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Review article

Marine mammal cognition and captive care:
A proposal for cognitive enrichment in zoos and aquariums

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Abstract

Marine mammals, particularly cetaceans (whales, dolphins and porpoises) and pinnipeds (seals, sea lions and walruses) are popular in zoos and aquariums worldwide. Bottlenose dolphins and California sea lions have also been popular study species in animal cognition research since the 1950s, and many dolphin cognitive skills are on par with great apes. This paper proposes that 'cognitive challenges' can enhance the well-being of marine mammals, in line with previous studies on farm animals and great apes. While most captive marine mammals are trained and this challenges their social-cognitive skills to a moderate or high level, their physical-cognitive skills are not being challenged to a high level by floating 'toys' in the pool. This paper suggests that tasks originally developed to test the limits of dolphin and sea lion cognitive skill could be modified and implemented as 'cognitive enrichment' in zoos and aquariums. To be enriching, cognitive challenges should be relevant, motivating, controllable, and possible to master.

Introduction

Marine mammals are cetaceans (whales, dolphins and porpoises), pinnipeds (seals, sea lions and walruses), sirenians (manatees and dugongs), sea otters and polar bears (Rice 1998). Many thousands of marine mammals are housed in zoos and aquariums worldwide, the most popular being the bottlenose dolphin (*Tursiops truncatus*), and California sea lion (*Zalophus californianus*) (ISIS 2012). Hereafter, the bottlenose dolphin and California sea lion shall be referred to generically as dolphins and sea lions, and other species will be specifically stated.

To begin, this review explores the emerging branch of animal welfare science combining cognition and care, and suggests that 'cognitive challenges' can enhance animal well-being. Second, evidence that current marine mammal enrichment provides a low level of cognitive challenge will be discussed. Third, over half a century of cognitive research will be condensed, in order to summarise our current knowledge of marine mammal cognition. Finally, a new framework for marine mammal cognitive enrichment will be proposed, with suggestions on how this can be practically achieved in zoos and aquariums. The cognitive literature is expansive, and therefore we shall focus on studies of dolphins and sea lions which have taken place in the laboratory. More expansive reviews of marine mammal cognition can be found in Herman (2002a; 2010), Schusterman *et al.* (2002) and Jaakkola (2012).

A literature search was performed using Web of Science® citation database and Google Scholar. Boolean searches were performed for peer-reviewed papers, books, book chapters and conference proceedings using combinations of key terms such as 'marine mammal', 'cognition' and 'welfare'. The literature search spanned over four decades (1970 to present) owing to the long history of cognitive research on marine mammals.

Cognitive challenges for captive animals

Wild animals face many challenges that require the application of evolved cognitive skills (Meehan and Mench 2007). In contrast, captive animals tend to live in highly predictable and structured environments, and their cognitive skills may be challenged at a low or inappropriate level (Špinka and Wemelsfelder 2011). Fortunately, the provision of more cognitively challenging enrichment programmes for captive animals has increased over the last five years (Meehan and Mench 2007; Clark 2011). As Ross (2010 p.310) states, "Working to improve captive animal care without an understanding of how animal minds work, or the scope in which they perceive and interact with their social and physical environments, is akin to drawing a map without knowledge of any landmarks or bearings". In order to maximise well-being, animals should possess enough skill to master the challenge, and be motivated to do so (Meehan and Mench 2007). Clark (2011 p.6) incorporated these thoughts into the following definition of cognitive enrichment: "…a task (or tasks) whose use (1) engages evolved cognitive skills by providing opportunities to solve problems and control some aspect of the environment, and (2) is correlated to one or more validated measures of wellbeing".

Cognitive challenges have benefitted animal well-being on the farm, and more recently in the zoo. On the farm, Ernst *et al.* (2005) and Puppe *et al.* (2007) challenged pigs with a discrimination task several times a day in their normal social group. Pigs exposed to this challenge over a ten-week period exhibited a significant reduction in abnormal behaviour (Puppe *et al.* 2007). Langbein *et al.* (2009) also found that dwarf goats (*Capra hircus*) continued to solve a previously learnt cognitive problem without an external reward. Although it was a cognitive study with no focus on well-being, Mackay (1981) similarly found that dolphins trained to whistle at a specific frequency in order to activate a food dispenser continued to do so without a food reward. Independently learning the solution to a task can have a positive impact on well-being, as shown in domestic cows (Hagan and Broom 2004). Clark *et al.* (in review) showed that when zoo-housed chimpanzees (*Pan troglodytes*) interacted with a maze-like cognitive challenge device, they displayed increased 'competence' (prolonged exploration of the device including innovative problem-solving strategies) and 'agency' (exploration of the wider captive environment, and social play).

Marine mammal well-being and enrichment in captivity

Behavioural problems

The most commonly reported behaviour of concern in captive marine mammals is repetitive swimming in a fixed pattern around the pool (e.g. cetaceans: Gygax 1993; Sobel *et al.*, 1994; pinnipeds: Hunter *et al.* 2002; Smith and Litchfield 2010). However, a more recent study by Miller *et al.* (2011) found the repetitive swimming across six dolphin facilities was low (less than 5% scans). Although this type of swimming fits the definition of stereotypical behaviour because it is unvarying and repetitive (Mason 1991), it may also have an obvious function. Continuous swimming around the pool could be interpreted as functional patrolling behaviour, because the 'outer patrol border' of the pool never changes. Furthermore, stereotypical behaviour is linked to good or neutral well-being nearly as often as poor well-being (Mason and Latham 2004). Another behaviour which may or may not be problematic in dolphins is surface-directed behaviour. Galhardo *et al.* (1996) found that captive dolphins spent a disproportionate amount of time with their heads above water. This is not a particularly natural behaviour for dolphins (similar to repetitive swimming as discussed above) but could be interpreted as functional because most environmental complexity is on or above the water-surface (e.g. the presence of animal staff, floating enrichment objects).

Other reported behavioural problems in cetaceans are low and come from outdated publications; for example repeated head-pressing against the wall (Greenwood 1977), bumping the head against the floor while swimming (Amundin 1974), and excessive aggressive or sexual activity (Sweeney 1990; Samuels and Spradin 1995). In pinnipeds, flipper chewing, excessive self-grooming and body-scratching against hard surfaces have been reported (Kastelein and Wiepkema 1989; Smith and Litchfield 2010). These self-directed and injurious behaviours are widely accepted as signs of compromised well-being (Moberg and Mench 2000). In summary, data are lacking on the aetiology of problem behaviours in cetaceans and pinnipeds. A survey of current behaviour is needed to establish the form and function of behaviours, an objective assessment of whether they are problematic, and a measure of how intensely they have been studied.

Enrichment

Marine mammal exhibits in zoos and aquariums are usually smooth-edged concrete pools with glass windows. This design helps to achieve the highest safety and hygiene standards (Joseph and Antrim 2010), but is also criticised for being sterile (Rose *et al.*, 2009). Indeed, it is surprising that although enrichment could be used to compensate for a lack of structural exhibit complexity, it is usually simplistic. A literature search yielded twelve peer-reviewed papers and book chapters on cetacean and pinniped enrichment (not including 'social' enrichment provided by training). Within this small amount of published literature, there is a clear trend for using plastic and rubber enrichment 'toys' that float on the surface of the water (e.g. cetaceans: Gewalt 1989; Kuczaj *et al.* 2002; Delfour and Beyer 2011; pinnipeds: Grindod and Cleaver 2001). These studies show that, as a general rule, floating objects rouse immediate interest and interaction but are quickly habituated to. Submerged objects have been used far less (weather vane: Amundin 1974; fire hose: Amundin 1974; Berglind 2005).

The most advanced dolphin enrichment study thus far was by Berglind (unpublished thesis, 2005), who ran water through submerged fire hose so that it moved erratically, subsequently triggering group hunting displays and increased sonar activity. For pinnipeds, Kastelein and Wiepkema (1989) recognised that walruses (Odobenus rosmarus) had a lack of naturalistic foraging opportunities, and decreased repetitive swimming behaviour by providing buried food. However at large, the specific characteristics of objects which make them effective enrichment for marine mammals (for example buoyancy, destructibility and complexity) have been largely unexplored.

Despite the fact that most captive marine mammals live in physically un-complex environments (especially under the water's surface), most species have their social cognitive skills challenged to a moderate or high level via training and less formal interactions with humans. Positive reinforcement training is an integral part of marine mammal management (Brando 2010), and is thought to be enriching for captive animals because it increases an animal's sense of control in the environment (Laule and Desmond 1998). Repetitive swimming in Steller sea lions (*Eumetopias jubatus*) was significantly decreased by incorporating training into their management routine (Kastelein and Wiepkema 1988). However, it is not clear whether increased human contact or the training process itself was beneficial to the subjects. Human-dolphin swim programmes have become increasingly popular in zoos and aquariums worldwide (Miller *et al.* 2011), but evidence for whether these programmes are enriching is mixed. For example, a multi-facility study (Miller *et al.* 2011) provided convincing evidence that swim programmes were enriching because they were associated with increased dolphin play and behavioural diversity (including swimming style). Conversely, swim programmes that are less structured, for example where visitors can swim freely with the dolphins for a period of time, have been associated with avoidance of, or aggression towards, humans (Samuels and Spradin 1995; Kyngdon *et al.* 2003).

Cognitive skills of dolphins and sea lions

History of study

Whether marine mammals are 'too intelligent for captivity' is a topic of on-going scientific and public debate that will not be discussed here (see Rose *et al.* 2009; Grimm 2011; Marino and Frohoff 2011). However, this paper will condense the evidence taken from over half a century of cognitive study in the laboratory and field (Schusterman and Kastak 2004; Pack 2010), that dolphins and sea lions have high cognitive skills. The dolphin has been of particular interest to cognitive scientists because it has an exceptionally large brain relative to body size (Marino 2002), a high level of 'intelligence' comparable to humans and great apes (Marino 2002), and is relatively easy to manage in shallow pools (Herman 2002a). There is less cognitive research on the sea lion, but significantly more so than any other pinniped species. Similar to the dolphin, the sea lion has high 'intelligence', is easy to train, and adapts well to living in shallow pools (Schusterman *et al.* 2002). Furthermore, many of the methods used to test dolphin cognition have been transferable to sea lions (Schusterman and Kastak 2004).

Dolphin echolocation

Echolocation in dolphins refers to their ability to locate and discriminate underwater obstacles, by producing high-frequency sound waves and receiving the echoes that reflect off these obstacles (Au 1993). In contrast to dolphins, sea lions do not echolocate (Schusterman *et al.* 2000). Echolocation was discovered in captive dolphins in the 1950's and has since been studied rigorously by concealing underwater objects in black boxes, and by placing rubber cups over dolphins' eyes to prevent them using normal sight (reviewed by Au 1993). Not only can dolphins use echolocation to recognise three-dimensional shapes, they can also correctly match a shape inspected through echolocation with an identical shape inspected through vision and vice versa (Pack *et al.* 2004). Furthermore, dolphins can 'eavesdrop' on the echolocation of conspecifics and use this to recognise objects (Xitco and Roitblat 1996).

Concept formation

'Concepts' are general rules that animals apply to the novel problems they encounter in life (Schusterman and Kastak 2004). These concepts can be abstract (e.g. same/different), relational (e.g. larger/smaller) and perceptual (e.g. food/non-food). Concept formation in marine mammals has been tested in the laboratory using an experimental method called matching-to-sample (MTS), where a subject is shown a 'sample stimulus' and reinforced (for example with a fish) for choosing the correct stimulus from two or more 'comparison stimuli'. Dolphins have shown that they understand the concept of larger/smaller quantities (Jaakkola *et al.* 2005), and Abramson *et al.* (2011) recently demonstrated that South American sea lions (*Otaria flavescens*) could assess and select the larger of two sets of quantities.

Being able to recognise objects when they have been rotated in three dimensions is another useful skill for animals living in complex environments. Tests of mental rotations on marine mammals have been undertaken using the MTS method described above, where a subject must match an object with its mirror image or rotation. Studies on dolphins (Herman *et al.* 1993), beluga whales (*Delphinapterus leucas*; Murayama and Tobayama 1995) and sea lions (Mauck and Dehnhart 1997) show that marine mammals can recognise rotated objects, but similar to humans, the time it takes them to do so is positively correlated to the degree of rotation.

Learning and memory

Dolphins and sea lions have excellent short-term memory for sights and sounds (Herman 2002a; Schusterman *et al*. 2002). In 'delayed' MTS tests, the time delay between presentation of the sample stimulus and comparison stimuli is increased to find the maximum length of time a subject can retain the memory of the sample stimulus. Not only can dolphins remember specific sounds, one dolphin could remember lists of up to four novel sounds, compared to a maximum of seven in humans (Thompson and Herman 1977).

Dolphins also possess good spatial memory; in other words memory for the spatial location of events or objects. Thompson and Herman (1981) played underwater sounds in one of four pool locations, and a dolphin correctly swam to the location of the sound after a time delay of up to 70 seconds. Jaakkola *et al.* (2010) found that like many terrestrial animals, dolphins can track the spatial location of visible objects, but in contrast to great apes they cannot track the spatial location of hidden objects. This is probably because dolphins rely on their echolocation to identify objects hidden from sight (Jaakkola 2012).

Understanding symbols and televised images

Following in the footsteps of great ape research, 'artificial languages' were taught to captive dolphins in the 1980's (reviewed by Herman 2002a; Jaakkola 2012). These languages contained symbols for objects (e.g. ball), their positions in the pool (e.g. left), actions (e.g. jump over) as well as questions relating to objects (e.g. is the object in the pool?). Similar to human language, symbol order changed meaning; for example 'take the ball to the bucket' is different from 'take the bucket to the ball'. Dolphins appear to understand both semantics (meaning) and syntax (order) of symbols (reviewed by Herman 2002a), and studies on sea lions have yielded comparable results (Schusterman and Kastak 2004). The ability of dolphins and sea lions to correctly answer 'yes/no' questions (e.g. is the ball in the pool?) is particularly impressive, and is achieved by the subject pressing one paddle for 'yes' and another for 'no' (Herman and Forestell 1985; Schusterman *et al.* 2002)

Television screens have been used to test whether marine mammals understand external representations of objects and actions. Thus far, dolphins have followed commands given to them by humans on a television screen, imitated televised dolphins, and correctly responded in MTS trials when the sample stimuli are presented on-screen (Herman 2002). In fact, the immediate, spontaneous response of dolphins to televised images outperforms that of chimpanzees, who respond correctly to televised images only after intensive training (Savage-Rumbaugh 1986).

Awareness of self and others

The large brains of dolphins (and great apes) probably evolved due to strong social forces (reviewed by Marino *et al.* 2007), and therefore both taxa have a good understanding of themselves and others. The traditional method of testing whether large-brained animals recognise themselves (i.e. have self-awareness) is through the mirror self-recognition mark test (Gallup 1970). According to this test, great apes and some other primates, elephants, cetaceans, and corvids (crows) are the only nonhuman animals that are self-aware (reviewed by Herman 2012). The evidence is fairly unequivocal in dolphins (Reiss and Marino 2001); killer whales (*Orcinus orca*) and false killer whales (*Pseudorca crassidens*) could also be self-aware (in contrast to sea lions) because they appear to look significantly more at a body part in the mirror if the body part has been marked with a spot (Delfour and Marten 2001).

In a further examination of self-awareness, Mercado *et al.* (1998) found that a dolphin could repeat (imitate) its previous behaviour on command. In order to perform imitative behaviour, an animal must have a mental representation of others and/or itself; therefore imitation is regarded as a very high-level cognitive ability. Dolphins and sea lions are known to be excellent imitators of both actions and vocalisations, of both conspecifics and humans, often doing so spontaneously (reviewed by Herman 2002b). It is particularly impressive that dolphins and sea lions can imitate a human's motor actions despite having vastly different body shapes, interpreting for example that their fins are equivalent to human arms. Dolphins and beluga whales are capable of mimicking human sounds (Herman 2002b; Ridgway *et al.* 2012) and interestingly, a captive harbour seal could apparently mimic ten human words (Ralls *et al.* 1985).

In addition to imitation, dolphins possess a range of cognitive skills related to the understanding of other's actions, known as 'joint attention' (reviewed by Pack and Herman 2007). In fact, some of the joint attention abilities of dolphins exceed those shown by great apes. Dolphins are one of few non-domesticated species that understand the meaning of human pointing without prior training, and can determine which object a person is gazing at (Pack and Herman 2007). Furthermore, Xitco *et al.* (2004) found that dolphins pointed (oriented) their bodies toward an object, while looking to see if they had the attention of a human.

Planning and problem-solving

The ability to create appropriate plans when confronted with novel problems has obvious survival advantages, but has been demonstrated in relatively few species. Examples of planned behaviour in wild cetaceans are numerous, and include the cooperation of male dolphins when mating (Connor 2007), cooperation of killer whales when hunting (Visser *et al.* 2008), and dolphins using sponges to protect their rostrums while foraging in sharp rocks (Smolker *et al.* 2007). Incidentally, sponge-use is the only reported example of tool use in wild cetaceans, in contrast to more numerous accounts in captivity (see Jaakkola 2012).

Kuczaj *et al.* (2010) examined how two dolphins planned their behaviour when faced with a novel underwater task. The task required dolphins to transport and drop four weights into a compartment in order to release a fish reward. The task was demonstrated to the dolphins by a diver, using one weight at a time. Interestingly, however, dolphins chose to carry multiple weights to the apparatus rather than simply imitating the diver's actions. The same dolphins were presented with a new task requiring the placement of weights into three compartments, and were able to use the weights in the most economical manner to maximise the quantity of food reward (Kuczaj *et al.* 2010). Dolphins can also be commanded to produce novel behaviours (Herman 2006), suggesting they possess another rare trait in the animal kingdom: creativity. Herman (2006) also commanded a pair of dolphins to create a novel behaviour at the same time, which they were able to do successfully. No other animal species tested, other than humans, has revealed the capacity for synchronous creative behaviour at such an accomplished level (Herman 2010).

Marine mammal cognition and captive care

A cognitive enrichment framework for marine mammals

So far, this review has summarised why dolphins and sea lions are highly intelligent animals, with dolphins being on par with (or exceeding) great apes based on the cognitive tests provided thus far. However, it is doubtful that the physical cognitive skills of sea lions and dolphins are being challenged to a high level in the clean, smooth-sided concrete and glass pools usually found in zoos and aquariums. Hitherto, floating 'toy' objects have provided more complexity above the water-surface than below. For dolphins, this type of enrichment does not make full use of their echolocation; their most sophisticated and unique cognitive ability.

This paper now culminates with a new proposal for marine mammal cognitive enrichment. In this framework, previous laboratory cognitive tests are examined; their principles are deconstructed; and then reconstructed to create cognitive challenges practical for zoos and aquariums. Of course, it is important to evaluate the effect of cognitive challenges on well-being before they can be characterised as enriching, and this procedure will be discussed in due course. First, three examples of cognitive challenge will be suggested, with a particular emphasis on challenging physical cognitive skills. The first approach requires a protracted period of animal training, while the other two approaches rely on giving subjects opportunities to solve challenges for themselves with minimum human intervention.

(i) Stimulus matching: control over the environment

When animals are given increased choice and control over their environment, this can lead to enhanced well-being (Laule and Desmond 1998). The first suggested approach to cognitive enrichment is to allow subjects more control by participating in discrimination trials. Both dolphins and sea lions have been tested using MTS procedures for many decades, and have demonstrated a strong understanding of symbols (Schusterman and Kastak 2004). Using this procedure in a zoo or aquarium setting, visual or acoustic cues are used to summon subjects to various reward stations. Then, subjects are given the opportunity to correctly discriminate between different visual stimuli to receive a reward (Ernst *et al.* 2005; Puppe *et al.* 2007). To take advantage of their multi-modal natures, underwater tones will be played (Kuczaj *et al.* 1998), thus requiring animals to touch corresponding symbols displayed on wooden boards (see von Fersen *et al.* 2000) or television screens (see Delfour and Marten 2006), placed in or near to the pool.

By voluntarily participating in these tasks, subjects will gain more control over their environment (Langbein *et al.* 2009) and potentially benefit from their own learning success over time (Hagan and Broom 2004). The reward could be food, access to objects, or more control over resources such as fountain water or lighting. This is no doubt a labour-intensive method of providing cognitive challenge, but it capitalizes on the strong bond already developed between marine mammals and their trainers. In fact, Herman (2002a) suggests that teaching subjects (i.e. physical demonstration of the relationships between objects and symbols) may be more efficient than training. The equipment for this approach will be low cost, requiring at minimum a set of underwater speakers and wooden display boards, and a trainer to reinforce subjects for correct responses (whereas incorrect responses will be ignored). If funding permits, this approach could also incorporate the use of computer touch screens (Delfour and Marten 2006) and automatic feeders (Mackay 1981).

(ii) Submerged problem-solving devices

The second approach to cognitive challenge uses submerged 'problem-solving devices', temporarily secured to the pool wall (Clark *et al.* In review). This was alluded to, four decades ago by Amundin (1974), who suggested (but never formally evaluated) textured 'structure plates' attached to the walls of marine mammal pools. Kuczaj *et al.* (2010) recently found that dolphins efficiently planned their responses to a submerged physical task, but little work on dolphin problem-solving has been attempted since. In particular, visually hidden challenges will stimulate dolphin echolocation and provide a more acoustically rich environment than concrete pool walls. Current research on cognitive challenge devices for dolphins suggests they are highly motivated to interact with devices, even in the absence of a food or other external reward (Clark, personal observation).

Ideally, a cognitive challenge device requires very little human intervention in terms of demonstration or providing food rewards. At any one time, several marine mammals in an exhibit may be off-show in holding pools (Joseph and Antrim 2010), and cognitive challenge devices could be particularly useful in these situations to prevent boredom or distract from social tensions. Furthermore, if a cognitive challenge device is modular, virtually hundreds of versions of the device can be built and implemented over time, therefore varying task complexity and sustaining task novelty. This is a relatively low-cost approach to cognitive challenge, because the component modular pieces of the device can be re-used over time.

(iii) Submerged spatial problem-solving tasks

The third and final approach is an extension of the second approach, and uses problem-solving tasks over a larger area to challenge spatio-cognitive skills. This takes inspiration from dolphin cognition studies undertaken at The Seas facility (Disneyworld, Florida), where the public can watch dolphins participating in cognitive tests in their normal pool (Harley *et al.* 2010). The approach is to create a cognitively challenging 'obstacle course' in the centre of the pool. A number of tasks are laid out and the rate or method of completion by subjects will affect the level of reward gained.

Spatial problems are potentially more naturalistic (and therefore motivating) to dolphins and sea lions than static devices attached to the pool wall. This approach also requires little or no training, and the cost of equipment can be low (e.g. Perspex tubes containing weights) or high (e.g. fully automated underwater keyboards; see Harley *et al.* 2010). It may be economical to build a number of permanent connection points in the pool where task components can be temporarily attached when needed.

Limitations in the zoo and aquarium environment

There are of course several caveats when providing cognitive challenges to marine mammals. First, it is important to acknowledge that most cognitive data discussed in this paper have been collected on a few 'well-schooled' individuals (Herman 2002a Pack 2010) and therefore generalisation to other individuals should be conservative. It is unrealistic to expect the average captive dolphin or sea lion to spontaneously exhibit the same level of cognitive skill as the handful of laboratory subjects. Rather, we should recognise the cognitive potential of each subject, and try to cultivate this potential over time.

A note on health and safety is also necessary. Often, marine mammals pick up, manipulate and intentionally or unintentionally ingest objects that fall into their pools (Joseph and Antrim 2010). Notably, large air-filled balls can lodge in an animal's throat when diving, and tethering objects can also be dangerous because this can result in entanglement (Joseph and Antrim 2010). All the necessary precautions should be taken; an observer should always be present when apparatus are used in the pool, particularly when they are submerged or contain moving parts.

Evaluating cognitive challenges

Re-visiting Clark's definition of cognitive enrichment (Clark 2011), a cognitive challenge must have a positive impact on well-being before it can be called enrichment. Unfortunately, this may be easier said than done in marine mammals, because fundamental research is lacking on indicators of positive and negative well-being. However, there are several guiding principles we can take from cognitive challenge research on other animals. First, if the level of challenge is relevant or un-motivating (i.e. does not suit an animal's anatomy, natural history and cognitive skill level), apathy, boredom or frustration may be observed (Meehan and Mench 2007). Second, control and mastery of a cognitive challenge are important for well-being (Meehan and Mench 2007). Herman (2002a p.276) suggests that "When introducing new (cognitive) problems, we take care that they are at an initial level likely to lead to success, and then increase the difficulty and complexity at a rate or in contexts that tend to promote overall success".

Conclusions

Dolphins possess complex cognitive skills largely on par with (and sometimes exceeding) great apes. Sea lions also perform strongly on many of the same laboratory cognitive tests. Both dolphins and sea lions have good short and long term memory skills, an understanding of abstract concepts and symbols, and creative problem-solving abilities. It is therefore surprising that previous attempts at enrichment have provided little opportunity to apply these skills to solve complex physical problems. By providing floating objects as enrichment, we are barely catering for the high cognitive skills of marine mammals.

With over five decades of dolphin and sea lion cognitive study at their disposal, marine mammal carers are in a strong position to provide more appropriate, relevant enrichment. This review suggests that 'cognitive challenges' should be provided to marine mammals as a form of enrichment; these challenges can range from small match-to-sample discrimination trials, to large underwater obstacle courses. To some extent, cognitive challenges might help offset the fundamental limitations of housing large-brained aquatic mammals in sterile pools. The opportunities for cognitive challenge design are endless, and inspiration is available from the cognitive literature. This paper aims to inspire further developments in marine mammal enrichment, and encourages more debate on the link between cognition and care in large-brained animals.

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