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Original Article

Human readiness to throw: the size–weight illusion is not an illusion when picking the best objects to throw☆

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Abstract

Long-distance throwing is uniquely human and enabled *Homo sapiens* to survive and even thrive during the ice ages. The precise motoric timing required relates throwing and speech abilities as dependent on the same uniquely human brain structures. Evidence from studies of brain evolution is consistent with this understanding of the evolution and success of *H. sapiens*. Recent theories of language development find readiness to develop language capabilities in perceptual biases that help generate ability to detect relevant higher order acoustic units that underlie speech. Might human throwing capabilities exhibit similar forms of readiness? Recently, human perception of optimal objects for long-distance throwing was found to exhibit a size–weight relation similar to the size–weight illusion; greater weights were picked for larger objects and were thrown the farthest. The size–weight illusion is: lift two objects of equal mass but different size, the larger is misperceived to be less heavy than the smaller. The illusion is reliable and robust. It persists when people know the masses are equal and handle objects properly. Children less than 2 years of age exhibit it. These findings suggest the illusion is intrinsic to humans. Here we show that perception of heaviness (including the illusion) and perception of optimal objects for throwing are equivalent. Thus, the illusion is functional, not a misperception: optimal objects for throwing are picked as having a particular heaviness. The best heaviness is learned while acquiring throwing skill. We suggest that the illusion is a perceptual bias that reflects readiness to acquire fully functional throwing ability. This unites human throwing and speaking abilities in development in a manner that is consistent with the evolutionary history.

Keywords: Size–weight illusion; Overarm throwing; Language; Human evolution

1. Introduction

Long-distance (≈20–30 m) throwing is an ability that is both uniquely human and known to have been essential to the survival and successes of *Homo sapiens* over evolutionary time (e.g. Bingham, 1999; Calvin, 1983; Darlington, 1975; Isaac, 1987; Knusel, 1992; Martin, 2005; Meltzer, 2009; Shea, 2006). Other primates and monkeys can throw, but only to relatively short distances (Cleveland, Rocca, Wendt & Westergaard, 2003). Today, human throwing abilities are used primarily in sport where we celebrate the long pass by the quarterback to hit a receiver 30 yards down the field in American football or the throw to home plate or wicket from the outfield in baseball or cricket. During most of our existence, however, we humans used our unique throwing abilities for defence and to obtain food. The ability to throw objects long distance is known to have been of central importance to the survival of humans through the last ice age and to the spread of humans to occupy habitats all over the globe, and North America in particular, where *H. sapiens* used throwing ability to hunt the existing American megafauna and contribute to its extinction (Bingham, 1999; Martin, 2005; Meltzer, 2009; Finlayson, 2009; Flannery, 2001). The ability to throw long distance meant that a human hunter could stay beyond the devastating reach of a giant sloth's claws or a mammoth's tusks while striking with spears and stones to bring the prey down (Meltzer, 2009). Also, when global temperature dropped and

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forested regions became de-forested steppe tundra, a hunter could no longer hide well to ambush its prey from short distance. The ability to throw to take down prey at long distance became crucial for survival (Finlayson, 2009).

Long-distance throwing requires precise timing in motor coordination (e.g., Jöris, van Muyen, van Ingen Schenau & Kemper, 1985), and this, in turn, is supported by the cerebellum and posterior parietal structures in the brain of *H. sapiens* (Ivry & Spencer, 2004; Ivry, 1997). There has been a puzzle in the understanding of the evolution of the human brain. These structures are featured in a recently proposed solution to the puzzle. The proto-human species with the larger brain was always the one to succeed and survive, with the sole exception of Neanderthals, whose brain was actually larger than that of *H. sapiens*. Why did *H. sapiens* win out despite the smaller brain size? Evidence now reveals structural differences, namely, *H. sapiens* had relatively enlarged cerebellum and posterior parietal cortex as compared to Neanderthals (Weaver, 2005). Concurrent discussions have suggested that, indeed, throwing ability was key to the survival of *H. sapiens* in contrast to Neanderthals (Finlayson, 2009).

Long-distance throwing is an ability that is as essentially human as is language (Bingham, 1999; Calvin, 1983). The motoric timing required for speech is similar in its requisite precision to that for throwing and is similarly supported by relevant brain structures (Mathiak, Hertrich, Grodd & Ackermann, 2002; Ackermann & Hertrich, 2000; Calvin, 1993; Keller, 1990; Ivry & Spencer, 2004). Speech is understood to have been essential to allow socially coordinated throwing in hunting of large game, so throwing and speech are coupled in having made humans uniquely successful (Bingham, 1999; Calvin, 1983; Finlayson, 2009; Flannery, 2001; Martin, 2005; Meltzer, 2009). Speech has been widely appreciated as intrinsic to humans, something very young humans exhibit readiness to learn with rapidity (Kuhl, 2000; Kuhl, Conboy, Padden, Nelson & Pruitt, 2005; Kuhl & Rivera-Gaviola, 2008; Lenneberg, 1967). What of throwing in this regard? We now present a result that supports the possibility that throwing is similarly intrinsic by showing that it is related to a long and well-known phenomenon in human haptic perception of graspable objects, namely, the size–weight illusion. Our finding reveals that this illusion represents a readiness in humans to acquire fully functional throwing abilities.

Weight perception studies have sought to discover how relevant dimensions of a physical stimulus are scaled by the human perceptual system to produce experience of heaviness. Early studies quantified heaviness as a function of object weight (Weber, 1834/1978). However, Charpentier (1891) found that object size also affected perceived heaviness. A larger object is perceived to be substantially less heavy than a smaller one of equal weight. This phenomenon is known as the “size–weight illusion” and is by far among the best known, most reliable and robust perceptual illusions.

Many theories have been advanced to account for the illusion in terms of either afferent or efferent processing. From the afferent point of view, the illusion merely reflects a complex sensory variable composed of size and weight. Different size–weight relations including density (Huang, 1945; Ross & DiLollo, 1970), a power law (Stevens & Rubin, 1970) and an inertia tensor (Amazeen & Turvey, 1996) have been proposed. The scaling of size and weight to heaviness as described by the power law, for instance, has not been found to support the hypothesis that it is really density that is being perceived, but the real meaning of the property captured by the power law remains unclear. The inertia tensor hypothesis was originally tested by having participants wield specially weighted rods. More recently, the hypothesis was tested using weighted balls that were grasped and hefted, that is, the standard circumstance in which the illusion is experienced (Zhu, Shockley, Riley & Bingham, submitted for publication). The results failed to support the inertia tensor hypothesis.

In the efferent view, the illusion is a cognitive resolution of a conflict between planned and updated motor commands for lifting an object. According to this expectation hypothesis (Ross, 1966), a greater neuromuscular force is planned before lifting larger objects in response to visual and haptic size cues, and when the force actually required is less than expected, the object feels light. Because the expectation was assumed to come from average experience of larger objects as weighing more, the illusion was also considered to be modifiable by experience. Flanagan and Beltzner (2000) demonstrated that the illusion could be inverted after extensive training with objects in which size and weight were negatively correlated. More recently, Brayanov and Smith (2010) found that perceptual judgments and motoric responses in object handling were different in respect to the illusion. They reported that perceptual judgments were less affected by prior experience than motoric responses were.

The experience-based hypothesis has been undermined by other findings, some of which suggest that the illusion might be intrinsic to humans. The illusion is universally and reliably experienced by adults and children as young as 18 months (Robinson, 1964; Kloos & Amazeen, 2002). The illusion is very robust. Knowing that two objects are of the same weight does not prevent the illusion from occurring. It has been found to persist after an object has been lifted and its weight thoroughly tested with the result that lifting trajectories are appropriate (Mon-Williams & Murray, 2000).

While the origin of the size–weight illusion remains controversial, the fact that it is so reliable and robust suggests that it might be in some way functional in the guiding of action. If so, then from the evidence, it is experiential and would have to do with judgments about objects made in planning actions rather than with continuous online control of actions. So, it might serve in