# FROM NUDGE TO NETWORK: EARLY CONTACT AND BEHAVIORAL DEVELOPMENT IN BELUGA WHALES

by

BRIANNA ERCK

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Oakland University
Rochester, Michigan

Thesis Advisory Committee:

Jennifer Vonk, Ph.D., Chair
Todd Shackelford, Ph.D.
Heather Hill, Ph.D.

DEDICATION

*I dedicate this thesis to the late Dr. Jennifer Zwahr Castro; her compassion and courage is what motivates me every day.*

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ABSTRACT

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Brianna Erck

Adviser: Jennifer Vonk, Ph.D

Early social experiences play a critical role in shaping social development. However, the extent to which specific forms of early tactile interaction influence later social outcomes in cetaceans remains unclear. Video data from 11 beluga (*Delphinapterus leucas*) calves from six mothers from birth through three years in a managed-care setting provided measures of overall contact and calf-initiated pectoral-fin contact during the first two years and social (mother- and conspecific-directed) and non-social behaviors in the third year. Overall contact did not predict behavioral outcomes. In contrast, pectoral-fin contact predicted mother-directed social behavior. Neither form of contact was associated with conspecific-directed social behavior or non-social behavior, and the consistency of contact did not moderate the effects. These findings suggest that specific forms of tactile interaction are associated with later mother-directed social behavior. Future research that better disentangles genetic and experiential effects is needed before causal conclusions can be drawn.

*Keywords:* Beluga, *Delphinapterus leucas*, Calf, Social Interactions, Contact

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# CHAPTER ONE

## INTRODUCTION

In comparative psychology, researchers aim to identify and understand the ways in which behaviors are similar or different across species, often using humans as a reference point to help explain the evolution and development of behavioral traits. Among the traits that are thought of as characteristically human, the extensive parental care and long-term social bonds between mothers and their offspring can be expected to have deep evolutionary roots as all mammals depend to some degree on maternal care. Although there are numerous studies of parental care and offspring development in nonhuman primates (Berman, 1990; Dettling et al., 2002; Kölliker et al., 2012; Maestripieri, 2001; Suomi, 1997), for a full appreciation of the evolution of such behaviors, it is important to study more distantly related and ecologically distinct species that exhibit complex social structures and long-term maternal care. Species may vary in terms of how dependent typical social development is on early maternal care, and this variance is likely to be at least in part a function of social complexity. Beluga whales are well suited to this line of research because they live in complex social groups characterized by long-term maternal associations and enduring social bonds. Given these characteristics, beluga whales provide a useful model for examining whether early physical contact is associated with later social behavior. This study examines whether variation in early physical contact is associated with social behaviors exhibited by beluga whales during their third year of life.

Physical contact plays a central role in the social lives of many nonhuman animals, particularly within the context of parental care. Rather than functioning as a

single, uniform behavior, contact encompasses a range of tactile and affiliative interactions such as proximity maintenance and grooming. These interactions are closely tied to caregiving processes and have been associated with relationship formation, communication, and behavioral development across the lifespan (Broad et al., 2006; Clutton-Brock et al., 2001; Suomi, 1997). Likewise, research has identified associations between early experiences with physical and social contact and later social competence in humans, including differences in how individuals engage with others and respond to social challenges (Ding & He, 2022; Pavard et al., 2007; Wan & Green, 2009). However, these associations should be interpreted cautiously because observational studies cannot readily distinguish the effects of early experience from shared genetic influences between parents and offspring, or from a combination of both (Harris, 1998). By examining variation in early contact behaviors, the present study first aims to clarify whether early mother–calf tactile interactions are associated with later social behavior in beluga whales, thereby contributing to our understanding of the evolution of maternal care and social relationships among mammals and setting the stage for future explorations of genetic contributions.

**Maternal Care in Humans**

Parental care refers to behaviors or traits that enhance offspring survival and may involve both maternal and paternal contributions (Kölliker et al., 2012). Although maternal care typically plays a more important role in many species, paternal care encompasses similar behaviors, including food provision, protection, affection, and teaching (Kölliker et al., 2012). This care contributes to offspring development in species

that rely on it. In fact, human childcare begins even before birth, with expectant mothers often engaging in prenatal activities such as taking childbirth and parenting classes, reading books on caregiving, and physically preparing for the baby's arrival (e.g., building a place for the baby to sleep). After birth, humans will engage in extensive care for their baby (e.g., feeding, changing diapers, and monitoring health). This care does not end after a few weeks or months, rather parents engage in caring for their children until they grow up and become more independent (Philips, 2013). Because this prolonged period of caregiving involves repeated and emotionally significant interactions between caregiver and infant, it forms the developmental context in which early socio-emotional bonds emerge. One theoretical framework that explains how these bonds develop is attachment theory.

**Attachment**

Attachment theory was proposed by Bowlby (1969) to explain how human infants may be biologically predisposed to seek proximity to caregivers and form emotional bonds, particularly in times of distress (Waters & Cummings, 2000). These early attachment experiences contribute to the development of internal working models, which influence how individuals perceive themselves, others, and relationships later in life (Bowlby, 1969; Waters & Cummings, 2000). Building on this line of thought, Ainsworth and colleagues identified three attachment styles based on their studies of parent–child interactions and: secure, anxious, and avoidant (Ainsworth & Bell, 1970; Ainsworth et al., 1978). Then, a fourth attachment style, known as disorganized attachment, was identified by Main and Solomon (Main & Solomon, 1990). Whereas attachment is often

described in discrete categories (i.e., secure, avoidant, anxious, disorganized), contemporary research increasingly conceptualizes attachment along continuous dimensions, particularly anxiety and avoidance. Within this framework, secure attachment is often inferred from low levels of both attachment anxiety and avoidance (Decarli et al., 2022; Waters & Cummings, 2000).

It is also important to acknowledge the behaviors that parents exhibit toward their children to better understand how attachment styles form during childhood. Many factors may influence a child's attachment style, including caregiver behavior (Ainsworth et al., 1978; Bowlby, 1969; Broad et al., 2006; Phillips, 2013; Radke, 2022). Caregiving is characterized by the quality and consistency of time spent together, emotional availability, physical affection, and responsiveness to a child's needs, all of which contribute to how children learn to interpret caregiver reliability and emotional safety (Bowlby, 1969). However, research also suggests that attachment styles are partially heritable, meaning that some of the variation in attachment may be attributable to genetic influences shared between parents and children rather than caregiving experiences alone (Erkoreka et al., 2021). This suggests that parent–child similarities in attachment-related behaviors may reflect both environmental and genetic influences, complicating simple causal interpretations of caregiving effects.

Secure attachment develops when a caregiver consistently provides loving care and responds to the child's distress in a reliable and comforting manner. Children with secure attachment tend to feel safe exploring their environment, show confidence in seeking help when needed, and are better able to regulate their emotions. Children are also observed to use their caregiver as the primary source of safety. When separated from

their caregiver, the child is visibly distressed; however, once their caregiver arrives, the child is observed to be easily soothed. As the child grows, they often develop healthy self-esteem, strong social skills, and the ability to form trusting relationships (Ainsworth et al., 1978). However, these outcomes may also be influenced by inherited temperament and genetic factors shared between parents and children, meaning they cannot be attributed solely to caregiving experiences (Erkoreka et al., 2021).

The remaining styles indicate insecure attachment. Anxious attachment is characterized by inconsistent caregiving, where the child experiences both positive and negative responses from the caregiver, resulting in heightened anxiety and uncertainty. Similar to securely attached children, those with anxious attachment display heightened distress when the caregiver is absent. However, upon reunion, they seek contact but struggle to accept comfort, often pushing the caregiver away and displaying signs of anger or frustration. Children with this style may become clingy, fear abandonment, and have difficulty calming themselves, which can later translate into low self-confidence and intense emotional reactions (Ainsworth et al., 1978).

Avoidant attachment occurs when a caregiver is emotionally distant or unresponsive, leading the child to suppress their need for comfort and rely on themselves. This can be observed when the child shows little attention to or engagement with their caregiver and has few “check-ins.” Once the caregiver returns, these children are observed not to notice or seek comfort from their caregiver. Avoidant children may appear independent but often struggle to express emotions, form close relationships, and ask for support, reflecting a tendency to deactivate attachment-related emotional needs in response to chronic unavailability of care (Ainsworth et al., 1978).

Disorganized attachment emerges when a child is exposed to unpredictable, neglectful, or abusive caregiving. Because the caregiver is inconsistently available or may simultaneously represent both a source of comfort and fear, the child is unable to develop a coherent strategy for seeking security or managing distress. This inconsistency prevents the child from forming reliable expectations of how their emotional needs will be met, impairing the development of effective emotion regulation. Consequently, their emotional and behavioral responses to stress may fluctuate depending on the situation, with the child alternating between seeking comfort, avoiding the caregiver, displaying heightened distress, or appearing emotionally detached. Rather than relying on a consistent attachment strategy, these children often exhibit contradictory or disorganized behaviors that reflect difficulties in regulating emotions and coping with stress (Main & Solomon, 1986).

Consistent with these behavioral patterns, attachment styles are associated with broader developmental outcomes. Early disorganized attachment has been linked to higher aggression at age five, poorer peer relationships, lower math comprehension between ages five and seven, reduced academic self-esteem, and increased peer rejection in middle to late childhood (Decarli et al., 2022; Francis et al., 1999; Green & Goldwyn, 2002; Johnson et al., 1996; Verschueren & Marcoen, 1999). In contrast, secure attachment supports strong emotion regulation, coping skills, and the ability to form stable, trusting relationships, which are critical for successful adjustment within families, peer groups, and society (Decarli et al., 2022; Ding & He, 2022; Hetsgaard et al., 1995; Pavard et al., 2007; Joas & Möhler, 2021).

Attachment patterns have been widely associated with early caregiver–child interactions, particularly caregiver sensitivity and responsiveness (Ainsworth et al., 1978; Main & Solomon, 1986). These interactions are thought to contribute to the development of internal working models that shape expectations about relationships (Bowlby, 1969; Waters & Cummings, 2000). However, interpretations of these associations should be made cautiously, as genetic influences and broader environmental factors, including peer socialization processes, may also contribute to individual differences in attachment-related behaviors, as suggested by alternative perspectives such as Harris' group-socialization theory (Harris, 1998).

**Attachment in Nonhuman Animals**

In humans, attachment can be assessed through both behavioral observations and self-report measures that provide insight into individuals' thoughts, emotions, and relationship patterns. In contrast, because nonhuman animals cannot verbally communicate their internal experiences or complete self-report assessments, researchers must infer attachment from observable behaviors. Behaviors such as proximity seeking, maintaining contact with a caregiver, distress during separation, and comfort upon reunion are therefore commonly used as indicators of attachment, as they reflect the tendency to seek safety and security from an attachment figure. As a result, attachment in nonhuman animals is typically operationalized through behavioral indicators such as proximity seeking, maintenance of contact, distress during separation, and reunion behavior, which reflect the functional components of attachment systems rather than subjective emotional states. Accordingly, the strength of the bond between mothers and

their offspring may be expected to shape later social behavior in nonhuman animals, as it does in humans. Some nonhuman animals have demonstrated the capacity to display attachment-related behaviors similar to those observed in Ainsworth's (1978) study. Topál et al. (1998) adapted Ainsworth's Strange Situation Procedure to examine attachment-like behaviors in dogs toward their owners. They found that dogs exhibited behaviors consistent with attachment, such as seeking proximity to their owners, showing distress upon separation, and displaying a mix of affiliative and cautious behaviors when interacting with strangers. These findings suggest that dogs form attachment bonds with their owners that resemble those observed in human infants. Subsequent research has extended attachment theory to other species, including cats, demonstrating that cats also display secure and insecure attachment styles toward their owners (Vitale et al., 2019). However, these studies did not assess variation in caregiving styles (e.g., through surveys or behavioral measures of owner interaction), limiting the ability to determine how differences in owner behavior may influence attachment outcomes. This represents a gap in the literature, as it remains unclear how specific caregiving patterns shape attachment in nonhuman animals. Together, these findings highlight the need for longitudinal research that examines how early caregiving experiences influence the development of attachment and long-term social bonds across species.

**Maternal Care in Nonhuman Animals**

Similar patterns of maternal influence can also be observed in nonhuman animals, particularly in species with complex social structures. Social animals rely on prolonged maternal investment to acquire essential social skills such as communication, cooperation, and group coordination (Maestripieri, 2001). Maternal care is especially

significant for altricial species - those born in a highly dependent state. Research suggests that maternal behaviors, such as engaging offspring in social exploration and movement, have been associated with survival outcomes and broader behavioral traits. For instance, Johnson et al. (1996) found that parental engagement in social experiences had a measurable impact on young marmosets' (*Callithrix jacchus*) weight, emphasizing the role of maternal care in physical and social development. However, these findings should be interpreted cautiously, as the association between maternal care and offspring weight may not reflect environmental influences alone. Mothers that are healthier or of higher phenotypic quality may both provide more effective care and transmit genetic factors associated with growth, metabolism, or stress regulation to their offspring. Consequently, offspring weight may partly reflect inherited biological characteristics rather than the effects of maternal caregiving alone, making it difficult to disentangle environmental and genetic influences (Harris, 1998). Alternatively, it is possible that the same genetic factors contributing to maternal caregiving behavior may also contribute to offspring behavioral outcomes, making it difficult to disentangle environmental effects from inherited predispositions.

In cooperative breeders like meerkats (*Suricata suricatta*) and some primates, maternal care is not solely the responsibility of the mother but is supported by alloparents, individuals within the group who assist with caregiving. This shared caregiving system enhances offspring survival and provides additional learning opportunities, which are important for species with prolonged developmental periods (Clutton-Brock et al., 2001). Because offspring in these species remain dependent for extended periods, they require sustained access to food, protection, and social learning

opportunities. Alloparental care helps distribute the energetic and protective demands of caregiving, reducing the burden on the mother while ensuring that offspring receive consistent support. Additionally, exposure to multiple caregivers increases opportunities for social interaction and learning, allowing young individuals to develop the complex social and cooperative skills necessary for functioning within their group.

Similarly, in cetaceans such as beluga whales (*Delphinapterus leucas*), prolonged maternal investment may play an important role in shaping social bonds, communication skills, and group cohesion. Beluga calves rely on their mothers not only for nourishment and protection but also for social learning, acquiring behaviors essential for integrating into the pod (Hill et al., 2013). This extended dependency period allows calves to develop critical survival and social competencies within a highly structured social environment, where close maternal proximity facilitates both behavioral learning and social familiarity with group members. Evidence from other cetacean species further highlights the importance of sustained mother–offspring associations. For example, aerial observations of cetaceans (e.g., grey whale [*Eschrichtius robustus*], fin whale [*Balaenoptera physalus*], blue whale [*Balaenoptera musculus*], and killer whale [*Orcinus orca*]) off the coasts of Southern California document tightly coordinated mother–calf interactions, including nursing, synchronized swimming, and "back-riding" behavior, in which calves maintain continuous physical contact with their mothers (Smultea et al., 2017). These behaviors not only ensure nutritional support but also may function to maintain social cohesion and reduce energetic costs for the calf while reinforcing spatial coordination within dynamic marine environments. Importantly, these interactions demonstrate that maternal care is not limited to discrete nursing events but instead involves continuous

behavioral engagement that supports both physiological development and social integration. Similarly, research on Bigg's killer whales reveals that mother–offspring relationships can persist well beyond weaning, with post-reproductive females maintaining long-term associations with their adult offspring and potentially providing indirect benefits through experience-based guidance, leadership, and kin-directed support (Brent et al., 2015). Such extended associations suggest that maternal investment in cetaceans may operate across multiple life stages, shaping not only early development but also long-term social structure and group stability.

Thus, although maternal care is often examined at the dyadic level between mother and offspring, its effects may extend far beyond individual development. Across species, maternal investment may contribute to broader social structures by ensuring that offspring acquire the social and cognitive skills necessary to function within their group, reinforcing the idea that caregiving is not only about survival but also about facilitating social integration and cohesion.

**Contact in Nonhuman Animals**

Contact between parents and offspring, or among group members, is a widespread feature of social behavior that serves multiple developmental, social, and survival functions. Contact behaviors are specific, observable actions through which animals maintain physical proximity, provide care, and communicate important social information (Duda et al., 2024; Dudzinski et al., 2009; Mann, 2019). These behaviors vary across species in form, frequency, and function, but consistently are associated with offspring outcomes. Mammals, for example, typically provide extensive postnatal care,

often involving tactile contact, nursing, grooming, huddling, and carrying (Broad et al., 2006; Kölliker et al., 2012; Maestripieri, 2001). In prairie voles (*Microtus ochrogaster*), parental contact is quantified by measuring huddling, licking/grooming, pup retrieval, and nursing postures; pups receiving higher levels of contact show increased social exploration and affiliative behavior and reduced anxiety in adolescence compared with low-contact pups (Ahern & Young, 2009).

Further effects of parental care can be understood by examining how infants respond to a lack of support. For example, early deprivation of parental care has been associated with elevated stress physiology in infant marmosets, highlighting the importance of tactile caregiving for physiological regulation (Berman, 1990; Dettling et al., 2002). Additionally, maternal neglect in rats has been linked to heightened fear responses and impaired social behavior with conspecifics later in life (Francis et al., 1999). The importance of physical contact has also been demonstrated in research with rhesus macaques (*Macaca mulatta*). In a classic laboratory study, Harlow (1958) found that infant monkeys preferred a soft cloth surrogate mother that provided no food over a wire surrogate that did provide nourishment. Although this study was not a direct test of attachment, it highlighted the critical role of comfort and physical contact in early development and laid the groundwork for later attachment research. Building on this foundation, Suomi (1997) examined rhesus macaques living in free-ranging conditions to better understand the long-term effects of early social bonds. His findings showed that lower levels of early contact and affiliative behavior were associated with weaker social bonds, increased anxiety, and poorer stress regulation later in life. Because many of

Suomi's studies experimentally manipulated early rearing environments, these findings provide stronger evidence for a causal role of early experience than correlational research, reducing the likelihood that the observed effects are solely attributable to shared genetic influences. However, aspects of Suomi's work have been critiqued, including questions regarding the ecological validity of nursery-rearing paradigms and the extent to which findings generalize to naturally occurring maternal care. Together, these findings underscore the importance of consistent parental care in shaping emotional regulation and social relationships across development.

### Contact in Cetaceans

Across odontocetes (toothed whales), physical contact is a core component of maternal care and social interaction. Species such as bottlenose dolphins (*Tursiops Truncatus*), killer whales, and pilot whales engage in frequent mother–calf contact, coordinated swimming, and tactile interactions that support calf survival, social learning, and behavioral development (Duda et al., 2024; Dudzinski et al., 2009; Mann, 2019). These contact-based interactions are not merely affiliative but also may play a regulatory role in maintaining cohesion during movement, foraging, and group coordination, particularly in fission–fusion societies where individuals frequently separate and reunite (Madsen & de Silva, 2024).

For beluga whales, contact appears to play an important role in social development. Contact is observed at all stages of life and is considered essential for maintaining social cohesion and communication within beluga groups. Unlike many

mammals, in which mothers initiate physical contact and affiliative interactions with their offspring (Broad et al., 2006; Mann, 2019), beluga calves initiate contact more frequently than their mothers do, suggesting a more active and reciprocal role in shaping mother–calf interactions (Duda et al., 2024; Hill et al., 2018). This pattern indicates that maternal care in belugas may be less unidirectional than in many terrestrial species, with calves actively participating in maintaining proximity and tactile connection, which may facilitate social learning and integration into broader group dynamics.

Evidence from other cetaceans further highlights the complexity and functional significance of tactile maternal behaviors. In adult bottlenose dolphins, fine-scale analyses of pectoral fin contact demonstrate consistent patterns of "maternal style," where individual females differ in the frequency, duration, and context of physical contact with their calves (Dudzinski et al., 2021). These differences suggest that maternal care is not uniform but instead reflects stable behavioral tendencies that may influence calf development, social responsiveness, and integration into the group's social network. Such variation implies that offspring may experience distinct developmental environments depending on maternal behavioral style, potentially shaping long-term social strategies and affiliative tendencies.

Similarly, in larger baleen whale systems, tactile behavior also may serve important protective and affiliative functions. Observations of humpback whale mother–calf pairs in competitive social groups at Abrolhos Bank, Brazil, document behaviors in which mothers use their bodies—particularly pectoral fins and positioning—to shield calves from approaching escorts and potentially dangerous adult males (Glockner-Ferrari

et al., 2023). These protective “hug-like” behaviors highlight the importance of physical contact as a defensive strategy in high-risk social contexts, where calves are vulnerable to separation or harassment. In these situations, maternal contact functions not only to maintain proximity but also to actively buffer offspring from social and physical threats within complex group interactions.

**Beluga Whales**

Beluga whales are odontocete cetaceans inhabiting Arctic and sub-Arctic waters. At birth, calves are dark gray and gradually transition to lighter gray, eventually nearly pure white as they mature. This is not only a developmental marker, but also an evolved protection against predators. The waters that belugas inhabit have low transparency, causing the grey calf to be unnoticed by predators due to the similar dark coloration of its environment (Krasnova et al., 2009; O’Corry-Crowe, 2009).

Belugas are highly social and are often referred to as the “canaries of the sea” due to their extensive and complex vocal repertoire (O’Corry-Crowe, 2009). They live within fission–fusion societies, in which group composition varies with environmental conditions, seasonality, and social context. Belugas live within fission–fusion societies, in which group composition varies with environmental conditions, seasonality, and social context. Social groups typically consist of two to 50 individuals and may include animals of different ages, sexes, and degrees of relatedness, although larger aggregations can form under certain ecological conditions (O'Corry-Crowe et al., 2020). In the wild, pods may separate into smaller maternal or bachelor groups (Hauser et al., 2014; Madsen & de Silva, 2024; O’Corry-Crowe et al., 2020). However, due to the challenges of tracking

individuals in wild environments, it remains unclear how consistently individuals return to the same primary social groups over time.

The social structure of belugas has been studied in both wild and captive populations, with consistent evidence of strong, prolonged mother–calf bonds (Hill, 2009; Hill et al., 2013; O'Corry-Crowe, 2009). Calves remain closely associated with their mothers for approximately two to three years following birth, during which they receive continuous care and support. A central feature of this relationship is frequent physical contact and coordinated swimming between mother and calf, which has been measured through direct observation and video recording, recording frequency, duration, and body positioning (Duda et al., 2024; Hill et al., 2018). Two commonly observed contact-based swimming positions are the echelon and infant position.

In the echelon position, the calf swims slightly above and alongside the mother's dorsal ridge, allowing it to remain within a hydrodynamic slipstream generated by the mother's movement (Figure 2). This positioning reduces locomotor effort by allowing calves to exploit hydrodynamic drafting, thereby decreasing energetic costs while maintaining proximity to the mother (Fish et al., 2013; Hill et al., 2018). Calves may also partially rest their body weight against the mother, a behavior known as "piggyback," further reducing physical strain and conserving energy (Hill et al., 2018).

In the infant position, the calf is positioned directly beneath the mother's body near the mammary region, with the calf's melon in close contact with the mother's genital area as shown in Figure 2. This position facilitates nursing but also appears to

function as a protective behavior. By tucking the calf beneath her body, the mother reduces the calf's visibility to potential predators and maintains close physical contact (Hill, 2009; Hill et al., 2013). Similar to huddling behaviors observed in other mammals, this close-contact positioning likely supports safety and bonding (Ahern & Young, 2009).

In managed care settings, beluga mother–calf pairs exhibit strong and structured social bonds characterized by sustained proximity and coordinated behavior. Calves spend extended periods close to their mothers during their first year of life, with much of their activity involving synchronized, side-by-side swimming and maintaining close physical proximity, a pattern that closely resembles observations of wild beluga mother–calf pairs in the White Sea (Hill et al., 2013; 2015; Krasnova et al., 2009; 2014). In addition to these coordinated behaviors, calves initiate many interactions independently, suggesting that the bond is not maintained solely by the mother but involves active participation from the calf. Furthermore, beluga mother–calf pairs display lateralized swimming preferences, with calves spending more time on their mother's right side, indicating a consistent spatial pattern in their interactions that has also been documented in free-ranging beluga populations in the White Sea and Sea of Okhotsk (Hill et al., 2017; Madsen & de Silva, 2024; Karenina et al., 2010; 2013). Together, these findings demonstrate that beluga mother–calf relationships are dynamic and involve both close physical association and patterned, reciprocal interactions across both managed-care and wild populations.

In captive and wild populations, belugas also engage in affiliative interactions with peers that emerge early in development and increase in complexity over time,

suggesting that social relationships extend beyond the mother–calf bond and may provide opportunities for the development of broader social skills (Krasnova et al., 2009, 2014; Ham et al., 2022; Hill et al., 2015).These observations of young beluga calves show repeated mouth-to-mouth interactions among similarly aged individuals, emerging early without adult modeling. These patterns indicate that peer contact may play a role in social and physical development (Ham et al., 2022; Hill et al., 2015). Additionally, belugas frequently associate with both related and unrelated individuals, forming multi-scale social networks and complex societies with long-lasting affiliations (O'Corry-Crowe, 2009; O'Corry-Crowe et al., 2020; Madsen & de Silva, 2024).

Beluga calves develop socio-sexual behaviors that contribute to social bonding and the development of mating repertoires. In managed care, immature individuals have been observed engaging in behaviors such as S-postures and pelvic thrusts (Ham et al., 2022). These behaviors, observed in both males and females, are thought to function as early forms of social and sexual practice, helping individuals develop coordination, social awareness, and appropriate interaction patterns with conspecifics (Hill et al., 2015; 2024). The gradual emergence of these behaviors highlights the importance of early social environments in shaping species-typical social and reproductive repertoires (Ham et al., 2022; Hill et al., 2015; 2024).

In addition to general proximity and coordinated swimming, belugas engage in discrete forms of physical contact, such as pectoral-fin contact, which requires precise motor coordination and intentional social engagement. This behavior is systematically measured by recording frequency, duration, and social

context, allowing researchers to distinguish intentional affiliative touch from incidental body contact (Duda et al., 2024; Hill et al., 2018). Although the social functions of pectoral-fin contact have been studied more extensively in bottlenose dolphins, where it has been associated with affiliation, social bonding, and relationship maintenance (Dudzinski et al., 2009), comparatively little is known about its developmental role in beluga whales. Given that belugas also engage in pectoral-fin contact, it is possible that repeated interactions during early development similarly provide opportunities to practice social coordination, receive reassurance, and strengthen affiliative bonds. Consequently, variation in early pectoral-fin contact may predict later social competence beyond general proximity alone, a possibility that has yet to be examined in belugas.

**Current Study**

The present study investigated contact initiation between beluga mothers and offspring during the first two years of life and examined how these interactions may predict the frequency (duration) of offspring social behaviors in their third year. In this study, social behaviors were defined as interactions between conspecifics and the mother, whereas non-social behaviors included solitary activities without conspecific involvement, such as independent swimming and object play. Duration of contact and social behavior were used as an indicator of engagement, with longer durations reflecting more sustained engagement and potentially stronger social bonds.

The first two years of life represent a critical developmental period in beluga whales, during which calves remain highly dependent on maternal interaction and social

learning opportunities. As a result, examining contact patterns during this period provides a meaningful basis for predicting social behavior in the third year of life.

Previous research has shown that beluga calves engage in prolonged and reciprocal interactions with their mothers throughout early development, including coordinated swimming, sustained proximity, and calf-initiated pectoral-fin contact (Duda et al., 2024; Hill et al., 2013, 2015, 2018). Although these behaviors have been well documented, it remains unclear whether variation in the amount and consistency of these interactions is associated with later social behavior. The present study therefore examined whether calf-initiated general contact and pectoral-fin contact during the first two years of life predict social behavior during the third year. Because attachment research in humans demonstrates that consistent caregiver interactions are associated with secure attachment, whereas inconsistent caregiving is associated with insecure attachment (Ainsworth et al., 1978; Main & Solomon, 1986), consistency in mother–calf contact was also examined. Although attachment cannot be directly assessed in belugas, repeated and consistent contact may reflect stable mother–calf relationships that support healthy social development. By examining both the duration and consistency of calf-initiated contact, this study explores whether these early interactions are associated with subsequent social engagement in beluga whales.

The purpose of this study is to expand the understanding of how early contact between beluga mothers and offspring might predict later social behavior in beluga whales. Belugas are highly social animals, engaging in frequent interactions

with both caregivers and conspecifics throughout development. Because social bonds play a central role in beluga society, examining early contact patterns offers an important opportunity to identify developmental factors that are associated with later social competence. Beluga whales are well-suited for investigating maternal behaviors and their long-term associations with social relationships due to their complex social structures and prolonged periods of parental care. Conducting this research in a managed-care setting provides additional advantages, including the ability to observe individuals at a close range, collect detailed longitudinal data, and maintain consistent identification of mothers and offspring across years. Findings from this study may also inform best practices in human care facilities for animal welfare by identifying social conditions that support healthy behavioral development and promote environments that reflect natural social systems.

**Hypotheses**

1. Calves with greater overall mother–offspring contact during the first two years of life will exhibit higher levels of social behavior (both toward the mother and toward conspecifics).

2. Calves with higher levels of early pectoral-fin contact will exhibit greater social behavior (both toward the mother and toward conspecifics) in the third year.

3. These effects will be moderated by the consistency of contact such that higher frequencies of contact in the first two years will predict more social behavior in

the third year only when contact is highly consistent (i.e., less variable, as measured with standard deviations across all observations).

4. Contact in the first two years will not predict the frequency of non-social behaviors in the third year.

# CHAPTER TWO

# METHOD

## Data Set

Videos for analysis were selected with permission from SeaWorld, San Antonio, from archived video records dated from 2007 to 2025. Video data were organized by year and month. For each month, all available video files were first identified, and a random number generator was then used to select a subset of four videos for analysis (e.g., January, 2010). This process was repeated for each month to ensure that video selection was unbiased and representative across the full observation period.

## Subjects

Subjects were 17 beluga whales and one Pacific white-sided dolphin (*Lagenorhynchus obliquidens*) that served as a foster mother to one orphaned beluga calf. The sample included six mothers: LN, CR, MR, SI, TI, and BT, and 11 of their offspring: AT, SM, KE, TU, BL, ST, IN, GR, QI, OL, and TY. Details on the mother–calf dyads are shown in Table 1.

The belugas were cared for at SeaWorld San Antonio (SWSA), where they had access to seven pools (Figure 1) that collectively contained 20 million gallons of water, reaching a maximum depth of 25 feet. SWSA is in San Antonio, Texas, and is part of the SeaWorld corporation. Social groups were changed daily by trainers. Belugas were not restricted by sex or age and were often grouped in mixed-sex and mixed-age arrangements. Grouping restrictions occurred in certain cases, such as when a new calf was born. Once the calf appeared to be developing normally, trainers gradually

introduced it to other members of social groups. Groupings sometimes consisted of all belugas across multiple pools, allowing movement between three to four pools. At other times, belugas were separated into smaller groups of four to five individuals with access to one or two pools. During specific periods, such as mating season, staff adjusted social groupings by placing mature males and females together. Additionally, if a group included a pregnant female, her social grouping was adjusted accordingly (e.g., housing her with other pregnant females or with females that exhibited alloparenting behaviors).

## Materials

An external hard drive (My Passport 4T) was used to store videos. For each mother-offspring pair, four videos were randomly selected from each month between birth and three years of life, resulting in 1,327 videos. Each video consisted of 15–20 minutes of observations of a social grouping recorded at randomly selected times throughout the week. Videos were recorded from multiple vantage points, including above the habitat, along the sides, and through the glass of the primary habitat. During recording, narrators identified subjects and verbally logged behaviors and behavioral sequences.

## Procedure

**Behavior Coding.** Videos were coded using Behavioral Observation Research Interactive Software (BORIS; Friard & Gamba, 2016). All behaviors were coded using an all-occurrence sampling method, with durations recorded continuously in seconds. Coders viewed videos with audio enabled to allow for accurate identification of individual whales based on the narrator's descriptions.

Prior to coding, all coders underwent training to ensure accurate identification of individual whales and reliable behavioral coding. Training included reviewing video materials and participating in in-person sessions with the primary researcher, during which coders practiced coding behaviors and identifying individuals. Coders were required to achieve at least 80% agreement with the primary researcher on practice videos before independently coding study data.

During the first two years of a calf's life, coders recorded all instances of physical contact between mother–calf pairs. Contact was defined as any direct bodily contact between the mother and calf, including but not limited to body contact and pectoral-fin contact (Table 2). To minimize the inclusion of incidental or accidental contact, only interactions lasting longer than three seconds were coded. For each contact event, coders recorded both the duration and the initiator (mother or calf). Pectoral-fin contact initiated by the calf toward the mother was additionally coded as a specific subtype of contact behavior (Table 2), allowing for separate analysis while still contributing to overall contact measures.

During the third year, coding expanded to include all calf behaviors outlined in the ethogram (Table 2), including those directed toward conspecifics. Behaviors were categorized as social or non-social, with social behaviors defined as those involving direct interaction with another individual, such as physical contact, coordinated swimming, or other affiliative behaviors (Table 3).

**Data Analysis.** All statistical analyses were conducted using SPSS v 31.0.0.0. Prior to analysis, descriptive statistics (means and standard deviations) were computed for all variables. To reduce multicollinearity and facilitate interpretation of interaction effects, continuous predictor variables were mean-centered prior to analysis.

Two primary predictors were examined: (1) contact and (2) pectoral fin contact behavior. To capture variability in responses across observation sessions, the standard deviation for each was also included as a moderator of social behavior with lower SDs indicating greater consistency in contact. Consistent with prior predictions, it was expected that calves with higher levels of early contact would exhibit greater social behavior (toward both the mother and conspecifics) in the third year, and that higher levels of early pectoral-fin contact would similarly predict greater social behavior toward both mothers and conspecifics. In addition, it was predicted that the consistency of these behaviors would moderate these associations, such that calves experiencing consistently high levels of contact would show stronger social engagement than those experiencing high but variable levels. Contact was not hypothesized to predict later non-social behaviors. For each predictor, mean-centered values and mean-centered standard deviation values were computed. Interaction terms were then created by multiplying the corresponding mean-centered variables (i.e., contact mean-centered × contact SD-centered; pectoral fin contact mean-centered × pectoral fin SD-centered).

To examine simple associations among variables, Pearson bivariate correlation analyses were conducted across all predictor and outcome variables, including contact

measures, pectoral fin contact measures, and behavioral outcomes (non-social behavior, social behavior toward mother, and social behavior toward conspecifics).

To test the study hypotheses, a series of hierarchical multiple regression analyses were conducted. Separate regression models were run for each of the three dependent variables: social behavior toward mother, social behavior toward conspecifics, and non-social behavior. For each dependent variable, two regression models were tested: one for overall contact and one for pectoral fin contact in particular. In each model, mean-centered predictor variables were entered in Step 1 to assess main effects. Interaction terms were entered in Step 2 to determine whether they explained additional variance in the dependent variables beyond the main effects. Changes in $R^2$ were examined to evaluate the contribution of interaction effects.

# CHAPTER THREE

# RESULTS

## Descriptive Statistics

Across the 11 juvenile whales sampled, non-social behaviors occurred more frequently than social behaviors overall (Table 4). Detailed frequencies of individual behaviors, including the duration of each behavior observed across Year 3, are presented in Tables 5–6.

Although non-social behaviors were generally more frequent at the group level, substantial individual variation was observed. Non-social behavior frequencies varied considerably among individuals, with social behavior frequencies showing a similarly broad range (Table 3). Two individuals demonstrated notably distinct behavioral patterns: AT exhibited the lowest frequency of social behavior among sampled whales, whereas TU exhibited substantially higher social behavior than all other individuals. In contrast, most individuals displayed higher frequencies of non-social than social behaviors, with variation in the relative distribution of behaviors across individuals.

Overall, these descriptive findings indicate considerable individual variability in Year 3 behavioral patterns despite the general predominance of non-social behaviors across the sample.

## Bivariate Correlations

Pearson bivariate correlations were conducted to examine associations among contact measures, pectoral fin contact measures, and behavioral outcomes. Results indicated several significant relationships among predictor variables (Table 7). Contact average and contact standard deviation were highly positively correlated, $r = .998$, $p < .001$, as were pectoral fin contact average and pectoral fin standard deviation, $r = .923$, $p < .001$. Positive correlations were also observed between contact and pectoral fin contact measures (e.g., contact average with pectoral fin standard deviation, $r = .672$, $p = .024$).

With respect to behavioral outcomes, pectoral fin contact measures, including pectoral fin average ($r = .830$, $p = .002$) and pectoral fin standard deviation ($r = .705$, $p = .015$) were positively associated with social behavior toward the mother. No correlations were observed between any contact or pectoral fin contact variables and non-social behavior (all $ps > .45$). Additionally, social behavior toward conspecifics was not associated with any predictor variables (all $ps > .30$).

## Regression Analyses

A series of hierarchical multiple regression analyses were conducted to examine whether contact and pectoral fin contact measures predicted behavioral outcomes. For each dependent variable, mean-centered predictor variables were entered in Step 1, followed by the interaction term in Step 2 (Tables 8 and 9).

## Contact

**Social Behavior Toward Mother.** The model predicting social behavior toward the mother from overall contact was not significant, $F(2, 8) = 2.91$, $p = .112$. The

interaction term did not improve the model, $\Delta R^2 = .004$, $\Delta F(1, 7) = 0.05$, $p = .824$. No individual predictors were significant (all *ps* > .24).

**Social Behavior Toward Conspecifics.** The regression model predicting social behavior toward conspecifics from contact was not significant, $F(2, 8) = 0.11$, $p = .901$. The addition of the interaction term did not improve model fit, $\Delta R^2 = .041$, $\Delta F(1, 7) = 0.31$, $p = .595$. No predictors were significant (all *p-s* > .70).

**Non-Social Behavior.** The model predicting non-social behavior from overall contact was not significant, $F(2, 8) = 0.55$, $p = .599$. The addition of the interaction term did not improve the model, $\Delta R^2 = .03$, $\Delta F(1, 7) = 0.25$, $p = .636$. Neither contact average nor contact variability nor their interaction were predictors (all *ps* > .44).

**Pectoral Fin Contact**

**Social Behavior Toward Mother.** The pectoral fin contact model predicted social behavior toward the mother, $F(2, 8) = 10.03$, $p = .007$, accounting for 71.5% of the variance. Average pectoral fin contact was a positive predictor of social behavior toward the mother, $B = 1547.35$, 95% CI [106.88, 2987.83], $\beta = 1.22$, $t = 2.48$, $p = .038$. The standard deviation of pectoral fin contact was not a significant predictor, $B = -334.457$, 95% CI [-1240.21, 571.30], $\beta = -0.85$, $t = -0.28$, $p = .792$. The interaction term did not improve model fit, $\Delta R^2 = .001$, $\Delta F(1, 7) = 0.01$, $p = .912$.

**Social Behavior Toward Conspecifics.** The model predicting social behavior toward conspecifics from pectoral fin contact was not significant, $F(2, 8) = 0.33$, $p =$

.726. The interaction term did not improve model fit, $\Delta R^2 = .122$, $\Delta F(1, 7) = 1.07$, $p = .336$. No predictors were significant (all *ps*> .36).

**Non-Social Behavior.** The pectoral fin contact model predicting non-social behavior was not significant, $F(2, 8) = 0.15$, $p = .860$. The interaction term did not improve the model, $\Delta R^2 < .001$, $\Delta F(1, 7) = 0.001$, $p = .978$. No predictors were significant (all *ps* > .86).

# CHAPTER FOUR

## DISCUSSION

The present study examined whether early mother–calf contact predicts later social behavior in beluga whales. Originally, the study included mother-initiated contact as an additional predictor; however, because mother-initiated contact occurred at very low frequencies, it was necessary to combine mother- and calf-initiated contact into a single overall contact measure. Hypothesis 1 predicted that greater overall mother–offspring contact during the first two years of life would be associated with higher levels of social behavior toward both the mother and conspecifics in the third year. This hypothesis was not supported. Contrary to expectations, overall contact between mothers and calves during the first two years of life did not predict social behavior directed toward either the mother or conspecifics in the third year. These findings suggest that the quantity of mother–calf contact alone may not be sufficient to explain later social development. However, pectoral-fin contact emerged as a predictor of social behavior directed toward the mother, suggesting that not all forms of contact are equally predictive of developmental outcomes.

The lack of significant findings for overall contact contrasts with prior research suggesting that early tactile interactions are critical for social and emotional development across species (Ahern & Young, 2009; Suomi, 1997). One possible explanation is that overall contact, as measured in this study, may be too broad to capture meaningful variation in social bonding. Because contact behaviors such as proximity, coordinated

swimming, and incidental touch are essential in beluga mother–calf interactions, particularly in the first two years of life, they may not differentiate between stronger and weaker social relationships later on. Rather than reflecting differences in relationship quality, overall contact may instead represent a normative component of early development that is expressed consistently across mother–calf pairs. In this context, the high frequency of contact across individuals may have reduced variability, limiting its predictive power.

An additional consideration is that the present analyses did not differentiate between calf-initiated and mother-initiated contact. This distinction may be theoretically important, as these behaviors may reflect different motivational and social processes. Calf-initiated contact may reflect dependency, exploration, and general affiliative behavior, whereas mother-initiated contact may better index selective social investment and reinforcement of the mother–calf bond. Notably, mother-initiated contact occurred at extremely low frequencies in the present dataset, which limited its suitability for independent statistical analysis and required its inclusion within the overall contact measure.

However, the low frequency of mother-initiated contact may itself be theoretically meaningful. Rather than reflecting a stable or continuous behavioral pattern, mother-initiated contact may represent a low-frequency but high-salience behavior that occurs in response to specific contextual conditions or calf-initiated signals. In this sense, even infrequent maternal contact events may carry disproportionate functional significance in reinforcing the mother–calf bond, rather than being expressed regularly across time. This

is consistent with the highly asymmetrical nature of early mother–calf interactions in cetaceans. Future research should therefore examine whether mother-initiated contact is reactive in nature, potentially occurring in response to specific calf behaviors or environmental contexts, rather than representing a stable behavioral tendency.

Whereas Hypothesis 1 focused on the overall quantity of mother–calf contact, Hypothesis 2 examined whether a more specific form of tactile interaction—pectoral-fin contact—would better predict later social behavior. Hypothesis 2 predicted that calves receiving higher levels of early pectoral-fin contact would exhibit greater social behavior toward both the mother and conspecifics in the third year. This hypothesis was partially supported. Specifically, pectoral-fin contact predicted later social behavior directed toward the mother but did not predict social behavior toward conspecifics. These findings suggest that not all forms of maternal contact contribute equally to social development and that specific tactile interactions may play a more meaningful role in strengthening the mother–calf relationship.

Pectoral-fin contact may represent a more intentional and socially meaningful form of interaction. Unlike general proximity or coordinated movement, pectoral-fin contact requires active engagement and precise motor coordination. In belugas, this behavior has been systematically measured to distinguish intentional affiliative touch from incidental body contact (Hill et al., 2018), while related work in other odontocetes highlights the role of tactile interactions in social communication and bonding (Duda et al., 2024; Dudzinski et al., 2009). The finding that pectoral-fin contact predicts later social behavior toward the mother is therefore consistent with previous research

demonstrating that specific tactile behaviors can reinforce affiliative bonds and facilitate social coordination across cetacean species. This distinction highlights the importance of examining discrete, functionally meaningful behaviors rather than broad behavioral categories when assessing developmental outcomes.

Interestingly, neither general contact nor pectoral-fin contact predicted social behavior toward conspecifics. This finding suggests that early mother–calf interactions may primarily influence dyadic relationships rather than broader social competence. Although tactile interactions may strengthen the bond between mothers and calves, they may not generalize to relationships with unrelated group members. Given that beluga whales live in complex, fission–fusion societies (Hauser et al., 2014; Madsen & de Silva, 2024; O'Corry-Crowe et al., 2020), it is possible that peer interactions and broader social experiences play a more substantial role in shaping social behavior toward conspecifics. This interpretation is consistent with observations of early peer contact and affiliative interactions among calves, which may contribute independently to social development (Ham et al., 2022).

Hypothesis 3 proposed that the consistency of early mother–calf contact would moderate the relationship between contact and later social behavior, such that more consistent contact would strengthen these associations. This hypothesis was not supported. Variation in contact frequency did not significantly moderate any of the relationships examined, indicating that neither the quantity nor the consistency of early contact predicted later behavioral outcomes.

One possible explanation is that the developmental processes underlying social behavior are influenced by multiple interacting factors that extend beyond the frequency or regularity of maternal contact. Although consistent maternal interactions may still be biologically important, their effects may be difficult to detect when considered independently of other developmental influences, such as calf temperament, peer interactions, or environmental experiences. Additionally, the relatively small sample size and strong correlations between average contact and variability may have reduced statistical power and limited the ability to detect moderation effects.

Hypothesis 4 predicted that overall mother–offspring contact during the first two years of life would not predict non-social behavior in the third year. This hypothesis was supported, as neither the correlational nor regression analyses identified a significant relationship between early contact and later non-social behavior. These findings suggest that the quantity of maternal contact received early in life may have little influence on the development of independent or non-social behaviors. Instead, non-social behavior may be shaped by other developmental factors, including individual temperament, peer interactions, or aspects of maternal care not captured by overall contact frequency.

Although early contact did not predict non-social behavior at the group level, descriptive analyses revealed substantial individual variation in behavioral outcomes. In particular, two individuals (AT and TU) represented extreme but contrasting behavioral profiles. AT exhibited exceptionally low levels of social behavior paired with relatively high non-social activity, whereas TU showed markedly elevated social behavior compared to all other individuals in the sample. Notably, these individuals share the same

mother (LN), yet displayed markedly different developmental outcomes. This finding suggests that maternal identity alone cannot account for the observed variation in later social behavior. Although genetic differences between siblings may contribute to these contrasting outcomes, the contrast between AT and TU suggests that inherited maternal identity alone is insufficient to explain later behavioral development. Instead, this pattern raises the possibility that maternal influences operate at the level of the individual mother–calf relationship rather than through a uniform maternal effect. In other words, mothers may respond differently to individual calves, individual calves may differ in how they perceive or respond to maternal care, or both processes may occur simultaneously. Thus, even offspring raised by the same mother may follow markedly different developmental trajectories despite sharing a maternal lineage.

This interpretation aligns with broader developmental theory, which emphasizes that social behavior emerges through dynamic interactions between inherited characteristics and environmental experiences rather than either factor operating independently. Rather than viewing genetics and maternal care as competing explanations, it is more likely that calf temperament, maternal behavior, and the reciprocal interactions between them jointly shape developmental outcomes. Consequently, future studies examining maternal care should consider not only how much contact occurs, but also whether mothers differentially invest in individual offspring and whether calves differ in their responsiveness to similar maternal behaviors.

Although these findings provide valuable insight into the role of early mother–calf contact, several limitations should be considered when interpreting the results. First,

the sample size was relatively small, which limited statistical power and the ability to detect effects. Second, the high correlations between average levels and variability in levels of contact over time suggest potential multicollinearity, which may have influenced the regression analyses. Of note, the regression models accounted for a substantial proportion of variance in outcomes despite not reaching statistical significance, suggesting that the analyses may have been underpowered.

Another limitation is that the study was conducted in a managed-care setting. Whereas this environment allows for detailed longitudinal observation, it may also constrain variability in social experiences. However, previous research has demonstrated that belugas in managed-care settings exhibit a wide range of species-typical behaviors, including complex mother–calf interactions and affiliative social behaviors consistent across both captive and wild populations (Hill et al., 2009; 2013; 2015; Krasnova et al., 2009). Thus, whereas environmental conditions may influence the frequency or expression of certain behaviors, managed-care populations still provide a valid and informative context for examining mother–calf social development.

Future research should expand on these findings by examining additional forms of contact and social interaction, particularly those occurring between peers. Longitudinal studies in both managed-care and wild populations would provide valuable insight into how early experiences shape long-term social outcomes. Examining how contact in the third year predicts even later bonds may also be informative, as mother–offspring interactions may become more variable later in development. Furthermore, incorporating

measures of relationship quality, such as reciprocity or consistency of interaction, may help clarify the mechanisms underlying social development.

It is also important to interpret these findings within a broader biopsychosocial framework in which early social behavior may reflect both environmental and biological influences. Although early mother–calf contact is commonly interpreted as a driver of later social development, an alternative explanation is that individual differences in both maternal caregiving behavior and calf social responsiveness may be partially shaped by shared genetic factors influencing temperament, sociability, and affiliative tendencies. From this perspective, what appears to be an effect of early tactile interaction may also reflect inherited predispositions that co-structure both the frequency of maternal engagement and the calf's later social behavior. This interpretation is consistent with gene–environment correlation models, which emphasize that behavioral similarities within dyads may arise from genetic relatedness in addition to direct experiential effects. Accordingly, while the present findings highlight associations between specific forms of mother–calf contact and later social outcomes, causal interpretations should be made cautiously, as disentangling the relative contributions of inherited traits and early social experience remains methodologically challenging.

Overall, this study contributes to understanding how early social experiences shape developmental trajectories in a highly social cetacean species. The findings indicate that early tactile interactions, particularly pectoral-fin contact, are associated with later social behavior within the mother–calf relationship but do not appear to generalize to broader conspecific interactions. These results suggest that early maternal

contact may function primarily to establish and maintain relationship-specific bonds rather than broadly enhance social behavior. By identifying a specific form of tactile interaction associated with later maternal affiliation, this study extends previous work emphasizing the importance of proximity and coordinated behavior in cetacean development. These findings provide insight into the mechanisms underlying social development and highlight the importance of supporting meaningful mother–offspring interactions in managed-care settings.

## References


Ahern, T. H., & Young, L. J. (2009). The impact of early life family structure on adult social attachment, alloparental behavior, and the neuropeptide systems regulating affiliative behaviors in the monogamous prairie vole (*Microtus ochrogaster*). *Frontiers in Behavioral Neuroscience*, *3*, 748. https://doi.org/10.3389/neuro.08.017.2009

Ainsworth, M. D. S., & Bell, S. M. (1970). Attachment, exploration, and separation: Illustrated by the behavior of one-year-olds in a strange situation. *Child Development, 41*(1), 49–67. https://doi.org/10.2307/1127388

Ainsworth, M. D. S., Blehar, M. C., Waters, E., & Wall, S. (1978). Patterns of attachment: A psychological study of the strange situation. Erlbaum.

Berman, C. M. (1990). Consistency in maternal behavior within families of free-ranging rhesus monkeys: An extension of the concept of maternal style. *American Journal of Primatology*, *22*(3), 159–169. https://doi.org/10.1002/ajp.1350220303

Bowlby, J. (1969). *Attachment and loss: Vol. 1. Attachment*. Basic Books.

Broad, K. D., Curley, J. P., & Keverne, E. B. (2006). Mother–infant bonding and the evolution of mammalian social relationships. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *361*(1476), 2199–2214. https://doi.org/10.1098/rstb.2006.1940

Clutton-Brock, T. H., Russell, A. F., Sharpe, L. L., Brotherton, P. N. M., McIlrath, G. M., White, S., & Cameron, E. Z. (2001). Effects of helpers on juvenile

development and survival in meerkats. *Science*, *293*(5539), 2446–2449. https://doi.org/10.1126/science.1061274

Decarli, A., Pierrehumbert, B., Schulz, A., Schaan, V. K., & Vögele, C. (2022). Disorganized attachment in adolescence: Emotional and physiological dysregulation during the Friends and Family Interview and a conflict interaction. *Development and Psychopathology*, *34*(1), 431–445. https://doi.org/10.1017/S0954579420001352

Dettling, A. C., Feldon, J., & Pryce, C. R. (2002). Repeated parental deprivation in the infant common marmoset (*Callithrix jacchus*, primates) and analysis of its effects on early development. *Biological Psychiatry*, *52*(11), 1037–1046. https://doi.org/10.1016/S0006-3223(02)01460-9

Ding, R., & He, P. (2022). Parenting styles and health in mid-and late life: Evidence from the China health and retirement longitudinal study. *BMC Geriatrics*, *22*(1), 463. https://doi.org/10.1186/s12877-022-03157-6

Duda, S. M., Themelin, M., Hirons, A. C., & Dudzinski, K. M. (2024). Contact exchanges in bottlenose dolphin mother-calf pairs. *Aquatic Mammals*, *50*(1). https://doi.org/10.1578/AM.50.1.2024.19

Dudzinski, K. M., Thomas, J. A., & Gregg, J. D. (2009). Communication in marine mammals. In *Encyclopedia of Marine Mammals* (pp. 260–269). Academic Press. https://doi.org/10.1016/B978-0-12-373553-9.00064-X

Dudzinski, K. M., & Ribic, C. A. Manitzas Hill, HM & Bolton, TT (2021). Evidence for maternal style among adult female dolphins when sharing pectoral fin contacts

with their calves. *Animal Behavior Cognition*, *8*, 52–68. https://doi.org/10.26451/abc.08.01.05.2021

Erkoreka, L., Zumarraga, M., Arrue, A., Zamalloa, M. I., Arnaiz, A., Olivas, O., ... & Basterreche, N. (2021). Genetics of adult attachment: An updated review of the literature. World Journal of Psychiatry, 11(9), 530. https://doi.org/10.5498/wjp.v11.i9.530

Fish, E., Goetz, K. T., Rugh, D. J., & Brattström, L. V. (2013). Hydrodynamic patterns associated with echelon formation swimming by feeding bowhead whales (*Balaena mysticetus*). *Marine Mammal Science*, *29*(4). https://doi.org/10.1111/mms.12004

Francis, D., Diorio, J., Liu, D., & Meaney, M. J. (1999). Nongenomic transmission across generations of maternal behavior and stress responses in the rat. *Science*, *286*(5442), 1155–1158. https://doi.org/10.1126/science.286.5442.1155

Friard, O., & Gamba, M. (2016). BORIS: A free, versatile open-source event-logging software for video/audio coding and live observations. *Methods in Ecology and Evolution*, *7*(11), 1325–1330. https://doi.org/10.1111/2041-210X.12584

Green, J., & Goldwyn, R. (2002). Annotation: Attachment disorganisation and psychopathology: New findings in attachment research and their potential implications for developmental psychopathology in childhood. *Journal of Child Psychology and Psychiatry*, *43*(7), 835–846. https://doi.org/10.1111/1469-7610.00102

Ham, J. R., Lilley, M. K., Lelekach, J., Miller, M. R., Robeck, T. R., Pellis, S. M., & Hill, H. M. (2022). The emergence and early development of socio-sexual

behavior in beluga calves (Delphinapterus leucas). *Behavioural Processes*, *200*, 104695. https://doi.org/10.1016/j.beproc.2022.104695

Harlow, H. F. (1958). The nature of love. *American Psychologist*, *13*(12), 673. https://doi.org/10.1037/h0047884

Harris, J. R. (2009). The nurture assumption: Why children turn out the way they do, revised and updated. Simon and Schuster.

Hauser, D. D., Laidre, K. L., Suydam, R. S., & Richard, P. R. (2014). Population-specific home ranges and migration timing of Pacific Arctic beluga whales (Delphinapterus leucas). *Polar Biology*, *37*, 1171–1183. https://doi.org/10.1007/s00300-014-1510-1

Hertsgaard, L., Gunnar, M., Erickson, M. F., & Nachmias, M. (1995). Adrenocortical responses to the strange situation in infants with disorganized/disoriented attachment relationships. *Child Development*, *66*(4), 1100–1106. https://doi.org/10.1111/j.1467-8624.1995.tb00925.x

Hill, H. M. (2009). The behavioral development of two beluga calves during the first year of life. *International Journal of Comparative Psychology*, *22*(4). https://doi.org/10.46867/ijcp.2009.22.04.02

Hill, H. M., Campbell, C., Dalton, L., & Osborn, S. (2013). The first year of behavioral development and maternal care of beluga (*Delphinapterus leucas*) calves in human care. *Zoo Biology*, *32*(5), 565–570. https://doi.org/10.1002/zoo.21093

Hill, H. M., Dietrich, S., Yeater, D., McKinnon, M., Miller, M., Aibel, S., & Dove, A. (2015). Developing a catalog of socio-sexual behaviors of beluga whales

(*Delphinapterus leucas*) in the care of humans. *Animal Behavior and Cognition, 2*(2), 105–123. https://doi.org/10.12966/abc.05.01.2015

Hill, H. M., Guarino, S., Calvillo, A., Gonzalez III, A., Zuniga, K., Bellows, C., Polasek, L., & Sims, C. (2017). Lateralized swim positions are conserved across environments for beluga (*Delphinapterus leucas*) mother–calf pairs. *Behavioural Processes*, *138*, 22–28. https://doi.org/10.1016/j.beproc.2017.01.018

Hill, H.M., Dietrich, S., Jantea, R. F., Garza, S., & Lacy, K. (2018). The frequency of contact in beluga (*Delphinapterus leucas*) calf social interactions. *Aquatic Mammals*, *44*(1), 62–75. https://doi.org/10.1578/AM.44.1.2018.62

Hill, H. M., Lilley, M. K., Ham, J. R., & Robeck, T. (2024). A review of beluga (*Delphinapterus leucas*) sexual behavior and reproductive physiology leading to conception. *Theriogenology Wild*, 100071. https://doi.org/10.1016/j.therwi.2024.100071

Joas, J., & Möhler, E. (2021). Maternal bonding in early infancy predicts children's social competences in preschool age. *Frontiers in Psychiatry*, *12*, 687535. https://doi.org/10.3389/fpsyt.2021.687535

Johnson, E. O., Kamilaris, T. C., Calogero, A. E., Gold, P. W., & Chrousos, G. P. (1996). Effects of early parenting on growth and development in a small primate. *Pediatric Research*, *39*(6), 999–1005. https://doi.org/10.1203/00006450-199606000-00012

Kölliker, M., Royle, N. J., & Smiseth, P. T. (Eds.). (2012). *The Evolution of Parental Care* (Vol. 587). Oxford University Press. https://doi.org/10.1093/acprof:oso/9780199692576.001.0001

Karenina, K., Giljov, A., Baranov, V., Osipova, L., Krasnova, V., & Malashichev, Y. (2010). Visual laterality of calf–mother interactions in wild whales. *PloS one*, *5*(11), e13787. https://doi.org/10.1371/journal.pone.0013787

Karenina, K., Giljov, A., Glazov, D., & Malashichev, Y. (2013). Social laterality in wild beluga whale infants: comparisons between locations, escort conditions, and ages. *Behavioral Ecology and Sociobiology*, *67*(7), 1195-1204. https://doi.org/10.1007/s00265-013-1545-2

Krasnova, V. V., Bel'Kovich, V. M., & Chernetskii, A. D. (2009). Formation of behavior in the White Sea beluga calf, *Delphinapterus leucas*, during early postnatal ontogenesis. *Russian Journal of Marine Biology*, *35*, 53–59. https://doi.org/10.1134/S1063074009010088

Krasnova, V. V., Chernetsky, A. D., Zheludkova, A. I., & Bel'Kovich, V. M. (2014). Parental behavior of the beluga whale (Delphinapterus leucas) in natural environment. Biology Bulletin, 41(4), 349-356. https://doi.org/10.1134/S1062359014040062

Madsen, A., & de Silva, S. (2024). Societies with fission–fusion dynamics as complex adaptive systems: The importance of scale. *Philosophical Transactions B*, *379*(1909). https://doi.org/10.1098/rstb.2023.0175

Maestripieri, D. (2001). Is there mother–infant bonding in primates?. *Developmental Review*, *21*(1), 93–120. https://doi.org/10.1006/drev.2000.0522

Main, M., & Solomon, J. (1990). Procedures for identifying infants as disorganized/disoriented during the Ainsworth Strange Situation. Attachment in the preschool years: Theory, research, and intervention, 1, 121-160.

Main, M., & Solomon, J. (1986). Discovery of an insecure-disorganized/disoriented attachment pattern. In T. B. Brazelton & M. W. Yogman (Eds.), *Affective Development in Infancy* (pp. 95–124). Ablex Publishing.

Mann, J. (2019). Maternal care and offspring development in odontocetes. *Ethology and Behavioral Ecology of Odontocetes*, 95–116. https://doi.org/10.1007/978-3-030-16663-2_5

Meaney, M. J. (2001). Maternal care, gene expression, and the transmission of individual differences in stress reactivity across generations. *Annual Review of Neuroscience, 24*, 1161–1192. https://doi.org/10.1146/annurev.neuro.24.1.1161

Nielsen, M. L. K., Ellis, S., Weiss, M. N., Towers, J. R., Doniol-Valcroze, T., Franks, D. W., ... & Croft, D. P. (2023). Temporal dynamics of mother–offspring relationships in Bigg's killer whales: Opportunities for kin-directed help by post-reproductive females. *Proceedings of the Royal Society B: Biological Sciences*, *290*(2000). https://doi.org/10.1098/rspb.2023.0139

O'Corry-Crowe, G. M. (2009). Beluga whale: Delphinapterus leucas. In *Encyclopedia of Marine Mammals* (pp. 108-112). Academic Press. https://doi.org/10.1016/B978-0-12-373553-9.00030-4

O'Corry-Crowe, G., Suydam, R., Quakenbush, L., Smith, T. G., Lydersen, C., Kovacs, K. M., Orr, J., Harwood, L., Litovka, D., & Ferrer, T. (2020). Group structure and kinship in beluga whale societies. *Scientific Reports*, *10*(1), 11462. https://doi.org/10.1038/s41598-020-67314-w

Pavard, S., Koons, D. N., & Heyer, E. (2007). The influence of maternal care in shaping human survival and fertility. *Evolution*, *61*(12), 2801-2810. https://doi.org/10.1111/j.1558-5646.2007.00236.x

Phillips, R. (2013). The sacred hour: Uninterrupted skin-to-skin contact immediately after birth. *Newborn and Infant Nursing Reviews*, *13*(2), 67-72. https://doi.org/10.1053/j.nainr.2013.04.001

Radke, S. M. (2022). Common complications of breastfeeding and lactation: An overview for clinicians. *Clinical Obstetrics and Gynecology*, *65*(3), 524-537. https://doi.org/10.1097/GRF.0000000000000716

Righi, B. M., Aguillar, L., Marcondes, M. C., & Le Pendu, Y. (2025). The hug of a humpback whale mother: Protective behaviors of a calf toward escorts in a competitive group at Abrolhos Bank, Brazil. *Animals*, *15*(24), 3610. https://doi.org/10.3390/ani15243610

Smultea, M. A., Fertl, D., Bacon, C. E., Moore, M. R., James, V. R., & Würsig, B. (2017). Cetacean mother-calf behavior observed from a small aircraft off Southern California. *Animal Behavior and Cognition*, *4*(1), 1-23. https://doi.org/10.12966/abc.01.02.2017

Suomi, S. J. (1997). Early determinants of behaviour: Evidence from primate studies. *British Medical Bulletin*, *53*(1), 170–184. https://doi.org/10.1093/oxfordjournals.bmb.a011598

Topál, J., Miklósi, Á., Csányi, V., & Dóka, A. (1998). Attachment behavior in dogs (Canis familiaris): A new application of Ainsworth's (1969) Strange Situation

Test. *Journal of Comparative Psychology*, *112*(3), 219. https://doi.org/10.1037/0735-7036.112.3.219

Verschueren, K., & Marcoen, A. (1999). Representation of self and socioemotional competence in kindergartners: Differential and combined effects of attachment to mother and to father. *Child Development*, *70*(1), 183–201. https://doi.org/10.1111/1467-8624.00014

Vitale, K. R., Behnke, A. C., & Udell, M. A. (2019). Attachment bonds between domestic cats and humans. *Current Biology*, *29*(18), R864-R865. https://doi.org/10.1016/j.cub.2019.08.036

Wan, M. W., & Green, J. (2009). The impact of maternal psychopathology on child–mother attachment. *Archives of Women's Mental Health*, *12*, 123-134. https://doi.org/10.1007/s00737-009-0066-5

Waters, E., & Cummings, E. M. (2000). A secure base from which to explore close relationships. *Child Development*, *71*(1), 164–172. https://doi.org/10.1111/1467-8624.00130

Table 1: Mother and Calf Pairs

| Mother | Offspring |
|---|---|
| LN | AT<br>SM<br>KE<br>TU |
| CR | BL<br>ST<br>IN |
| MR | GR |
| SI | QI |
| TI | OL |
| BT* | TY |

***Note.*** * Indicates foster dolphin

Table 2: Beluga Behavior Ethogram

| Beluga Behaviors | Operational Definition |
|---|---|
| Echelon Swim | Calf swims parallel to the adult, positioned near the dorsal ridge region and slightly staggered, and maintains its relative position to adult for at least 3 seconds. There is often contact, with the calf touching the adult's flank. |
| Infant Swim | Calf swims directly below an adult, positioned near the mammary slits or genital slit. This swim is usually accompanied by bumping or nuzzling. |
| Follow Swim | Calf/adult swims directly behind the adult/calf, maintaining relative position for at least 3 seconds. The actions of the following animal are dictated by the lead animal. |
| Pair swim | Subject swims to the side of their conspecific, maintaining relative position for at least 3 seconds. |
| Orientation | Subject looks at environment, head turns, or eye turns to different area of its environment |
| Nursing | The calf takes a teat in its mouth, and holds on. There is a reduction of swimming movements by the mother and distinctive rapid short tail motions by the calf, maintaining relative position to the mother. |
| Herding | Adult maneuvers calf away from its current activity and directs the calf to a new activity, usually swimming together. This action usually involves contact initited by the adult. |
| Intervene | Adult will prevent the calf from entering an activity or association with another animal or will end a current activity or association. The adult will maneuver herself between the calf and the activity, which disrupts the calf's actions. It may result in a pair swim. |

| | |
|---|---|
| Solo Swim | Subject swims independently of other available animals. |
| Floating | Subject remains motionless in one location, usually at the surface, or drifts very slowly across the water for 3 or more seconds. |
| Rub | An extended form of contact in which one Subject rubs part of its body against conspecifics or elements of habitat. |
| Nuzzle | Contact in which subject slowly and gently brings its head into contact with another animal's body |
| Chase | The actor swims rapidly behind another subject, who subsequently swims away at a rapid pace with the actor following. The recipient of the action does not reciprocate a chase action. |
| Jaw Clap | The actor, while facing another subject, rapidly opens and then closes its mouth, producing a sharp sound which resembles a gunshot. |
| Head Jerk | The actor, while facing away from another subject, moves its head quickly in a lateral direction towards the threatening animal or recipient. |
| Hit | Contact in which the actor rapidly and forcefully strikes (with tail, side body or rostrum) the recipient's body |
| Bite | A particular type of contact in which the actor opens its mouth fully and closes its mouth on the recipient, often leaving indentations or marks |
| Vocalization | Any sound produced (e.g., whistles, clicks, squawks, and squeals. |
| Bumping | Calf swims under adult, repeatedly raising and lowering its head, contacting mammary region. |
| Presenting | An animal turns on its side and presents its ventral side to another animal. It may be reciprocal. Often accompanied by bubble streams from the blowhole. |

| | |
|---|---|
| S-Posture | Similar to posturing, the adult is manipulating its body to form an “S” shape. This behavior is towards another animal. At time an erection is present. |
| Bubble play | An animal blows bubbles and chases after them. Bubbles may be round or donut-shaped |
| Water Toss | An animal moves its head in an upward direction which displaces a mouthful of water. The animal may try to catch the water again as it returns to the surface. |
| Object Play | An animal manipulates objects using any part of their body |
| Pectoral Fin Contact | Animal engages in contact using pectoral fin |

Table 3: Year Three Behavior Sub-Categories

| Behavior Categories | Behaviors |
|---|---|
| Social | Pair Swim<br>Group Swim<br>Contact<br>Nuzzle<br>Socio-Sexual<br>Water toss*<br>Object Play* |
| Non-Social | Solo Swim<br>Floating<br>Rub Objects |

***Note***. * These behaviors can be non-social if engaged independently

Table 4: Behavioral Activity Summary (Social vs. Non-Social) in Year-3

| Whale ID | Social Behaviors | Non-Social Behaviors |
|---|---|---|
| BL | 2592.27 | 39997.33 |
| IN | 4928.29 | 15533.86 |
| ST | 4312.74 | 4051.94 |
| AT | 231.90 | 27823.90 |
| KN | 4659.17 | 37067.91 |
| SM | 5450.47 | 44591.79 |
| TU | 16584.23 | 22062.46 |
| GR | 6004.41 | 39617 |
| QI | 6054.58 | 6462.26 |
| OL | 2474.78 | 33337.15 |
| TY | 574.37 | 37099.55 |

***Note.*** Behaviors were documented in seconds

Table 5: Frequencies of Contact Initiation in Years 1 and 2

| ID | Year 1-2 | | |
|---|---|---|---|
| | MI Contact | CI Contact | Pec-Fin Contact |
| BL | 466 | 6785 | 209 |
| IN | 25 | 12026 | 285 |
| ST | 4 | 9055 | 37 |
| AT | 0 | 0 | 0 |
| KN | 20 | 14006 | 98 |
| SM | 21 | 5380 | 205 |
| TU | 354 | 12227 | 830 |
| GR | 49 | 9473 | 54 |
| QI | 26 | 7406 | 270 |
| OL | 18 | 4913 | 68 |
| TY | 0 | 0 | 0 |

***Note.*** All frequencies documented in seconds

Table 6: Frequency of Behaviors Observed in Year 3 Beluga Whale

| | BL | IN | ST | AT | KN | SM | TU | GR | QI | OL | TY |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Float Swim | 2092 | 0 | 0 | 11387 | 0 | 0 | 18 | 0 | 0 | 32 | 305 |
| Solo Swim | 29911 | 13859 | 3684 | 13963 | 32604 | 36405 | 20883 | 23149 | 4726 | 26060 | 33280 |
| PSC | 115 | 1866 | 932 | 55 | 1163 | 4765 | 2499 | 543 | 0 | 2171 | 3875 |
| PSM | 2157 | 1801 | 3380 | 35 | 2068 | 0 | 7730 | 1978 | 6054 | 0 | 509 |
| Group Swim | 0 | 0 | 0 | 0 | 0 | 0 | 365 | 0 | 0 | 247 | 354 |
| Infant Swim | 0 | 777 | 0 | 0 | 397 | 0 | 4751 | 3411 | 0 | 0 | 266 |
| Rubbing Objects | 5945 | 106 | 0 | 1679 | 2495 | 772 | 12 | 14799 | 0 | 6696 | 19 |
| Echelon | 72 | 0 | 0 | 0 | 0 | 0 | 53 | 0 | 0 | 0 | 0 |
| Beaching | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 137 | 0 |
| Contact C | 0 | 107 | 0 | 128 | 263 | 273 | 46 | 0 | 0 | 0 | 174 |
| Contact M | 0 | 0 | 0 | 0 | 0 | 0 | 174 | 0 | 0 | 0 | 57 |
| Socio Sexual | 0 | 200 | 0 | 0 | 320 | 411 | 210 | 70 | 0 | 55 | 234 |
| Water Play S | 456 | 92 | 0 | 203 | 791 | 2865 | 377 | 0 | 0 | 283 | 8 |
| Water Play C | 0 | 141 | 0 | 0 | 446 | 0 | 303 | 0 | 0 | 0 | 0 |
| Water Play M | 0 | 0 | 0 | 0 | 0 | 0 | 136 | 0 | 0 | 0 | 0 |
| Object Play S | 1591 | 1476 | 367 | 590 | 1176 | 4547 | 0 | 1667 | 1735 | 264 | 3486 |
| Object Play C | 0 | 33 | 0 | 11 | 0 | 0 | 311 | 0 | 0 | 0 | 127 |
| Object Play M | 247 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 140 |

***Note.*** All frequencies documented in seconds, C= Conspecific, M = Mom PSM = Pair swim mom, PSC = Pair swim conspecific

Table 7: Descriptive Statistics and Correlations for Study Variables

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| Contact Mean | — | | | | | | |
| Contact SD | .998** | — | | | | | |
| Pecfin Mean | .497 | .472 | — | | | | |
| Pecfin SD | .672 | .655* | .923** | — | | | |
| Non-Social | -.239 | -.253 | -.192 | -.182 | — | | |
| Social-Mom | .573 | .555 | .830** | .705* | -.367 | — | |
| Social-Conspecifics | -.089 | -.081 | .273 | .270 | .380 | -.059 | — |
| *M (sec)* | 2495.41 | 4238.14 | 2.25 | 5.90 | 27967.74 | 3291.12 | 2075.54 |
| *SD* | 1560.29 | 2670.95 | 2.97 | 4.73 | 14056.15 | 3779.47 | 1917.45 |

***Note.*** *p < .05, **p <.01.

Table 8: Hierarchical Regression Results for Contact

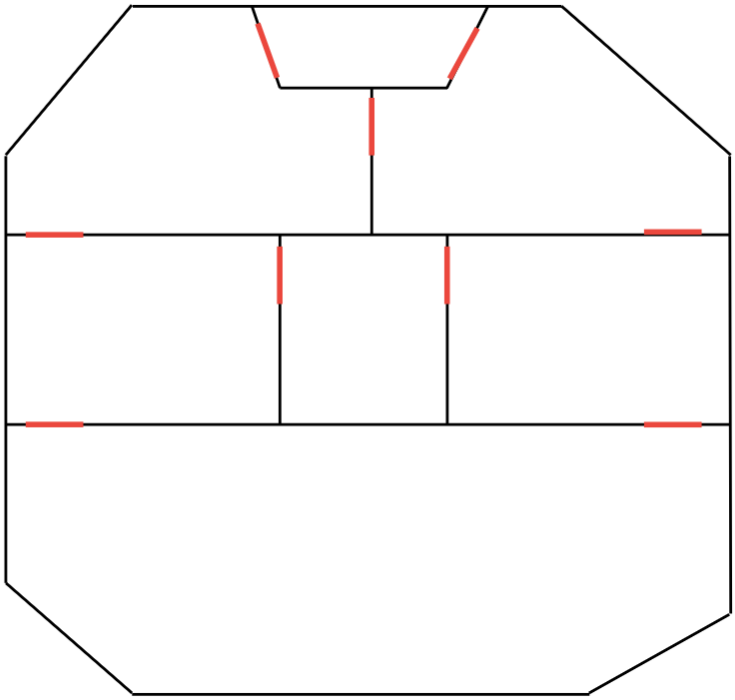
| Predictor Variables | Non-Social | | Social (Mother) | | Social (Conspecific) | |
|---|---|---|---|---|---|---|
| | $R^2$ | $\beta$ | $R^2$ | $\beta$ | $R^2$ | $\beta$ |
| Step 1 | .120 | | .421 | | .026 | |
| Contact- Mean | | 4.22 | | 5.98 | | -2.45 |
| Contact-SD | | -4.469 | | -5.418 | | 2.37 |
| Step 2 | .150 | | .425 | | .067 | |
| Contact- Mean | | 4.95 | | 6.26 | | -1.60 |
| Contact-SD | | -5.14 | | -5.68 | | 1.58 |
| Contact-Mean x SD | | .186 | | .072 | | .220 |

Table 9: Hierarchical Regression Results for Pectoral-Fin Contact

| Predictor Variables | Non-Social | | Social (Mother) | | Social (Conspecific) | |
|---|---|---|---|---|---|---|
| | $R^2$ | $\beta$ | $R^2$ | $\beta$ | $R^2$ | $\beta$ |
| Step 1 | .037 | | .715 | | .077 | |
| Pectoral-Fin - Mean | | -.163 | | **1.22*** | | .160 |
| Pectoral-Fin -SD | | -.032 | | -.42 | | .123 |
| Step 2 | .037 | | .715 | | .199 | |
| Pectoral-Fin - Mean | | -.077 | | 1.03 | | -2.64 |
| Pectoral-Fin -SD | | -.084 | | -.305 | | 1.82 |
| Pectoral-Fin - Mean x SD | | -.044 | | .095 | | 1.44 |

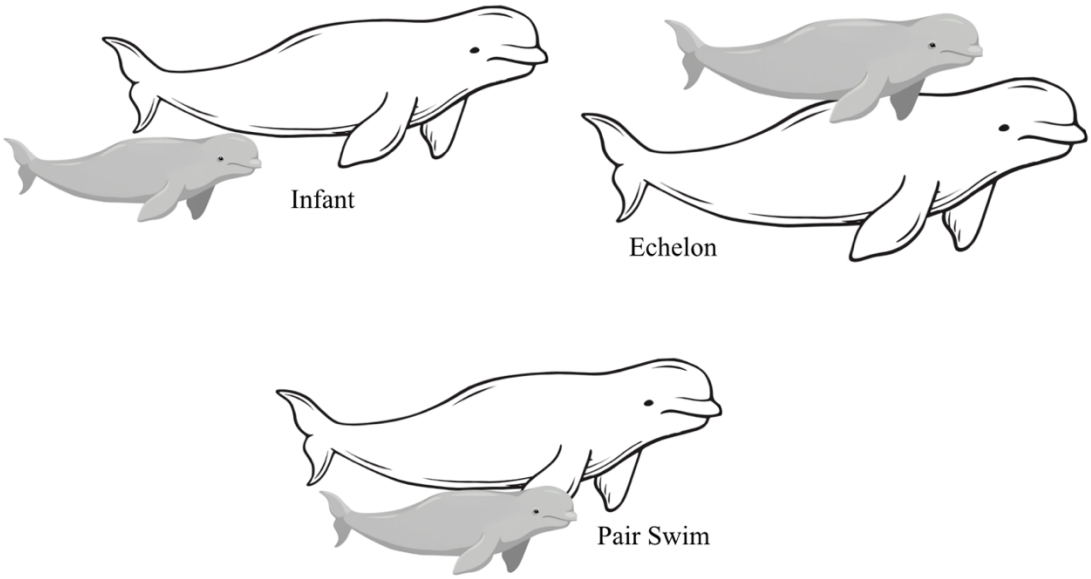
***Note.*** * $p < .05$

Figure 1: Map of pool habitats at SWSA



***Note.*** The red lines represent gates the belugas can pass through when open

Figure 2: Common Mother Calf Positions




***Note.*** Grey indicates calf