

# Aerospace Medicine & Human Performance

## Distortion of prospective time perception underwater

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<b>Abstract:</b>	<p>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 second (s) interval time production task, in deep water (35m-42m) with a shallow water control (3-12m). Using the same task, study 2 (n=31) tested performance at the surface and at a range of depths underwater (1m; 11m; 20m; 30m; 40m). 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 1m but productions at 11m-40m were significantly longer than at both 1m and on the surface. Time productions between 11m-40m 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 11m but that this effect does not deteriorate significantly once past 11m. This distortion of time perception underwater was attributed to the action of narcosis.</p>

1           **DISTORION OF PROSPECTIVE TIME PRODUCTION UNDERWATER**

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32 **Abstract**

33 *Background:* The few prior studies of time perception underwater have reached contradictory  
34 conclusions as to how, and if, time perception becomes distorted when submerged. The current paper  
35 expands upon this limited data by describing two studies of prospective time production in scuba  
36 divers. *Methods:* Study 1 ( $n=32$ ) compared performance, on a 30 second (s) interval time production  
37 task, in deep water (35m-42m) with a shallow water control (3-12m). Using the same task, study 2  
38 ( $n=31$ ) tested performance at the surface and at a range of depths underwater (1m; 11m; 20m; 30m;  
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40 shallow water. In study 2 time production at the surface was not significantly different from that at 1m  
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42 productions between 11m-40m did not differ significantly. *Discussion:* It was concluded that divers  
43 judge less time to have passed underwater than is objectively the case from a depth of 11m but that  
44 this effect does not deteriorate significantly once past 11m. This distortion of time perception  
45 underwater was attributed to the action of narcosis.

46 *Keywords:* narcosis, time perception, diving, underwater performance.

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## 60 **Introduction**

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

76           One reason to suspect narcosis may affect time perception is that it has been shown to be  
77 distorted by both alcohol (7) and anaesthetics (1). The effects of these pharmacological agents may be  
78 pertinent because they are posited to share commonalities with narcosis, both in their effects on  
79 underlying neurobiological mechanisms and on cognitive functions (6). Direct evidence for the effect  
80 of narcosis itself on time perception is limited to three studies (8, 9, 11) using a common measure of  
81 temporal cognition known as prospective time production. In production tasks subjects are required to  
82 delimit specific time intervals (such as by pressing a button), which is compared with objective time.  
83 Employing intervals of 18-60 seconds (s) Mears and Cleary (9) failed to find significant impairment  
84 of time production at depths of 6m and 30m underwater. In contrast, Lipperman-Kreda and Glicksohn  
85 (8) reported that, when compared with surface performance, time production intervals of 4 to 32s  
86 were significantly longer at 10m underwater and that this effect became significantly worse at 30m. A  
87 third study (11) using intervals from 4 to 24s also found time production was significantly longer  
88 underwater at multiple depths between 32m and 61m, when compared to surface performance.  
89 However, no significant change in performance between underwater depths was found.

90           The current paper describes two brief studies of prospective time production in scuba divers  
91 while underwater. Study 1 compared performance in deep water (35m-42m), where narcotic  
92 symptoms were expected, with a shallow water control (3-12m). Study 2 tracked performance from  
93 the surface at regular depth intervals down to 40m. These studies expand the limited data available on  
94 time perception underwater in two ways. Firstly, they add a new assessment to the existing studies

95 that are contradictory as to whether or not time perception becomes distorted underwater. Secondly,  
96 they test performance at a range of depths not used in prior research, and in a way that allows some  
97 determination of how time production is affected as a function of depth from mere immersion down to  
98 40m.

## 99 **METHODS**

### 100 *Subjects*

101 Thirty-two divers (22 male), aged 20 to 63 years ( $M = 34.7$ ;  $SD = 11.9$ ), volunteered for study  
102 1. These divers reported having completed 10 to 6000 dives ( $M=1187.7$ ;  $SD=1636.7$ ) over 0.1 to 48  
103 years ( $M=9.4$ ;  $SD=10.1$ ). Thirty-one divers (13 female), aged 19 to 53 years ( $M = 35.9$ ;  $SD = 10.5$ ),  
104 volunteered for study 2 and reported 10 to 6500 dives ( $M=680.8$ ;  $SD=1433.8$ ) over 0.1 to 42 years  
105 ( $M=8.72$ ;  $SD=10.4$ ). Recruitment took place through three dive operators on Roatan Island, Honduras:  
106 Ocean Connections and West End Divers (study 1); West Bay Divers (study 2). Each dive operator  
107 carried out screening procedures to ensure that all divers were suitably qualified, medically fit, and  
108 provided safety divers when deemed appropriate. Ethical permission for the protocol was granted by  
109 the University of Winchester.

### 110 *Design*

111 Study 1 utilised a 2-way repeated measures design testing the effect of depth (shallow vs.  
112 deep) on time production. Shallow conditions represented depths of 3m-12m ( $M=7.5m$ ;  $SD=2.1$ ) and  
113 deep conditions 35m-42m ( $M=38.2$ ;  $SD=1.9$ ). The order in which the depth conditions were  
114 completed was counterbalanced to control for practice effects. Divers either completed the shallow  
115 condition followed by the deep condition, or vice versa. Study 2 utilised a 6-way repeated measures  
116 design testing the effect of depth (surface vs. 1m vs. 11m vs. 20m vs. 30m vs. 40m) on time  
117 production. Order of depth conditions was again counterbalanced to control for practice effects.  
118 Fifteen divers were randomly assigned to begin with the shallowest condition followed by each  
119 consecutively deeper depth to 40m, while 16 divers completed the trials in the reverse order.

### 120 *Measure*

121 Time perception was measured in both studies using a typical method of prospective time  
122 production (5). Divers were asked to delimit an interval of 30s which was compared by the researcher,  
123 to the nearest second, with objective time on a stopwatch. To initiate the task the researcher gave the  
124 divers a countdown followed by a signal marking the start of the interval. When the divers judged 30s  
125 to have passed they provided their own signal to mark the end of the interval. An interval of 30s was  
126 chosen partly to conform to time limits at depth and because intervals under 30s have been claimed to  
127 be less sensitive in capturing the effects of other pharmacological agents (16). There was a concern

128 the researcher's own accuracy in recording responses might be affected by narcosis and so, as an  
129 added precaution, each trial was recorded with a head-mounted camera and responses checked for  
130 errors on the surface.

### 131 *Protocol & environmental conditions*

132 In both studies divers were briefed on the surface before completing a single dive led by the  
133 researcher. Divers were tested individually or as pairs. All divers breathed air (21% O<sub>2</sub>; 79% N<sub>2</sub>) and  
134 wore an extra 1kg of weight to ensure they sat comfortably on the ocean floor for testing. Depth  
135 measurements were taken by holding a dive computer at chest height.

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

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

## 157 **RESULTS**

158 Each dataset yielded mean scores for time production at each depth tested, and in study 2,  
159 also on the surface. In both studies exploratory analyses were done for age, gender, and dive  
160 experience (years of diving & number of dives to date) but no significant effects of these factors were

161 found and they are excluded from the analysis below. At initial analyses depth order condition was  
162 included as a factor but in both studies no significant effect was found ( $ps>.05$ ), indicating no practice  
163 effects. The data was therefore collapsed across depth order conditions. The lack of practice effects  
164 also justified including the study 2 surface data in the main analysis, which had not been included in  
165 the depth order counterbalancing strategy, being completed before the other trials. Time production  
166 was analysed using a paired  $t$ -test in study 1, and analysis of variance (ANOVA) in study 2. A  $p$  value  
167 of .05 was taken as the criterion of significance. In study 2, sphericity was violated which was  
168 addressed by using Greenhouse-Geisser values, and post hoc comparisons were explored with a series  
169 of paired  $t$ -tests with Holm's Sequential Bonferroni adjusted  $p$ -values.

#### 170 *Study 1*

171 Mean time produced was 3.3s longer in the deep water ( $M=39.2$  seconds;  $SD=7.1$ ) compared  
172 with the shallow water ( $M=35.9$  seconds;  $SD=6.2$ ), a difference that was confirmed as significant  
173 ( $t(31)=3.53$ ,  $p<.01$ ). This indicated that divers judged time as moving slower than objective time in  
174 the deep water, compared to the shallow water.

#### 175 *Study 2*

176 Figure 1 displays mean time produced at each depth, and on the surface. In every case time  
177 produced was longer than 30s, indicating more time passed than was judged to be the case.  
178 Numerically, this tendency to underestimate actual time steadily worsened from the surface ( $M=31.1$ ;  
179  $SD=4.2$ ) through 1m ( $M = 32.5$ ;  $SD = 5.7$ ), 11m ( $M=35.2$ ;  $SD=6.1$ ), and 20m ( $M=37.4$ ;  $SD=7.1$ ),  
180 before it levelled off at 30m ( $M=38.2$ ;  $SD=8.9$ ) and 40m ( $M=38.3$ ;  $SD=9.4$ ). The ANOVA revealed a  
181 significant effect of depth [ $F(2.4, 71.1) = 10.68$ ,  $p<.01$ ] and so post hoc comparisons were carried out,  
182 which are displayed in Table 1. The post hoc comparisons revealed that surface performance was no  
183 different from submersion at 1m but both surface and 1m performance was significantly more  
184 accurate (closer to 30s objective time) than at any other depth underwater. Between 11m and 40m  
185 performance did not significantly differ, although it should be noted that the 11m vs. 20m was  
186 borderline significant.

187 [INSERT FIGURE I AND TABLE I HERE]

#### 188 DISCUSSION

189 The two studies described above demonstrated prospective time production is significantly  
190 altered underwater. In study 1, time production was longer in deep water, compared with shallow  
191 water. In study 2, time production was longer at 11m-40m compared to the surface, or at 1m. Thus,  
192 from a depth of 11m the divers judged significantly less time to have passed than was objectively the  
193 case. These results support previous findings that time production is longer underwater (8, 11), and

194 the magnitude of change was approximate to that observed in prior studies when they used similar  
195 time intervals and depths to the current investigation. The results are, however, not in agreement with  
196 the report (8) that time production accuracy further declines from 10m to 30m. In the current  
197 investigation time production did not alter significantly between 11m and 40m.

198         The cause of the observed distortion in time perception is most likely due to the action of  
199 narcosis. In study 1 narcotic symptoms would certainly be expected in the deep water condition at  
200 35m-42m ( $M=38.2m$ ) but unlikely in the shallow water at 3m-12m ( $M=7.5m$ ). Furthermore, in study  
201 2, whilst time perception at mere immersion (1m) did not differ significantly from that measured at  
202 the surface, both differed significantly to time perception at deeper depths (11m-40m). Other causes  
203 for the distortion cannot of course be fully discounted, but two obvious candidates that have been  
204 shown to affect time perception can be considered unlikely: anxiety (2) and body temperature (18). A  
205 study of the impact of anxiety on time production underwater was the initial objective of study 1 but  
206 no evidence was found and the data was discarded. Body temperature can affect time perception but if  
207 this had been a significant factor in the current investigation this would have been apparent from the  
208 counterbalancing strategy. Performance would have differed when divers were tested at the beginning  
209 of the dive and at the end, something for which there was no evidence.

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

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

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

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

247           Alternative measures to time production may also be desirable, especially when considering  
248 the safety implications of distorted time perception underwater. The losses in time accuracy at 11m  
249 and deeper (5-9s on average) might initially be considered minor, although their contribution to lapses  
250 in timing behaviours would be more serious if they were shown to accumulate over the course of a  
251 dive. However, in prospective time production tasks, subjects are told in advance that they will be  
252 making a temporal judgement. The divers would therefore have focussed as many attentional  
253 resources as possible on the task. Arguably, a more realistic scenario underwater is for divers to focus  
254 their attention elsewhere while underwater, or be required to make a temporal judgement without  
255 prior awareness that one would be needed (e.g. after discovering a dive computer has failed).  
256 Retrospective timing measures may therefore provide a more realistic view of time perception  
257 underwater and act to compliment prospective measures (12). Also, as it is known that reducing  
258 attention to time reduces accuracy (13), the small distortions in time perception observed in the  
259 current investigation may indicate larger distortions in a typical everyday situation.

260           In conclusion, the current investigation expands the limited evidence demonstrating that time  
261 perception is distorted underwater by narcosis at the surprisingly shallow depth of 11m, causing  
262 divers to judge less time to be have passed than is objectively the case.

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350 Table I.  
351 Results of post hoc tests (*p* values) for time estimation.

Depth	Sig.	Depth	Sig,
Surface vs. 1m	n.s	1m vs. 40m	<.01*
Surface vs. 11m	<.01*	11m vs. 20m	n.s
Surface vs. 20m	<.01*	11m vs. 30m	n.s
Surface vs. 30m	<.01*	11m vs. 40m	n.s
Surface vs. 40m	<.01*	20m vs. 30m	n.s
1m vs. 11m	<.01*	20m vs. 40m	n.s
1m vs. 20m	<.01*	30m vs. 40m	n.s
1m vs. 30m	<.01*		

352 Note: \* indicates significant effect after Bonferroni adjustment; n.s = not significant.

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372 Figure I. Mean (+SE) time produced (judged) as a 30s interval at each depth.

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