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Diving with Swimming Goggles

Tauchen mit Schwimmbrillen

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ZUSAMMENFASSUNG

In Schulen und Schwimmvereinen war es schon von jeher üblich, Kinder und Erwachsene mit Schwimmbrillen in mäßige Tiefen tauchen zu lassen. In den letzten Jahren traten Zweifel an der Ungefährlichkeit des Tauchens mit Schwimmbrillen auf, die eine gewisse Berechtigung haben. Der beim Tauchen durch zunehmenden Wasserdruck entstehende Sog in der Brille kann nämlich durch den fehlenden Nasenerker nicht ausgeglichen werden, dadurch ist ab einer gewissen Tauchtiefe mit einem Barotrauma des Bereichs zu rechnen, den die Brille abdeckt. Eine Empfehlung der Deutschen Lebensrettungsgesellschaft (DLRG) im Jahre 2005, wegen dieser Gefahr mit Schwimmbrille nicht tiefer als 60 cm zu tauchen, hatte zur Folge, dass alle die, die nicht ohne Schwimmbrille tauchen wollten oder konnten, beim Tauchen auf der Bank saßen. Zur Abschätzung der Gefährdungen, die für Probanden auftreten könnten, tauchten vier der Autoren auf eigene Gefahr in einem Vorversuch mit verschiedenen Schwimmbrillenarten insgesamt 60 mal auf 2 Meter (15 bis 30 sec lang) und 5 Meter Tiefe (ohne längeren Aufenthalt). Verwendung fanden zwei kleine Schwimmbrillen, wie sie wegen ihres geringen Wasserwiderstandes bei Schwimmwettkämpfen vorwiegend getragen und auf den Augengeweben selbst durch meist starkes Anziehen der kopfumgreifenden Elastikbänder abgedichtet werden. Daneben wurden zwei große Schwimmbrillen eingesetzt, die sich an der knöchernen Augenhöhle abstützen und somit keinen Druck auf die Augen selbst ausüben. Die insgesamt durchgeführten 230 Versuche zeigten, dass durch mangelnden Druckausgleich in den Schwimmbrillen bis 3 Meter Tauchtiefe keine und bis 5 Meter nur geringe temporäre subjektive und objektive Beeinträchtigungen auftreten. Da die kleinen Schwimmbrillen durch Druck auf die Augen Probleme machen können, werden vor allem für Kinder und Jugendliche größere Schwimmbrillen empfohlen, die keinen Druck auf die Augen ausüben.
Nachdem das Team die DLRG über seine Versuchsergebnisse in Kenntnis gesetzt hatte, gestattete diese wieder das kurzzeitige Tauchen mit Schwimmbrillen bis zwei Meter.

Schlüsselwörter: DLRG, Barotrauma, Schwimmbrillen, Tauchverbot, Tauchversuche

SUMMARY

It has always been customary to let children and adults dive to moderate depths wearing swimming goggles. In recent years, some doubt has arisen about the safety of diving with goggles and the doubt is justified to some extent. The pressure which arises in the goggles from increasing water pressure in diving cannot be offset due to the lack of nosepiece and thus a barotrauma can be expected in the area covered by the goggles. The recommendation of the German Life-Saving League (DLRG) in 2005 of not diving to depths greater than 60 cm meant that those who could not or did not want to dive without goggles were excluded from diving. To estimate the danger which might arise for subjects, the four authors dived at their own risk a total of 60 times to 2 meters (15-20 seconds) and 5 meters (without staying for any length of time at that depth) in a pretrial with various goggles. Two small goggles, like those used in swimming competitions because of their low water resistance and made water-tight on the eye tissue itself by usually strong tension of the elastic band around the head, were used. In addition, two large goggles were used which rest on the bony ocular cavity and thus do not put any pressure on the eye itself. The 230 trials performed showed that to 3 meters in depth no and to 5 meters in depth only slight, transient subjective and objective detriments occur due to the lack of pressure equilibrium in the goggles. Since the small goggles can cause problems due to pressure on the eyes, larger goggles which do not exert pressure on the eyes are recommended especially for children and adolescents.
After the team informed the DLRG of the results of the trials, the DLRG once again permitted short-term diving with goggles to a depth of 2 meters.

Key words: DLRG, barotraumas, swimming goggles, diving ban, diving tests.

PROBLEM AND OBJECTIVE

The reason for the diving trials with swimming goggles undertaken by our group was a statement by the German Life-Saving League (DLRG) in 2005 that warned against diving with swimming goggles to a depth of more than 60 cm in order to prevent barotrauma.
As a result of this recommendation, many children and adolescents remained out of the water during swimming instruction in school sports or in swimming clubs when underwater swimming or diving to depths of 2-3 meters was planned. These youngsters could not or would not dive without swimming goggles either due to allergies, or an insurmountable lid closure reflex under water, or fear of "blind diving". Visual acuity under water with no air-space in front of the eyes is 10-20 cm for hand movement.

Many experienced diving instructors and swim trainers considered the recommendation an exaggeration, and even the DLRG

Figure 1: Swimming goggles No. 1 (SB 1), small, two-chamber with narrow elastic rim.

Figure 2: Swimming goggles No. 2 (SB 2), small, two-chamber with no elastic components (Swedish goggles).

Figure 3: Swimming goggles No. 3 (SB 3), large, single-chamber with extremely large elastic rim.

Figure 4: Swimming goggles No. 4 (SB 4), large, two-chamber with elastic components.

admitted that it was probably overcautious with no adequate scientific basis. Since diving masks generally should generally not be used or are forbidden during school swimming or in club activities, there appeared to be no practicable solution for this group of youngsters, as long as the recommendation of this acclaimed league was not altered. After discussions with the DLRG, a team consisting of three sport ophthalmologists, one sports scientist and diving instructor, an ENT specialist and a master optician with diving experience decided to perform a self-test to determine the limits of danger for the eyes in diving with swimming goggles. This was conducted in two test series. The first was to obtain rough orienting information about the potential danger to the test persons and the second was to deliver an adequate number of detailed results.

MATERIAL AND METHOD

In order to not endanger other subjects, four of the authors themselves undertook the diving tests to a depth of 5 meters on the first diving day. In the second test series, the objective was to determine on the basis of systematic diving tests whether subjective or objective detriment or even damage in the sense of a beginning barotrauma occurs at the usual diving depth of 2-3 meters with swimming goggles.

Common types of swimming goggles were tested: 1. two small goggles which are sealed by pressure on the soft tissues around the eyes. 2. Two large swimming goggles which lie on the skin over the eye socket area and are water-tight without pressure on the eye. These swimming goggles are available without and with elastic rims of various types of rubber, silicone or special plastics which improve the seal and diminish the pressure on the tissue. The following swimming goggles (SB) were used in the swimming goggle test series:

1. Small swimming goggles, two-chambered with elastic band (SB 1: Figure 1).
2. Small swimming goggles, two-chambered, with no elastic elements, known as "Swedish goggles" (SB 2, Figure 2)
3. Large swimming goggles, single-chambered with extremely elastic, broad rim (SB 3, Figure 3)
4. Large swimming goggles, two-chambered, with elastic rim (SB 4, Figure 4).

First Diving Day

To begin, the anterior segment of all test persons was examined first macroscopically then microscopically with the split lamp. Then the four subjects put the swimming goggles on and reported their subjective impressions after about five minutes. The goggles were removed and the split lamp examination repeated. Subsequently, each of the four subjects made 10 dives to 2 meters and remained at that depth for 15 to 30 seconds. Then subjective and objective findings in the anterior segment were recorded. No retinal examination was made, since, unlike in diving with compressed air, no retinal damage was to be expected in these apnea dives (1,2,3,8,9,10). The dives were performed under observation by one participant on a pole fastened under water and marked with meter depth markings. In the 2-meter dives, the subject held fast to the pole for about 15 to 30 seconds, whereby the eyes were to be kept at the level of the marking. At the end, all four subjects performed 5 dives each to a depth of 5 meters. Subjective and objective findings were then recorded.

Thus, a total 40 dives at 2 meters up to 30 seconds duration and 20 dives to 5 meters (with no set duration) were performed with the four different swimming goggles. After no lasting effects or damage were found in any of the participants, the 2nd diving day was scheduled with additional subjects.

Second Diving Day

Seven sports students, four adolescents between 12 and 14 years of age, and a sports scientist and diving instructor participated in the diving test on the second diving day. An otorhinolaryngologist (ENT-Dr.) and three ophthalmologists were available for examinations.

First, the visual acuity, ocular motility, stereo vision (Test Titmus Hausfliege), anterior segment with the split lamp (Figure 5, left), central-paracentral visual field (Amsler's marker) and the ocular fundus (indirect fundoscopy examination, Figure 5, middle) were examined. The ENT-Dr. inspected the tympanic membrane and checked the middle-ear pressure (Figure 5, right). Each subject put on the swimming goggles assigned to him, took them off again 5 minutes later and the eyes were again examined macroscopically and microscopically (split lamp) for pressure effects of the goggles. Then the subject dived.

While the adolescents only had to dive 5 times each to a depth of 2 meters at 3-4 minute intervals, the sport students first performed a series of 10 dives to a depth of 2 meters and when there

were no pathological findings, another series of 10 dives at a depth of 3 meters after a pause of 15-20 minutes. Subject No 12 suffered acute malaise and could only perform the 10 dives to 2 meters and not to 3 meters. After completion of each dive series, the four doctors repeated the examinations as described above.

Figure 5: Left: split-lamp examination. Middle: retinal ophthalmoscopy, Right: ENT examination.

Pressure Measurement in the Swimming Goggles

The interior pressure in the goggles was measured order to determine what pressure or suction is present in the swimming goggles at the various depths. In the diving tests, the instrument to measure the inner goggle pressure failed. The measurements were performed later by Müller (6). In that test, 11 subjects dived with goggles type SB3 and goggles practically identical to SB4. Each subject dived three times to a depth of one, two and three meters, and as a safety precaution, only three times to one and two meters wearing the Swedish goggles (SB2).

RESULTS

The mean age of all divers in our study was 32.6 years. As expected, most ocular functions and findings did not change because of the dives, including visual acuity, motility, stereovision, central-paracentral visual field (examined with the Amsler table) and objective retinal findings (Table 1.)

Subjective ocular complaints already occurred shortly after putting some of the swimming goggles on. The greatest effect was noted by wearers of small goggles, since it was necessary to press them strongly into the eye socket to make them water-tight. Seven of the eight subjects who wore small goggles reported primarily suction or a sensation of pressure, while this was the case in only one of eight wearers of large goggles. Accordingly, mild to moderate vascular dilatation and irritation were observed even before the dives in these seven subjects. On the first diving day, vascular dilatation to various extents was observed after the dive to 5 meters in the two subjects wearing small swimming goggles. Subject 3, who wore Swedish goggles, also had vascular congestion and punctate bleeding (Figure 6). The two subjects with large goggles showed very slight conjunctival irritations.

On the second diving day, the primary subjective complaints and objective findings caused by the swimming goggles did not increase in any case during the 2 and 3 meter dives. While the conjunctival vascular changes had disappeared in all subjects after 5 to 10 hours, the microbleedings required 2 days to resorption. On the first diving day, the four subjects felt pressure and suction in the ears increasing with depth, so they were forced to create pressure equilibrium in the nasopharyngeal space by the usual techniques. The ear complaints then disappeared at once. Subjectively, no or only mild pressure symptoms in the ears were reported during dives to 2 and 3 meters. In seven of the 24 ears examined on the second diving day, the ENT-Dr. noted sight reddening of the tympanic membrane and/or slight underpressure in the middle ear due to a lack of pressure equilibrium in diving to 2 or 3 meters. The findings were not rated serious or even dangerous in any case. There were

Figure g 6: Left: Vascular dilatation, congestion and petechiae after 5 dives to 5 m. Right: 3 days later, normal findings.

no pathological findings in the skin of any subject.

Measurement of inner goggle pressure was undertaken in goggle types SB2, SB3 and goggles corresponding to goggles SB4 in our test. Each of the 11 subjects dived with all 3 goggles, three times each to each of the three depths (with SB2 only to 1 and 2 meters). The dives were with compressed air. The 4 women and 7 men stayed at each of the diving depths for at least 10 seconds. For details of the examination method, see the article by Müller (6). All measurement curves showed similar course: the lowest pressure value was usually found at the start of a dive, and on average was 11 mbar higher

Table 1: Findings which remained unchanged after the dives (light blue: 1st diving day, blue, 2nd diving day).

Subject No.	Age (yrs)	Vision Subjes. c.	Motility	Stereo-vision	Amsler-Marker	Fundus
1	50	-	-	-	-	-
2	40	-	-	-	-	-
3	68	-	-	-	-	-
4	58	-	-	-	-	-
5	50	1,0/1,0	normal	normal	normal	normal
6	14	1,0/1,0	normal	normal	normal	normal
7	12	1,0/0,6	normal	normal	normal	normal
8	12	1,0/1,0	normal	normal	normal	normal
9	12	1,0/1,0	normal	normal	normal	normal
10	36	1,0/1,0	normal	normal	normal	normal
11	25	1,0/1,0	normal	normal	normal	normal
12	50	1,0/1,0	normal	normal	normal	normal
13	24	0,1/0,8	Strab. conv.	none	normal	normal
14	26	1,0/1,0	normal	normal	normal	normal
15	21	0,7/0,7	normal	normal	normal	normal
16	23	1,0/1,0	normal	normal	normal	normal

Table 2: Findings changed after dives
(light blue: 1st diving day: Subjects 1-4. Blue: 2nd diving day, Subjects 5-16).

Subject No.	SB type	Diving depth (m)	Subj. due to SB	Subj. on and after diving	Anterior segment before and after last dive	Subj. and obj. ear findings after last dive
1	4	2/5	Normal	Feeling of suction	Slight conjunctival irritation	At 5 m subj. ear pressure
2	3	2/5	Suction	Suction starting at 3 m	Slight conjunctival irritation	At 5 m subj. ear pressure
3	2	2/5	Strong pressure	Stronger pressure	Marked vascular dilatation and congestions, petechial after diving (Fig. 7)	At 5 m subj. ear pressure
4	1	2/5	Suction	Suction	Mild vascular dilatation	At 5 m subj. ear pressure
5	1	2	Suction	Normal	Slight vascular filling before	Imp:R. -50, T normal both sides
6	3	2	Normal	Normal	Normal	Imp.L -50 T: L reddened
7	4	2	Normal	Normal	Normal	Imp: R: -50 T: normal both sides
8	4	2	Normal	Normal	Normal	Imp: 0 T normal both sides
9	3	2/3	Normal	Normal	Normal	Imp. R -46, L -9, T reddened both sides
10	1	2/3	Suction	Suction pressure	Increased conj. Injections before	Imp. :-50, T: normal both sides
11	1	2/3	Pressure	Mild suction	Expanded conjun. Vessels before	Imp 0, T normal both sides
12	2	2	Pressure	Pressure	Slight conjunct. Injections before	Imp. 0, T: L reddened
13	3	2/3	Normal	Normal	Normal	Imp: 0, T normal both sides
14	2	2/3	Pressure	Pressure	Slight vascular dilatations before	Imp: 0, T normal both sides
15	4	2/3	Normal	Normal	normal	Imp: 0, T normal both sides
16	2	2/3	Normal	Normal	normal	Imp. L -50, T normal both sides

SB=Swimming Goggles, Imp.=Impedance in ws, T=Drumhead

at the end (Figure 7). Incomplete tests due to leaking goggles or apparatus deficiency were excluded. 220 dives could be evaluated. It was noteworthy that the pressure in the goggles at the start of the staying time at the individual depth was often lower than that corresponding to the diving depth. This was not the case only for SB3, where the pressure values at the end of the 1 m dive was in the + range on average, so there was slight overpressure in the goggles. If the mean pressure values among the 3 goggles in the three dives are calculated, it is apparent that on average, constant values below the expected pressure value at each diving depth was measured with the Swedish goggles (Figure 8). The pressure in the other two goggles, apart from a slight decrease in goggles SB4 at 1 m, was always on average slightly to greatly above the pressure value of the diving depth attained. No examination of the inner ocular pressure was made, even though a not inconsiderable increase in intraocular pressure must be expected in a certain percentage of swimmers using small goggles (5). The goggles were worn for a maximum of 10 minutes, which is well below the time at which impairments or even damage would be expected.

DISCUSSION

Due to a lack of nosepiece, equalization of pressure differences arising according to the Boyle-Mariotte Law between the space in front of and in the goggles, is not possible in diving with swimming goggles. This underpressure, which increases with increasing depth, exerts suction on the skin and eyes under the swimming goggles and leads to reddening starting at a certain power and length of time, and finally to bleeding of the skin and conjunctiva which is termed barotrauma (4,7,8,10).

In swimming competitions, even laymen note that many of the athletes practically tear their goggles off at the end of the race. The reason for this is that they wear small swimming goggles which, as already mentioned, are water-tight due to extreme suction on the soft tissue of the eyes, often causing pain according to the athletes. These small swimming goggles, comparable to goggles 1 and 2, in our test, are worn because compared to the large goggles, they supposedly offer less water resistance, they practically disappear into the eye socket.

Several years ago we tested the adhesion capacity of various

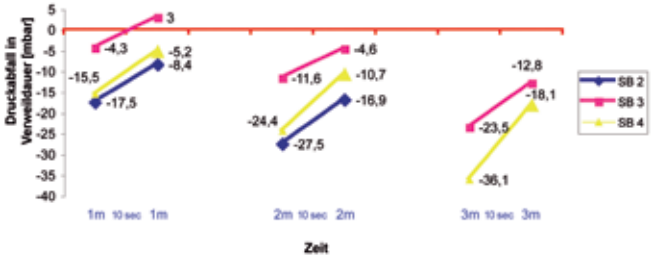

Figure 7: Average values of interior goggle pressure in dives with goggles SB 2, SB 3 and SB 4 at the start and end of diving time of at least 10 seconds, at depths of 1, 2 and 3 meters.

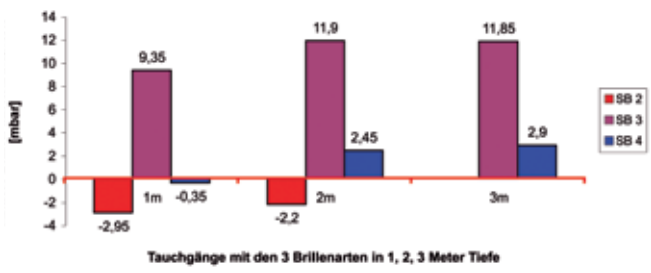

Figure 8: Average mean pressure within the three swimming goggles at each diving depth.

types of contact lenses under water at the University swimming center in Cologne. In the split lamp examination of swimming athletes after training, we found signs of congestion, in some cases even small hematomas in the conjunctiva caused by wearing tightly-fitted small swimming goggles. Some scientific articles describe eye injuries, bleeding and formation of tumors due to these small goggles (4,8,10,11,12). Since then, to protect the eyes, we recommend always using large swimming goggles that lie on the bony eye socket and exert no pressure on the ocular tissue. This applies especially and particularly for children. These goggles, which are less dangerous, are also recommended for swimming competitions. The water resistance of these somewhat more protruding goggles is, experts tell us, greatly overestimated.

As expected, pressure measurements in the goggles (6) show that a larger airspace (the single-chamber SB3 has the largest air volume) and elastic rims on swimming goggles made of silicone, rubber or other materials (SB 3 and SB 4) reduce the suction effect. This is also confirmed by the considerably lower pressure in the Swedish goggles compared to the other two, since the Swedish goggles have no pressure-reducing plastic rim. That a certain reduction in suction arises from the water-tight skin which is sucked into the goggles, underlines the fact that the pressure even in the Swedish goggles decreases over the 10-second staying time at each diving depth. It can be concluded from the measurements that the suction effect under swimming goggles at each diving depth is lower inversely to the airspace in the goggles, the strength of the pressure reduction by the rim and the degree to which the skin tissue on which the goggles sit is pliable (Figures 1-4, 7, 8). Our diving tests also confirm that a feeling of pressure or suction in small swimming goggles, even when they are unpadded, occur more frequently than with large goggles, and the tighter the headband is pulled, the greater the pressure or suction. Extreme pressure on ocular tissue sometimes leads thus to congested vessels even out of the water.

As the most important result, it is noted that neither pathological findings on the skin or eyes, nor functional reduction occurred to a diving depth of 3 meters. The same applies to the ears, where a slight underpressure and tympanic membrane reddening was found in about one-third of the cases but there was no serious danger to health at all. Conjunctival vascular changes and petechiae which occurred (with the two small swimming goggles) after 20 dives to 5 m, can be rated as mild to moderate and healed without sequelae. The suction or pressure in the ears was subjectively unpleasant even at a depth of 5 m, thus with an underpressure of -0.5 bar.

After the authors informed the German Life-Saving League of the results of their study, the DLRG in their publication (6) again permitted short dives with swimming goggles to 2 meters water depth. The DLRG advises children and adolescents not to use Swedish goggles.

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