References

Formosa, D. P., Mason, B. & Burkett, B. (2011). The force-time profile of elite front crawl swimmers. *Journal of Sports Sciences*, 29, 811–819.

Hollander, A. P., De Groot, G., van Ingen Schenau, G. J., Toussaint, H. M., De Best, H., Peeters, W., … Schreurs, A. W. (1986). Measurement of active drag during crawl arm stroke swimming. *Journal of Sports Sciences*, 4, 21–30.

Nakashima M., Takahashi A. (2012). Clarification of unsteady fluid forces acting on limbs in swimming using an underwater robot arm. Journal of Fluid Science and Technology, 7, 100–113.

Kudo, S., Yanai, T., Wilson, B., Takagi, H., Vennell, R. (2008). Prediction of fluid forces acting on a hand model in unsteady flow conditions. *Journal of Biomechanics*, 41, 1131–1136.

Takagi, H. & Wilson, B. (1999). Calculating hydrodynamic force by using pressure differences in swimming. *Proceedings of the XIII International Symposium on Biomechanics and Medicine in Swimming*, Jyväskylä, Finland.

Real-time sonification in swimming—from pressure changes of displaced water to sound

Bodo E Ungerechts[1], Daniel Cesarini[2], Thomas Hermann[3]

[1]Neurocognition-Biomechanics, Bielefeld University, [2]Department of Information Engineering, University of Pisa, Italy, [3]Ambient Intelligence Group, CITEC, Germany

Introduction

The communication about the swimmers' internal perception of flow and the movement control is hampered because of missing mutual information about effect of interaction of actions of limbs and invisible motion of displaced (clear) water. Interaction as part of the connectivity of a two-bodies energy sphere. According to Schack (2004) the sensory picture of a voluntary action is a template to organise motor commands and guide motor control. It is widely known that elite swimmers have an excellent perception of water motion using somatosensory, proprioceptive or vestibular and visual cues. Swimming as a self-induced activity in aquatic space means displacing water mass at low energy costs while yielding high swimming speeds in reaction and this is what elite swimmers strive to reach using a right feel for water. Takagi & Wilson (1999) emphasised that without pressure no propulsion exists and a pressure differential method is potentially a useful means in stroke analysis of cyclic 3D hand action. Pressure-time recordings are 'essential complementary information' (Loetz et al. 1988) helping to detect wrong hand positions when unusual pressure graphs occur (Van Manen et al. 1975). Klauck & Ungerechts (1997) pointed out that the interaction goes with pressure changes and momentum-induced effects of displaced water mass while drag—even if it is repeated often—does not explain the interaction effects sufficiently. Hence, kinematics of limbs' actions is not necessarily a direct indicator of flow effects. Ungerechts & Klauck (2014) highlighted that interaction is a means to transfer metabolic energy via limb's action to a unit volume of water which changes the energy-density, known as 'pressure' which in liquids or currents differs from the term pressure solid body mechanics (although in both cases the physical unit is [Pa]). Hermann et al. (2012) pointed out the importance of change of pressure, as an 'intermediate level' (Fig. 1) in connection with momentum-induced locomotion in aquatic space, a level which lacks attention in most swimming literature.

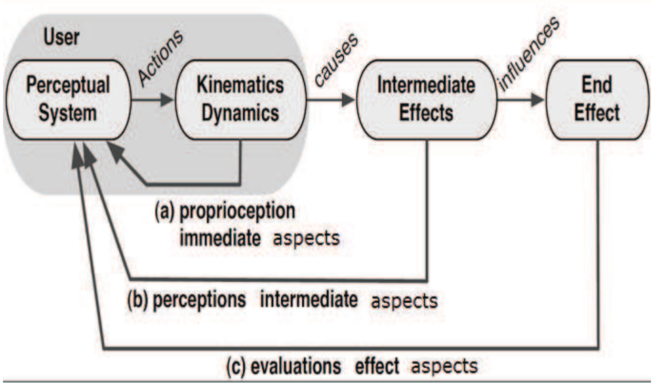

Figure 1 **Different event levels on the route to self-induced locomotion in aquatic space**

Presenting pressure changes as graphs lacks interactive aspects. Therefore the idea came up to use interactive sonification as an audible real-time feedback for the swimmer and the coach, simultaneously. Sonification is a means to map any data-flow like static pressure into functional sound emphasising cognitive attentiveness for the essential aspects in noisy surrounding (which is more than just rhythm or change in pitch). Using audible signals as an information carrier like fishes do (profiting from the fact that pressure wave and sound wave are similar) also exists in human swimming. Kliche & Effenberg (1996) presented a breaststroking avatar while the kinematic data of wrists and ankles were made audible using 'Fairlight Aahs'. Following Effenberg & Mechling (2005) interactive sonification improve motor performance and perception of movements, after the individuals became acquainted to the functional sound and motor and auditory systems were co-activated (the relationship of cognitive levels is still a matter of multi-disciplinary research). It can be expected that swimmers, even without detailed introduction into sound perception, will optimise their perception of displaced water and thus increase performance. Moreover sonification may highlight novel aspects concerning local change of pressure and allows for a fruitful communication of aquatic events between different experts. The sonification of the intermediate level demands the selection of tools like pressure probes, pressure sensors, sonification program, loudspeakers and equipment joint in a new setting enabling operation at the deck of a pool. Before this new approach of augmented perception can be used widely e.g. as a support for talks between swimmer and coach or in cognitive studies, the device needs to be tested. It is the purpose of this paper to inform about the new setting how to generate auditory movement information, to give report on the mapping selected and the quality of the real-time feedback issue.

Materials and methods

The particularity of liquid substance demands an appropriate tool to represent the intermediate level effects (Fig 1) namely the changes of static pressure or change of energy-density in a water volume (þz) in flowing water due to non-steady interaction of body and water mass. The focus on changes in static pressure (not the same like the water column induced hydrostatic pressure) for sonification is justified because it represents the origin of the work done on the water (Webber et al. 2001). Historically the omnidirectional static pressure component (þz) in a current is measured by means of a Piezo-probe, which is a tube bluntly ending normal to the surface of an object, always perpendicular to the stream line (Fig. 2):

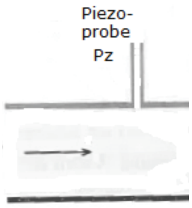

Figure 2 **Schema of a Piezo-probe to measure the change of energy-density per unit volume (þz)**

Piezo-probes are established tools to measure the change of energy-density in a water volume (þz) (e.g. around a hand) due to interaction (Ungerechts 1981). Whether some energy is added to water volume via body motion and accelerates (thrusting) water or the flow per unit volume slows down (braking) can be substantiated by the difference between two probes values (þz). The setting to determine the effect of the hand action on the water mass and the transfer into sound is presented in Fig. 3.

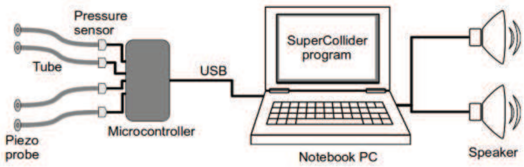

Figure 3 **Draft version of the setting of used tools (measure pressure (þz) until sound emitting)**

Two Piezo-probes per hand, one facing to the palmar side hand the other to the back side are connected via flexible tubes (Diameter 4mm) running along the arm via shoulder to the pressure sensors (Specs: Freescale MXP5010DP analog pressure sensor, 0-10 kPa pressure range) to a waterproof box fixed to a rod outside water held above the moving swimmer. The data from the pressure sensors (sampled at 100Hz) were processed via a microcontroller (Specs: Atmel ATmega328, 8-bit RISC, operating at 8MHz, programmed in C) and transmitted via USB cable to a Notebook carried on a hawker's tray. The sound was processed by a SuperCollider program and emitted via Stereo Loudspeakers.

Instrumentation of swimmers

The openings of Piezo-Probes, 2 per hand, were placed parallel to the surface, respectively; the connecting tube fastened to lower, upper arm and between the scapulae ending in the waterproof box with microcontroller and sensors, attached to a fishing rod; the rod was held by an assistant at pool deck who also carried the hawker's tray with PC and loudspeakers (Fig. 4).

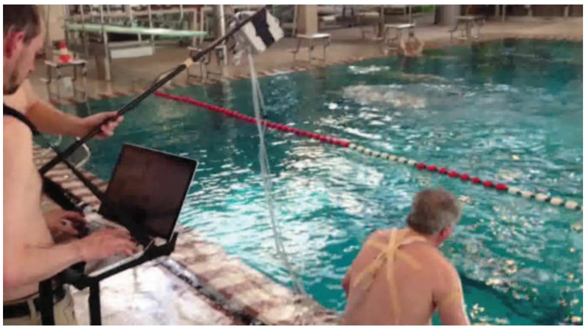

Figure 4 **The test setup, with the waterproof-box fixed on fishing rod, notebook on hawker's-tray and tape-fixing of tubes on back of test person**

Selection of sound mapping

SuperCollider provides qualified functional sound and the mapping of changing pressure data (þz) can be based on modulation of e.g. pitch, amplitude, loudness, loudspeaker orientation. Because of continuous flow of sound is repeated over a longer period in time (depending of the period to cover a certain distance from 25 m to 400 m) the mapping should be aesthetically accepted by the recipient to fulfill the task of a supplement feedback. Cesarini et al. (2013) investigated a 12 tones scale for usage on a mobile system in rowing sonification. It was noticed that using either approach, discrete or continuous actually enhances different aspects of the original signal. Grond & Hermann (2012) emphasised 'Parameter mapping sonification (PMSon) involves the association of information with auditory parameters for the purpose of data display'. PMSon provides a way to build a repeatable transformation from the domain of the monitored signal to that of human hearing. Before applying PMSon to data the actual difference of palmar to back pressure value is calculated. Then the left hand difference and the right hand difference pressures (þz) were fed into the particular PMSon, respectively. The selected mapping is a 3-tone scale mapping (stepwise) using the SuperCollider code: (55+leftPressure.linlin(0,5000,0,24)).round(3).midicps) according to the Handbook of Sonification (Hermann et al. 2011). The code represents a linear conversion from pressure values to midi numbers, rounding the result to 3 (obtaining a 3-tone scale), and finally the midi number is converted to the correct frequency value to be played back by the synthesiser. The stepwise mapping is selected to yield some aesthetics emphasising better perception of pronounced changes in the data-flow; in addition sound of left and right hand was presented on left and right loudspeaker, respectively.

Qualification of real-time aspect in terms of latency

The processes of this new setting of tools required some time and the latency of the setting needs to be evaluated. Here latency means the time delay between the voluntary start of outsweep hand action causing change of (þz) until the sound is emitted via loudspeakers. To check the latency a fully instrumented breaststroke swimmer was videotaped (30 fps) swimming with extremely long gliding phases in a 25 m pool. The time instant when the hands started sweeping outwards was determined from the video and the time instant of emitted sound was determined after the video's soundtrack was transferred to an Audacity program (Fig. 5).

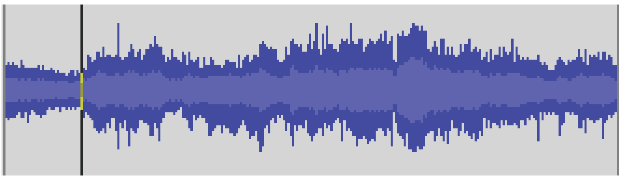

Figure 5 ***Density cloud*** **including the total noise of a swimming pool plus the sound from the loudspeakers; a vertical line indicates the start of the sound induced by pressure changes (þz) due to the start of the hand action after gliding**

The difference of both time instants represent the latency. There is no proof value existing in the literature but probably this time should be related to the time of cognitive control loops.

Results

First, the pressure data (þz) were checked. It was shown, the pressure data (þz) per crawl stoke cycle perfectly match in magnitude and dynamic behavior to what is found in literature (Toussaint et al. 2002) using different type of pressure sensors.

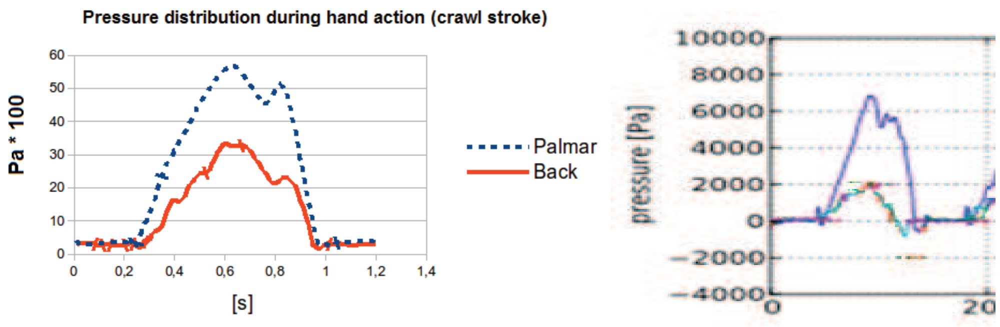

Figure 6 **Pressure distribution (þz) acquired via the Piezo-probes during hand action below water (crawl stroke) of a slow swimming person (left) and results from Toussaint et al. 2002 (right)**

Next, the latency or the quality of the real-time aspect was checked quantitatively using a test when the swimmer swam breaststroke with a remarkable long glide; per 25 m lane 8 breaststroke cycles were executed.

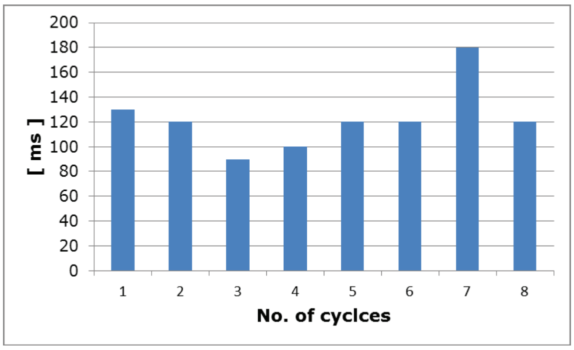

Figure 7 **Time between start of hands into a cycle and the change of the sound from the loudspeakers**

The time duration between the voluntary start of outsweep hand action and the sound emitting via loudspeakers was in the range between | 100 – 123| ms (Fig. 7) while the mean is 123 ± 27 ms. A difference of one video frame equals 33 ms. The calculation of latency due to the 'internal' time of the 'electronic' transit of the setting gives 14,6 ms.

Discussion

Different pressure zones on the palm and the back might resemble Bernoulli's approach used in steady flow to explain circulating flow components; in non-steady flow with drastically changes of acceleration Bernoulli's approach does not apply (Matsuuchi et al. 2009; Ungerechts & Klauck 2008). Using the presented Piezo-probe based setting for sonification of change of energy density per volume (þz) due to disturbed water mass in aquatic actions can be advised. An identification of the effect of the sound mappings on the swimmers actual motoric activities was not of priority of this first testing. All subjects told a) the tubes did not disturb stroking and b) the real-time quality was perceived as if 'each action in water gives immediate reaction'. The real-time check yields positive results, because a delay of 123 ms is not far from reaction threshold of sportive actions.

The functional sound designs selected here is not yet fixed. There will be the choice of two functionality opposite schemes which needs to be deeper analyzed and tested: discrete mappings allow having an enhanced perception of changes of signals, representing the change in a complete new tone, whereas continuous mappings allow perceiving changes in the signal immediately in the output sound at expense of level of perception; the latter is especially important considering that the sounds should be listened to while performing movements in water. The selection of the 3-tone scale mapping (sounds more aesthetic than a continuous one) was not accidentally because of experience with former mappings of pressure curves (Hermann et al. 2012). One might assume that the relatively small number of trials is a limitation of our study and it is too early to judge which mapping would please the swimmer when using the real-time sonification of displaced water in training situation as well as to report which mapping is functionally the most appropriate for the non-steady flow situation.

Future perspectives

This paper concentrates on individual swimmers to increase his/her ability to perceive water motion in combination with self-perception of the body action. The interactive sonification of pressure data might have the potential as augmented feedback to the swimmer directly and as a support to communicate about flow and sensation of flow. Since the link between kinematics of the hand and the resulting body motion is not yet fully understood sonification -probably in conjunction with an effect variable like intracyclic velocity-variation- a better communication between swimmers/experts about flow and the sensation of flow is needed.

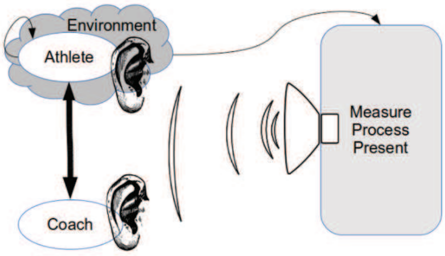

Figure 8 **Schema of a new approach of training communication using a new setting**

The real-time sonification of pressure changes due to displaced water mass is expected a major step towards the aims a) to enhance interrelated perceptions of effects of actions via sound (instead of prescribing a movement) and b) to discover unknown relevant patterns of the (non-steady flow) data. Real-time sonification of is undoubtedly a promising tool for training sessions with elite swimmers at least concerning two aspects: one is related to the cognition-levels of the swimmer who can now use another channel together with the existing own neural network concerning the intimate 'feel for water'-competence and the other aspect is a completely new way of communication between coach and (elite) swimmers about a more effective action of hands (Fig 8). If communication about sensing the flow, a somewhat neglected topic until now, surely will lead to improvements is likely but need to be examined. Compared to 'informative paddles' introduced by Chollet et al. (1992) for real-time auditive feedback of manual hydrodynamic pressure to the swimmer the new setting provides some developments. Here the hand needs not to be equipped with paddles, no 'chosen strength limit' needs to be overtaken and the conflict of mixing terms like 'hydrodynamic pressure', 'static pressure' and 'hydrodynamic forces' is solved because the new setting is opt to be sensitive to static pressure (which is not possible with the paddles). In summary, swimmers benefit from this interactive bio-feedback as a 'self-control means' learning, coaches will be informed more detailed and experts from flow physics could use the original pressure-time-data for analysis of non-steady flow behavior.

Literature

Cesarini, D., Schaffert, N., Manganiello, C., Mattes, K. & Avvenuti, M. (2013)—A Smartphone based sonification and telemetry platform for on-water rowing training. International Conference on Auditory Display*:* 297-300.

Chollet D, Madani M, Micallef JP. (1992) Effects of two types of biomechanical bio-feedback on crawl performance. In MacLaren D, Reilly T, Lees A. (Eds), Swimming Science VI. SPON Press: 57-62.

Dubois, A. B., Cavagna, G. A. & Fox, R. S. (1974). Pressure distribution on the body surface of swimming fish. *Journal of experimental Biology*, *60*, 581-591.

Effenberg, A. O. & Mechling, H. (2005): Movement-Sonification: A New Approach in Motor Control and Learning. Journal of Sport & Exercise Psychology, 27, S58.

Grond, F. & Hermann, T. (2012) Aesthetic strategies in sonification. AI and Society 27 (2):213-222

Hermann, T., Hunt, A., Neuhoff J.G. (2011) The Sonification Handbook. Logos Publishing House, Berlin, GER.

Hermann, T., Ungerechts B., Toussaint, H., Grote, M. (2012) „Sonification of Pressure Changes in Swimming for Analysis and Optimization. In: ICAD, Atlanta, GA, 60-67

Klauck J.M. & & Ungerechts, B.E. (1997) Swimming power output measurements in a flume vs power transfer in swimming using external weights—a comparison of devices. B O Eriksson, L Gullstrand (eds.) XII FINA World Congress on Swimming Medicine, Goeteborg. FINA Lausanne, 291-297.

Kliche, D. & Effenberg, A. O. (1996): Biomechanische Betrachtung zum intrazyklischen Geschwindigkeitsprofil im Brustschwimmen über die Sprint-Distanz. In: DSTV, Rüsselsheim, Bd. 12:56-64.

Loetz, C., Reischle, K. and Schmitt, G. (1988) The evaluation of highly skilled swimmers via quantitative and qualitative analysis, In: Swimming V pp. 361-367, Human Kinetics Publishers, Champaign, IL.

Van Manen, J. D. and Rijken, H. (1975) Dynamic measurement techniques on swimming bodies at the Netherlands ship model basin. In: Swimming II, University Park Press, Baltimore,70-79.

Matsuuchi, K., Miwa, T., Nomura, T., Sakakibara, J., Shintani, H. & Ungerechts, B. E. (2009). Unsteady flow field around a human hand and propulsive force in swimming. Journal of Biomechanics, *42*(1), 42-47.

Nomura &. Ungerechts, 2008, Proceedings of the 1st Intern. Sci. Conf. of Aquatic Space Activities. University of Tsukuba/Japan

Schack, T. (2004) The cognitive architecture of complex movement. Int. Journal of Sport and Exercise Psychology, 2, 403-438

Takagi and Wilson (1999) Calculating hydrodynamic force by using pressure differences in swimming. In K. Keskinen, P. Komi, A. P. Hollander (EDS) Biomechanics and medicine in swimming VIII: 101-106

Toussaint, H.M., Berg v d, C, Beek, W.J. (2002) Pumped-up propulsion during front crawl swimming. Medicine and Science in Sports and Exercise, Vol. 34, No. 2. 314-319

Ungerechts, B. (1981) Über die Hydrodynamik schnell schwimmender Wirbeltiere. Ruhr-Universitat Bochum.

Ungerechts B. E. & Klauck J. (2008). Aquatic Space Activities – Practise needs Theory. In: T. Nomura & B. E. Ungerechts (eds.) The Book of Proceedings of the 1st International Scientific Conference of Aquatic Space Activities, University of Tsukuba, Japan, 283-290.

Ungerechts B.E. & Klauck J.M (2014) Pressure induced by non-steady flow in Swimming. In: BMS XI, Canberra (in Press)

Webber, D. M., R. G. Boutilier, S. R. Kerr, and M. J. Smale (2001) Caudal differential pressure as a predictor of swimming speed of cod (Gadus morphua). J. Exp. Biol, 204:3561-3570.

The determination of 'added mass' of swimmers as a part of studies of non-steady flow patterns

Jürgen M Klauck[1], Bodo E Ungerechts[2]
[1]Biomechanics, SPOHO Cologne, [2]Neucognition-Biomechanics, University Bielefeld, Germany

Keywords: non-steady flow, virtual added mass, semi-tethered, accelerated swimmer, steady drag-factor

Introduction

Swimmers displace mass of water because there cannot be two bodies which share the same space. Due to the cyclic interaction of body and water mass there are flow effects on the body beyond common consideration of thrust and drag known from steady flow mechanics which was developed for ship construction. A ship, with given shape, should not sink and not produce too much drag to keep the energy costs low. Concerning ships the 'hull' is separated from the propulsive propellers and flow effects are sufficiently described by using steady flow mechanics. In contrast, biological