Effect of Human Body Position on the Swimming Behavior of Bull Sharks, *Carcharhinus leucas*

Erich Ritter* and Raid Amin**
* Shark Research Institute
erichritter@att.net
** University of West Florida

Abstract

This study tested whether human body orientation can influence the behavior of bull sharks by examining sharks' approach distances from a person positioned vertically or horizontally in the water. Results showed that bull sharks, *Carcharhinus leuca*s, kept a significantly greater distance when the test subject was standing in chest-deep water with his head above water versus lying on the ocean floor. Furthermore, larger bull sharks in the immediate area withdrew when the subject entered the water.

Introduction

Although scientific research on nonphysical encounters between sharks and humans exists (Ritter, Lutz, & Levine, 2008), shark-human interaction research typically addresses the physical or combative aspect of shark attacks. The media and popular literature prominently feature shark attacks and their prevention (e.g., Tougias, 2007; May & Willis, 2002; Allen, 2001) but rarely, if ever, focus on scientific verification of their information. A consequence is that false information and unsubstantiated assumptions spread, increasing the anxiety many ocean enthusiasts experience during their excursions into the marine environment (Ritter, 2006).

Research aimed at understanding the factors that influence shark behavior provides advice on the proper behavior people should adopt upon an encounter with an inquisitive shark (Ritter & Levine, 2004, 2005). For example, advice based upon a scientifically unverified anecdote suggests that potential shark attack victims should assume an upright position when a shark approaches (Ritter, 2006). The scarcity of vertically oriented, living objects of

human size in marine environments may deter a shark's approach by increasing the animal's vigilance around an object the shark has not previously encountered (Treves, 2002). The only available scientific literature that addresses this relationship between human body position and shark response asserts that humans who are horizontally oriented at the surface, mainly surfers or swimmers, seem more prone to shark bites because of the victim's similarity to the silhouette of a shark's prey—e.g., turtles or seals (Tricas & McCosker, 1984). Nevertheless, this speculation has not been verified (Ritter, 2004).

This project was designed to investigate the effect of human body position on observed shark approach patterns. A significant challenge was to create a method that allowed measurement of the distance between a shark and a person while simultaneously excluding other factors that might influence the shark's behavior. The species studied was the bull shark, *Carcharhinus leucas*, who tends to approach humans closely upon encounters (Ritter & Levine, 2005). Offering a scientifically tested recommendation about how to act within the vicinity of sharks could help not only demystify situations when people meet these animals, but also reduce fear of them.

Methods

The study was conducted on 10 nonconsecutive days between November 2002 and February 2003 in the Northern Abaco Islands of the Bahamas. The directorate of the Shark Research Institute, Princeton, NJ, was the overseeing authority and approved this project. No additional permits or authorizations were necessary.

Participants

Free-swimming bull sharks, *Carcharhinus leucas*, were the research subjects. Tagging the sharks for individual recognition was rejected to avoid any undue pain or distress to the sharks (Braithwaite & Boulcott, 2007; Huntingford et al., 2006; Chandroo, Duncan, & Moccia, 2004) and because commonly applied procedures were likely to alter a shark's short-term behavior and may have altered the results of the study (Skomal & Bernal, 2010). Thus, the data may involve the same sharks during different observations.

One of the two authors (ER), from here on referred to as the test subject, did all in-water activities to maintain test consistency. At the time of testing he was 44 years old, 179 cm (5′10″) in height and 85 kg (187 lbs.) in weight. For all tests, he wore a blue, full-body wetsuit with yellow sleeves. He was able

to observe all sharks at any given time and knew how to respond if a shark exhibited unusual behavior.

Materials

On a rig, mounted on a platform, approximately 3 meters off the shoreline, a digital video camera (Sony DCR-PC9E) was mounted 7 meters above the waterline, encompassing a recording field of view of approximately 30 m^2.

Procedure

The test subject was positioned in the center of the test area, where the water was approximately 1.5 meters in depth (around high tide). To test the effect of a person's body position on the approach behavior of sharks, he alternated between standing upright and lying flat on the bottom while holding his breath. An alternating body-orientation test was used instead of a single body-orientation test, as sharks often become less hesitant to approach over time. To avoid possible habituation of the sharks to a certain rhythm, the test subject kept each position for an unspecified time, such that neither the bottom time (horizontal, submerged duration, T_B) nor the surface time (vertical, standing duration, T_S) was limited to a fixed time period. Although neither period of time was specified, it was decided 1) not to submerge or stand up when a shark was approaching, but only when an animal was swimming away, and 2) not to exceed the bottom time beyond a comfortable limit, and so unknowingly add any other potentially attracting physical factors beyond the study design's control. Because the duration of T_S and T_B were not specified, T_B and T_S varied in duration through the testing period, averaging 41.4 seconds (SE = 12.3) (N = 83) and 19.4 seconds (SE = 6.8) (N = 75), respectively. The lower number of T_S was due to the rule that a test always ended after an ascent once the 10-minute time limit was reached, or was close. Despite the fact that the duration of testing per day was kept short, its overall duration, as well as the longer bottom times (T_B) could have biased the experiment, possibly reducing some of the sharks' hesitation to approach the test subject as time carried on. Therefore we focused on 1) the duration difference between T_S and T_B, and 2) the interval until the first approach of a shark toward the test subject for either position. To test the first possible bias, we divided each bottom time into two sections, T_{Diff} and T_{adj}, where the former represented the time period of T_B that surpassed the duration of the preceding T_S, and the latter equaled the time period of the preceding T_S within the duration of T_B. Between T_{Diff} and T_B, as well as T_{adj} and T_S, we compared *approach frequency*

and *relative distance* (see definitions below). We stipulated that if neither comparison showed a statistically different outcome than the actual comparison between T_B and T_S, it could be fairly assumed that the longer bottom times did not cause a biasing effect within this context. For the second possible bias—that animals could get more accustomed to one or both position(s) while the experiments continued, we used the time that passed until the first approach occurred (T_{First}) for each T_B and T_S, and compared their ratios T_{First} / T_B and T_{First} / T_S, respectively. A decrease could indicate that the longer the tests were prolonged, the less some animals hesitated to approach.

Because approaches lasted several seconds, an approach was excluded from the analysis, where T_{Diff} was concerned, if a shark came nearest to the test subject within the first two seconds of T_{Diff}. An encounter was tallied if a bull shark approached the test subject (i.e., decreased the distance between them). We counted the number of sharks who approached the person during the time period in which he was in each position (including 0 for no approaches), and derived an approach frequency in terms of the number of approaches per minute. Because sharks were not tagged, for reasons mentioned above, and so were not individually recognizable, multiple recordings for the same shark could have occurred during any given period when the test subject was in a vertical (or horizontal) position.

A test started with the first submersion of the test subject and continued as follows: after the suggested minimum bottom time, he stood up at the same spot, caught his breath, then submerged again, and continued this routine of lying down and standing up for 10 minutes. Each shark swimming within the recorded areas had its absolute and relative distances (as a fraction of a shark's body length) from the subject taken by a video measurement technique. Distance measurements were calculated from the closest body part of a shark (pectoral fins excluded) to either the center of the test subject when standing or to his closest body part when submerged, thereby reducing potential refraction effects.

For consistency among tests, recordings were limited to the following conditions of daylight, visual distortion, and water depth: (a) between 1000 and 1500 hours; (b) calm water surface; and (c) high tide (± 1 hour). Two days were excluded from the 10 nonconsecutive days of testing, due to bad weather and low number of sharks, such that data from only 8 days were evaluated, including the 83 horizontal (submerged) positions and 75 vertical (standing) positions.

Analysis

Before each test, a calibration using length markers was performed to compensate for tidal changes. To further minimize optical effects, only sharks swimming within a radius of 2.5 meters from the center were included. If it was later determined that the video camera had shifted while collecting data (e.g., due to wind), postrecording adaptations of the measuring areas were performed. Single video frames, taken from Apple© Final Cut Pro© 5.0 or iMovie HD 6.0.3, were transferred into Adobe© Photoshop© 10.0.1 for measuring individual distances, or then directly measured through Pixelated Software's PixelStick 1.1, respectively. If a single frame did not offer an accurate measurement, several video frames within one second were evaluated and the measurement's average taken. If an exact measurement was still not possible, the approach was excluded from the analysis.

A shark's body length (BL), rounded to the nearest 10 cm, and its relative swim speed (BL/sec), were used as baseline measurements for each test. When at least five sharks were present at the site, BL and BL/sec were measured for each animal passing within the recorded field of view for at least 10 minutes before the beginning of a testing period.

The absence of tagging in this study prevented the differentiation of individual animals; therefore, each encounter was treated as an independent event. While the variables *absolute distance* and *relative distance* appeared to follow a normal distribution based on the Shapiro-Wilk Test ($p > .10$, both variables), the variables *length* ($p < .05$) and *relative speed* were nonnormal ($p < .05$). We used a t-test for independent samples for the normally distributed variables, and a nonparametric test (Mann-Whitney U) for the other two variables.

Results

During the eight nonconsecutive days of tests, 96 encounters between bull sharks and the test subject were tallied: 21 when the test subject was submerged and 75 when he was standing.

Shark Length, Speed, and Distance Regarding Human Position

The bull sharks kept a significantly greater distance from the test subject when he was standing compared to when he was submerged [$t(94) = 5.48$, $n1 = 75$, $n2 = 21$, $p < 0.05$; see Table 1]. Similarly, their relative distances were significantly larger when the test subject was standing [$t(94) = 3.82$, $n1 = 75$, $n2 = 21$, $p < 0.05$; see also Table 1].

Table 1. 95% Confidence Intervals and Tests for the Mean Absolute and Relative Distance between Sharks and the Test Subject

Body position	N	$D_{abs} \pm SD$ (L, U)	$D_{rel} \pm SD$ (L, U)
vertical	21	2.33 ± 0.37 (2.17, 2.50)	1.21 ± 0.25 (1.09, 1.32)
horizontal	75	1.72 ± 0.47 (1.61, 1.82)	0.93 ± 0.33 (0.86, 1.00)
Test		t = 5.48	t = 3.82
p-value		< .05	< .05

Note: N = Number of measurements; D_{abs} = Absolute distance (in m); D_{rel} = Relative distance (D_{abs}/BL, whereas BL = Shark body length); SD = Standard deviation; (L, U) = Lower and upper limit of the 95% confidence interval. Test = t-test for independent samples.

The same results occurred using T_{adj} instead of T_B [$t(55) = 3.25$, *n1 = 36*, *n2 = 21*, *p* < 0.05], indicating that the longer bottom times did not change the outcome. Likewise, a possible "habituation" during longer bottom times did not seem to happen either, since the relative distances did not get shorter between T_B and T_{Diff} [$t(92) = 1.0$, *n1 = 47*, *n2 = 47*, *ns*]. Independent of human position, relative distances were negatively correlated with the lengths of the sharks (*r* = -0.26, *N* = 96, *p* < .05).

The average length of the sharks decreased significantly once the test subject entered the water (*N* = 196, *p* < .05; see Table 2), as larger bull sharks then less frequently entered the recording area.

Table 2. 95% Confidence Interval and Tests for the Average Body Length and Relative Swim Speed of Sharks with and without Presence of the Test Subject

Test subject presence	N	$BL \pm SD$ (L, U)	$v_{rel} \pm SD$ (L, U)
no	101	2.25 ± 0.22 (2.20, 2.29)	0.25 ± 0.06 (0.24, 0.26)
yes	96	1.93 ± 0.19 (1.89, 1.97)	0.29 ± 0.09 (0.27, 0.30)
Test		z = -8.91	z = 2.93
p-value		< .05	< .05

Note: N = Number of measurements; BL = Shark body length (in m); v_{rel} = Relative swim speed (BL/sec); SD = Standard deviation; (L, U) = Lower and upper limit of the 95% confidence interval. Test = z-test conversion of Mann-Whitney-U.

Approach Frequency and Prolonged Bottom Times

A significant approach frequency difference occurred between T_S and T_B [$t(156) = 2.650$, $n1 = 83$, $n2 = 75$, $p < .05$] as well as for T_S and T_{adj} [$t(109) = 2.660$, $n1 = 75$, $n2 = 36$, $p < .05$; see Table 3]. That the actual position and not the longer bottom times caused the dissimilar approach frequencies is supported by the nonsignificant frequency differences between T_{Diff} and T_B [$t(102) = 0.06$, $n1 = 52$, $n2 = 52$, *ns*; see also Table 3].

In addition, the average ratios of initial approaches for T_B and T_S, 0.6 (± 0.2) and 0.6 (± 0.3), respectively, were not significantly different [$t(70) = 0.75$, $n1 = 53$, $n2 = 19$, *ns*], suggesting that each position was approached equally quickly by the sharks during the tests.

Discussion

These results are the first to support recommendations (based previously on anecdotes) that adopting a vertical rather than a horizontal body position when a shark is present should keep a shark at a greater distance during an encounter. The sharks did not just keep a significantly greater distance from the test subject when he was standing vertically rather than when he was lying horizontally on the ocean bottom, but he was also less frequently approached when standing, independent of the activity's duration.

The chosen study area restricted neither the sharks' nor the test subject's movements and permitted unlimited escape routes for the sharks, irrespective of approach directions. In addition, the water visibility did not drop below 20 meters, allowing the sharks and subject to see each other from a distance beyond the testing area. In natural encounters between people and sharks,

Table 3. 95% Confidence Interval and Average Approach Frequencies of the Different Time Periods

	T_S	T_B	T_{adj}	T_{Diff}
N	36	47	36	47
Approach frequency ± *SD*	1.48 ± 1.52	2.30 ± 1.79	2.95 ± 2.48	1.78 ± 1.78
95% interval (L, U)	0.96, 1.99	1.78, 2.83	2.11, 3.79	1.26, 2.30

Note: T_S = Duration while person was standing; T_B = Duration while the person was submerged; T_{adj} = Time period of the preceding T_S within the duration of TS; T_{Diff} = Time period of T_B that surpassed the duration of the preceding T_S; N = Number of measurements; SD = Standard deviation; (L, U) = Lower and upper limit of the 95% confidence interval.

visibility is often limited due to changing currents, mixing water layers, crepuscular light, and other factors. Under reduced visibility, human sounds might be a more potent trigger for sharks to approach than the body position of the human making the sounds. It has been verified that sharks can be attracted by sound emanating from items they cannot see (Myrberg, Ha, Walewski, & Banbury, 1972; Myrberg, Banner, & Richard, 1969; Nelson & Gruber, 1963). Frequencies of sound at which human activity may lure sharks into proximity are currently unknown. Our results indicate that the mere presence of a person upon first encounter might be a more significant factor than his or her body position in shark approaches, as no difference was noticed in time passing until the first approach for the two positions.

Larger sharks withdrew beyond the measured area when the test subject was present. This result supports one author's observations (ER), made during other encounters, that smaller sharks are often less hesitant to stay in a human's vicinity than are larger sharks. The minimal distance between a shark and a person is synonymous with the flight initiation distance and is largely influenced by some degree of vigilance (see, for example, Cooper & Frederick, 2007; Stankowich & Blumstein, 2005; Frid & Dill, 2002). Caution is naturally a beneficial behavioral trait for most large predators; thus, increased vigilance might be more prominent among larger carnivores within a species (Pangle & Holekamp, 2010). Interestingly, this is the first indication that size-influenced vigilance seems to exist in sharks when humans are in proximity.

Martin (2007) and Ritter (2006) have proposed the hypothesis that sharks require a minimum amount of empty space around their bodies; this is referred to as an "idiosphere" or "inner circle," estimated to lie within one to two body lengths of a shark. Using the flight initiation distance as an equivalent measure for the radius of this space, this study indicates that the idiosphere for bull sharks is closer to one body length.

Although the main focus of this study was to measure shark behavior in response to human body orientation and not to typical water activities, these results are the first to support the anecdotal recommendation that adopting a vertical body position when a shark is present should keep a shark at a greater distance during an encounter. To examine how more natural human activities affect the approach behavior and attack likelihood of sharks, more research is required. For example, future studies should include an examination of how shark behavior is influenced by the degree of motion in human activities or by the sound patterns that result from human activities.

Currently, the complexity of encounters between sharks and humans is poorly understood. Although some researchers are working to determine the factors influencing shark-human interactions (Ritter, 2006), the present study

provides the first quantitative data on the influence of human body orientation on the approach behavior of a shark species. We suggest that further field testing should be undertaken using more natural human activities, including studies focused on selachophobia, the fear of sharks, to better understand shark-human interactions. Although scientific literature pertaining to selachophobia is scarce, it seems that the inaccurate perception of sharks as aggressive predators is predominantly formed through a "noncognitive component," suggesting that stories and pictures are sufficient to create a biologically significant fear (Hygge & Öhmann, 1978). This phobia will likely be further supported during a shark encounter by a general fear of nature as well (Kellert, 1996; Ulrich, 1993; Krop & Krause, 1976; Seligman, 1971, 1988). In this case, a person's mind-set likely affects not only the way a situation is perceived but also the person's activity. For example, the frantic paddling of a terrified person is quite different from the motion of a calm swimmer. These changes are likely to increase the sounds emitted by the activity, thereby increasing the level of attractiveness to a shark and reducing the distance between the animal and the targeted person (Ritter, Lutz, & Levine, 2008).

If a greater appreciation of the physical and psychological interactions between sharks and humans can be acquired, the pervasive fear of sharks held by the general public may be dispelled. If the true nature of sharks can be clearly and accurately presented to, and understood by, the public, shark conservation efforts would likely be more successful than they currently are (Kaltenborn, Bjerke, & Nyahongo, 2006; Ritter, 2006; Shelton & Rogers, 2006).

Acknowledgments

References

Allen, T. B. (2001). *Shark attacks: Their causes and avoidance*. Gilford, CT: The Lyons Press.

Braithwaite, V. A., & Boulcott, P. (2007). Pain perception, aversion and fear in fish. *Diseases of Aquatic Organisms, 75*, 131-138.

Chandroo, K. P., Duncan, I. J. H., & Moccia, R. D. (2004). Can fish suffer?: Perspectives on sentience, pain, fear and stress. *Applied Animal Behaviour Science, 86*(3), 225-250.

Cooper, W. E., & Frederick, W. G. (2007). Optimal flight initiation distance. *Journal of Theoretical Biology, 244*(1), 59-67.

Frid, A., & Dill, L. (2002). Human-caused disturbance stimuli as a form of predation risk. *Conservation Ecology, 6*(1), 11. http://www.consecol.org/vol6/iss1/art11.

Huntingford, F. A., Adams, C., Braithwaite, V. A., Kadri, S., Pottinger, T. G., Sandøe, P., & Turnbull, J. F. (2006). Current issues in fish welfare. *Journal of Fish Biology, 68*, 332-372.

Hygge, S., & Öhmann, A. (1978). Modeling processes in the acquisition of fears: Vicarious electrodermal conditioning to fear-relevant stimuli. *Journal of Personality and Social Psychology, 36*(3), 271-279.

Kaltenborn, B. P., Bjerke, T., & Nyahongo, J. (2006). Living with problem animals: Self-reported fear of potentially dangerous species in the Serengeti Region, Tanzania. *Human Dimensions of Wildlife, 11*(6), 397-409.

Kellert, S. R. (1996). *The value of life*. Washington, D.C.: Island Press.

Krop, H., & Krause, S. (1976). The elimination of a shark phobia by self-administering systematic desensitization: A case study. *Journal of Behavior Therapy and Experimental Psychiatry, 7*(3), 293-294.

Martin, R. A. (2007). A review of shark agonistic displays: Comparison of display features and implications for shark-human interactions. *Marine and Freshwater Behaviour and Physiology, 40*(1), 3-34.

May, N., & Willis, C. (2002). *Shark: Stories of life and death from the world's most dangerous waters*. Cambridge, MA: Da Capo Press.

Myrberg, A. A., Banner, A., & Richard, J. D. (1969). Shark attraction using video-acoustic system. *Marine Biology, 2*(3), 264-276.

Myrberg, A. A., Ha, S. J., Walewski, S., & Banbury, J. C. (1972). Effectiveness of acoustic signals in attracting epipelagic sharks to an underwater sound source. *Bulletin of Marine Science, 22*(4), 926-949.

Nelson, D. R., & Gruber, S. H. (1963). Sharks: Attraction by low-frequency sounds. *Science, 142*(3594), 975-977.

Pangle, W. M., & Holekamp, K. E. (2010). Functions of vigilance in a social carnivore, the spotted hyaena, *Crocuta crocuta. Animal Behaviour, 80*(2), 257-267.

Ritter, E. K. (2004). Sharks: Mistaken identity? In M. Bekoff (Ed.), *Encyclopedia of animal behavior* (pp. 963-964). Westport, CT: Greenwood Press.

—— (2006). *Understanding sharks: The fascinating behavior of a threatened hunter*. Malabar, FL: Krieger Publishing Company.

Ritter, E. K., & Levine, M. (2004). Use of forensic analysis to better understand shark attack behaviour. *Journal of Forensic Odonto-Stomatology, 22*(2), 40-46.

—— (2005). Bite motivation of sharks reflected by the wound structure on humans. *Journal of Forensic Medicine and Pathology, 26*(2), 136-140.

Ritter, E., Lutz, K., & Levine, M. (2008). When humans and sharks meet. In F. Olsson (Ed.), *New developments in the psychology of motivation* (pp. 45-52). New York: Nova Biomedical Books.

Seligman, M. (1971). Phobias and preparedness. *Behavior Therapy, 2*(3), 307-320.

—— (1988). Competing theories of panic. In S. Rachman & J. D. Maser (Eds.), *Panic: Psychological perspectives* (pp. 321-320). Hillsdale, NJ: Lawrence Erlbaum Associates.

Shelton, M. L., & Rogers, R. W. (2006). Fear-arousing and empathy-arousing appeals to help: The pathos of persuasion. *Journal of Applied Social Psychology, 11*(4), 366-378.

Skomal, G., & Bernal, D. (2010). Physiological responses to stress in sharks. In J. C. Carrier, J. A. Musick, & M. R. Heithaus (Eds.), *Sharks and their relatives II* (pp. 459-490). Boca Raton, FL: CRC Press.

Stankowich, T., & Blumstein, D. T. (2005). Fear in animals: A meta-analysis and review of risk management. *Proceedings of the Royal Society, 272*(1581), 2627-2634.

Tougias, T. (2007). *When man is the prey*. New York: St. Martin's Griffin.

Treves, A. (2002). Theory and method in studies of vigilance and aggregation. *Animal Behaviour, 60*(6), 711-722.

Tricas, T. C., & McCosker, J. E. (1984). Predatory behavior of the white shark (*Carcharodon carcharias*), with notes on its biology. *Proceedings of the California Academy of Sciences, 43*, 221-238.

Ulrich, R. S. (1993). Biophilia, biophobia, and natural landscapes. In S. R. Kellert & E. O. Wilson (Eds.), *The biophilia hypothesis* (pp. 73-137). Washington, D.C.: Island Press.