



# Humeral torsion does not dictate shoulder position, but does influence throwing speed



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## 1. Introduction

A debate has emerged in the last few years over the shape and position of the shoulder in early *Homo*. That the shoulder joint underwent changes approximately 2 million years ago is not in dispute. A number of newly discovered and relatively complete scapulae show that the orientation of the glenohumeral joint shifted caudally from the more cranial orientation seen in the apes and earlier hominins (Walker and Leakey, 1993; Larson et al., 2007; Lordkipanidze et al., 2007; Haile-Selassie et al., 2010; Green and Alemseged, 2012; Churchill et al., 2013). However, just how modern human-like this caudally rotated shoulder complex is remains less clear. Larson (2007, 2009) has proposed that early *Homo* possessed a novel, transitional shoulder morphology in which the shoulder joint faced anteriorly. We have proposed that *Homo erectus* had an essentially modern human-like shoulder complex with a laterally oriented glenohumeral joint (Roach et al., 2013; Roach and Richmond, 2015). Why does this debate matter? These differing reconstructions of the shoulder have important functional implications for a number of crucial behavioral shifts hypothesized to occur at or near the origins of our genus (e.g., reduced climbing behavior, intensification of tool manufacture and use, endurance running, and high speed throwing).

Much of this debate has hinged on the length of the clavicle. As the only bony strut attaching the shoulder complex to the torso,

clavicle length may be an important factor in determining shoulder position. Along these lines, Larson (2007, 2009) has argued that relatively short clavicles found in early *Homo* suggest that their shoulders had a more anterior orientation. We tested this idea, but found that the relative clavicle length measure Larson used as data support for her model does not accurately predict shoulder position (Roach and Richmond, 2015). We further concluded that the data better support the presence of modern human-like, laterally facing shoulders dating back to *H. erectus* or earlier. Larson (2015) does not agree with our conclusions or with the way we present her research.

Our paper addressed the role of clavicle length in determining shoulder position and throwing performance (Roach and Richmond, 2015). Larson's reply (2015), "Humeral torsion and throwing proficiency in early human evolution," does not address clavicle length and does not dispute either the data we present or our methodology. Instead, Larson refocuses her anterior shoulder model on humeral torsion (Fig. 1). She argues that 1) we misrepresent her anterior shoulder hypothesis, 2) very low humeral torsion presents an unresolved problem for our reconstruction of the *H. erectus* shoulder as modern human-like, 3) low torsion is associated with higher injury risk in throwers, and 4) very low torsion does not support the capacity for high-speed throwing dating back to *H. erectus*. We disagree with Larson on all of these points and in this paper present data that strongly support our position.

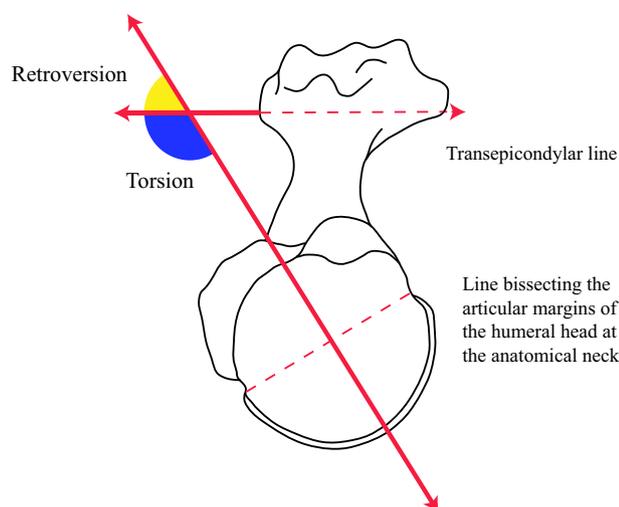
## 2. A distinction without a difference

We disagree that we misrepresented Larson's work by stating that she proposed an anterior facing shoulder joint was necessary

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**Figure 1.** Humeral torsion. The degree of humeral torsion (in blue) is measured as the difference between the orientation of the humeral head and the distal condyle in the elbow. In the clinical literature, humeral retroversion (in yellow) refers to the same angle measured in the opposing direction. Used with permission from Roach et al. (2012). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

to overcome deficits in internal rotation at the shoulder due to low humeral torsion (Larson, 2015). Larson (2015: 199) states that very low torsion in early hominins “(does not) make sense if they all possessed a human-like scapular position.” She further states that “the need for internal humeral rotation with growing dependence on tools” makes low torsion without an anteriorly facing shoulder unlikely (Larson, 2015: 200). The “problem” Larson proposes for combining a laterally oriented shoulder with low humeral torsion is the same in both of our descriptions.

What Larson (2007, 2009) has previously argued is that when relatively short clavicles are found in association with a caudally rotated scapula, the result is a shoulder pulled anteriorly around the ribcage. With the glenoid fossae now facing anteriorly, Larson (2007, 2009, 2015) argues that low humeral torsion does not provide any impediment to tool use as shoulder rotational range of motion (ROM) easily allows the hands to overlap. Based on this logic, and an observation that clavicle lengths in KNM-WT 15000 and LB1 appear to be short relative to humeral length, Larson (2007, 2009) proposed the anterior shoulder model for early *Homo*. Furthermore, she explicitly argued that this anterior shoulder morphology would “negatively (affect) overhand throwing ability” (Larson, 2007: 182). Given that relative clavicle length is both the only data support for the anterior shoulder model and the primary logic behind it, understanding the clavicle is clearly the key to evaluating Larson’s hypothesis.

Larson (2015) suggests that our summary of her work conflates what anatomical factors are causes and what are effects. We have not proposed any hypotheses about cause and effect. However, Larson does. In her reply to our paper, Larson (2015: 200) defines her anterior shoulder model as “essentially a neutral by-product of other evolutionary changes, and low torsion (as) an accommodation to the resulting more anteriorly facing glenoid fossae.” While it is difficult to reconcile this “neutrality” with her statements about tool use (Larson, 2007, 2015), here we focus instead on what the evolutionary changes Larson alludes to might be. If this is meant to reference a more caudally rotated glenoid, modern humans living today have caudally rotated glenoids and do not have anteriorly facing shoulders, demonstrating that these features are not

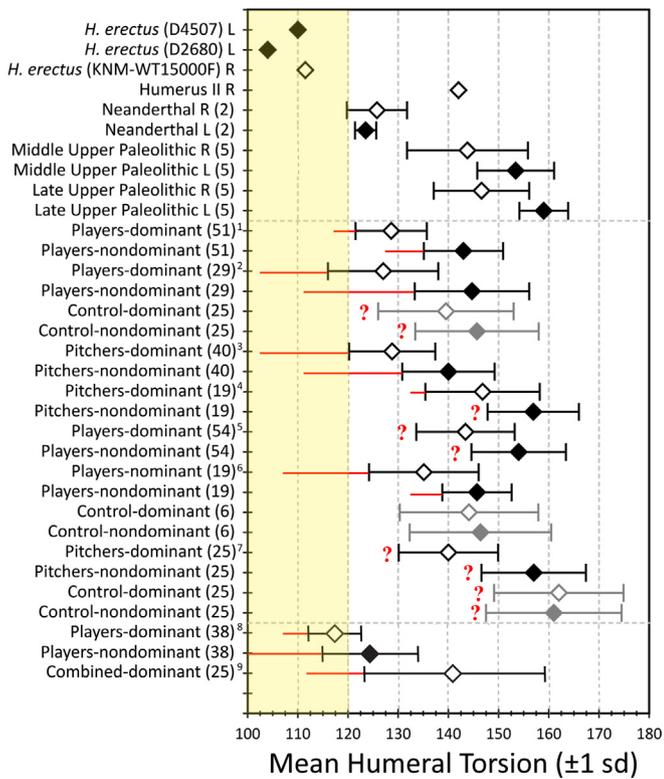
necessarily linked. Moreover, if low humeral torsion is simply an accommodation to an anterior shoulder position, then torsion cannot simultaneously be the evolutionary change driving this novel shoulder configuration. Larson’s earlier papers (2007, 2009) make it clear that the evolutionary change she is alluding to is clavicle length.

Our recent paper shows that reconstructions of the shoulder using relative clavicle length are flawed (Roach and Richmond, 2015). The claviculohumeral ratio (clavicle length/humeral length\*100) that Larson used to justify her anterior shoulder model failed to account for independent changes in the breadth of the thorax that occur in human evolution. These changes to the ribcage have a significant effect on shoulder position. Furthermore, we show that *H. erectus* had significantly greater variation in relative clavicle length than previously thought, with the Dmanisi individuals falling squarely in the modern human range (Jashashvili, 2005; Lordkipanidze et al., 2007). We also reported very short clavicles in some of the Daasanach people living today on the eastern side of Lake Turkana (Roach and Richmond, 2015). Importantly, these individuals have no shoulder pathology, suggesting that an anteriorly oriented scapula is not required to accommodate such a short clavicle. Larson (2015: 200) now recognizes that these data “(call) into question” her hypothesis that “a more laterally positioned scapula in early *Homo* was largely the result of a relatively short clavicle.”

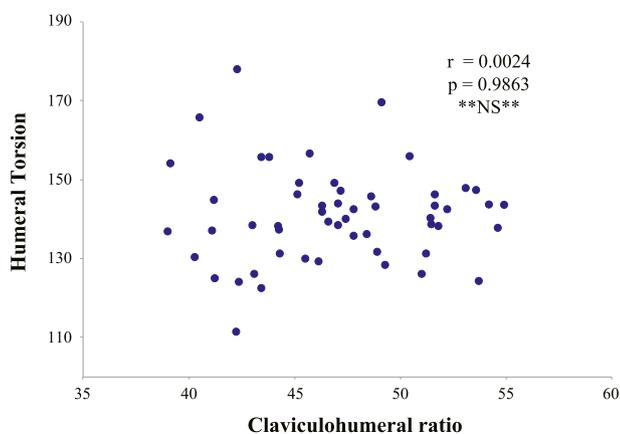
### 3. The humeral torsion “problem”

Larson (2015) remains unconvinced that an anterior shoulder model is unnecessary and believes there is an unresolved problem with humeral torsion in early *Homo*. She argues that some amount of shoulder internal rotation must be necessary for manipulation (Larson, 2015), reinforced by the assumption that *Homo* must be more dependent on manipulatory abilities than earlier hominins (Larson, 2007). Given that shoulder rotation ROM is tightly linked to humeral torsion (and that low torsion individuals have reduced internal rotation; Osbahr et al., 2002; Reagan et al., 2002; Chant et al., 2007; Roach et al., 2012), Larson sees the combination of very low torsion in early *Homo* with a laterally facing shoulder as being at odds with evidence of stone tool use in the genus *Homo* (Larson, 2007, 2009, 2015). We do not believe such a problem exists.

We agree with Larson that early *Homo* used tools and also that *H. erectus* had very low humeral torsion ( $\leq 120^\circ$ ). Furthermore, we agree that torsion in *H. erectus* is significantly lower than in modern humans or even than most baseball players, who generally have lower torsion in their dominant, throwing arm than non-athletes (Larson, 2015). However, Larson’s statistical support for lower torsion in *H. erectus* does not make the point that she aims to make. In Figure 5 of her reply, Larson (2015) shows mean and standard deviation data from a number of studies measuring humeral torsion in baseball players. While early *Homo* humeri generally have lower torsion, four of the seven studies Larson cites contain individual subjects with humeral torsion less than  $120^\circ$  (Fig. 2). Our own previous work on torsion and ROM, which Larson does not reference, also contains CT measurements of adult, modern human subjects with less than  $120^\circ$  of humeral torsion (Roach et al., 2012). Some of these baseball players have torsion as low as the *H. erectus* individuals Larson reports. Furthermore, Larson’s arguments about measurement technique do not discredit these low modern human values, as two of the lowest three measurements reported come from the more accurate CT studies (Chant et al., 2007; Roach et al., 2012). These very low torsion subjects matter because they show that the low torsion “problem” does not exist (Fig. 3). These low torsion individuals are not described as having abnormal, anteriorly



**Figure 2.** Some baseball players have torsion values as low as early hominins. These very low torsion modern humans ( $\leq 120^\circ$ —in the yellow box) have normal, laterally facing shoulders and throw well, suggesting that Larson's low torsion "problem" does not exist. Note: the D2680 fossil humerus is a subadult, likely with incomplete torsional development (Lordkipanidze et al., 2007). This figure is modified after Larson (2015) with permission from Elsevier. Mean torsion values are shown as diamonds,  $\pm 1$  standard deviation are shown with black whiskers, and minimum range values are shown in red. Numbers in parentheses show sample sizes. Minimum data taken from: <sup>1</sup>Whiteley et al. (2006); <sup>2,3</sup>Myers et al. (2009, 2011, pers. comm.; full sample size=750 subjects); <sup>4</sup>Osahr et al. (2002); <sup>5</sup>Reagan et al. (2002); <sup>6</sup>Chant et al. (2007); <sup>7</sup>Crockett et al. (2002); <sup>8</sup>Pieper (1998); <sup>9</sup>Roach et al. (2012). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)



**Figure 3.** Humeral torsion and relative clavicle length. If the degree of humeral torsion is a neutral byproduct of shoulder position as Larson (2015) states, then short claviced individuals would be expected to have lower torsion than long claviced individuals. This is not the case. Given these data, humeral torsion is likely not related to shoulder position, but rather to underlying genetics and functional demands. Data are taken from: Roach and Richmond (2015); soft tape clavicular measures of 36 Daasanach males and torsion estimates after Roach et al. [2012]; Daasanach only regression values— $R^2 = 0.08$ ,  $p = 0.09$  and Roach et al. (2012); 18 computed tomography based clavicular length and humeral torsion measures; CT only regression values— $R^2 < 0.001$ ,  $p = 0.99$ .

positioned shoulders. They are able to manipulate objects well. Simply, these individuals prove that it is possible to have both very low humeral torsion and a laterally oriented shoulder, and to lead a normal, tool and technology-laden modern human life. Some modern humans do and they are very good throwers.

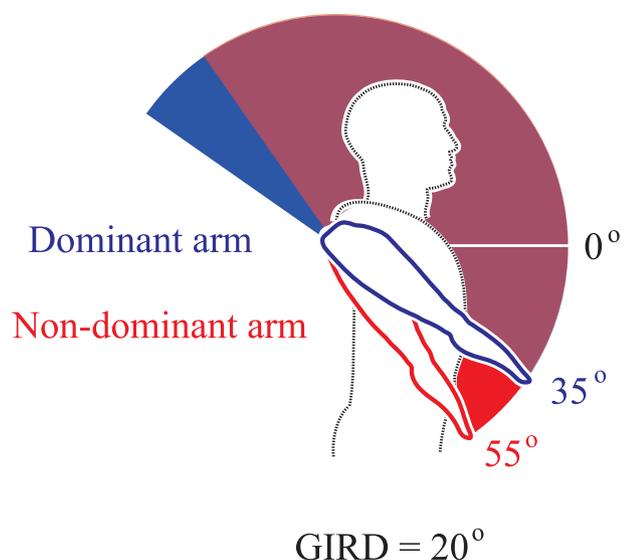
#### 4. Humeral torsion and injury risk

Larson (2015) argues that low torsion is associated with injury in throwing athletes. The evolutionary implication of this argument is that an injury prone morphology is a fitness liability and is therefore unlikely to arise. While the evolutionary ramifications of an injury-prone morphology raise interesting questions, we do not believe it has relevance to the debate here. Larson (2015) asserts that we cannot know whether modern, professional baseball players throw more or less frequently than our hominin ancestors. As a point about not being able to know the unknowable, this is fair. However, we question Larson's assumption that throwing prevalence and injury rates of modern baseball players are a good proxy for those in extinct hominins. Data from modern hunter-gatherers shows that most time spent hunting is in fact spent tracking or approaching prey (e.g., DeVore and Lee, 1968; Lee, 1979; O'Connell et al., 1988; Marlowe, 2010). Actual killing or wounding opportunities are rare and, frequently, singular events. Accordingly, even when considering time for practice, it is very unlikely that our ancestors engaged in throwing any object 100+ times in the span of a couple of hours, as modern baseball players routinely do. Given that the single most important predictor of injury in baseball players is the number of pitches they throw in each game (Lyman et al., 2002; Olsen et al., 2006; Fleisig et al., 2009, 2011), reaching agreement about what assumptions are reasonable for our hominin ancestors is important. We argue that when it comes to throwing frequency, modern baseball players are an extreme case. We propose that the heightened injury rates in throwing athletes result from serious overuse of our throwing abilities, an overuse that was unlikely to have occurred during our evolutionary history (Roach, 2012; Roach et al., 2013; Roach and Lieberman, 2014).

#### 5. A clinical digression

Given injury prevalence in modern athletes, we will digress briefly here to discuss Larson's injury assertions. Rotational range of motion (ROM) at the shoulder (i.e., movement around the long axis of the humerus) is highly variable and many studies have shown it is closely linked to humeral torsion (Pieper, 1998; Crockett et al., 2002; Osahr et al., 2002; Reagan et al., 2002; Chant et al., 2007; Roach et al., 2012). While humeral torsion does not affect the total ROM (i.e., how many degrees the arm can rotate from endpoint to endpoint), it does affect where the endpoints of this rotation are located. Therefore, low torsion individuals will have a ROM arc that is shifted externally, while high torsion individuals will have an ROM arc shifted internally (Fig. 4). The particular clinical condition Larson (2015) highlights is glenohumeral internal rotation deficiency (GIRD; Burkhart et al., 2003). This is simply a measure of the asymmetry between the throwing and non-throwing arm in the degree of internal rotation. It can also be thought of as a proxy for asymmetry in humeral torsion. Larson (2015) cites a number of studies highlighting the relationship between GIRD and throwing injury prevalence and makes the assumption that low humeral torsion in the throwing arm leads to larger asymmetry (i.e., higher GIRD). She thus implies that the very low torsion in early *Homo* would have left our ancestors injury prone and ineffective throwers.

However, the clinical data do not support Larson's assertion. The initial study measuring GIRD only examined injured athletes and



**Figure 4.** Rotational range of motion (ROM) asymmetry at the shoulder. Rotational ROM at the glenohumeral joint is directly related to underlying humeral torsion. Thus, asymmetry in torsion, due to differential loading of the dominant versus non-dominant arms during development, can lead to ROM asymmetry. In healthy modern humans, this asymmetry affects the position of the endpoints of the rotational ROM arc, but not the total ROM. Clinical measurements of asymmetry in internal rotation of the humerus is referred to as glenohumeral internal rotation deficit (GIRD). There is no consensus in the sport medicine literature as to whether GIRD is related to increased injury prevalence.

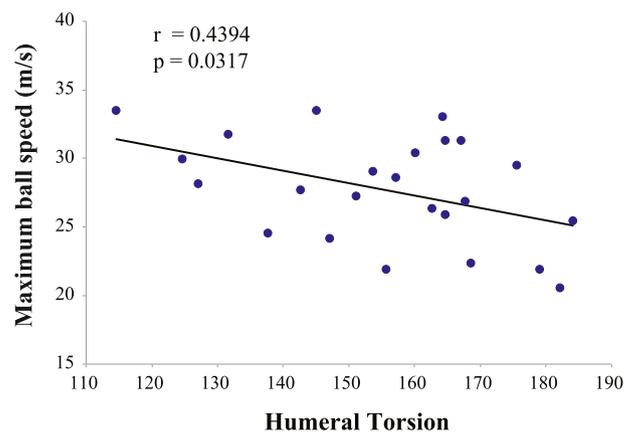
found that asymmetry in internal rotation was common (Burkhart et al., 2003). This is not surprising as asymmetries in both humeral torsion and shoulder rotational ROM are well documented in throwing athletes, injured or otherwise (Pieper, 1998; Crockett et al., 2002; Osbahr et al., 2002; Reagan et al., 2002; Chant et al., 2007). Some follow-up studies suggest that injured athletes may have increased GIRD/increased torsional asymmetry compared to their uninjured teammates (Dines et al., 2009; Shanley et al., 2011a; Wilk et al., 2011). These studies provide support for Larson's position that higher asymmetry, and the low torsion that may cause it, are linked to injury. However, the study Larson (2015) cites to illustrate a statistically increased injury risk does not separate pitchers from other players (Shanley et al., 2011a). This is important because the same dataset shows that pitchers are five times more likely to suffer a shoulder injury than players at any other position (Shanley et al., 2011b). Given that pitchers are also likely to have the highest levels of torsional asymmetry, it is difficult to assess whether the increased injury risk is related to GIRD or is simply correlated with what position these athletes played. Further, larger studies using only pitchers suggest that it is not the loss of internal rotation that is associated with injury, but rather a reduction in the total ROM at the shoulder (Dines et al., 2009; Garrison et al., 2012; Wilk et al., 2014). Given that variation in torsion is not linked to total ROM deficits, injury risk is more likely to be related to soft tissue differences and not to torsion (Wilk et al., 2014). This link between soft tissue and injury is confirmed by many studies (e.g., Miyashita et al., 2008; Niederbracht et al., 2008; Stickley et al., 2008; Kibler et al., 2013; Tonin et al., 2013). Interestingly, the one well-controlled study that does document increased injury prevalence in low torsion individuals notes that these injuries occur at the elbow and not the shoulder (Myers et al., 2011). This is consistent with increased elastic energy storage in low torsion individuals resulting in higher valgus torques at the elbow (Roach et al., 2013; Roach and Lieberman, 2014). However, recent studies highlight that it is in fact the higher torsion in the non-throwing

arm that is driving the statistical association with injury (Whiteley et al., 2010), again calling into question the role of torsion in throwing injury prevalence. In the light of these data, it is very difficult to link injury prevalence to low torsion. Larson's attempt to use this link to circuitously undermine throwing as a potential explanation for very low torsion in early *Homo* does not hold.

## 6. Humeral torsion and throwing performance

Larson (2015: 204) states that very low humeral torsion does not support the capacity for high-speed throwing in *H. erectus*, noting that "even if low humeral torsion is good (in this regard), it doesn't necessarily mean that even lower torsion is better." We disagree. Many studies have shown that torsion levels are lower in the dominant, throwing arm (Pieper, 1998; Crockett et al., 2002; Osbahr et al., 2002; Reagan et al., 2002; Whiteley et al., 2006; Rhodes, 2007; Myers et al., 2009, 2011; Roach et al., 2012). Individuals with lower torsion store more elastic energy in the soft tissues of their shoulder and use that stored energy to produce faster throws (Roach et al., 2013; Roach and Lieberman, 2014; Fig. 5). This is especially true of the lowest torsion individuals (who fall within the *H. erectus* range), who store the most elastic energy and produce the fastest throws. Thus, the link between low torsion, including very low torsion, and throwing performance is theoretically sound and well supported.

We do not hypothesize that the capacity to produce high-speed throws rests on humeral torsion alone. We have proposed, and functionally tested, three critical aspects of upper body anatomy that enable high-speed throwing behavior to occur (i.e., a mobile waist, caudally rotated scapula, and low humeral torsion; Roach, 2012; Roach et al., 2013; Roach and Lieberman, 2014). According to current fossil data, these features first appear together in *H. erectus* (Roach, 2012; Roach et al., 2013). We have been careful to argue that this simply shows that the capacity for high-speed throwing appeared at this time. While we do not claim that low torsion is an adaptation for high-speed throwing, it is logical that the very low torsion in earlier hominins could be co-opted for throwing in *Homo*. Once the caudal rotation of the glenoid in *Homo* made elastic energy storage at the shoulder (and thus, high-speed throwing) possible, low humeral torsion could be exapted to improve throwing performance.



**Figure 5.** Humeral torsion and throwing velocity. Individuals with low humeral torsion store more elastic energy in the ligaments, tendons, and muscles crossing their shoulders. This additional stored energy is used to produce faster throws. Despite the complexity of the throwing motion, this single bony character accounts for approximately 20% of the variance in throwing velocity. Used with permission from Roach et al. (2013).

## 7. The evolution of the shoulder

The presence of laterally oriented, modern human-like shoulders in *H. erectus* remains the most parsimonious reconstruction. We agree with Larson (2015) that there may be a lag between when the scapula rotates caudally and when the clavicle fully elongates (Roach and Richmond, 2015). However, we have proposed that a short clavicle can easily be overcome by sitting slightly higher on the thorax (Roach and Richmond, 2015). This would allow the clavicle to extend beyond the smaller diameter superior rib cage and maintain normal, modern human orientation and function. This minor scapular elevation may be reflected in slightly higher superior clavicular curvature in short claviced individuals (Voisin, 2006a, b). Such increased superior curvature is present in the KNM-WT 15000 clavicles (Voisin, 2006b). Further fossil finds, as well as anatomical and functional studies of modern humans with short clavicles are needed to test this hypothesis more fully.

Early *Homo* had very low humeral torsion (Larson, 2007, 2009). Very low torsion in modern humans does not result in an inability to maintain bimanual overlap or manipulate objects. We have proposed that this is because any impediments to rotational ROM at the shoulder caused by low torsion are easily overcome by scapular mobility (e.g., increased protraction, horizontal flexion). In fact, Larson cites literature supporting our repositioning hypothesis showing that low torsion individuals move their scapulae to alter shoulder ROM as needed, and not permanently as her anterior shoulder model suggests (Borich et al., 2006; Thomas et al., 2010; Kibler et al., 2012). This allows individuals with low humeral torsion to maintain a laterally facing shoulder complex without suffering performance tradeoffs.

We agree with Larson that low humeral torsion in early *Homo* is interesting in the light of an apparent increase in tool use behaviors. Given that torsional development is thought to be related to an imbalance of muscular forces acting around the shoulder joint (Krahl, 1947; Cowgill, 2007), we propose that there are two credible alternative explanations for the persistence of low torsion in *Homo*: 1) early *Homo* did not engage in behaviors that generated strong internal shoulder rotation forces to modify the humerus (e.g., tool making/use was either infrequent or low intensity), or 2) external rotation forces due to throwing are sufficient to keep any modification of the dominant humerus due to stone tool use in check. While these hypotheses are not mutually exclusive, they do set up differing expectations. If tool use intensity is low, torsion levels should remain low in both arms, as they seemingly do in the australopithecids and early *Homo* (Larson, 2007, 2009). This low torsion in early *Homo* may have improved throwing performance, but it does not confirm that they were throwing. Instead, it simply suggests that tool use had minimal effects on upper body morphology. However, if another behavior provides the counter forces to offset forces due to knapping, we would expect to see higher torsion develop in the non-throwing arm where manipulatory forces dominate. This asymmetry in humeral torsion characterizes later *Homo* (Churchill, 1994; Churchill and Formicola, 1997; Larson, 2007, 2009; Churchill and Rhodes, 2009). We believe this indicates both that tool use activities intensify later in human evolution and that high-speed throwing is present and frequent enough to generate sufficiently large external rotation forces to maintain lower torsion in the dominant arm.

We agree with Larson that it is possible that throwing is not solely responsible and that another behavior is generating sufficient external shoulder rotation forces to alter humeral torsion. However, there are currently no credible alternatives. Further studies of the biomechanical underpinnings of many evolutionarily important actions of the upper body are needed (e.g., climbing, knapping, digging, hide scraping). However, none of these

behaviors are likely to result in high external rotation forces at the shoulder. Those motions that probably do generate large external shoulder rotation forces (e.g., rowing, arm wrestling) offer amusing alternatives, but lack evolutionary credibility. Given that throwing provides a credible explanation, links large external rotation forces at the shoulder and low humeral torsion (Roach et al., 2013; Roach and Lieberman, 2014), and that direct evidence of throwing behavior does exist in the later archaeological record (e.g., Bratlund, 1991; Thieme, 1997; Boeda et al., 1999; Roberts and Parfitt, 1999; Shea, 2006), it seems unreasonable to dismiss throwing out of hand.

In sum, our reconstruction of the *H. erectus* shoulder as modern human-like is the best-supported hypothesis. Our study of clavicular proportions in the Daasanach and how such proportions affect throwing performance supports this reconstruction. We have argued that high-speed throwing is an important behavior in human evolution (Roach, 2012; Roach et al., 2013; Roach and Richmond, 2015). The current fossil and biomechanical data suggest the capacity for high-speed throwing first appears nearly 2 million years ago (Roach, 2012; Roach et al., 2013). Therefore, the case for a modern human-like shoulder and throwing performance in *H. erectus* remains strong and unchanged.

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