CHAPTER 15

The Central Nervous System and Bipedal Use of Weapons

"The soundest argument by far for the throwing hypothesis is the enormous [neural] demands of the human high-performance throw…The brain entered entirely new realms of achievement"
[Kirschmann, 1999, 1.2].

"Clearly, a perfectly accurate, real-time internal model of arm mechanics would need enormous computational power…"
[Hore, et al., 1999b, p. 1187].

Introduction. The central nervous system is the major regulator of behavior. If natural selection acted to improve throwing, then heritable variations in the central nervous system that facilitated throwing would have been naturally selected due to the enhanced reproductive success of individuals who possessed these genes. If so, distinctive traces of this adaptive process should be demonstrable in the central nervous system in modern humans. The following discussion shows unequivocally that convincing evidence in support of this prediction is available.

Kirschmann [1999] was the first to propose and elaborate the idea that natural selection for aimed throwing would have had important consequences for the evolution of the brain. Only humans throw well, he wrote, and the human act of throwing is exceedingly complex, involving numerous rotations of different parts of the body. Furthermore, it happens very rapidly. A high-performance, well-aimed throw makes enormous demands on the central nervous system. Possibly no greater feat of coordination than the human throwing motion has ever evolved. This must have involved highly significant modifications of the brain [Kirschmann, 1999, 3.3.1].

Among the changes Kirschmann anticipated was improvement in calculating target distance, which is crucial to an accurate throw [1999,1.4]. In his view, this was a major factor in remodeling brain structure and causing brain expansion. Target distance is partly determined from a comparison of remembered size of objects with the size of the object's image on the retina [3.3.4]. This means it is dependent upon *memory*, which contributes importantly to human cognition. Because cognitive ability that evolved to solve one task can be applied to others, the human ability to devise complex scenarios may have arisen from this mental faculty. This and the evolved thrower's abilities to process sequential data may play a role in the human ability for advanced planning and the development of language [3.3.4; 6.8; 7].

Kirschmann thought the adaptive traits for throwing were substantially more demanding of the brain than those in the rest of the body [1999, 3.3.4]. The throwing adaptation involved decisive changes in the hominin body plan, but the required parts were already present. In contrast, neural pathways in the brain needed substantial revisions to meet the enormous demands of a high-performance, aimed throw. Because it was a novel behavior, absent in hominin ancestors, unprecedented neural interactions had to be created. This adaptation within the brain was very significant in the evolution of human mental capacity [Kirschmann, 1999, 1.2; 3.3.1].

When Kirschmann's book was published, neuro- physiological analysis of the control of throwing had just been initiated by Jonathan Hore and his colleagues at the University of Western Ontario. They focused their research program on central nervous system control of the arm and hand during aimed throwing, using high-speed analysis of the throwing motion based on magnetic-field search-coil technique. Subjects equipped with search coils taped to the back of the third distal manual phalanx, the back of the hand and forearm, the lateral aspect of the upper arm, the scapula and sternum threw balls while seated in three orthogonal alternating magnetic fields. Coil voltages were used to calculate the angular positions of each segment in 3D space. Timing of ball release was measured with a microswitch attached to the distal phalanx of the third finger; ball speed was recorded by a radar gun. EMG activity was also analyzed [Hore, et al., 1999b; Debicki, et al., 2011].

Control of hand and arm movement during throwing. A feature of skilled throwing is fast speeds, which approach 160 km/h in the most rapid throws. Wrist flexion is important in achieving a high ball velocity [Gray, et al., 2006]. As the forearm accelerates forward, the hand lags behind, moving into full extension at the wrist joint (~ 30°). This represents an *interaction torque*, which occurs when a muscular torque at one joint elicits a torque at an adjacent joint. Interaction torques are maximized when the adjacent limb rapidly changes its angular velocity or reverses it [Sarlegna and Sainburg, 2009]. Many interaction torques occur throughout the throwing motion.

When the forearm accelerates and the wrist lags behind, wrist flexor muscle activity begins, contributing an active (muscular) flexion torque at the wrist joint [Debicki, et al., 2004; Hirashima, et al., 2003]. This adds to a passive, interaction flexion torque that results when forearm deceleration occurs (a whip-like effect) [Debicki, et al., 2004; Gray, et al., 2006; Hirashima, et al., 2007]. Skilled throwers produce a large elbow extension deceleration before ball release [Hore, et al., 2005a, b; Gray, et al., 2006; Hirashima, et al., 2007, 2008]. This deceleration may also counteract wrist extensor interaction and viscoelastic torques [Debicki, et al., 2011]. (Deceleration of elbow extension after ball release by a passive interaction torque initiated by the CNS at the shoulder joint acts to prevent injury [Hore, et al., 2011]). At the release point, wrist flexion velocity reaches its peak and the hand is aligned with the forearm [Gray, et al., 2006; Debicki, et al., 2004]. The forearm is aligned with the upper arm and the plane of the shoulders for a leverage effect that maximizes the speed transferred to the arm and hand from rotation of the trunk [Atwater 1979] (Chapter 13 Fig. 12).

In the upper body, the velocity of ball release is mainly produced by forward rotation of the trunk, internal rotation of the humerus, elbow extension and wrist flexion. Skilled throwers configure the limb to maximize all four of these angular velocities [Hirashima and Ohtsuki, 2008] and all of these joint-rotation angular velocities are the net outcome of the effects of interaction torques, muscle torques, gravity torques and velocity-dependent torques [Hirashima and Ohtsuki, 2008]. Hirashima, et al. [2007, 2008] use the term "velocity-dependent torques" to emphasize that some interaction torques may be traced back to origins in body segments some distance from where their ultimate effects can be measured.

The velocity-dependent torque is the result of the history of the muscle torques acting at the joint under consideration. "The effect of the velocity-dependent torque on the joint angular acceleration is related to the phenomena called 'whip-like effect,' 'proximal-to-distal sequence' and 'kinetic chain'" [Hirashima, et al., 2008, p.2875] (Chapter 13). Some velocity dependent torques affecting the arm may prove to have a history that included muscular torques generated in the legs and hips. However, the participation of several parts of the body during throwing has yet to be examined from this perspective, so that "...future studies need to examine the over arm throwing with a more accurate model that includes the non-throwing arm, finger joints, or the lower extremity with foot ground contacts" [Hirashima, et al., 2008, p. 2882].

Fast throws are associated with large back forces from the ball on the fingers that must be controlled if accuracy is to be achieved and injury prevented. These forces occur because as the fingers exert force on the ball to accelerate it, the ball exerts an equal force on the fingers [Hore, et al., 1999b]. Back forces begin with the start of hand acceleration and increase progressively throughout it. In the process of ball release the back force on the fingers' distal phalanges increases during extension and peaks at final release from the fingertips as kinetic energy is transferred to the missile through the extended index and middle fingers [Hore, et al., 2001]. This back force may contribute to extending the fingers, but the fingers do not extend fully because the CNS anticipates the size of the back forces and generates appropriate finger flexor torque to oppose them [Hore, et al., 1999b, 2001]. Computation by the cerebellum of finger stiffness based on hand acceleration may also be involved [Hore and Watts, 2011].

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