Distortion of Prospective Time Production Underwater

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BACKGROUND: The few prior studies of time perception underwater have reached contradictory conclusions as to how, and if, time perception becomes distorted when submerged. The current paper expands upon this limited data by describing two studies of prospective time production in scuba divers.

METHODS: Study 1 ($N = 32$) compared performance on a 30-s interval time production task in deep water (35 m–42 m/∼115–138 ft) with a shallow water control (3–12 m/∼10–39 ft). Using the same task, study 2 ($N = 31$) tested performance at the surface and at a range of depths underwater (1 m/3 ft; 11 m/36 ft; 20 m/66 ft; 30 m/98 ft; 40 m/131 ft).

RESULTS: Study 1 revealed time production to be significantly longer in deep water compared to shallow water. In study 2 time production at the surface was not significantly different from that at 1 m, but productions at 11–40 m were significantly longer than at both 1 m and on the surface. Time productions between 11–40 m did not differ significantly.

DISCUSSION: It was concluded that divers judge less time to have passed underwater than is objectively the case from a depth of 11 m, but that this effect does not deteriorate significantly once past 11 m. The cause of this distortion of time perception underwater was suggested to be the action of gas narcosis.

KEYWORDS: narcosis, time perception, diving, underwater performance.

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Timing is considered an essential component for most actions, behaviors, and cognitive abilities,[10] and therefore, distortion of time perception can have important safety implications for some activities. One setting in which it is essential to keep track of time is in an underwater environment. Undersea divers are constrained in the amount of time they can remain submerged due to limited air supplies and the need to follow strict schedules to avoid potentially fatal decompression illness.[17] Much of the effort of tracking time is taken care of by personal computers and air gauges, but mistakes in time-related behavior remain possible: individuals can forget to check instruments, turn off 'annoying' safety alarms, underestimate how long air will last, and experience equipment failures. Divers also face an insidious and progressive form of intoxication known as gas narcosis, which becomes apparent from around depths of 30 m (98 ft).[4] The neural mechanisms of narcosis are poorly understood, but are primarily caused by the absorption of inert gases from breathing mixtures which interfere with neurotransmission.[15] Narcotic symptoms include a spectrum of cognitive impairments, which may include time perception, although the evidence is inconclusive at present. If narcosis does distort time perception, this may cause or compound dangerous lapses in timing behavior underwater.

One reason to suspect narcosis may affect time perception is that it has been shown to be distorted by both alcohol[7] and anesthetics.[1] The effects of these pharmacological agents may be pertinent because they are posited to share commonalities with narcosis, both in their effects on underlying neurobiological mechanisms and on cognitive functions.[6] Direct evidence for the effect of narcosis itself on time perception is limited to three studies[8,9,11] using a common measure of temporal cognition known as prospective time production. In production tasks subjects are required to delimit specific time intervals (such as by pressing a button), which is compared with objective time. Employing intervals of 18–60 s, Mears and Cleary[9] failed to find significant impairment of time production at depths of 6 m (20 ft) and 30 m (98 ft) underwater. In contrast, Lipperman-Kreda and Glicksohn[8] reported that, when

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compared with surface performance, time production intervals of 4 to 32 s were significantly longer at 10 m (33 ft) underwater and that this effect became significantly worse at 30 m. A third study[11] using intervals from 4 to 24 s also found time production was significantly longer underwater at multiple depths between 32 m and 61 m (105 and 200 ft) when compared to surface performance. However, no significant change in performance between underwater depths was found.

The current paper describes two brief studies of prospective time production in scuba divers while underwater. Study 1 compared performance in deep water (35–42 m/115–138 ft), where narcotic symptoms were expected, with a shallow water control (3–12 m/10–39 ft). Study 2 tracked performance from the surface at regular depth intervals down to 40 m (131 ft). These studies expand the limited data available on time perception underwater in two ways. Firstly, they add a new assessment to the existing studies that are contradictory as to whether or not time perception becomes distorted underwater. Secondly, they test performance at a range of depths not used in prior research and in a way that allows some determination of how time production is affected as a function of depth from mere immersion down to 40 m.

METHODS

Subjects

Volunteering for study 1 were 32 divers (22 male), ages 20 to 63 yr (M = 34.7; SD = 11.9). These divers reported having completed 10 to 6000 dives (M = 1187.7; SD = 1636.7) over 0.1 to 48 yr (M = 9.4; SD = 10.1). Volunteering for study 2 were 31 divers (13 women), ages 19 to 53 yr (M = 35.9; SD = 10.5), who reported 10 to 6500 dives (M = 680.8; SD = 1433.8) over 0.1 to 42 yr (M = 8.72; SD = 10.4). Recruitment took place through three dive operators on Roatan Island, Honduras: Ocean Connections and West End Divers (study 1) and West Bay Divers (study 2). Each dive operator carried out screening procedures to ensure that all divers were suitably qualified, medically fit, and provided safety divers when deemed appropriate. Ethical permission for the protocol was granted by the University of Winchester.

Design

Study 1 used a 2-way repeated measures design testing the effect of depth (shallow vs. deep) on time production. Shallow conditions represented depths of 3–12 m (10–39 ft; M = 7.5 m; SD = 2.1) and deep conditions 35–42 m (115–138 ft; M = 38.2 m; SD = 1.9). The order in which the depth conditions were completed was counterbalanced to control for practice effects. Divers either completed the shallow condition followed by the deep condition, or vice versa. Study 2 used a 6-way repeated measures design testing the effect of depth (surface vs. 1 m/3 ft vs. 11 m/36 ft vs. 20 m/66 ft vs. 30 m/98 ft vs. 40 m/131 ft) on time production. Order of depth conditions was again counterbalanced to control for practice effects. There were 15 divers who were randomly assigned to begin with the shallowest condition followed by each consecutively deeper depth to 40 m, while 16 divers completed the trials in the reverse order.

Measure

Time perception was measured in both studies using a typical method of prospective time production.[5] Divers were asked to delimit an interval of 30 s which was compared by the researcher, to the nearest second, with objective time on a stopwatch. To initiate the task the researcher gave the divers a countdown followed by a signal marking the start of the interval. When the divers judged 30 s to have passed, they provided their own signal to mark the end of the interval. An interval of 30 s was chosen partly to conform to time limits at depth and because intervals under 30 s have been claimed to be less sensitive in capturing the effects of other pharmacological agents.[16] There was a concern the researcher's own accuracy in recording responses might be affected by narcosis and so, as an added precaution, each trial was recorded with a head-mounted camera and responses checked for errors on the surface.

Protocol and Environmental Conditions

In both studies divers were briefed on the surface before completing a single dive led by the researcher. Divers were tested individually or as pairs. All divers breathed air (21% O_2; 79% N_2) and wore an extra 1 kg of weight to ensure they sat comfortably on the ocean floor for testing. Depth measurements were taken by holding a dive computer at chest height.

In study 1 divers completed the task twice underwater, once at a shallow depth and once at a deep depth. The researcher led divers to suitable locations at each depth and instructed them to kneel on the sand and complete the time production task. When divers were tested as a pair they faced away from each other so that they were blind to each other's responses. Once testing in both depth conditions was completed, all divers returned to the surface and exited the water. Study 1 was initially conducted as an investigation into anxiety effects. For this reason divers also completed a state anxiety measure after each time production task, the data of which is not reported as we failed to find significant effects on this dimension. All dives were conducted from a boat at multiple sites along the southwestern reef of Roatan because data collection had to conform to the logistics of the dive operators. Nevertheless, taking place on the same section of reef, each site was topographically and environmentally similar with flat, sandy ocean bottoms in the shallow and deep water. Water temperatures ranged from 27–29°C, there was no discernible current, and visibility was 20 m (66 ft)+ with little change in ambient light between depths.

In study 2, divers first completed the task at the surface before completing it another five times underwater. The protocol for carrying out the task in each case was the same as in study 1. Testing in study 2 took place at a single site (Mandy's Eel Garden) on the same section of reef as in study 1, and in the same ocean conditions. The site was accessed via the beach into a sandy lagoon, which, approximately 91 m (300 ft) out to sea, dropped to a gently sloping sandy bank. Five suitable positions on the sand were identified where the ocean floor gradient was minimal and divers could kneel easily. The 1-m (3-ft) condition took place at the entrance to the lagoon and the other depth conditions on the sandy bank at 11 m (36 ft), 20 m (66 ft), 30 m (98 ft), and 40 m (131 ft).

RESULTS

Each dataset yielded mean scores for time production at each depth tested and, in study 2, also on the surface. In both studies exploratory analyses were done for age, gender, and dive experience (years of diving and number of dives to date) but no significant effects of these factors were found and they are excluded from the analysis below. At initial analyses depth order condition was included as a factor, but in both studies no significant effect was found (Ps > 0.05), indicating no practice effects. The data was therefore collapsed across depth order conditions. The lack of practice effects also justified including the study 2 surface data in the main analysis, which had not been included in the depth order counterbalancing strategy, being completed before the other trials. Time production was analyzed using a paired t-test in study 1 and analysis of variance (ANOVA) in study 2. A P-value of 0.05 was taken as the criterion of significance. In study 2, sphericity was violated, which was addressed by using Greenhouse-Geisser values, and post hoc comparisons were explored with a series of paired t-tests with Holm's Sequential Bonferroni adjusted P-values.

Study 1

Mean time produced was 3.3 s longer in the deep water (M = 39.2 s; SD = 7.1) compared with the shallow water (M = 35.9 s; SD = 6.2), a difference that was confirmed as significant [$t(31) = 3.53$, $P < 0.01$]. This indicated that divers judged time as moving slower than objective time in the deep water, compared to the shallow water.

Study 2

Fig. 1 displays mean time produced at each depth and on the surface. In every case time produced was longer than 30 s, indicating more time passed than was judged to be the case. Numerically, this tendency to underestimate actual time steadily worsened from the surface (M = 31.1; SD = 4.2) through 1 m (3 ft; M = 32.5 m; SD = 5.7), 11 m (36 ft; M = 35.2 m; SD = 6.1), and 20 m (66 ft; M = 37.4 m; SD = 7.1), before it leveled off at 30 m (98 ft; M = 38.2 m; SD = 8.9) and 40 m (131 ft; M = 38.3; SD = 9.4). The ANOVA revealed a significant effect of depth [$F(2.4, 71.1) = 10.68$, $P < 0.01$] and so post hoc comparisons were carried out, which are displayed in **Table I**. The post hoc comparisons revealed that surface performance was no different from submersion at 1 m, but both surface and 1-m performance were significantly more accurate (closer to 30 s objective time) than at any other depth underwater. Between 11 m and 40 m, performance did not significantly differ, although it should be noted that the 11 m vs. 20 m was borderline significant.

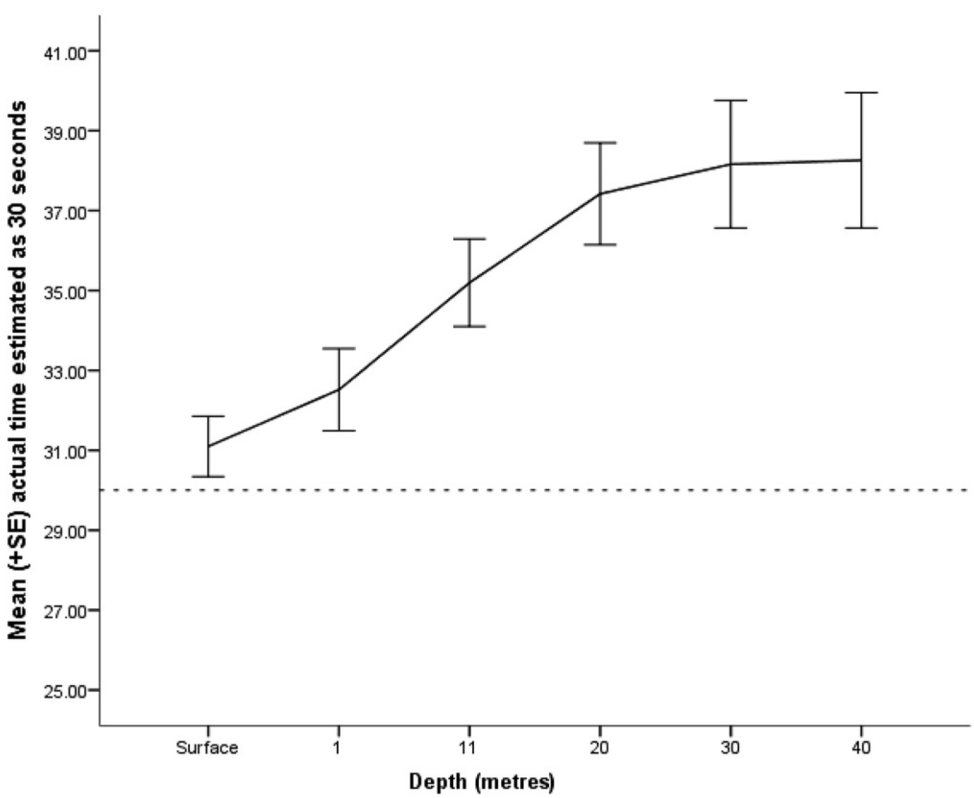

Fig. 1. Mean (+ SE) time produced (judged) as a 30-s interval at each depth.

DISCUSSION

The two studies described above demonstrated prospective time production is significantly altered underwater. In study 1, time production was longer in deep water compared with shallow water. In study 2, time production was longer at 11–40 m (36–131 ft) compared to the surface, or at 1 m (3 ft). Thus, from a depth of 11 m the divers judged significantly less time to have passed than was objectively the case. These results support previous findings that time production is longer underwater,[8,11] and the magnitude of change was approximate to that observed in prior studies when they used similar time intervals and depths to the current investigation. The results are, however, not in agreement with the report[8] that time production accuracy further declines from 10 m to 30 m (33 to 98 ft). In the current investigation time production did not alter significantly between 11 m and 40 m.

The cause of the observed distortion in time perception is suggested to be due to the action of narcosis. In study 1 narcotic symptoms would be expected in

Table I. Results of Post Hoc Tests (*P*-Values) for Time Estimation.

DEPTH	SIG.	DEPTH	SIG.
Surface vs. 1 m	n.s.	1 m vs. 40 m	<0.01*
Surface vs. 11 m	<0.01*	11 m vs. 20 m	n.s.
Surface vs. 20 m	<0.01*	11 m vs. 30 m	n.s.
Surface vs. 30 m	<0.01*	11 m vs. 40 m	n.s.
Surface vs. 40 m	<0.01*	20 m vs. 30 m	n.s.
1 m vs. 11 m	<0.01*	20 m vs. 40 m	n.s.
1 m vs. 20 m	<0.01*	30 m vs. 40 m	n.s.
1 m vs. 30 m	<0.01*		

* Indicates significant effect after Bonferroni adjustment; n.s. = not significant.

the deep water condition at 35–42 m (115–138 ft; M = 38.2 m), but unlikely in the shallow water at 3–12 m (10–39 ft; M = 7.5 m). Furthermore, in study 2, while time perception at mere immersion (1 m/3 ft) did not differ significantly from that measured at the surface, both differed significantly from time perception at deeper depths (11–40 m/36–131 ft). Other causes for the distortion cannot of course be fully discounted, but two obvious candidates that have been shown to affect time perception can be considered unlikely: anxiety[2] and body temperature.[18] A study of the impact of anxiety on time production underwater was the initial objective of study 1, but no evidence was found and the data was discarded. Body temperature can affect time perception, but if this had been a significant factor in the current investigation this would have been apparent from the counterbalancing strategy. Performance would have differed when divers were tested at the beginning of the dive and at the end, something for which there was no evidence.

We therefore suggest that the current investigation implies evidence of narcotic impairment at 11 m (36 ft). Although such a shallow depth for narcosis may initially seem surprising (symptoms are usually considered to manifest at 30 m/98 ft+), it should be noted that other studies have also reported evidence of narcosis much shallower than 30 m.[3] The results of study 1 may appear to contradict the claim that time perception is distorted by narcosis at 11 m because the shallow water condition included depths down to 12 m (39 ft), precluding a significant difference between the shallow and deep conditions. However, this discrepancy might be reconciled by noting the mean depth in the shallow condition was only 7.5 m (24.6 ft), which may have been shallow enough to produce performance comparable to the 1-m (3-ft) condition in study 2.

Several hypotheses can be suggested as to why narcosis lengthens time production by considering theories of temporal cognition that posit the existence of a neurally based 'internal clock.'[5] According to these models, the clock consists of a pacemaker which sends pulses, via an attentional gate, to an accumulator, which counts the pulses to produce raw information on time. This information is then manipulated by memory processes and outputted (e.g., verbalized) as temporal judgements. Accuracy on the 30-s interval production task used in the current investigation relies on internal clock speed (i.e., rate of pulses), processing speed, working memory, and comparison with temporal representations in long-term memory. Thus, interference with any of these components may distort time perception and explain the longer time productions observed underwater.

One hypothesis is that, because narcosis acts as a depressant on the central nervous system, the pacemaker of the internal clock is slowed, resulting in fewer pulses accumulating for a set interval. This would lead to longer time productions and be consistent with findings that time perception is affected by arousal[19] and explanations of similar effects by alcohol and anesthetics.[1,5,16] Secondly, narcosis may affect time production by disrupting other systems that have a role in processing temporal information, most notably memory,[6] but also by reducing attentional resources.[13] Thirdly, a reduction in arousal by narcosis could cause a more general reduction of the processing speed of the entire temporal cognition system, in line with the slowed processing theory of narcosis.[4] Finally, it should be noted that these hypotheses are not necessarily exclusive from one another and that narcosis may affect time perception through more than one of these mechanisms.

A key limitation of this investigation was the reliance on one time interval, narrowly focused because the original study objectives changed, and because of time limits when collecting data at deeper depths. Future studies would benefit from expanding the range of production intervals tested, in line with prior studies that have shown distortions of time perception can be specific to certain interval ranges.[5] Expanding the range of intervals is certainly possible given that time production was shown to be affected at shallower depths than expected, where decompression limits and air supplies last longer. Other intervals may also be appropriate for testing specific hypotheses. For example, very short intervals may be useful for determining the effect on the pacemaker because those judgements are more perceptual in nature and reduce the role of memory systems.[14]

Alternative measures to time production may also be desirable, especially when considering the safety implications of distorted time perception underwater. The losses in time accuracy at 11 m (36 ft) and deeper (5–9 s on average) might initially be considered minor, although their contribution to lapses in timing behaviors would be more serious if they were shown to accumulate over the course of a dive. However, in prospective time production tasks, subjects are told in advance that they will be making a temporal judgement. The divers would, therefore, have focused as many attentional resources as possible on the task. Arguably, a more realistic scenario underwater is for divers to focus their attention elsewhere while underwater, or be required to make a temporal judgement without prior awareness that one would be needed (e.g., after discovering a dive computer has failed). Retrospective timing measures may, therefore, provide a more realistic view of time perception underwater and act to compliment prospective measures.[12] Also, as it is known that reducing attention to time reduces accuracy.[13] Thus, the small distortions in time perception observed in the current investigation may indicate larger distortions in a typical everyday situation. In conclusion, the current investigation expands the limited evidence demonstrating that time perception is distorted underwater by narcosis at the surprisingly shallow depth of 11 m, causing divers to judge less time to have passed than is objectively the case.

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