

Biological significance of sperm whale responses to sonar: comparison with anti-predator responses

Charlotte Curé*, Saana Isojunno, Fleur Visser, Paul J. Wensveen, Lise D. Sivle,
Petter H. Kvadsheim, Frans-Peter A. Lam, Patrick J. O. Miller

*Corresponding author: charlotte.cure@cerema.fr

Endangered Species Research 31: 89–102 (2016)

Table S1: Severity score details of the two sperm whales exposed to the KW sounds and noise CTRL playbacks in 2010 (sw10_149a and sw10_150a). Each playback can have several scores for different types of behavioral changes. The severity scores to each behavioral metric are based upon the duration of the response versus the duration of the exposure, similarly as it was applied in Miller et al. 2012. The brief, minor, moderate and prolonged responses are defined as following: Brief - significantly shorter than the exposures. Minor - shorter in duration than the exposure sessions, but longer than brief. Moderate - roughly the duration of the exposure session. Prolonged - significantly longer than the exposures.

Tag ID	Sound playback	Score	Behavioral justification
Sw10_149a	noise CTRL	3	Minor change in locomotion (no avoidance): the animal made a first brief horizontal turn a couple of minutes after the playback started and then quickly changed horizontal course again in direction to a food patch where it was feeding 2 to 3h earlier.
Sw10_149a	noise CTRL	4	Prolonged change in vocal behavior: the animal started to produce slow clicks at the onset of the playback and this slow clicks production lasted for more than 1h.
Sw10_149a	KW	3	Minor change in locomotion (no avoidance): the animal made two changes in the direction of horizontal movement, the first one at the onset of the playback and the second one later during the exposure.
Sw10_149a	KW	4	Moderate change in the dive profile: the animal was in a feeding dive mode before the start of the playback and interrupted a dive at the onset of playback. The animal conducted an atypical short and shallow dive and then remained close to the surface for roughly the duration of the exposure. After the end of playback, it went back to a feeding dive mode.
Sw10_149a	KW	6	Moderate cessation of feeding: the animal was performing feeding dives (associated with production of foraging acoustic cues, i.e. regular clicks and buzzes) before the onset of the exposure and stopped feeding when the playback started.
Sw10_149a	KW	4	Moderate change in vocal behavior: the animal stopped producing regular clicks and buzzes and started to produce codas (alarm signals) at the onset of playback.
Sw10_150a	noise CTRL	1	Brief orientation response: the animal changed horizontal direction of movement sooner after the onset of playback. Then, it made another turn which was not unusual compared to baseline.
Sw10_150a	KW	6	Moderate avoidance of the sound source: the animal made a sharp turn away from the playback source and maintained directional avoidance for roughly the duration of the exposure.
Sw10_150a	KW	3	Minor change in the dive profile: the animal was in a feeding dive mode before the start of playback and interrupted a dive about 2min after the onset of the playback to conduct an atypical short and shallow dive. It started a new dive cycle about 2min before the end of the exposure.
Sw10_150a	KW	5	Minor cessation of feeding: the animal stopped feeding during the first dive of the exposure (interruption of the feeding dive, no buzzes) and went back feeding about 2min after the end of exposure.
Sw10_150a	KW	2	Brief change in vocal behavior: the animal stopped buzzing.
Sw10_150a	KW	6	Prolonged change in group distribution: the animal was initially solitary. It started to join other whales during the exposure and appeared in a group of 4 whales at the first surfacing event after the end of playback. The association with other whales lasted until about 1h after the end of playback.

Table S2: Number of 1min bins per 15min period with respectively presence of codas (C), and presence of slow clicks (S) during the Pre, Dur and Post periods of each sound exposure (given in this order and separated by ‘ - ’ with non-zero values in bold). These results were used for making a qualitative analysis (Table S5) on changes of social sound production in response to sound exposures. Pre: 15min period preceding start of exposure; Dur: duration of the exposure (as shown on Table 1, Dur was not always 15min, so numbers of 1min bins per 15min were corrected accordingly); Post: 15min period following end of exposure.

Whale ID	LFAS	LFAS-DS	MFAS	no-sonar CTRL	KW	noise CTRL
Sw08_152a	C: 2 - 0 - 1 S: 0 - 0.5 - 0		C: 0 - 0.2 - 0 S: 0 - 0.5 - 0			
Sw09_141a	C: 0 - 8 - 0 S: 2 - 3 - 0		C: 0 - 0.8 - 1 S: 0 - 2.5 - 0	C: 0 - 0 - 0 S: 0 - 0 - 0	C: 0 - 0 - 0 S: 4 - 10 - 6	
Sw09_142a	C: 0 - 0 - 0 S: 0 - 0 - 0	C: 0 - 0 - 0 S: 0 - 0 - 0	C: 0 - 0 - 0 S: 0 - 0 - 0	C: 0 - 0 - 0 S: 1 - 0.4 - 1	C: 0 - 0 - 0 S: 0 - 0 - 0	
Sw09_160a	C: 0 - 0 - 0 S: 4 - 0.4 - 1	C: 0 - 0 - 0 S: 0 - 1 - 0	C: 0 - 0 - 0 S: 0 - 0.4 - 2		C: 0 - 0 - 0 S: 0 - 1.6 - 0	
Sw10_149a					C: 0 - 2 - 0 S: 2 - 0 - 1	C: 0 - 0 - 0 S: 0 - 1 - 2
Sw10_150a					C: 0 - 0 - 0 S: 0 - 1 - 0	C: 0 - 0 - 0 S: 0 - 1 - 0

Table S3: Summary table of the changes in horizontal movement in response to the sound exposures (from Miller et al. 2012; Curé et al. 2013; Table S1).

Letters indicate the type of behavioral response and associated numbers indicate the severity scores on the 0-9 scale (Miller et al 2012; new results on Table S1). A letter with no associated number means that the given behavioral metric was scored as 0 in the qualitative severity scoring method although it was indicated as with a change based upon additional descriptive analysis (Curé et al. 2013).

Whale ID	LFAS	LFAS-DS	MFAS	no-sonar CTRL	KW	noise CTRL
Sw08_152a	--		A6			
Sw09_141a	A6		A6	--	A7	
Sw09_142a	O1; A6	L3	--	O1	L4	
Sw09_160a	A4	A4	--		--	
Sw10_149a					L3	L3; A
Sw10_150a					A6	O1
Sources that indicated a change	Miller et al. 2012	Miller et al. 2012; new data on Table S1; Curé et al. 2013	new data on Table S1; Curé et al. 2013			

O: orientation response (horizontal); score 1 = brief turn.

L: change in locomotion (horizontal speed and/or heading); score 3 = minor change; score 4 = moderate change.

A: horizontal avoidance; scores 4, 6 and 7 = respectively brief, moderate and prolonged avoidance.

‘--’ means there was no change for all three behavioral response types (O, L and A). The absence of a behavioral response type means there was no change for this parameter.

Table S4: Summary table of the changes in the dive profile (vertical movement) and associated foraging/resting behaviors in response to the sound exposures (from Miller et al. 2012; Sivle et al. 2012; Curé et al. 2013; Isojunno et al. 2016; new data on Table S1).

Cells highlighted with solid and dashed bold lines indicate exposures for which the whales were performing respectively non-foraging and resting dives before the start of exposure. All other cells concern exposures for which the whales were in a foraging mode preceding the start of exposure. Letters and associated numbers indicate respectively the type of behavioral metric that was altered and the severity score (qualitative severity scoring method: results of Miller et al. 2012 and new results presented in Table S1). A letter with no associated number means that the given behavioral parameter was scored as 0 in the qualitative severity scoring method although it was indicated as with a significant change based upon other analysis approaches (univariate, descriptive, hidden state-switching model, see Table S1)

Whale ID	LFAS		LFAS-DS		MFAS		no-sonar CTRL		KW		noise CTRL	
	Vertical movement	Foraging /Resting	Vertical movement	Foraging /Resting	Vertical movement	Foraging /Resting						
Sw08_152a	O1	F*6			--	--						
Sw09_141a	O2; D	---			--	---	D	---	D	F*		
Sw09_142a	D4	F*	D4	F*6 started resting	--	--	--	--	O1; D4	R6		
Sw09_160a	D4	F*6	O1	--	--	--			O2	F*		
Sw10_149a									D4	F*6	--	--
Sw10_150a									D3	F*5	--	--
Sources that indicated a change	Sivle et al. 2012; Miller et al. 2012	Miller et al. 2012; Isojunno et al. 2016	Sivle et al. 2012; Miller et al. 2012	Miller et al. 2012; Isojunno et al. 2016	Sivle et al. 2012; Miller et al. 2012	Miller et al. 2012; Isojunno et al. 2016	Sivle et al. 2012; Miller et al. 2012	Miller et al. 2012; Isojunno et al. 2016	Miller et al. 2012; Curé et al. 2013; New data (Table S1)	Miller et al. 2012; Curé et al. 2013; Isojunno et al. 2016; New data (Table S1)	Curé et al. 2013; New data (Table S1)	Curé et al. 2013; Isojunno et al. 2016; New data (Table S1)

Table S4 notes:

Changes in the vertical movements:

O: orientation (vertical) response; score 1 = brief change of direction (1 wiggle or 1 spyhop); score 2 = multiple wiggles and/or changes of direction.

D: change in the dive profile (i.e. shallower and shorter dives); scores 2, 3 and 4 = respectively brief, minor and moderate change in the dive profile.

Absence of one of the two behavioral metrics (O or D) means there was no change for this parameter whereas '--' means there was no change for both behavioral metrics (O and D).

Alteration of foraging or resting behaviors:

R: cessation of resting behavior (based upon changes in the stereotyped dive profile of a resting behavior); score 6 = moderate cessation of resting behavior.

F: alteration of foraging behavior (based upon interruption of production of regular clicks and buzzes).

Letter F with no score indicates a decrease in the production of regular clicks but a remaining presence of buzzes, indicating that the animal was still feeding so not scored in the severity scale as a cessation of foraging; scores 5 or 6 indicate respectively minor or moderate cessation of feeding.

The superscript '*' associated to letter F indicate a reduction of both the time spent in foraging states and the probability of prey capture attempts during the given type of exposure (LFAS/LFAS-DS and KWPB) with little change in overall locomotion activity (Isojunno et al. 2016).

'--' and '---' mean there was no change of the foraging activity with respectively animals continuing foraging, and animals continuing not foraging.

Table S5: Summary table of the changes of the social behavior in response to sound exposures, including changes in the production rate of codas and slow clicks (indicated respectively by letter C and S) as well as occurrences of grouping behavior (G) (from Miller et al. 2012; Curé et al. 2013; new data on Tables S1 and S2). A number associated to a letter indicates the severity score given to the considered change in vocal or grouping behavior (provided by the qualitative severity scoring method: results from Miller et al. 2012 and new results on Table S1). A letter with no associated number means that the given behavioral metric was scored as 0 in the qualitative severity scoring method although it was indicated as with a change based upon descriptive analyses (Curé et al. 2013, new results on Table S2).

Whale ID	LFAS	LFAS-DS	MFAS	no-sonar CTRL	KW	noise CTRL
Sw08_152a	-C _{dur&post} S _{dur}		C _{dur} S _{dur}			
Sw09_141a	C _{4dur} S _{dur} -S _{post}		C _{dur&post} S _{4dur}	--	C _{post>15min} S _{4dur&post} G	
Sw09_142a	--	--	--	-S _{dur}	S _{post>15min}	
Sw09_160a	-S _{dur&post}	S _{dur}	C _{post>15min} S _{dur&post}		S _{dur}	
Sw10_149a					C _{4dur} -S _{dur&post}	S _{4dur&post}
Sw10_150a					S _{dur} G6	S _{dur}
Sources that indicated a change	Miller et al. 2012; new data (Table S2)	new data (Table S2)	Miller et al. 2012; new data (Table S2)	new data (Table S2)	Miller et al. 2012; new data (Tables S1, S2)	new data (Tables S1, S2)

Table S5 notes:

Cells with letters C or S correspond to experiments for which there was a change in the production rate of social sounds during the Dur or Post period compared to the Pre period (new data presented on Table S2). Cells with ‘--’ means that there was no change for both sound types production (C and S) and that they concerned exposures for which the animals were not producing social sounds during the Pre period and continued not producing them during the Dur and Post periods.

Cells with letter G indicate experiments for which a grouping behavior was observed at the first surfacing following the end of sound exposure (group size changed from 1 to >1, i.e. one or more associated whales were seen at the surface within 200m of the focal whale). For all other experiments, the tagged whale was solitary (i.e. group size =1) for the 15min preceding the start of exposure (=Pre period), for the duration of the exposure (=Dur period), and for the 15min following the end of exposure (=Post period).

Absence of one of the behavioral metrics (C, S or G) means there was no change for this metric.

Letters C or S preceded by a minus sign ‘-’ means a decrease or interruption of the sound production whereas letters not preceded by a minus sign indicates a start or increase of the given social sound production. A score 4 associated to letters C or S indicates a moderate increase of the production rate of the given social sound type (C or S) in the Dur period. A score 6 associated to letter G indicates a prolonged change in the group distribution.

Indices:

These detailed parts of the results are from the new data analysis provided on Table S2. dur: change of sound production occurring during the exposure; post: change of sound production occurring during the Post period compared to the Pre period; dur&post: change of sound production occurring during the exposure and maintained for the Post period compared to the Pre period; post>15min: notable start of sound production (compared to the no production during the Pre, Dur and Post periods) occurring more than 15min after the end of exposure but still within the first dive or first surfacing period (i.e. period between two dives during which the animal stays close to the surface to breath) following the end of exposure.

A social sound type production that changed during the Dur period but that returned to the Pre period production state during the Post period, is represented by a letter (C or S) associated to index *dur* but has no association with index *post*.

LITERATURE CITED

- Curé C, Antunes R, Alves AC, Visser F, Kvadsheim PH, Miller PJO (2013) Responses of male sperm whales (*Physeter macrocephalus*) to killer whale sounds: implications for anti-predator strategies. *Sci Rep* 3(1579):1–7 [PubMed doi:10.1038/srep01579](#)
- Isojunno S, Curé C, Kvadsheim PH, Lam F-P, Tyack PL, Wensveen P, Miller PJO (2016) Sperm whale reduce foraging effort during exposure to 1-2 kHz sonar and killer whale sounds. *Ecol Appl* 26(1): 77–93
- Miller PJO, Kvadsheim PH, Lam FP, Wensveen PJ and others (2012) The severity of behavioral changes observed during experimental exposures of killer (*Orcinus orca*), long-finned pilot (*Globicephala melas*), and sperm (*Physeter macrocephalus*) whales to Naval Sonar. *Aquat Mamm* 38:362–401 [doi:10.1578/AM.38.4.2012.362](#)
- Sivle LD, Kvadsheim PH, Fahlman A, Lam FP, Tyack PL, Miller PJO (2012) Changes in dive behavior during naval sonar exposure in killer whales, long-finned pilot whales, and sperm whales. *Front Physiol* 3(400):1–11 [PubMed doi:10.3389/fphys.2012.00400](#)