espèces de poissons à partir de leur locomotion, activité pouvant être réalisée par des professionnels dans le cadre de la protection des espèces et de la biodiversité : comment ces patterns dynamiques fonctionnent-ils et comment favoriser leur apprentissage ? La présente expérimentation a été réalisée dans le cadre d'un projet international plus vaste : le projet "Fish Locomotion" visant à concevoir et tester des outils multimédias pour la formation à la reconnaissance des espèces. Cette recherche s'intéresse particulièrement à la formation des compétences des professionnels dans des tâches de surveillance des espèces de poissons des mers et océans, lors d'enquêtes sur la bio-diversité. Ils doivent identifier les espèces de poissons à partir des vidéos enregistrées dans les océans, les mers (ou les lacs). Traditionnellement, la reconnaissance des espèces de poissons est effectuée en utilisant la classification biologique conventionnelle qui est basée sur les caractéristiques des formes corporelles. Cependant, très souvent, lorsque les conditions d'observation deviennent difficiles (turbidité de l'eau par exemple), la reconnaissance conventionnelle basée sur la forme semble ne plus être efficace. Une autre classification, basée sur les types de locomotion, donc fondée sur des traits plus dynamiques, a été développée par des biologistes. Dans la présente étude, le but est d'explorer le bénéfice potentiel d'une méthode d'apprentissage fondée sur l'effet de génération d'animation interne. Dans le cadre théorique de l'imagerie cognitive, et des systèmes de neurones miroirs en neuroscience, la présente expérience a étudié l'effet de l'imagination par rapport à la visualisation des animations de la locomotion des poissons. Des novices (étudiants) ont appris la locomotion de poissons, à partir d'animation 3D. Au cours d'une tâche d'apprentissage perceptif, nous avons comparé 4 conditions de présentation de l'animation du poisson : selon le groupe, les apprenants pouvaient voir soit uniquement la tête du poisson, seulement le milieu du corps, la queue seule ou le poisson entier, condition de contrôle. Le movement des yeux de chaque participant a été enregistré durant l'apprentissage afin d'évaluer l'hypothése de la mise en oeuvre d'une animation interne du mouvement du poisson de type simulation mentale. Le post-test était une tâche de reconnaissance de la locomotion du poisson (par rapport à d'autres mouvements de poissons différents, comme une anguille par exemple). Les résultats ont indiqué que l'apprentissage à partir de movements de locomotion incomplets (comme la tête seule) de poisson conduisait à des gains plus élevés que l'apprentissage à partir du mouvement complet (condition contrôle). L'implication des résultats pour la conception pédagogique de la formation est discutée.

Mots-clés : *Eye tracking, effet de génération, locomotion des poissons, apprentissage perceptif, imagerie mentale.*

I. INTRODUCTION

Current technology allows us to generate huge data sets which are useful only if they can be analyzed in a timely and cost effective manner. The ability to make useful inferences from large sets of incomplete information will undoubtedly become an increasingly sought after skill in the future.

The research reported in this paper addressed some fundamental aspects of human information processing that are likely to be crucial for acquiring such understandings. It is set in the context of recent advances in cognitive psychology and neuroscience with respect to how people extract relevant information from complex dynamic situations and generate inferences when that information is incomplete.

I.1. Fish species identification from environmental monitoring videos

Determining and monitoring the populations of various fish species that inhabit particular localities has become an integral part of environmental assessment procedures. The inclusion of base-line fish survey results in environmental impact projections is now generally mandatory for major marine engineering developments such as the construction of off-shore oil and gas facilities around countries and continents (as for example in Australia). In recent years, earlier survey methods that relied on problematic techniques such as line fishing, netting, poisoning and electrical stunning have been replaced by non-intrusive video-based approaches. These involve the continuous recording of the fish that pass by underwater video cameras stationed at the target sites.

At present, identification of the different species shown on these video recordings is done by highly trained human observers using data analysis approaches based on traditional approaches. They rely on being able to detect distinctive constellations of many individual highly localized aspects of a fish's bodily structure and appearance. Expertise in taxonomy-based fish identification is developed by learning about the various combinations of static features that make each species distinctive (such as fins, tail, body shape, colors etc., Jarodzka, Scheiter, Gerjets, & van Gog, 2010; Imhof, Scheiter, & Gerjets, 2011). Because the counting and measurement of various features (such as the number of cheek scales or the pectoral fin length) is often required, this form of species identification is typically an extremely slow, expensive process. Although there have been attempts in recent years to overcome the resulting data analysis log-jam by using computer-based image analysis methods, these have not proven particularly effective to date, especially when the images available are sub-optimal. At present, human observers are far better at identifying fish under these less-than-ideal circumstances. A fundamental problem is that the traditional taxonomic approach to fish identification assumes visual and physical analysis of a stationary and complete physical specimen that can be examined in detail while lying flat with its left side facing upward. The information available to the observer in most fish survey videos is typically considerably more impoverished, partial, and ambiguous than that available from such specimens. Fish captured in the recordings are typically moving rather than stationary, may be only partially within the camera's field of view or somewhat obscured by other entities, and may never present the required flat left-side view to the camera.

Rather than using variations in localized body sub-structures, identification could be based on more global aspects such as their overall body shape and distinctive locomotion patterns. Neither of these characteristics relies on the high level of detail required in traditional identification approaches. For example, an eel and a trout can readily be distinguished both in terms of their different body shapes (long and thin, versus more compact) and in terms of their characteristic swimming patterns (Anguilliform – large uniform amplitude waves along the whole body, versus Subcarangiform – limited amplitude waves increasing posteriorly). These characteristics are a far more robust basis for identification than taxonomic approaches with respect to their tolerance for missing, occluded or indistinct information (as when only part the target fish crosses the camera's field of view, other objects are interposed between the fish and the camera, or the water is turbid rather than clear).

The present study investigates the issue of the ability to recognize fish categories from "incomplete" or partial depictions of their locomotion pattern. With regard to this issue, previous literature in cognitive psychology and neuroscience on the internal processing of external animations can be most illuminating. It is plausible to suggest that perceptual learning requiring learners to elaborate movements of a partial fish into those of the whole fish could help develop motion-based identification skill. The present research used a controlled experimental design set within a theoretical framework that draws on aspects of cognition and neuroscience including biological motion recognition, human mental imagery and perceptual training, (Kosslyn, Pascual-Leone, Felician, Camposano, Keenan, Thompson, Ganis, Sukel & Alpert, 1999; Wright & Fitzgerald 2001; Ahissar, 2001; Kosslyn, Ganis & Thompson, 2001; Shapiro, 2009; de Koning & Tabber, 2011).

Partial depictions of the motion pattern traced out by a fish swimming can be conceptualized as a dynamic Gestalt-like situation. From this perspective, inferences made from such stimuli may be considered as an example of reification in that they involve a constructive or generative aspect of perception (Wright & Fitzgerald, 2001). With *dynamic* images, one might expect reification to result in the observer perceiving more explicit *spatiotemporal* information than was actually provided. According to this expectation, the observer would mentally elaborate the fragmentary dynamic information provided by the partial fish animation to generate a coherent spatiotemporal whole. Such a possibility is broadly consistent with what has been found about our perception of incomplete dynamic stimuli. Previous research on the recognition of biological motion from arrays of point lights alone, (i.e., where visuo-spatial information has been essentially removed so that only the raw dynamics remain) shows that naive observers are able to distinguish human motion from other types of motion. With training, such observers become more proficient at discriminating between biological and scrambled animations that are embedded in an array of dynamic dot noise. This change in performance is accompanied by changes in the intensity of activation of specific brain areas (posterior temporal sulcus and the fusiform "face area", see Grossman, Blake, & Kim, 2004) suggesting the involvement of fundamental neural processes in learning to identify whole biological motions from their partial depictions.

I.2. COGNITIVE PROCESSES INVOLVED IN LEARNING FROM ANIMATIONS

Nowadays, animations are commonly used as learning resources across a varied range of education and training contexts. Their ready adoption for this purpose appears to be based on the widespread belief that, when it comes to presenting dynamic subject matter, animated depictions are inherently superior to text or static pictures. However, this assumed superiority of animations has been questioned in recent years (Lowe & Schnotz, 2008; Lowe & Boucheix 2008; Höffler & Leutner, 2007; Bétrancourt, 2005; Boucheix & Lowe, 2010; Lowe, Boucheix, Putri & Groff, 2013; Boucheix, Lowe & Bugaiska, 2015; Berney & Bétrancourt, 2009). In order for animations showing the swimming motion of partial fish to be effective as training aids for learning fish identification skills, it is important to consider the costs that can be associated with such depictions as well as their potential benefits. In this section, we highlight the importance of animation processing and suggest how this activity might be investigated, particularly with respect to the making of inferences.

I.2.1. Internal processing of external animations

To date, our understanding of the internal processing of dynamic visualizations during comprehension and learning is in its infancy (Lowe & Boucheix, 2008). Recognition, or learning from pictures and animations, when full information is not available may require inferential processes. Inferences rely on part-whole elaboration from available sub-set of information. Previous research has shown a powerful effect of inferential processes in learning from static graphics (Hegarty, 1992; 2004, 2005). The piecemeal strategy used by learners seems consistent with a discrete representation of the local events manifested within a mental simulation activity.

More recent studies have focused on possible ways to design a more "apprehendable" representation of dynamic processes than is available in traditional continuous and transient animation. These approaches involved the use of multiple static frames which subtlely but accurately depicted the key steps of a dynamic process. This static design was employed with the intention of supporting learners' cognitive simulation of the dynamic process. It requires learners to infer motion transitions between successive pairs of discrete static pictures in order to simulate the missing dynamics from the available information. This inferential task was considered to be based on active comparisons made between the available key steps (Boucheix & Schneider, 2009; Hegarty, 1992, 2004; Hegarty, Kriz, & Cate, 2003; Mayer, Hegarty, Mayer & Campbell, 2005; Paas, Van Gerven, & Wouters, 2007; Zacks & Tversky, 2001; Jamet & Arguel, 2007).

A key benefit posited for this type of inferential task is that the relational processing it fosters should facilitate the inter-linking of individual aspects of the content subject matter and thus help assure global coherence of the learner's internal representation. For a dynamic mental model, this implies that individual events are well interconnected (Lowe & Boucheix, 2008). Temporal micro structures of the animation need to be subsumed by temporal macro structures, and individual temporal micro structures also need to be integrated across space. This type of coherence would be necessary for demanding tasks such as identifying a fish from its movements when the available information is of relatively low quality.

I.2.2. Inferential processing: Its nature and detection

The complex nature of animal locomotion makes the task inferring the movement of missing fish parts very demanding for non-experts. Because they lack domain-specific knowledge, novices' necessarily selective extraction of information is likely to be largely bottom-up (perceptually-based) and therefore driven by visual conspicuity (Lowe & Boucheix, 2008). However, the most perceptually compelling aspects may not be those that need to be extracted because they have low task relevance. For the resulting mental models to be useful for fish identification, they need to be characterized by a hierarchical knowledge structure that allows viewers to make best use of the poor quality information available. Imagining the movement of missing parts of an animation from available information can be conceptualized in terms of the generation effect. This effect has mainly been studied with respect to language processing and refers to the robust finding that information will be better remembered if it is generated rather than simply read (Jacoby, 1978; Crutcher & Healy, 1989; Mulligan, 2001; Jacoby, 1978; DeWinstanley & Bjork, 2004; Kinjo & Snodgrass, 2000; Mac Namara & Healy, 2000; Mulligan & Neil, 2004; Bertsch & al., 2007).

I.2.3 Cognitive and neuro-psychological considerations for Learning Global Dynamics from Animated Partial Depictions

The task faced by novices in learning the overall locomotion pattern of a particular fish species by studying an animation depicting only a part of its entire body can be broken down into external and internal processing components. To begin with, the learner must extract and internalize suitable information from the partial depiction presented by the external animation. If this largely perceptually-based process is successful, the learner can then use this internalized information as a basis for inferring missing task relevant information in order to mentally image the whole fish's locomotion pattern.

Research in neuroscience and investigations that draw on this research provide valuable insights into the possible nature of the processing activities mentioned above. Concerning the extraction and internalization of information about dynamic subject matter, the concept of mirror neurons has recently been adopted by educational researchers with regard to learning from animations. The finding that the same cortical circuits involved in executing an action oneself are also activated when someone else executes that action (Rizzolatti, Luppini & Matelli, 1998; Rizzolatti & Craighero, 2004) has been offered, by several researchers, as a possible explanation for why animated instructional materials based on human movements can be particularly beneficial for learning, and especially for hand procedures (Ayres, Marcus, Chan & Qian, 2009; Höffler & Leutner, 2007; Marcus, Cleary, Wong & Ayres, 2013; Van Gog, Paas, Marcus, Ayres & Sweller, 2009; Wong, Marcus, Ayres, Smith, Cooper, Paas & Sweller, 2009; Wong, Leahy, Marcus & Sweller, 2012). Benefits posited from the activation of mirror neurons with regard to learning from observations have even been extended to encompass non-human biological movement. In a recent paper on animation and learning, brain imagery information was provided to support a suggestion that watching a demonstrated fish locomotion pattern activated part of the mirror neuron system (Brucker, Ehlis, Häußinger, Fallgatter & Gerjets, 2015). This extension of the mirror neuron explanation to benefits achieved for non-human biological motion that shares crucial features of human action could be related to the assumed presence in this situation of a task-directed goal, and intentional, comprehensible actions (Rizzolatti, 2005; van Gog & al., 2009; Shipley, 2003; Gazzola, Rizzolatti, Wicker, & Keyser, 2007; Keyser & Gazzola, 2007; Rizzolatti & Craighero, 2004).

Findings from neuroscience may also provide a basis for explaining why mental imaging based on animations of partially depicted fish could be beneficial for learning about fish locomotion patterns. For example, studies of areas of the cortex that are activated early in visual processing (e.g., Kosslyn & al., 1999) and in mental rotation tasks (e.g., Kosslyn, Thompson, Wraga & Alpert, 2001) indicate the powerful way in which information generated from internal imaging can parallel that obtained from direct perception. “Imagery not only engages the motor system but also affects the body, much as can actual perceptual experience” (Kosslyn & al., 2001, pp. 2519). This is consistent with the same brain areas being involved when people imagine performing an action (without actually doing the movement) as are involved in the execution and observations of motor actions (Grézes & Decety, 2001; Heurley, 2008). Imagining a procedure or a concept being acted out has also been found beneficial compared with studying alone (Leahy & Sweller, 2008). As a consequence, imagining and inferring movements from a partial depiction could boost the mental simulation and the building of an accurate and complete mental model of this movement. It seems plausible that generating simulations of motions in this way would support mental model building activity by fostering deeper processing of the dynamics of each fish part and the relations between parts. This expectation could be the basis of the putative link (and very speculative at the moment) between the generation effect and the mirror neurons theory.

I.3. Eye movements to analyze online perceptual and cognitive processing

Eye tracking techniques are becoming widely used in the ergonomics areas and in ecological situations. New systems, non invasive, light, mobile, are nowadays able to record online information, very precise spatially as well as temporally eye movements’ measures. In this present study, the eye tracking method was used to investigate precisely when, and how the missing parts of the presented partial fish were processed, and to open a window on online cognitive generative processing. In this way, eye tracking was used to investigate when and how parts of the fish were processed during inferential activities.

I.4. RESEARCH QUESTIONS OF THE PRESENT STUDY AND HYPOTHESES

The experiment reported below was motivated by two related questions: (i) Is it possible to identify fishes from their locomotion pattern? (ii) If so, how might skill in this identification approach best be developed? We investigated the capacity to elaborate information obtained from observing how just part of a fish moves into a characterization of the fish's movement as a whole. In this experiment, we aimed to increase the understanding of fishes locomotion, in a short training session, and compared (i) standard viewing of a complete animated depiction with (ii) generative imaging based on an animation in which the subject matter depiction was only partial. The learning task was to imagine how the missing parts of the fish would move in order to characterize the complete locomotion pattern.

From the perspective developed above, the following two hypothesis were proposed. (H1) It is possible to identify fishes from an observation of their movements, e.g., their locomotion pattern, because humans have the ability to perceptually process, learn and then recognize effectively biological motions from direct observation. (H2) For training we postulated that a generation effect with respect to the missing part of fish locomotion from the observation of the actual moving parts of the fish would boost observational learning, compared to a condition where the whole fish movement is presented. Such "Perceptual learning" would make the trace in memory more robust. If so, participants who "studied" the animation of specific fish locomotion pattern in the imagination condition would perform better than the participants who studied a whole fish locomotion pattern, in a subsequent specific fish locomotion recognition post-test task.

With regard to the eye movements measures, it was expected, H3, that within a fixed and limited study time of the fish locomotion animation, eye fixation time and eye movements, would be higher in the missing part areas of the partial fish animations than in the same parts areas of the whole fish. This would suggest a more active and deeper internal processing of the missing of the fish in the imagining condition than in the whole fish presentation condition. One dynamic sub-part area of the partial fish might be of particular interest for the learner, which corresponds to the junctions between parts of the fish (see below in the method section).With regard to the subsequent recognition post-test, it was predicted that learners in the part fish condition, e.g. the generation condition, would outperform learners in the whole fish condition, e.g. the viewing condition.

II. METHOD

The experiment was realized in association with international multidisciplinary project (including biological as well as cognitive and educational aspects) related to expert and novice fish locomotion classification and recognition (Gerjets, Imhof, Kühl, Pfeiffer, Scheiter, & Gemballa, 2010; Imhof, Scheiter, Edelmann, & Gerjets, 2012; Imhof, Scheiter, & Gerjets, 2011; Jarodzka, Scheiter, Gerjets, & van Gog, 2010; Kühl, Scheiter, Gerjets, & Gemballa, 2011, see the acknowledgment). The overall design of the experiment was composed of a short learning-studying phase, followed by a post-test which assessed the effect of the learning-studying session. The learners' goal in the first phase was to study precisely how a trout swims (focusing on the fish motion instead of fish shape and features) through viewing of a 3D realistic animation of the fish (the digital model of the fish was built from a true physiological model of the trout locomotion, see figure 1).

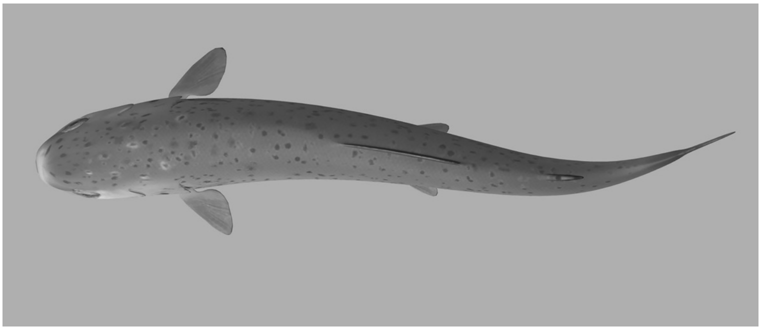

Figure 1. Screen shot of the tout locomotion (Fario).

Figure 1. Capture d'écran mouvement d'une truite (Fario).

The learning session was divided in two stages. The first stage consisted in an exposure to the whole fish animation and in the second stage, immediately following, participants in the experimental group were presented only an animation of a part of fish only, while participants in a control group were, once again, presented the animation of the whole fish. Thus, four study conditions were designed: animation could show (i) head only (ii) body (middle) only (iii) tail only (iv) whole fish.

The learning outcome measure was a post-test involving a fish locomotion recognition task. We developed an approach which respected the essentially non-verbal nature of processing involved in the learning activity. The post-test was based on a forced choice situation in which participants had to nominate whether a presented animation either correctly or incorrectly depicted the swimming motion of a trout. The animated stimulus materials were devised using contrasting fish motions (a trout motion versus an eel motion) but with the body type kept constant (a trout) so that participant decision-making needed to be based on the motion presented, not on visuospatial form.

II.1. PARTICIPANTS

Participants were 83 novices with respect to fish locomotion (undergraduate student from humanities area mainly, having only the common basic domain general knowledge on fish locomotion) with a mean age of 20.6

years (SD = 2.60); they participated for course credit. Before the experiment, participants were asked about their possible task-specific prior knowledge. None of the participants selected for the experiment had specific or high prior knowledge about fish locomotion. To control the homogeneity of the experimental and control groups, spatial abilities of the participants was tested with a specific test (the DAT, Bennett, Seashore & Wesman, 1973). Equal numbers of participants with low and high spatial abilities scores (median split) were assigned to the experimental and control conditions.

II.2. MATERIAL

II.2.1 Perceptual learning phase

In the learning phase, participants studied trout locomotion from realistically rendered animations (see Figures 1 and 2).

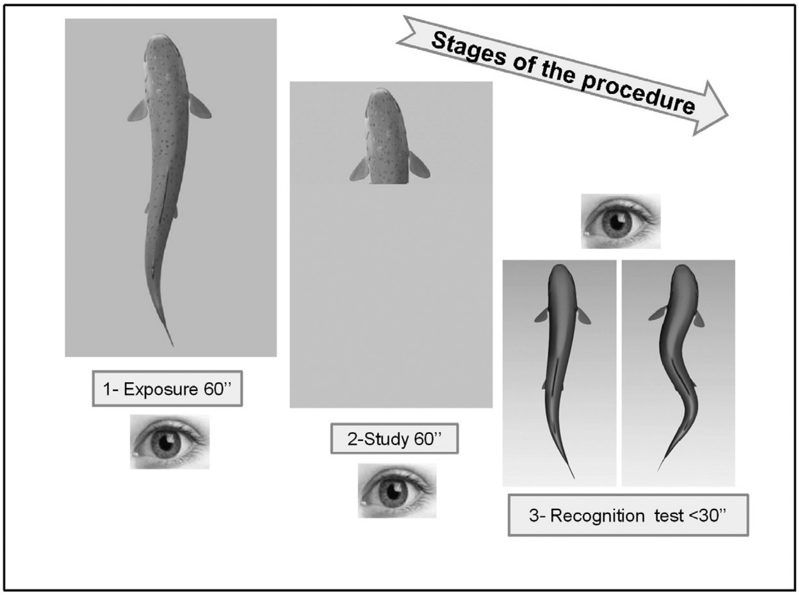

Figure 2. Procedure and material example.

Figure 2. Schéma de la procédure et du matériel utilisé.

This fish belongs to one of the most common and frequent locomotion category patterns ("pisciform fish", such as carp, trout, thon, etc. which show an undulatory movement spreading from the head to the tail, Figure 1). The shape and motion of the fish in the animations were based on a biologically accurate model of fish locomotion devised by experts in fish biology and computer science. For the learning task, all participants were first exposed to the whole fish animation (60 sec. Figure 2, picture 1) then spent a second period for which they were instructed to imagine the movements of the whole fish (60 sec., Figure 2, picture 2). During this second period, participants in the four presentation conditions received the different stimuli: the head of the fish only (N =20), the middle of the body only (N =18), the tail only (N = 19) or the whole fish (control group, N = 26). A screen shot from the animation for the head only condition is shown in Figure 2, picture 2. The spatial location of the boundaries delineating the head, body and tail were determined by two criteria: the first criterion was related to the distinction between head, body an tail fish parts as described in fish anatomy books; the second criterion concerned the need for a relative size similarity of each of the three parts.

The fish was always presented from the top view angle. Three criteria were used that led to this choice. (i) In the conventional fish classification system, fishes are presented in a side view angle. This angle optimizes the view of the shapes of the fish, but the movement (direction, amplitude) of the fish parts remains quite hidden. (ii) A top view optimizes the overall perceptibility of the locomotion pattern of the fish. However, it could be argued that from the top view on the fish chosen in the experimental material, it results that the head and the body could have a higher perceptual -visual- salience than the tail (see Figure 1). Although this argument may be relevant with respect to the spatial perceptual salience (the head and the body have a larger size than the tail), it is not relevant regarding the salience of the temporal dynamics of the parts. The tail movement is broader than both the head and the body movements. These dynamics are the core of the locomotion pattern, so that top view optimizes the visual quality of the fish locomotion.

The participants' task was to study the fish locomotion in preparation for a subsequent test. In the first exposure stage, participants were asked to *"look carefully at how the fish swims"*. In the second stage, experimental groups learning from fish parts only were asked to *"imagine (in your mind) as precisely as possible the motion of the missing part of the fish, e.g. the body and the tail (or alternatively, tail and body) (head group); the head and the tail (body group), the body and the head (tail group)"*. Participants in the control group (who saw only the whole fish) were asked to *"study carefully as precisely as possible the motion of all parts of the fish, the head, the body and the tail"* The order of the parts given in the instruction was randomized.

II.2.2. Post-test

Participants were asked to nominate (*"as quickly and accurately as possible"*) whether each of the presented test items was a correct or an incorrect depiction of trout movement. Eight short animations of a trout-shaped fish swimming were used as the basis of the test items. Although the fish in eight animations had the exactly the same shape, they differed with respect to their movements. The different movements were devised by blending various percentages trout and eel locomotion patterns, ranging from 100 % eel locomotion to 100 % of a trout locomotion by 14.28 % increments (see Figure 2, picture 3). These motion blends were derived from strict mathematical models of eel and trout locomotion that were provided by an expert in fish biology and generated by a computer simulation. Each of the eight animated test items was presented randomly one at a time to participants who nominated their answers (correct or incorrect) by key press.

II.2.3. Eye tracking equipment and measures

Eye movements were recorded with a binocular 60 Hz Tobii 1750 corneal reflectance and pupil centre eye tracker. Data were recorded with Tobii studio software. The 17" computer screen for displaying the animation was positioned approximately 60 centimeters from the participant. The same eye tracking indicators applied across all conditions and for three categories of AOIs, each of which corresponded to functionally relevant aspects of the fish (Figure 3).

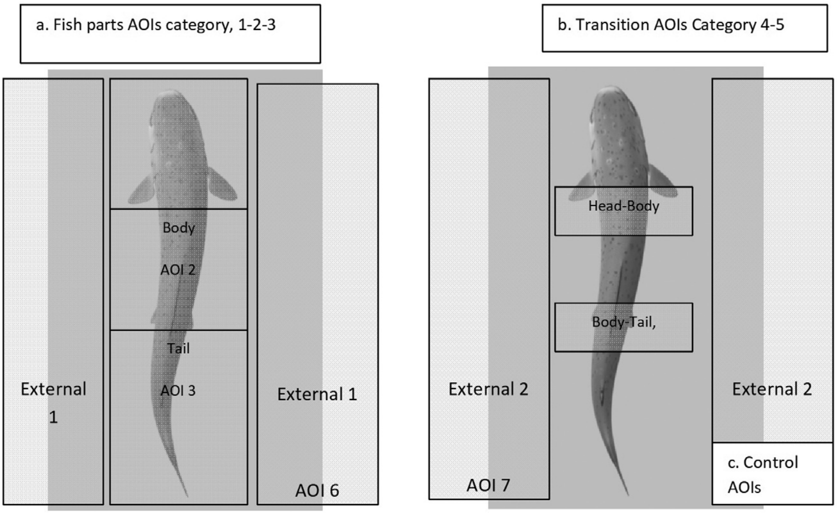

Figure 3. Seven AOIs (Areas Of Interest) used in the eye movement data processing.

Figure 3. Les sept Aires d'Intérêt (Area Of Interest) utilisées pour l'analyse du mouvement des yeux.

The first category of AOI, *fish parts AOIs*, encompassed respectively the head (AOI 1), the Body (AOI 2), and the Tail (AOI 3) and were the same size as the fish parts shown on the screen during the learning time. The second category, *the transition AOIs*, was designed to capture evidence of any relational processing activity the learner may exhibit between adjacent regions of the display corresponding to the different parts of the fish. There were: head-body transition (AOI 4) and body-tail transition (AOI 5). The third category of AOI, *control AOIs*, encompassed two zones which were external, left (AOI 6), and right (AOI 7) to the fish movement area. These two external AOIs were used to check possible occurrences of eye gaze outside of the fish area. Such checking was also a way to get information about the "scope of activity" of the learners of the experimental groups. Each of these seven AOIs was defined with sufficient scope to include the boundaries of the particular fish part's entire movement during its swimming cycle. One main eye movement indicator was employed: the dwell time duration in the predefined seven Area of Interest (AOIs) (see, Rayner, 1998; Holmqvist, Nyström, Andersson, Dewhurst, Jarodzka, & van de Weijer, 2011; Jarodzka, Scheiter, Gerjets, & van Gog, 2010). This main measure was used for each phase of the task: the exposure phase, the study time phase and the recognition phase (see Figure 2). The fixation filtering threshold was set at 100 ms.

For the forced choice recognition test, used with each of the animation clip presentations, participants were required to click as quickly as possible (but also as precisely as possible) on the "swims like a trout" or "does not swim like a trout" buttons presented at the bottom of the computer screen. Answers and response time were automatically recorded for subsequent analysis.

II.2.4. Procedure

Participants were first tested for spatial ability (DAT, booklet 4, spatial relations). Based on a median split, they were divided in low and high spatial ability groups. Within those two groups, participants were then randomly assigned to one of the four conditions. The experiment was run on an individual basis with participants seated at the computer (including the eye tracking apparatus) and given the instruction as a function if their group (experimental versus control). After the learning session, the post test followed immediately. The eye tracker was calibrated for each participant immediately prior to the session.

II.2.4. Statistical analyses

For the eye movements data of each studying phase (exposure time and imagining time), in order to test Hypothesis H3, we performed three repeated measures ANOVAs on the dwell time duration. The first ANOVA had group (Head *vs.* Body vs. Tail *vs.* Whole) as between subjects factor and the main fish parts AOIs (Head, Body, Tail) as within subjects repeated measures factor. The second ANOVA had group (Head *vs.* Body *vs.* Tail *vs.* Whole) as between subjects factor and the transition between parts AOIs (Head-Body and Body-Tail) as within subjects repeated measures factor. The third ANOVA had group (Head *vs.* Body *vs.* Tail *vs.* Whole) as between subjects factor and the two control AOIs (left-right together, as in table 1 and 2) as the dependant variable. For each ANOVA, post-hoc comparison were performed in relation with hypothesis H3.

For the recognition test, in order to test hypotheses H1 and H2, data from the answers "swims like a trout" were analyzed. Two series of statistical analyses were conducted. Firstly analyses were performed on the proportion of "trout" responses across the series of the 8 clips. Secondly analyses were performed on the proportion of "trout" responses on the series of clips which was categorized in three movements types. The first type, “eel type” grouped clips 1-2-3 which depicted a fish movement that was closest to the eel movement. The second type “intermediate eel-tout type”, grouped clips 4-5 which depicted a fish movement typically in between the eel and the trout locomotion. The third type “trout type” grouped clips 6-7-8 which shaped a fish movement closest to the trout locomotion category. Regarding the statistical analyses on the proportion of “trout” responses, our assumptions, hypotheses H1 and H2, did not at all predict a *null hypothesis*, and this may influence the distribution of the “trout” responses. As a consequence, we used not only ANOVAs, but also parametric tests were complemented with non-parametric tests, with the Kruskal-Wallis ANOVA for k, independent groups, especially for the recognition test results.

Finally, the eye movement data recorded during the recognition test allowed us to have a measure of response time. ANOVAs were performed on the fixation duration in the different fish parts AOIs.

III. RESULTS

III.1. Learning time eye tracking results

Table 1 and table 2 show the variation of mean total fixation duration in each AOI for each group, respectively for the whole fish exposure phase (Table 1) and for the imagining studying phase (Table 2). Figure 4 illustrates the typical pattern of eye movements in the region of the missing fish parts in the head only condition.

Table 1. Mean total fixation duration in seconds (and standard deviations) in each AOI during the whole fish first exposure phase for each group.

Tableau 1. *Durées moyennes de fixation oculaire en secondes (et écarts types) dans chaque Aire d’intérêt durant la première phase d’exposition au poisson entier, pour chaque groupe.*

Group	Fish Main Parts			Transition Between Parts		External AOIs
	Head	**Body**	**Tail**	**Head Body**	**Body-Tail**	**Left + right**
Head Group	18.64 (8.25)	26.40 (9.49)	10.54 (4.62)	15.94 (6.85)	9.81 (4.67)	2.17 (0.51)
Body Group	23.44 (8.01)	21.94 (5.80)	11.25 (5.05)	15.72 (6.28)	8.44 (3.37)	1.19 (6.67)
Tail Group	18.43 (7.64)	27.17 (6.82)	10.59 (5.35)	13.40 (5.90)	11.48 (4.50)	1.14 (3.90)
Whole Group	20.07 (7.35)	22.46 (7.39)	13.37 (5.88)	12.60 (5.75)	11.56 (4.05)	0.29 (3.64)
Total	20.08 (7.87)	24.37 (7.74)	11.59 (5.35)	14.27 (6.24)	10.45 (4.30)	1.13 (4.12)

Table 2. Mean fixation duration in seconds (and standard deviations) in each AOI during the main inferring-imagining phase of the learning task for each group.

Tableau 2. *Durées moyennes de fixation oculaire en secondes (et écarts types) dans chaque Aire d'intérêt durant la première phase d'inférence de la tâche d'apprentissage, pour chaque groupe.*

Group	**Fish Main parts**			**Transition between parts**		**External AOIs**
	Head	**Body**	**Tail**	**Head Body**	**Body Tail**	**Left + right**
Head	30.07 (19.59)	22.00 (17.73)	3.36 (6.93)	26.26 (10.16)	4.10 (4.90)	2.13 (7.39)
Body	42.48 (11.36)	3.64 (8.30)	10.31 (8.26)	15.44 (11.57)	19.11 (9.80)	1.78 (6.10)
Tail	33.21 (16.91)	17.00 (16.78)	4.42 (8.17)	6.69 (7.38)	19.51 (8.95)	1.94 (6.33)
Whole	22.75 (8.87)	20.91 (7.01)	13.08 (7.63)	13.64 (6.79)	10.63 (4.79)	0.32 (0.62)
Total	31.19 (15.94)	16.53 (14.62)	8.15 (8.67)	15.48 (11.18)	12.93 (9.44)	1.44 (5.57)

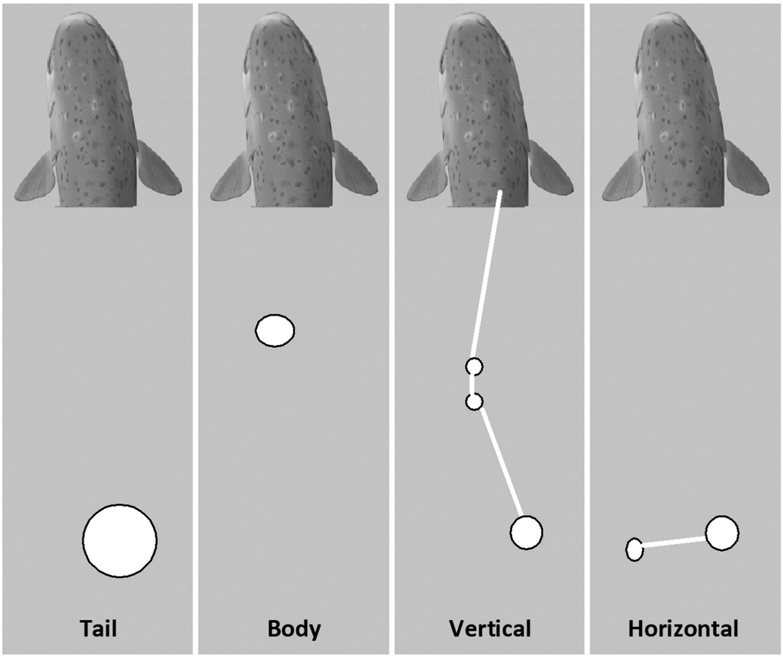

Figure 4. Example of the eye movement replay of a typical participant in the head only group. The red circles dots show fixations, the red lines show transitions saccades. The increase in the diameter of the red dots reflects the increase in the length of eye fixation duration.

Figure 4. Exemple de « replay » du mouvement des yeux d'un participant typique du groupe tête seule. L'augmentation du diamètre des points rouges reflète l'augmentation de la longueur du temps de fixation oculaire.

For the initial whole fish exposure phase, as expected, the first ANOVA for the three main fish parts AOIs showed, no effect of the experimental group, $F(3,79) = .0.74$, , $p = .53$, $\eta^2 = .03$; but an effect of the type of AOI, F (2,158) = 51.08, $p < .0001$, $\eta^2 = .39$. Regarding this latter result, post-hoc comparisons indicated longer fixation durations on the head and the body than on the tail, respectively for the comparison head *vs.* tail, $F(1, 79) = 57.005$, $p < .00001$; for the comparison body *vs.* tail, F (1,79) = 130, 81, $p < .00001$. Further, there were also longer fixation durations on the body than on the head, F (1, 79) = 8.20, $p = .005$. This pattern of results seems consistent with a vertical top-down viewing or "reading" path-way along the fish. However, the body was the most central watched area. No interaction between group and types of AOI was found ($F(6,158) = 1.4$, $p = .22$, $\eta^2 = .04$). The second ANOVA performed on the transition between parts AOIs also showed no effect of the group, $F(3,79) = 0.87$, $p = .46$, $\eta^2 = .03$ but a significant effect of the type of AOI, $F(1, 79) = 6.47$, $p < .02$, $\eta^2 = .075$, indicating that head-body transitions were longer than body-tail transitions. There was no interaction between group and type of AOI ($F(3,79) = 1.43$, $p = .24$, $\eta^2 = .05$). The third ANOVA was conducted on the two external AOIs taken together. As shown in Table 1, these external AOIs were not really fixated by the learners. We found no effect of group ($F(3,79) = 0.53$, $p = .66$, $\eta^2 = .01$). In summary, the experimental groups were equivalent for this first whole fish exposure stage.

For the subsequent imagining phase, the ANOVA for the three main AOIs (Head, Body and Tail) showed no overall significant effect of the group, $F(3,79) = 0{,}29$, $p = .83$, $\eta^2 = .01$. This result indicated that all four groups had similar total fixation lengths during the studying phase. There was a main effect of the type of AOI, $F(2,158) = 59.75$, $p < .00001$, $\eta^2 = .43$, which indicated longer fixation durations on the head and body than on the tail. Post-hoc univariates comparisons showed longer fixation duration on the head than on the tail, $F(1,79) = 133.62$, $p < .00001$; on the body than on the tail, F (1,79) = 22.92, $p < .00001$ and on the head than on the body, F (1,79) = 32.43, $p < .00001$.

The interaction between group and type of AOI was significant, $F(6,158) = 7{,}78$, $p < .00001$, $\eta^2 = .23$ (see Figure 5). This interaction revealed that the head group had longer fixation on the head AOI than on the two other AOIs (body and tail), $F(1,79) = 13{,}34$, $p < .0005$, but the head and the body were equally fixated (F (1,79) = 1,97, $p = .16$). The body group fixated far more on the head than on the fish's other parts, especially than the body which was fixated marginally, and less than the tail (F (1,79 = 3,44, $p = .067$). The tail group had longer fixations on the head than on the other AOIs (body and tail), $F(1,79) = 21{,}24$, $p < .00002$. The body was also fixated for longer than the tail (F (1,79) 12,93, $p = .0006$). For the whole fish group, the head and the body were fixated for longer than the tail ($F(1,79) = 15{,}17$, $p = .0002$), but the head and the body were equally fixated ($F(1,79) = 0.13$, $p = .71$).

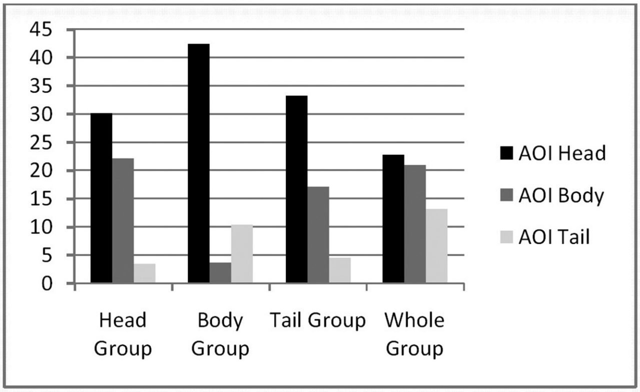

Figure 5. Interaction between groups and AOIs for fixation duration (seconds).

Figure 5. Graphique de l'interaction entre groupes expérimentaux et aires d'intérêt pour la durée de fixation.

The second ANOVA performed on the transition between parts AOIs showed a main effect of group. Experimental groups with missing parts fixated longer the transition AOIs than the control group, $F(3,79) = 4,08$, $p = .009$, $\eta^2 = .13$. Post hoc univariate pairwise comparisons indicated that this effect was significant for the head group *vs.* the control group ($F(1,79) = 3.70$, $p = .049$), for the body group *vs.* the control group ($F(1,79) = 10.65$, $p < .002$) but not for the tail group *vs.* the control group ($F(1,79) = 0.39$, $p = .53$). We found no effect of the type of AOI, $F(1,79) = 2,40$, $p = .12$, $\eta^2 = .03$; and a significant interaction between groups and type of AOIs, $F(3,79) = 26,83$, $p<.00001$, $\eta^2 = .50$. This interaction indicated that for experimental groups, there was an effect of proximity, with the most fixated transition areas being those closest to the available information. Post-hoc pairwise comparisons confirmed this trend. The head group had longer fixation on the head-body transition AOI than on the body-tail transition AOI, $F(1,79) = 61.40$, $p < .00001$; the body group had equal fixation duration on both transition AOIs, $F(1, 79) = 1.51$, $p = .22$; the tail group had longer fixation on the body-tail transition AOI than on the head-body transition AOI, $F(1,79) = 19.51$, $p = .00003$; and the control-whole fish group had equal fixation duration on both transition AOIs, $F(1,79) = 1.47$, $p = .23$.

The third ANOVA for the two external AOIs together, indicated that, as for the exposure phase, very few fixations were made inside these areas, and there was no effect of group on the fixation length in the external AOI, ($F(3,79) = 0.53$ $p = 0.65$). In summary, participants in the experimental group who were asked to imagine the motion in the missing parts have really fixated for longer (more deeply) on the missing parts regions and thus appeared to be engaged in the task.

III.2. Recognition test results

The recognition test performances are presented in Figure 6 and Table 3. Figure 6 shows the proportion of "swims like a trout" responses made by the four groups for each of the 8 clips (from "pure" eel movement- clip 1- to the "pure" trout movements- clip 8-). As mentioned above, in order to analyze these data, the series of clips was categorized in three movements types: the "eel type" (group of clips 1-2-3); the "intermediate eel-tout type", (group of clips 4-5); the "trout type" (group of clips 6-7-8). Table 3 shows the proportion of trout decision for each group across the three categories.

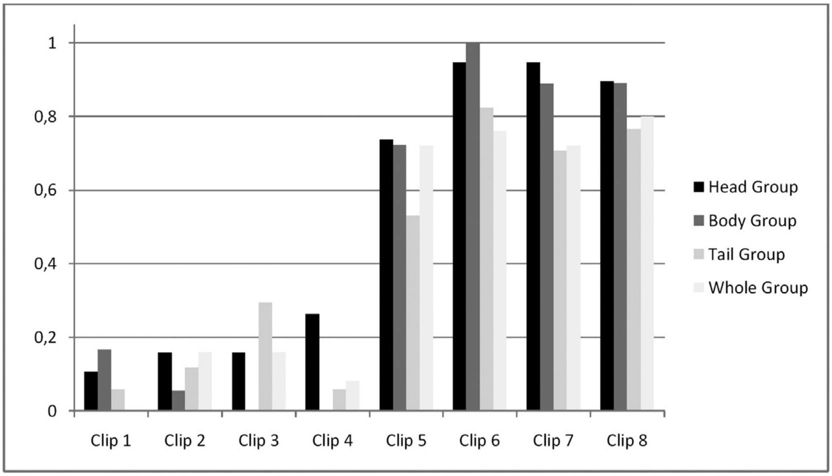

Figure 6. Proportion of "swims like a trout" responses made by the four groups for each of the 8 clips (from "pure" eel movement- clip 1- to "pure" trout movements- clip 8-).

Figure 6. Proportion de réponses « nage comme un truite » données par les quatre groupes pour chacun de 8 clips présentés (clip 1: mouvement pure d'anguille à clip 8: mouvement pure de truite).

TABLE 3. Proportion of "swims like a trout" responses given by the four groups for each of the three types of movement categories (Eel like movement, mixed, and trout like movement)

TABLEAU 3. *Proportion de réponses « nage comme une truite » données par les quatre groupes expérimentaux, en fonction des catégories de mouvement présentés (anguille, mixte et truite)*

	"Pure" Eel movement (clips 1,2,3)	Mixed Eel-Trout movement (clips 4,5)	"Pure" trout movement (clips 6,7,8)
Head Group	0.14 (0.27)	0.50 (0.28)	0. 930 (0.13)
Body group	0.074 (0.18)	0.361 (0.23)	0. 926 (0.14)
Tail group	0.156 (0.24)	0. 294 (0.31)	0.764 (0.25)
Whole control	0.11 (0.23)	0.40 (0.29)	0.760 (0.28)
Total	0.12 (0.23)	0.39 (0.28)	0.84 (0.23)

As mentioned earlier, these data were analyzed with a series of four ANOVAs, completed with non parametric Kruskal-Wallis ANOVAs tests for k independent groups. The first multivariate ANOVA tested hypothesis 1, and showed an overall significant increase of the decision trout from category eel to the category trout, F (2, 156) = 172,97, p < .000001, η^2 = .70. The three others ANOVAs tested hypothesis 2 (participants who "studied" the animation of the trout locomotion pattern in the imagination condition would perform better than the participants who studied a whole fish locomotion pattern, in a subsequent trout locomotion recognition post-test task) about the differences between the experimental groups, and were performed on each clip category.

For the "eel-like" locomotion category, the ANOVA showed no effect of the group, F (3,75) = 0.44, p = 0.75, η^2 = .02. This result indicated that all the groups were equally able to reject the eel-like locomotion as a trout like locomotion. Also, the Kruskal-Wallis test did not reveal differences between the groups (H (3, N = 79) = 1.760, p = .62). For the category intermediate between eel and trout locomotion, the ANOVA did not revealed an effect of the group, F(1,75) = 1.70, p = .17, η^2 = .06. Again, the Kruskal-Wallis test did not reveal differences between the groups (H (3, N = 79) = 4.91, p= .17). For the trout-like locomotion category, the ANOVA indicated a significant effect of the group, F(1,75) = 3,72, p = .014, η^2 = .13. Post hoc pairwise univariate comparison test showed that even for the short studying time of this experiment, participants who learnt from part fish animations, especially from the head only and the body only, outperformed participants who studied the locomotion from the whole fish presentation. This was true for the comparison head only vs. whole (F(1,75) = 6,40, p = .013); for the comparison body only group vs. whole group (F(1,75)= 5,92, p = .017), but not for the comparison tail group vs. whole (F(1,75) < 1, p >.05). Participants who studied the trout locomotion from part fish animations, were able to recognize more efficiently a tout like locomotion than the participants who learnt the trout locomotion from a whole fish presentation. This result is consistent with a perceptual generation effect. However, this effect was significant only for the head group and the body group, but not for the tail only group. Further, the Kruskal-Wallis test confirmed the effect of the group on the learning performance (H (3, N = 79) = 9.35, p = .024).

III.2.1. Recognition test eye movements: response time analysis

Table 4 presents data on how long participants of each group looked at the clip before making a decision, in other word eye fixation durations (dwell times) for each AOI (head, body, tail), by group, and for each category of locomotion (eel-like movement category to trout-like movement category).

TABLE 4. Eye fixation durations (mean dwell times in seconds and SD) for each AOI (head, body, tail), by group, and for each category of locomotion, eel-like movement category to trout-like movement category.

TABLEAU 4. *Durées moyennes des fixations oculaires (temps brutes en sec. et écarts types) pour chaque AOI (tête, corps, queue) par groupe, pour chaque catégorie de mouvement (anguille, mixte, truite).*

	Pure Eel movement (clips 1,2,3)			Mixed Eel-Trout movement (clips 4,5)			Pure Trout movement (clips 6,7,8)		
Group	Head AOI	Body AOI	Tail AOI	Head AOI	Body AOI	Tail AOI	Head AOI	Body AOI	Tail AOI
Head Group	1.29 (2.16)	1.59 (0.80)	0.38 (0.54)	1.04 (1.61)	1.58 (0.89)	0.58 (0.62)	0.85 (1.11)	1.59 (0.91)	0.44 (0.62)
Body group	0.74 (0.82)	2.27 (0.96)	0.36 (0.46)	0.73 (0.93)	2.46 (1.10)	0.77 (0.87)	0.99 (0.67)	2.04 (0.97)	0.72 (0.51)
Tail group	0.99 (1.11)	2.49 (1.46)	0.68 (0.88)	0.88 (0.95)	3.11 (1.56)	0.58 (1.04)	1.01 (0.83)	3.05 (1.76)	1.05 (1.06)
Whole control	1.02 (1.24)	1.85 (0.84)	0.47 (0.64)	0.93 (0.86)	2.08 (1.13)	0.54 (0.60)	1.05 (0.96)	2.10 (0.91)	0.82 (0.59)
Total	1.02 (1.44)	2.02 (1.07)	0.47 (0.65)	0.90 (1.13)	2.27 (1.29)	0.61 (0.78)	0.98 (0.91)	2.17 (1.26)	0.75 (0.74)

These data were also analyzed with a series of ANOVAs. For the eel-like locomotion category, we did not find an effect of the group on the overall fixation duration, e.g. the response time ($F(3, 75) = 0{,}93, p = .42, \eta^2 = .04$), but an effect of the AOIs ($F(2, 150) = 62{,}40, p < .00001, \eta^2 = .45$). Post hoc pairwise univariate comparisons showed that the head was fixated a longer time than the tail ($F\ (1{,}75) = 10.24, p = .0011$). The body was fixated for a longer time that the tail ($F\ (1{,}75) = 191.71, p < .0001$). And, the body was fixated for a longer time than the head ($F(1{,}75) = 43.06$, $p < .0001$). Further, a marginal interaction between the group and the fish parts AOIs was observed ($F(6{,}48) = 1{,}84, p = .09, \eta^2 = .07$).

For the intermediate eel-trout category, the ANOVA indicated no effect of the group ($F(3{,}75) = 1{,}71$, $\mathrm{p} = .17, \eta^2 = .06$), but a significant effect of the AOI ($F(2{,}150) = 114{,}10, p < .00001, \eta^2 = .46$). The post-hoc comparisons revealed that, again, the body was fixated for a longer time than the head ($F(1{,}75) = 57.01, p < .0001$), which was fixated for a longer time that the tail ($F\ (1{,}75) = 5.02,\ p = .028$). A significant interaction between the group and the AOI ($F(6{,}150) = 3{,}04, p = .008, \eta^2 = .11$) revealed that, fixation time on the body, which seems to be the crucial area for the decision, was fixated for a shorter time by participants in the head group only than in the others, especially the tail group in which fixations on the body were the longest ($F\ (1{,}75) = 5.97, p = .016$).

For the trout-like category, the ANOVA revealed a significant effect of the group ($F(3{,}75) = 3{,}98,\ p = .01,\ \eta^2 = .14$). Post-hoc pair-wise comparisons showed that participants in the head only part fish group were marginally faster than participants in the whole fish group ($F\ (1,\ 75) = 3.21,\ p = .077$), and faster than participants in the tail only group ($F\ (1{,}75) = 11.90,\ p = .0009$). Participants in the body only group were marginally faster than participants in the tail only group (*F*(1,75) = 3.60, p = .061) but as fast as the control group (*F* (1,75) = 0.02, p = .87). The effect of AOIs was also significant (*F*(2,150) = 62,63, p < .00001, η^2 = .45). Again the body was fixed a longer time than the head (*F*(1,75) = 78.84, p< .00001) and the tail (*F* (1,75) = 85.11, p < .00001), but the head was not fixated significantly longer than the tail (*F* (1,75) = 2.62, p = .11). Further, the interaction between the group and the AOIs was marginally significant (*F*(6,150) = 2,01, p = .066, η^2 = .07). The body part appeared to be the crucial part in the decision, and was fixed a longer time than the other parts of the fish. However participants in the head group tended to spend less time on the body part than the tail only group (*F* (1,75) = 14.46, p = .0003). In sum, the body, with to a less extend the head, were the more fixated parts of the fish for all groups.

IV. DISCUSSION AND CONCLUSION

The present study addressed the issue of professionals visual skills involved in fish species surveys. When conventional shape based visual fish recognition is no longer possible, for example because of frequent water turbidly, professionals have to switch to another recognition strategy. Instead of using shape based categorization, another strategy might be to use locomotion based categorization. Biologists recently developed fish locomotion classifications. This study addressed the issue of learning fish locomotion patterns, which aimed at designing and testing multimedia tools for training on fish identification skills. The goal of the present study was to test a potential learning method.

Within a cognitive framework mainly based on mental imagery and imagination complemented with the neural and brain foundations of the mirror neuron theory, two questions were addressed. (i) Is it possible to identify fishes from an observation of their movements, e.g., their locomotion pattern? Yes it is, because humans have the ability to perceptually process, learn and then recognize effectively biological motions from direct observation. (ii) How to train- or foster- this recognition skill? In the present study we postulated that inducing a visual generation of the missing part of fish locomotion from the observation of the actual moving parts of the fish would act as a “booster” of observational learning, compared to a condition where the whole fish movement is presented. Such “perceptual training”, in order to learn fish locomotion pattern from “realistic” animations, from partial fishes should make the trace in memory more robust. If so, participants who “studied” the animation in the imagination condition should perform better than the participants who studied a whole fish locomotion pattern, in fish locomotion recognition task. An eye tracking technique was used to analyze online processes of the fish parts and especially the missing part.

Results from a very short learning session, showed the benefit of a perceptual generation effect. Indeed it is possible to identify fish from the locomotion pattern from their direct observation, and even more from fish part. Eye movement data (dwell time fixation duration) suggested that, compared to the whole fish group, in the group who studied incomplete fish, missing parts were more deeply processed than the visible parts. Further, these results (see Figure 6) revealed also a kind of "reading rule" of the fish. In all groups, but especially in the fish parts learning groups, the head and the body were fixated and processed for longer and more deeply than the tail. This fact also occurs in the tail only group. Several reasons could be proposed to explain this "reading rule effect", but one seems to better fit with the theoretical framework underlying the rationale of the experiment. Firstly, it could be argued that from the top view on the fish chosen in the experimental material, it resulted that the head and the body could have a higher perceptual -visual- salience than the tail. However, although this argument may be relevant relatively to the spatial perceptual salience (the head and the body have a larger size than the tail), it is not relevant regarding the salience of the temporal dynamics of the parts. The tail movement is broader than both the head and the body movements. Secondly, a closer look to the trout locomotion showed it may well be that, in the case of that kind of fish movement studied here, the head and body movements are more useful to recognize the fish locomotion. This same tail movement could be shared by many fish species. This usefulness argument could rely on two underpinning theoretical and cognitive processing reasons. Eye movements' results showed an interaction between the missing parts, which were the most fixated by the participants, and the experimental conditions, e.g. the available visible part. This interaction indicated an effect of proximity from available information for the experimental groups: the most watched transition areas were the closest areas of available information. This could mean that the internal inference, e.g., the generation of the missing moving part from the available part, is easier when the missing part is close, adjacent, to the available part than when the missing part is far from, non adjacent, to the available part. Furthermore, mental simulation seems to work in a piecemeal process, step by step along the imagined fish parts, and starting from the available information.

Further, the results of the recognition post-test indicated that imagining the fish locomotion pattern from the head (head only group), and from the body (body group) was more effective than imagining the locomotion from the tail (tail only group) or from the whole fish (whole fish group). This effect suggests that a mental simulation from the head and/or from the body facilitates the whole fish locomotion learning, which is consistent with the cognitive models of embodied cognition used as an underpinning model of this study. Research in this area suggests that embodied cognition (Barsalou, 1999; De Koning & Tabbers, 2011, 2013; De Koning, Tabbers, Rikers, & Paas, 2010a; Shapiro, 2011) and perhaps part of the mirror neuron system (Rizzolattai & Craighero, 2004) could be involved in the learning of biological movements that have a purpose or an "intention", like here fish locomotion, by their observation. Imagining the fish locomotion from the head and the body of the animal may activate more effectively a "human like locomotion schema" (human swimming movement) because the same goal and the same spatio-temporal direction of the movements (moving ahead) are involved in the fish locomotion.

However, if this statement appears to be consistent with our results, it is of course highly speculative and further precise research is needed on this point. Furthermore, it may well be that inferring the movement of the most relevant fish part, e.g. the body and the head movements, relatively to the category of locomotion studied here, was more difficult when the available information, the tail, was not the most relevant to this category of motion and also spatially far from these important head and body parts. Our results suggested also that the spatial proximity of the missing part from the available part was a crucial condition for successful inferences, and deep processing of the missing parts motion.

Finally, there are some limitations of this study that must be underlined. First of all, for experimental reasons, we used only two kind of fish movement (eel and trout). The effectiveness of the "learning" method tested here should be examined for varied kind of fish locomotion patterns, in order to be generalized to different fish species. Secondly, the learning time (exposure plus study time) of the fish (parts) was very short. To build stable perceptual knowledge, usable in difficult fish visibility conditions, a longer learning should be necessary. However, we should never call our effective training effect a "complete" learning effect as there was neither retention delay between the training and the recognition test nor transfer session as in most of short learning studies in the field of animation and multimedia research (see the meta-analysis by Höffler and Leutner, 2007; Berney and Bétrancourt, 2009; Lowe & Schnotz, 2014). Thirdly, another issue is whether or not the generative processing of animated partial depiction of fish categories will have an extended long term effect. In sum, enhancing active production of internal visualization, by inferring processes, seems a new effective way to give learning gains. This new way could be an interesting approach in educational areas.

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