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Review

Understanding across the senses: cross-modal studies of cognition in cetaceans

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Abstract

Cross-modal approaches to the study of sensory perception, social recognition, cognition, and mental representations have proved fruitful in humans as well as in a variety of other species. Cetaceans (dolphins, porpoises, and whales) are a group of mammals that have undergone a dramatic adaptive radiation and have developed complex brains and behaviors. Cetaceans have also developed a complex and sophisticated acoustic communication system. Research on cetacean cognition has focused primarily on complex abilities such as the mirror test, understanding of communicative and cognitive intent, and the ability to understand and use complex gestures. Research on cetacean sensory perception has concentrated on the visual and auditory domains. Little is known about the cetacean sensory ecology, including the nature of an individual's mental representations or what it is like to understanding its behavior (Bradshaw 2003). However, approaches to understanding the cognitive and perceptual lives of other species have increasingly been approached from a cross-modal perspective. In this review, we discuss what is known about cetacean sensory ecology and cognition from a cross-modal perspective. We also discuss the implications of cetacean cognitive and perceptual abilities for understanding their mental representations and cognition in reality and future behavior. We highlight that "cross-modal" procedures or what is probably a more accurate substitution is one sensory modality and that always involves the integration of information across the senses, is a promising approach for understanding the cognitive and perceptual lives of cetaceans. We suggest that cross-modal approaches to understanding cetacean cognition and perception may be the most productive approach to understanding their mental representations and cognition. We also suggest that such approaches may be the most productive way to understand the nature of cetacean consciousness and self-awareness.

Keywords
Cetacean
Dolphin
Porpoise
Whale
Cognition
Perception
Communication
Consciousness
Self-awareness

The rationale behind cross-modal studies: a review across taxa

Research on human cognition and perception has increasingly been approached from a cross-modal perspective. Research on humans has provided a wealth of information about how information from different sensory modalities is integrated to form a coherent perception of the world and what these processes reveal about cognition. Research on other species has also increasingly been approached from a cross-modal perspective. Research on nonhuman primates has provided information about how information from different sensory modalities is integrated and how this information is used in social cognition. Research on other species has also increasingly approached from a cross-modal perspective. Research on cetaceans (dolphins, porpoises, and whales)

Atema J (1995) Chemical signals in the marine environment: dispersal, detection, and temporal signal analysis. In: Eisner T, Meinwald J (eds) Chemical ecology: the chemistry of biotic interaction. The National Academies Press, p 224. https://doi.org/10.17226/4979

Au WWL (1993) The sonar of dolphins. Springer-Verlag

Au W (2018) History of bioacoustics research on aquatic and marine organisms in Hawaii. J Acoust Soc Am 143(3):1769–1769. https://doi.org/10.1121/1.5035791

Au WWL, Nachtigall PE (1997) Acoustics of echolocating dolphins and small whales. Mar Freshw Physiol Behav 29:127–162

Au WWL, Schusterman RJ, Kersting DA (1980) Sphere-cylinder discrimination via echolocation by *Tursiops truncatus*. In: Busnel RG, Fish JF (eds) Animal sonar systems. Plenum Press, pp 859–862

Azzali M, Manzini A, Buracchi G (1995) Acoustic recognition by a dolphin of shapes. In: Kastelein RA, Thomas JA, Nachtigall PE (eds) Sensory systems in aquatic mammals. De Spil Publishers, pp 137–156

Bacindonna L, Sofvi C, La Grua S, Pilenga C, Gamba M, Favaro L (2021) Cross-modal individual recognition in the African penguin and the effect of partnership. Proc R Soc B B iol Sci 288(1960):20211463. https://doi.org/10.1098/rspb.2021.1463

Bradbury JW, Vehrencamp SL (2011) Principles of animal communication. Sinauer

Bruck JN (2013a) Decades-long social memory in bottlenose dolphins. Proc R Soc B 280:1726. https://doi.org/10.1098/rspb.2013.1726

Bruck JN (2013b) New perspectives on dolphin whistles: Evaluating signal context, categorization and memory. Ph.D. Dissertation, University of Chicago, Chicago

Bruck JN (2019a) Chemical signals. In: Vonk J, Shackelford T (eds) Encyclopedia of animal cognition and behavior. Springer International Publishing, pp 1–4. https://doi.org/10.1007/978-3-319-47829-6_1654-1

Bruck JN (2019b) Long-term memory. In: Vonk J, Shackelford T (eds) Encyclopedia of animal cognition and behavior. Springer International Publishing, pp 1–5. https://doi.org/10.1007/978-3-319-47829-6_783-1

Bruck JN, Wälmsley SF, Janik VM (2022) Cross-modal perception of identity by sound and taste in bottlenose dolphins. Sci Adv 8(20):eabm7684. https://doi.org/10.1126/sciadv.abm7684

Bryant PE, Jones P, Claxton V, Perkins GM (1972) Recognition of shapes across modalities by infants. Nature 240:303–304

Bushnell EW, Weinberger N (1987) Infants' detection of visual–tactual discrepancies: asymmetries that indicate a directive role of visual information. J Exp Psychol Hum Percept Perform 13:601–608

Caldwell MC, Caldwell DK (1965) Individualized whistle contours in bottlenosed dolphins (*Tursiops truncatus*). Nature 207:434–435

Church RM, Meck WH (1984) The numerical attribute of stimuli. In: Roitblat HL, Bever TG, Terrace HS (eds) Animal cognition. Lawrence Erlbaum Associates, pp 445–464

Cozzi B, Huggenberger S, Oelschläger H (2016) Anatomy of Dolphins, 1st edn. Academic Press

Davenport RK (1976) Cross-modal perception in apes. Ann N Y Acad Sci 280:143–149. https://doi.org/10.1111/j.1749-6632.1976.tb25482.x

Davenport RK, Rogers CM (1970) Intermodal equivalence of stimuli in apes. Science 168:279–280

Davenport RK, Rogers CM, Russell IS (1975) Cross-model perception in apes. Altered visual cues and delay. Neuropsychologia 13:229–235

DeLong CM, Fellner W, Wilcox KT, Odell K, Harley HE (2020) Visual perception in a bottlenose dolphin (*Tursiops truncatus*): successful recognition of 2-D objects rotated in the picture and depth planes. J Comp Psychol 134(2):180–196. https://doi.org/10.1037/com0000207

DiMattia BV, Posley KA, Foster JM (1990) Crossmodal short-term memory of haptic and visual information. Neuropsychologia 28(1):17–33. https://doi.org/10.1016/0028-3932(9)90083-Z

Ettlinger G, Garcha HS (1980) Cross-modal recognition by the monkey: the effects of cortical removals. Neuropsychologia 18(6):685–692. https://doi.org/10.1016/0028-3932(80)90108-6

Evans T, Howell S, Westergaard G (2005) Auditory-visual cross-modal perception of communicative stimuli in Tufted Capuchin Monkeys (*Cebus apella*). J Exp Psychol Anim Be hav Process 31:399–406. https://doi.org/10.1037/0097-7403.31.4.399

Féron J, Gentaz E, Streri A (2006) 04/01). Evidence of amodal representation of small numbers across visuo-tactile modalities in 5-month-old infants. Cogn Dev 21:81–92. https://doi.org/10.1016/j.cogdev.2006.01.005

Finneran JJ, Schlundt CE, Branstetter B, Dear RL (2007) Assessing temporary threshold shift in a bottlenose dolphin (*Tursiops truncatus*) using multiple simultaneous auditory ev oked potentials. J Acoust Soc Am 122(2):1249–1264. https://doi.org/10.1121/1.2749457

Friedl WA, Nachtigall PE, Moore PW, Chun NKW, Haun JE, Hall RW, Richards JE (1990) Taste reception in the Pacific bottlenose dolphin (*Tursiops truncatus gilli*) and the Calif ornia sea lion (*Zalophus californianus*). In: Thomas JA, Kastelein RA (eds) Sensory abilities of cetaceans: laboratory and field evidence. Plenum Press

Gibson EJ, Walker AS (1984) Development of knowledge of visual–tactual affordances of substance. Child Dev 55:360–453

Giffillan G, Vitale J, McNutt JW, McComb K (2016) Cross-modal individual recognition in wild African lions. Biol Lett 12(8):20160323. https://doi.org/10.1098/rsbl.2016.0323

Gunnars T, Bruck JN (2019) Visual perception. In: Vonk J, Shackelford T (eds) Encyclopedia of animal cognition and behavior. Springer International Publishing, pp 1–7. https://doi.org/10.1007/978-3-319-47829-6_610-1

Harley HE, DeLong CM (2008) Echoic object recognition by the bottlenose dolphin. Comp Cogn Behav Rev 3:46–65. https://doi.org/10.3819/ccbr.2008.30003

Harley H, Roitblat HL, Nachtigall PE (1996) Object representation in the bottlenosed dolphin (*Tursiops truncatus*): integration of visual and echoic information. J Exp Psychol Ani m Behav Process 22:164–174

Harley HE, Putman EA, Roitblat HL (2003) Bottlenose dolphins perceive object features through echolocation. Nature 424:667–669

Herman LM (1986) Cognition and language competencies of bottlenosed dolphins. In: Schusterman RJ, Thomas J, Wood FG (eds) Dolphin cognition and behavior: a comparative approach. Lawrence Erlbaum Associates, pp 221–251

Herman LM, Forestell PH (1985) Reporting presence or absence of named objects by a language-trained dolphin. Neurosci Behav Rev 9:667–691

Herman LM, Pack AA (1992) Echoic–visual cross-modal recognition by a dolphin. In: Thomas JR, Kastelein RA, Supin AY (eds) Sensory processes of marine mammals. Plenum, pp 709–726

Herman LM, Kuczaj SI III, Holder MD (1993) Responses to anomalous gestural sequences by a language-trained dolphin: evidence for processing of semantic relations and syntact ic information. J Exp Psychol Gen 122:184–194

Herman LM, Pack AA, Hoffmann-Kuhnt M (1998) Seeing through sound: dolphins perceive the spatial structure of objects through echolocation. J Comp Psychol 112:292–305

Herzing DL (1996) Vocalizations and associated underwater behavior of free-ranging Atlantic spotted dolphins, *Stenella frontalis* and bottlenose dolphins, *Tursiops truncatus*. Aqu at Mamm 22:61–79

Hoffmann-Kuhnt M, Chitre MA, Seekings PJ, Abel G (2008) Acoustics of shape recognition by a dolphin in a cross-modal matching-to-sample paradigm. J Acoust Soc Am 123(5):3361–3361. https://doi.org/10.1121/1.2933955

Izumi A (2013) Cross-modal representation in humans and nonhuman animals: a comparative perspective. In: Belin P, Campanella S, Ethofer T (eds) Integrating face and voice in person perception. Springer, New York, pp 29–43. https://doi.org/10.1007/978-1-4614-3385-3_2

Janik VM (1999) Origins and implications of vocal learning in bottlenose dolphins. In: Box HO, Gibson KR (eds) Mammalian social learning: comparative and ecological perspect ives. Cambridge University Press, pp 308–326

Janik VM (2000) Whistle matching in wild bottlenose dolphins (*Tursiops truncatus*). Science 289:1355–1357

Janik VM (2009) Acoustic communication in delphinids. Adv Stud Behav 40:123–157. https://doi.org/10.1016/S0065-3454(09)40004-4

Janik VM (2013) Cognitive skills in bottlenose dolphin communication. Trends Cogn Sci 17(4):157–159. https://doi.org/10.1016/j.tics.2013.02.005

Janik VM, Slater PJB (1997) Vocal learning in mammals. Adv Study Behav 26:59–99

Janik VM, Slater PJB (1998) Context-specific use suggests that bottlenose dolphin signature whistles are cohesion calls. Anim Behav 56:829–838

Janik VM, Slater PJB (2000) The different roles of social learning in vocal communication. Anim Behav 60:1–11

Janik VM, Sayigh LS, Wells RS (2006) Signature whistle shape conveys identity information to bottlenose dolphins. Proc Natl Acad Sci 103:8293–8297. https://doi.org/10.1073/pnas.0509093103

Jones B (1981) The developmental significance of cross-modal matching. In: Walk RD, Pick HL (eds) Intersensory perception and sensory integration. Plenum Press, pp 109–136

King SL, Janik VM (2013) Bottlenose dolphins can use learned vocal labels to address each other. Proc Natl Acad Sci USAm Early Edn 110:13216–13221

King SL, Sayigh L, Wells R, Fellner W, Janik VM (2013) Vocal copying of individually distinctive signature whistles in bottlenose dolphins. Proc R Soc Lond B Biol Sci. https://doi.org/10.1098/rspb.2013.0351

Kishida T, Thewissen J, Hayakawa T, Imai H, Agata K (2015) Aquatic adaptation and the evolution of smell and taste in whales. Zool Lett 1:9–9. https://doi.org/10.1186/s40851-014-0002-z

Kondo N, Izawa E-I, Watanabe S (2012) Crows cross-modally recognize group members but not non-group members. Proc R Soc B Biol Sci 279(1735):1937–1942. https://doi.org/10.1098/rspb.2011.2419

Kujala T, Alho K, Näätänen R (2000) Cross-modal reorganization of human cortical functions. Trends Neurosci 23(3):115–120. https://doi.org/10.1016/s0166-2236(99)01506-0

Kulahci IG, Ghazanfar AA (2013) Multisensory recognition in vertebrates (especially primates). Integrating face and voice in person perception. Springer Science + Business Medi a, pp 3–27. https://doi.org/10.1007/978-1-4614-3385-3_1

Kulahci IG, Drea CM, Rubenstein DI, Ghazanfar AA (2014) Individual recognition through olfactory–auditory matching in lemurs. Proc R Soc B Biol Sci 281(1784):20140071. https://doi.org/10.1098/rspb.2014.0071

Kuznetsov VB (1990) Chemical sense of dolphins: quasi-olfaction. In: Thomas JA, Kastelein RA (eds) Sensory abilities of cetaceans. Plenum Press, pp 481–503

Kuznetsov VB (1992) Quasi-olfaction of dolphins. In: Doty RL, Müller-Schwarze D (eds) Chemical signals in vertebrates 6. Springer US, pp 543–549

Lampe JF, Andre J (2012) Cross-modal recognition of human individuals in domestic horses (*Equus caballus*). Anim Cogn 15(4):623–630. https://doi.org/10.1007/s10071-012-0489-0x.1

Lindemann-Biehl KL, Reichmuth C (2013) Cross-modal transitivity in a California sea lion (*Zalophus californianus*). Anim Cogn 17(4):879–890. https://doi.org/10.1007/s10071-013-0721-0

Mann D, Hill-Cook M, Manire C, Greenhow D, Montie E, Powell J, Wells R, Bauer G, Cunningham-Smith P, Lingenfelser R, DiGiovanni R Jr, Stone A, Brodsky M, Stevens R, Kiefer G, Hoetjes P (2010) Hearing loss in stranded odontocete dolphins and whales. PLoS ONE 5(11):e13824–e13824. https://doi.org/10.1371/journal.pone.0013824

Meck W, Church R, Olton D (2013) 10/01). Hippocampus, time, and memory. (Reprinted for 30th anniversary). Behav Neurosci 127:655–668. https://doi.org/10.1037/a0033188

Meltzoff AN, Borton RW (1979) Intermodal matching by human neonates. Nature 282:403–404

Mezzera C, López-Bendito G (2016) Cross-modal reorganization of human cortical functions. Trends Neurosci 23(3):115–120. https://doi.org/10.1016/s0166-2236(99)01506-0

Kulahci IG, Ghazanfar AA (2013) Multisensory recognition in vertebrates (especially primates). Integrating face and voice in person perception. Springer Science + Business Medi a, pp 3–27. https://doi.org/10.1007/978-1-4614-3385-3_1

Kulahci IG, Drea CM, Rubenstein DI, Ghazanfar AA (2014) Individual recognition through olfactory–auditory matching in lemurs. Proc R Soc B Biol Sci 281(1784):20140071. https://doi.org/10.1098/rspb.2014.0071

Murace H, Kuczaj SA (2015) Conceptive estrus behavior in three bottlenose dolphins (*Tursiops truncatus*). Anim Behav Cogn 2:30–48. https://doi.org/10.12966/abc.02.03.2015

Murayama T, Suzuki R, Kondo Y, Koshikawa M, Katsumata H, Arai K (2017) Spontaneous establishing of cross-modal stimulus equivalence in a beluga whale. Sci Rep 7(1):9914. https://doi.org/10.1038/s41598-017-09925-4

Nachtigall PE (1986) Vision, audition, and chemoreception in dolphins and other marine mammals. In: Schusterman RJ, Thomas JA, Wood FG (eds) Dolphin cognition and behavi or: a comparative approach. Lawrence Erlbaum Associates, pp 79–113

Nachtigall P, Hall RW (1984) Taste reception in the bottlenosed dolphin. Acta Zoologica Fennica 172:147–148

Nachtigall PE, Murchison AE, Au WWL (1980) Cylinder and cube shape discrimination by an echolocating blindfolded bottlenose dolphin. In: Busnel RG, Fish JF (eds) Animal s onar systems. Plenum Press, pp 945–947

Norris K, Würsig B, Wells RS (1994) The spinner dolphin. In: Norris K, Würsig B, Wells RS, Würsig M (eds) The Hawaiian spinner dolphin. University of California Press, pp 1 4–27

Pack AA (2015) Experimental studies of dolphin cognitive abilities. In: Herzing D, Johnson C (eds) Dolphin cognition and communication. MIT Press, pp 175–200

Pack AA (2018) Language research: dolphins. In: Vonk J, Shackelford T (eds) Encyclopedia of animal cognition and behavior. Springer International Publishing, pp 1–10. https://doi.org/10.1007/978-3-319-47829-6_1628-1

Pack AA (2019) Pointing. In: Vonk J, Shackelford T (eds) Encyclopedia of animal cognition and behavior. Springer International Publishing, pp 1–19. https://doi.org/10.1007/978-3-319-47829-6_253-1

Pack AA, Herman LM (1995) Sensory integration in the bottlenosed dolphin: immediate recognition of complex shapes across the senses of echolocation and vision. J Acoust Soc Am 98:722–733

Pack AA, Herman LM, Hoffmann-Kuhnt M, Branstetter BK (2002) The object behind the echo: dolphins (*Tursiops truncatus*) perceive object shape globally through echolocation. Behav Proc 58:1–26

Pack AA, Herman LM, Hoffmann-Kuhnt M (2004) Dolphin echolocation shape perception: from sound to object. In: Thomas J, Moss C, Vater M (eds) Advances in the study of ec holocation in bats and dolphins. University of Chicago Press, pp 288–298

Parr LA (2004) Perceptual biases for multimodal cues in chimpanzee (*Pan troglodytes*) affect recognition. Anim Cogn 7(3):171–178. https://doi.org/10.1007/s10071-004-0205-3

Partan SR (2002) Single and multichannel signal composition: facial expressions and vocalizations of rhesus macaques (*Macaca mulatta*). Behaviour, 139(8):993–1027. http://www.jstor.org/stable/4535968

Pfeiffer BJ, Briefer EF, Bacindonna L, McElligott AG (2017) Cross-modal recognition of familiar conspecifics in goats. R Soc Open Sci 4(2):160346. https://doi.org/10.1098/rsos.160346

Proops L, McComb K (2012) Cross-modal individual recognition in domestic horses (*Equus caballus*) extends to familiar humans. Proc R Soc B Lond 279:3131–3138

Proops L, McComb K, Reby D (2009) Cross-modal individual recognition in domestic horses (*Equus caballus*). Proc Natl Acad Sci USA 106:947–951

Ratcliffe V, Taylor A, Reby D (2015) Cross-modal correspondences in non-human mammal communication. Multisens Res. https://doi.org/10.1163/22134808-00007509

Ridgway SH, Carder DA, Kamolnick T, Smith RR, Schlundt CE, Elsberry WR (2001) Hearing and whistling in the deep sea: Depth Influences whistle spectra but does not attenuat e hearing by white whales (*Delphinapterus leucas*, Odontoceti, Cetacea). J Exp Biol 204:3829–3841

Roitblat HL (1982) The meaning of representation in animal memory. Behav Brain Sci 5:353–406

Roitblat HL, Penner RH, Nachtigall PE (1990) Matching-to-sample by an echolocating dolphin. J Exp Psychol Anim Behav Process 16:85–95

Roitblat HL, Helweg DA, Harley HE (1995) Echolocation and imagery. In: Kastelein RA, Thomas JA, Nachtigall PE (eds) Sensory systems of aquatic mammals. De Spil Publisher s, pp 171–181

Rose SA, Orlian EK (1991) Asymmetries in infant cross-modal transfer. Child Dev 62:706–718

Rose SA, Ruff HA (1987) Cross-modal abilities in human infants. In: Osofsky JD (ed) Handbook of infant development. Wiley, pp 318–362

Rossbach KA, Herzing DL (1997) Underwater observations of benthic-feeding bottlenose dolphins (*Tursiops truncatus*) near Grand Bahama Island, Bahamas. Mar Mamm Sci 13:4 98–504

Ruff HA, Kohler CJ (1978) Tactual–visual transfer in six-month-old infants. Infant Behav Dev 1:259–264

Savage-Rumbaugh ES (1986) Ape language: from conditioned response to symbol. Columbia University Press

Savage-Rumbaugh ES, Rumbaugh DM, Smith ST, Lawson J (1980) Reference: the linguistic essential. Science 210(4472):922–925

Savage-Rumbaugh S, Sevcik RA, Hopkins WD (1988) Symbolic cross-modal transfer in two species of chimpanzees. Child Dev 59:617–625

Savage-Rumbaugh ES, Murphy J, Sevcik RA, Brakke KE, Williams SL, Rumbaugh DM (1993) Language comprehension in ape and child. Monogr Soc Res Child 58:1–252

Sayigh LS, Tyack PL, Wells RS, Solow AR, Scott MD, Irvine AB (1998) Individual recognition in wild bottlenose dolphins: a field test using playback experiments. Anim Behav 5 7:41–50

Sayigh LS, Esch HC, Wells RS, Janik VM (2007) Facts about signature whistles of bottlenose dolphins, *Tursiops truncatus*. Anim Behav 74:1631–1642

Sliwa J, Duhamel J, Pascalis O, Wirth S (2011) Spontaneous voice and face identity matching by rhesus monkeys for familiar conspecifics and humans. Proc Natl Acad Sci 108(4):1735–1740. https://doi.org/10.1073/pnas.1008169108

Sokolov V, Kuznetsov VB (1971) Chemoreception in the Black Sea bottlenose dolphin, *Tursiops truncatus* (*Montagua*). Dokl Akad Nauk SSSR 201:998–1000

Stein BE, Meredith MA (1993) The merging of the senses. The MIT Press

Streri A (1987) Tactile discrimination of shape and intermodal transfer in 2- to 3-month-old infants. Br J Dev Psychol 5(3):213–220. https://doi.org/10.1111/j.2044-835X.1987.tb01056.x

Takagi S, Arahori M, Chijiiwa H, Saito A, Kuroshima H, Fujita K (2019) Cats match voice and face: cross-modal representation of humans in cats (Felis catus). Anim Cogn 22(5):901–906. https://doi.org/10.1007/s10071-019-01285-2

Tolan JC, Rogers CM, Malone DR (1981) Cross-modal matching in monkeys: altered visual cues and delay. Neuropsychologia 19:289–300

Tumulty JP, Sheehan MJ (2020) What drives diversity in social recognition mechanisms? [Perspective]. Front Ecol Evol. https://doi.org/10.3389/fevo.2019.00517

Turner ML, Johnson SK, McNamara DS, Engle RW (1992) Effects of same-modality interference on immediate serial recall of auditory and visual information. J General Psychol 119(3):247–263. https://doi.org/10.1080/00221309.1992.9917806

Uttley L, de Bouiseren AM, Dupierris E, Lee K, Quinn PC, Slater AM, Pascalis O (2013) Six-month-old infants match other-race faces with a non-native language. Int J Behav De v 37(2):84–89. https://doi.org/10.1177/0165025412467583

Vishna H, Hoffmann-Kuhnt M, Chitre M, Ho A, Matrai E (2022) A dolphin-inspired compact sonar for underwater acoustic imaging. Commun Eng 1(1):10. https://doi.org/10.1038/s44172-022-00010-x

Wang Z, Chen Z, Xu S, Ren W, Zhou K, Yang G (2015) 'Obesity' is healthy for cetaceans? Evidence from pervasive positive selection in genes related to triacylglycerol metabolis m. Sci Rep 5(1):14187. https://doi.org/10.1038/srep14187

Wei C, Hoffmann-Kuhnt M, Au WWL, Hao Ho AZ, Matrai E, Feng W, Ketten DR, Zhang Y (2021) Possible limitations of dolphin echolocation: a simulation study based on a cro ss-modal matching experiment. Sci Rep 11:6689. https://doi.org/10.1038/s41598-021-85863-2