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Tracing Prehistoric Activities: Musculoskeletal Stress Marker Analysis of a Stone-Age Population on the Island of Gotland in the Baltic Sea

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ABSTRACT The skeletal remains from the Middle Neolithic (2750–2300 BC) burial ground at Ajvide, Gotland, are analyzed in order to explore musculoskeletal patterns and to attempt to trace general as well as three specific prehistoric activities (archery, harpooning, and kayaking) that are likely to have been performed in this marine setting of fishing, hunting, and gathering. Scoring of muscular and ligament attachments is performed using the scoring method of Hawkey and Merbs ([1995] Int. J. Osteoarchaeol. *5*:324–338) for muskuloskeletal stress markers (MSM). The skeletal material consists of 24 male and 15 female adult individuals divided into three age groups: young (<24 years), middle (25–39 years), and old (>40 years). Thirty upper body MSM sites, on both the left and right sides, are scored and form the basis of the study. Results show that males most frequently have higher mean MSM scores than females. Bilateral asymmetry was noted as low in both sexes. Age proved to be a contributing factor to increased MSM scores, with a greater age-related increase in females. MSM patterns were analyzed statistically in muscle groups associated with the three investigated activities. Significant positive correlations were observed in male individuals in muscle groups associated with archery and to some extent harpooning, an indication that these activities would mainly have been performed by men. Correlations in kayaking muscles were not evidently consistent with the kayaking motion. Furthermore, the costoclavicular ligament, often referred to in connection with "kayaker's clavicle," showed no positive statistical correlation with the kayaking muscles. Am J Phys Anthropol 129:12–23, 2006.

In physical anthropology, the term "stress" is often being used to describe a wide variety of skeletal features, including the remodeling of bone at sites of tendon and ligament attachment as well as other skeletal changes of various sorts, such as tooth attrition, enamel hypoplasia, and bone modifications caused by malnutrition. General activity-related features, such as remodeling of bone at sites of tendon and ligament attachment as well as other skeletal changes, were previously examined (e.g., Merbs, 1983; Dutour, 1986; Kennedy, 1989; Hawkey and Merbs, 1995; Jurmain, 1999; Knüsel, 2000; Nagy, 2000; Stirland, 2000; Eshed et al., 2004).

In a broad sense, activity-related changes in the skeleton and teeth were described by Kennedy (1989, 1998). These traits, skeletal markers of occupational stress (MOS), include all changes in the skeleton and teeth said to be caused by physical activities of some kind. Kennedy (1989) mentioned the following: attrition in teeth and eburnation of articular surfaces (for further discussion on activity and joint changes, see also Jurmain, 1999), enthesopathic lesions, trauma, bone degeneration, and nutrition. Various activities affect the teeth and the skeleton. Examples include using teeth as tools and the asserted linked arthritic changes of the caput of the mandible (Merbs, 1983). Enlargement and remodeling of articular surfaces were also attributed to habitual behavior. So-called squatting facets on the talus and on the distal articular surface of the tibia were described by Finnegan and Faust (1974), Ubelaker (1979), and Boulle (2001a,b). Correspondence between activity patterns and osteoarthritic changes was discussed by Merbs (1983), Nagy and Hawkey (1993), Nagy (1997, 2000), and Jurmain (1999). Trauma to the lower spine, known as spondylolysis, was also discussed in relation to activity (Merbs, 1983, 1989, 2001; Turkel, 1989; Jurmain, 1999).

The muskuloskeletal stress markers (MSM) of Hawkey and Merbs (1995) are a subset of the markers of occupational stress of Kennedy (1989). In MSM analysis, focus is solely on the sites of muscle origin, muscle insertion, and ligament attachments. These are sometimes labeled entheses or enthesopathies and are described as: "A distinct skeletal mark that occurs where a muscle, tendon or ligament inserts onto the periosteum and into the underlying bony cortex" and which generates "hypertrophy of bone which forms a crest, ridge, mound or exostosis; pitting and furrowing" (Hawkey and Merbs, 1995). Entheses

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can have a variety of appearances, and Hawkey and Merbs (1995) did in fact distinguish between robusticity markers caused by “normal reaction of the skeleton to habitual muscle use and [which] reflect daily activities that produce rugged markings at the musculoskeletal site of attachments” and stress lesions, “a pitting or furrow into the cortex to the degree that it superficially resembles a lytic lesion.” It was suggested that the differences in appearance reflect a continuous response to overload (Hawkey and Merbs, 1995). During muscle stress, the bone cells react to support the increased strain, and the surface of the attachment is modified. Most entheses display a range of different forms: from a smooth or rough protrusion, i.e., excess bone formation, to a cavity of varying size and shape (loss of bone mass). A combination of protuberance and cavity was also noted. The cavities can be relatively evenly shaped in the form of a ridge, circle, or semicircle, or they can have a very rugged appearance.

In Scandinavia, studies of activity-related skeletal changes in prehistoric settings have been relatively few. Gejvall (1974) interpreted the observation of “poplitear pitting” in male individuals (i.e., a skeletal change at the origin of the medial head of the gastrocnemius muscle) as a result of paddling and/or harpooning. During et al. (1994) presented a plausible occupation-related pathology in the skeletal remains of what is believed to be the “helmsman” of the capsized 17th century man-of-war Vasa. In addition, Ahlström (2000) discussed general applications, potentials, and predicaments concerning activity-related skeletal change using Scandinavian examples.

The present study documents skeletal evidence of prehistoric activities that are specific to a certain site, and discusses the potentials and approaches of studies of activity-related changes. Initial examinations of Middle Neolithic skeletal material from Ajvide in southern Sweden revealed excessively and obliquely worn teeth and specifically marked muscular attachments. The pits at the medial gastrocnemius origin described by Gejvall (1974) proved to be especially apparent, particularly in male individuals (Molnar, 1997). The activity-related features observed in the material motivated further analysis of general patterns of prehistoric activities, as well as the assessment of bony changes associated with specific activities in Scandinavian settings.

The aim of this study was to assess prospects of identifying general levels of physical activity in skeletal remains through statistical testing of MSM scores obtained from the Ajvide material. In addition, further activity patterns are examined, such as sexual dimorphism, age-related enthesial change, and bilateral asymmetry. Statistical analysis of certain MSM patterns is furthermore performed in order to investigate potential relationships between MSM at Ajvide and plausible prehistoric activities, such as archery, kayaking, and harpooning or spearing.

THE PITTED WARE CULTURE SITE AT AJVIDE

The burial ground at Ajvide (2750–2300 BC) is situated on the island of Gotland, off the east coast of southern Sweden (Fig. 1). The site includes 73 excavated graves as of 2002, positioned approximately 10–50 cm below the ground surface in older culture layers. The geographical positioning of the graves indicates visible grave markers during the forming of the grave field, although none are currently present. Today, the site is situated approximately 1 km from the shoreline, but was to be found directly at the shoreline during the Middle Neolithic. The archaeofauna at Ajvide consists mainly of fish and seal, but also wild boar/pig, birds, dog, and fox (Rowley-Conwy and Storå, 1997; Storå, 2002). Stable isotope values (δ^{13}C) of the human remains support the faunal records and indicate a mainly marine protein intake (Lidén, 1996; Lindqvist and Possnert, 1997).

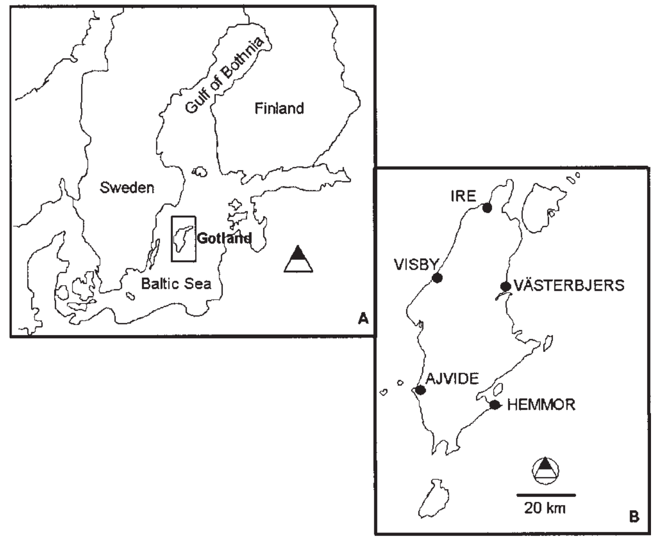

Fig. 1. A: Map of Sweden with Gotland in Baltic Sea. **B:** Gotland with Neolithic shore line and main Pitted Ware sites on the island.

Physical activity at Ajvide

Three human activities are essentially plausible at Ajvide: archery, harpooning, and kayaking. On the basis of the environment, material culture from the site, and subsistence patterns indicated by isotopic and archaeofaunal evidence, these three models of activity provide the foundation of the search for skeletal evidence in the individuals who would have performed them. A different set of muscles is used for each of these activities, and certain muscles are essentially needed to mechanically perform each movement. In some cases, mainly due to individual differences, there may be other additional muscles at work. However, the muscles used here are described as the primary working muscles for each activity (Jansson, personal communication; Jönhagen, personal communication; Berglund, personal communication; Logan and Holt, 1985).

Archery. Evidence of bows or the organic remains of arrows are absent in the cultural layers of Ajvide. However, considering the numerous arrowheads that have been recovered, it seems safe to conclude that archery was practiced at Ajvide. The bow and arrow may have been a means of hunting birds and possibly wild boar. Arrowheads are also common on other Pitted Ware Culture sites on Gotland (Janzon, 1974). Furthermore, organic remnants of both arrows and bows from the Mesolithic and Neolithic were recovered from Denmark and southern Sweden (Lindman, 1995).

Drawing the bowstring back by a right-handed archer involves mainly the supraspinatus and infraspinatus muscles (part of the rotator cuff) of the right humerus (string-arm). This is where modern archers tend to get inflammations. The flexors of the right hand would also be

TABLE 1. Muscles primarily in use in archery, kayaking, and harpooning[1]

	Left	Right
Deltoideus	A	K, H
Triceps	A	K
Rotator cuff		A, H
Flexors		A
Latissimus dorsi		K
Pectoralis major		H

[1] A, archery; K, kayaking; H, harpooning.

included in this movement. The deltoideus and triceps brachii are affected in the left arm, which would be the arm that extends the bow (bow-arm) (Table 1). Today, 7–10% of the population are thought to be left-handed, and consequently would use the opposite pattern when using a bow. In archery, however, not only handedness influences the technique used. Eye-dominance also plays an important role in aiming and shooting at a target (Janson, personal communication). In archery, it would be likely that the general movement and the asymmetry in the shoulder and arm muscles would be observable in the skeleton as well. Such a pattern would further be expected to be detectable in a skeletal population where archery is a known practice. This should result in high mean scores on the left side for the triceps and deltoideus muscles, and high scores for the supraspinatus, infraspinatus, and flexors on the right side.

Harpooning. The overhead throwing of a spear, javelin, or harpoon was most likely a common technique for seal hunting, either from a boat or perhaps directly on the ice (Storå, 2002). Both spearheads and harpoon points are common artifacts in graves and are frequently found in the culture layers at Ajvide. In harpooning or spearing, the throwing movement and therefore working muscles are similar to those of today's javelin throwers, who mainly use the deltoideus and pectoralis major and muscles of the so-called rotator cuff (or muscle-tendon cuff): teres minor, infraspinatus, supraspinatus, and subscapularis of the working arm (Jönhagen, personal communication) (Table 1).

Kayaking. Large amounts of fish remains and 30 bone fishhooks were recovered in the graves, as well as 379 hooks or hook fragments in the surrounding cultural layers of Ajvide (Norderäng, personal communication). There is no archaeological evidence of boats at Ajvide, but the physical remains of deep-sea fishing, as well as the marine environment, strongly indicate the use of boats or kayaks. There are a large variety of techniques for paddling a kayak or canoe, and it may be difficult to pinpoint the exact muscles used in prehistoric settings. Whether Ajvide hunters used one-bladed or two-bladed paddles cannot be known. However, if we assume that paddling occurred in association with seal hunting, where great speed and versatility were needed, it seems more likely that the one-bladed paddle was used to facilitate more rapid movements in the water. Furthermore, the stroke movements used for two-bladed and one-bladed paddles are quite different. Muscles used by today's kayak paddlers with a one-bladed paddle are for the right arm, mainly the latissimus dorsi, triceps, and deltoideus, the left being used merely for steering (Berglund, personal communication; see also Logan and Holt, 1985) (Table 1). MSM from both sides were analyzed statistically and evaluated using the same approach as with harpooning muscles.

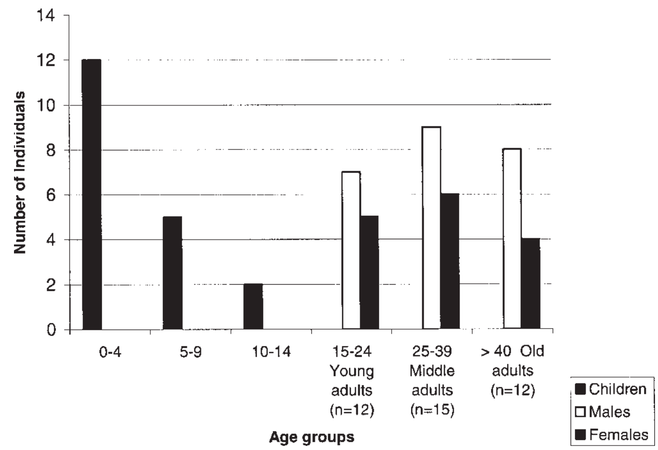

Fig. 2. Age and sex distribution at Ajvide.

According to Hawkey and Merbs (1995), paddling also leads to what is termed "kayaker's clavicle," i.e., changes at the attachment of the costoclavicular ligament that were noted in populations living in coastal environments, similar to those at Ajvide. Subsequently, this feature was attributed to the paddling or rowing of kayaks, and in most of these circumstances there was archaeological or historical evidence of kayaks being used (Hawkey and Merbs, 1995). Reviewed investigations of present-day kayakers and their movement patterns, however, do not mention this ligament as being especially affected during kayaking (Logan and Holt, 1985; Kameyama et al., 1999; Flodgren et al., 1999).

Kameyama et al. (1999) reported on 417 present-day canoeists who experienced lumbago, some with spondylolysis and spondylosis deformans, as well as shoulder pain, elbow pain, and wrist pain due to the strain placed on these areas during the paddling of a canoe or kayak. Spondylolysis is believed to be present in approximately 3–7% of today's general population. It is considered to be caused by the combination of a genetic predisposition triggered by stress in connection to activities of different sorts, leading to microtrauma (Turkel, 1989). In certain athletes, e.g., weightlifters and gymnasts, the incidence varies between 23–62%. It occurs 2–4 times more often in men than in women, and is often found in adolescents leading an active life (Weinberg, 2001; Moeller and Rifat, 2001).

MATERIALS

At Ajvide, most individuals were placed in single graves, although four double graves and two triple graves were also recovered. Sixty-nine graves found at Ajvide were analyzed for the present study, using methods according to Buikstra and Ubelaker (1994). Altogether, 18 females, 28 males, 14 children (aged 2–∼13), and 5 infants (0–2) were identified. Average age-at-death was estimated at 31.6 for females and 34.5 for males. The remains from four graves could not be aged or sexed. The skeletal material was generally in fairly good condition, and 24 adult male and 15 adult female individuals were sufficiently well-preserved and therefore chosen for MSM analysis. These individuals were also divided into three age groups: <24, 25–39, and >40 years (young, middle-aged, and old adults) (Fig. 2).

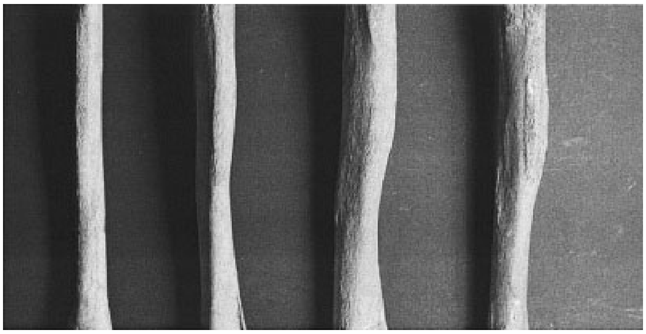

Fig. 3. MSM scores at the insertion of the deltoideus muscle on the humerus. Scores from left to right: 0, no expression or faint roundedness; 1, notable unevenness, pitting, or furrowing; 2, higher degree of well-defined skeletal change with furrowing and pitting, with rugged appearance; 3, extensive and clearly defined irregular surface, crest, ridge, pitting, or combination of both.

METHODS

Enthesial skeletal alterations have been described using a variety of expressions: enthesopathy or enthesophyte (Jurmain, 1999; Stirland, 2000); "activity-induced pathologies" (Merbs, 1983); "stress-induced remodeling" (Wilczak, 1998); or simply "muscle markings" (Robb, 1998). Throughout this paper, the term MSM will be used in association with the scoring method of Hawkey and Merbs (1995) and whenever these actual scores are discussed. The wider term "enthesial change" or simply "attachments" will be used in a more descriptive mode when discussing changes in general, since both muscles (origins and insertions) and ligaments attach to the bone. Given that the term "enthesopathy" was suggested for enthesial changes caused by a disease process, this term is avoided (Resnick and Niwayama, 1983).

Basic features of ocular scoring of enthesial data used by researchers are similar and are based on morphology (e.g., Hawkey and Merbs, 1995; Nagy, 2000; Ahlström, 2000; Eshed et al., 2004). Methods of measuring entheses were also employed (Wilczak, 1998).

The visual scoring method of Hawkey (1988) and Hawkey and Merbs (1995), with modifications by Nagy (2000), was used in this study. Subsequently, no distinction was made between the robusticity markers and stress lesions in Hawkey (1988) and Hawkey and Merbs (1995), as the different appearances represent a continuum rather than two different types of expressions (Hawkey and Merbs, 1995; Nagy, 2000). Skeletal markers were scored from 0–3.5 at 0.5 intervals, 3.5 being the most distinct (Fig. 3). Absent or eroded sites were not scored and subsequently not included in statistical analyses. No cases of exostoses were recorded at any of the MSM sites in the Ajvide material.

The focus of this study is on 30 upper limb MSM sites from six skeletal elements (clavicula, scapula, humerus, radius, ulna, and phalanges of the hand). They include 17 muscle insertions, 10 muscle origins, and 3 ligament attachments. One single attachment of the lower limb, the origin of the medial gastrocnemius on the femur, is also included in association with harpooning and kayaking movements. (For detailed descriptions of muscle and ligament attachments and their specific skeletal sites, see Gray, 1995; Platzer, 1992; Stone and Stone, 1997.)

Statistical methodology

MSM scores consist of ordinal data, and strictly speaking, the use of modes or medians in statistical processing would mathematically be more appropriate than the arithmetic mean. However, since the MSM scores at Ajvide are symmetrically distributed, the arithmetic mean is used throughout this paper as the measure of central tendency. The scoring of entheses between 0–3.5 implies even steps between different scores, even though they are not measurably so. However, the aim is evidently that each 0.5 step is equal in size, and after some experience with MSM scoring, variations in range of each step ought to be acceptable. Howell (2002) stated that "the underlying measurement scale is not crucial in our choice of statistical techniques. Obviously, a certain amount of common sense is required in interpreting the results of these statistical manipulations."

General MSM patterns. Frequencies of MSM observations in each scoring category were estimated for males and females, as well as frequencies of observations of each category in each age group in both males and females. Mean MSM scores for males and females (left and right sides in each age group) were also calculated.

Further statistical analysis was performed in order to investigate: 1) differences between the sexes in combined left and right mean scores for each MSM site; 2) bilateral asymmetry in males and females in the three age groups; and 3) bilateral asymmetry for each MSM for both males and females.

For the first test, a two-sample Wilcoxon rank sum (Mann-Whitney) test was used. For the second and third tests, a Wilcoxon matched-pairs signed-ranks test was used. Both tests were performed using STATA 8.0 computer software.

Bilateral asymmetry was examined for each sex by calculating (left MSM mean score/right MSM mean score) $\times$ 100 (Hall, 1982; Eshed et al., 2004). Results higher than 100 indicate left-hand dominance, and lower than 100, right-hand dominance. Sexual dimorphism was also calculated in percentages, where the difference between male and female MSM mean scores was calculated and divided by the male mean and then multiplied by 100 (Hall, 1982).

Tests made in different age groups were in some cases a predicament, since some age categories contain few observations, especially on individual sides. This may skew the results of mean scores in certain age groups as well as mean scores for individual skeletons. In some cases, individuals with few observations were excluded from analysis. Bilateral asymmetry tests only included individuals with paired left and right skeletal elements. When needed, adjustments were made for multiple testing to avoid false significance, using Bonferroni's correction. Statistical significance was determined at the 0.05 level in all tests.

Specific activities. The corresponding muscles for the three suggested activities (archery, harpooning, and kayaking) were analyzed for males and females for both sides, using reliability tests and correlations in the effort to identify collaborating muscles. Cronbach's alpha was employed in all reliability tests, and Spearman's rank-order correlation coefficient was used for correlation analyses, using SPSS for Windows statistical software, version 11.5. Accepted alpha values were set at 5%.

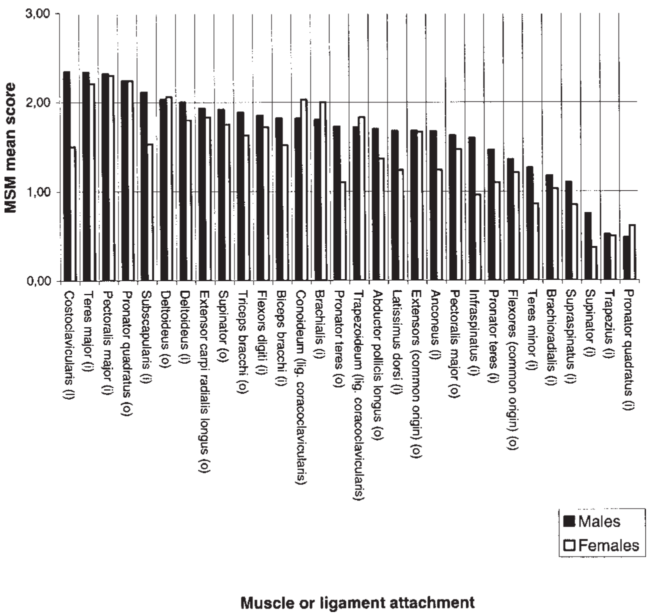

Fig. 4. Rank ordering of mean MSM scores at Ajvide. o, muscle origin; i, muscle insertion; l, ligament attachment.

RESULTS

General MSM patterns

Rank ordering of MSM resulted in highest scores for the costoclavicular ligament in males. However, the teres major and pectoralis major received nearly as high mean scores. Females also have high means for the teres major and pectoralis, although not for the costoclavicular ligament (Fig. 4).

The total mean for upper body MSM scores for males ($n = 24$) is 1.67, and for females ($n = 15$), 1.45 (Table 2). Means are generally higher in males than in females (Fig. 5). However, results of the Mann-Whitney test between male and female MSM scores for combined sides show that only two sites exhibited significantly higher mean scores for males, i.e., the anconeus and infraspinatus. When adjusted for multiple testing, to avoid false significance (using Bonferroni's correction), no significant differences were noted between sexes (Fig. 5).

Figure 6 shows the distribution of MSM scores for males and females. The scores display a separation of males from females in the sense that females have a larger proportion of lower scores, and males show the opposite image. The pattern is not true, however, for the older age groups, where females and males display similar MSM patterns (Fig. 6). Figure 7 presents the frequencies of MSM scores in each scoring category, with larger frequencies of high scores in the older age group for both males and females. None of the sites revealed significantly higher scores for females than males.

Bilateral asymmetry proved to be low overall, and when pooled, no significant differences were noted between the sexes in the different age groups (Fig. 8). The total upper body mean scores are 1.67 for males on the left side and 1.66 on the right side, and 1.45 for both sides in females. Bilateral asymmetry in individual skeletons resulted in 75% right-hand dominance in males and 85% in females. Two female individuals showed no dominance on either side (Table 3).

Tests for bilateral asymmetry in males and females resulted in significant differences for three sites in males (the conoideum part of the coracoclavicular ligament, the extensor carpi radialis longus origin, and the common origin of the flexores) and significant differences for four sites in females (the trapezius and brachialis insertions and the origin of the deltoideus and abductor pollicis longus) (Table 4).

Specific activities

Archery. Reliability tests were performed of the archery-related muscle groups for the right and left arm, respectively. The scores for the infraspinatus, supraspinatus, teres minor, and subscapularis proved not to be symmetrically distributed. These muscles, however, exhibited high alpha values (left, 0.88; right, 0.85) and were highly correlated, which would be expected, as they work together and are generally referred to as the "rotator cuff." These MSM scores were therefore pooled, and their combined means were used in statistical analyses. When pooled, the data proved to be symmetrically distributed for both sexes on the right side. For the left side, females displayed a symmetric distribution, while males did not. In males, the distribution was positively skewed, in all probability owing to generally lower mean scores on the left side compared to the right in these muscles (see below).

Muscles principally in use in the left arm (or bow-arm) in archery are the deltoideus and the triceps bracchi (Table 1). On the left side in males, a significant correlation (r_s) was found for the origin of the deltoideus and triceps, while females showed no significant correlation between the two muscles (excluding the left side between the origin and the insertion of the deltoideus muscle). This correlation was also evident for males on the left and right sides (Table 5). Mean scores for these muscles were also higher on the left arm than the right in males, and the opposite in females (Fig. 9a).

The muscles particularly used in the right arm (or string-arm) by the right-handed archer are the rotator cuff and flexors. Males exhibited significant correlations in these muscle groups on both sides, but these correlations were stronger on the right side. Females revealed no significant correlation between the rotator cuff and flexors on either side (Table 5). For these muscles, means were higher on the right side for both males and females (Fig. 9b).

Harpooning. Reliability tests were employed for the deltoideus, rotator cuff, and pectoralis major, which for females resulted in a Cronbach's alpha 0.85 for the left arm and 0.74 for the right, and for males, 0.75 for the left arm, and 0.76 for the right arm. Significant correlations were found in both males and females. In females, significant correlations were noted in the harpooning muscles on both sides, and were stronger, in fact, on the left (Table 6). No unambiguous evidence of harpooning was visible. Such evidence may, however, be indicated in males by the better-correlated muscle attachment scores on the right side than on the left. Females display a more symmetric correlation pattern in harpooning muscles of the left and right sides.

Correlation tests were also performed between harpooning muscles and the gastrocnemius mediale, a site suggested by Gejvall (1974) to be affected during harpooning and/or paddling. At Ajvide, this site is usually more marked in males, but scores as high as 2.5 were also noted

TABLE 2a. Mean scores for each individual and side, males[1]

Males, grave no.	Left side	n	Right side	n	Total score	n
6	1.38	8	1.30	5	1.34	13
25	1.97	23	1.54	12	1.76	35
30a	1.29	19	1.38	8	1.34	27
38b	2.00	15	1.63	20	1.82	35
51	0.50	1	1.25	8	0.88	9
63	1.38	17	1.27	30	1.33	47
70	1.48	29	1.52	30	1.50	59
Total YAM	1.50	112	1.43	113	1.47	225
4	1.57	30	1.93	7	1.75	37
37	1.46	12	1.77	13	1.62	25
38a	1.40	20	1.58	13	1.49	33
45	1.73	24	1.59	27	1.66	51
49	1.64	22	1.60	21	1.62	43
54	1.20	30	1.18	30	1.19	60
56	2.67	3	2.00	2	2.34	5
59	1.54	13	1.80	30	1.67	43
66	1.63	27	1.48	25	1.56	52
Total MAM	1.51	181	1.53	168	1.52	349
7	2.10	25	2.24	21	2.17	46
14	1.59	27	1.72	25	1.66	52
19	1.84	29	2.07	28	1.96	57
23a	1.96	23	1.82	19	1.89	42
24	2.00	8	2.25	12	2.13	20
58	1.90	29	2.03	19	1.97	48
61	2.41	11		0	2.41	11
67	2.19	21	2.09	17	2.14	38
Total OAM	1.90	173	2.00	141	1.95	314
Total all age groups	1.67	466	1.66	422	1.67	888

[1] YAM, young adult males; MAM, middle adult males; OAM, old adult males. Age groups: young adults, <24 years; middle adults, 25–39 years; old adults, >40 years. n, number of MSM available. A few individuals (such as 51, 56, and 61) have a small number of observations, which may skew mean score results.

TABLE 2b. Mean scores for each individual and side, females[1]

Females, grave no.	Left side	n	Right side	n	Total score	n
1		0	0.38	4	0.38	4
2	1.35	29	1.36	29	1.36	58
5	1.81	25	2.03	16	1.92	41
28	0.69	30	0.75	25	0.72	55
48	1.63	4	1.5	8	1.57	12
Total YAF	1.22	88	1.23	82	1.23	170
18	1.04	12	1.18	11	1.11	23
29a	1.75	14	1.73	21	1.74	35
36	1.59	29	1.69	28	1.64	57
39	1.46	23	1.38	28	1.42	51
41	1.36	27	1.41	26	1.39	53
62	1.32	29	1.32	24	1.32	53
Total MAF	1.41	134	1.43	138	1.42	272
13	2.03	21	1.75	22	1.89	43
17	2.17	12	1.95	11	2.06	23
53	1.77	25	2.03	28	1.90	53
57		0	1.50	6	1.50	6
Total OAF	1.98	58	1.84	67	1.91	125
Total all age groups	1.45	280	1.45	287	1.45	567

[1] YAF, young adult females; MAF, middle adult females; OAF, old adult females. Age groups: young adults, <24 years; middle adults, 25–39 years; old adults, >40 years. n, number of MSM available. A few individuals (such as 1, 48, and 57) have a small number of observations, which may skew mean score results.

in females. Also, the costoclavicular ligament was explored in association with the rotator cuff, deltoideus, and pectoralis major muscles. Neither the medial gastrocnemius nor the costoclavicular ligament proved to be significantly correlated with any of the harpooning muscles.

Kayaking. Reliability tests of the kayaking muscles (the latissimus dorsi, triceps brachii, and deltoideus origin and insertion) resulted in a Cronbach's alpha of 0.79 for the left side and 0.75 for the right side in females, and 0.73 for both sides in males. Correlations (r_s) were found in the kayaking muscles for both sexes (Table 7). Among females, strong significant correlations were found on the left side between the deltoideus and the latissimus dorsi, and on the right side between the latissimus dorsi and triceps brachii. Again, the triceps and deltoideus showed significant correlation on the left side for males. No statistically significant correlation (apart from the previously mentioned intracorrelation between the origin and insertion of the deltoideus) was found on the right side in males. Thus the MSM patterns provide no support for kayaking movements using a one-bladed paddle.

High mean MSM scores at the costoclavicular site (kayaker's clavicle) were noted at Ajvide, especially among males. This was the highest mean score noted of all MSM in males, with a mean of 2.34 (17th highest in females, with a mean of 1.5) (Fig. 4). Mean scores for the gastrocnemius mediale ("popliteal pitting") were 2.7 for males and 1.5 for females.

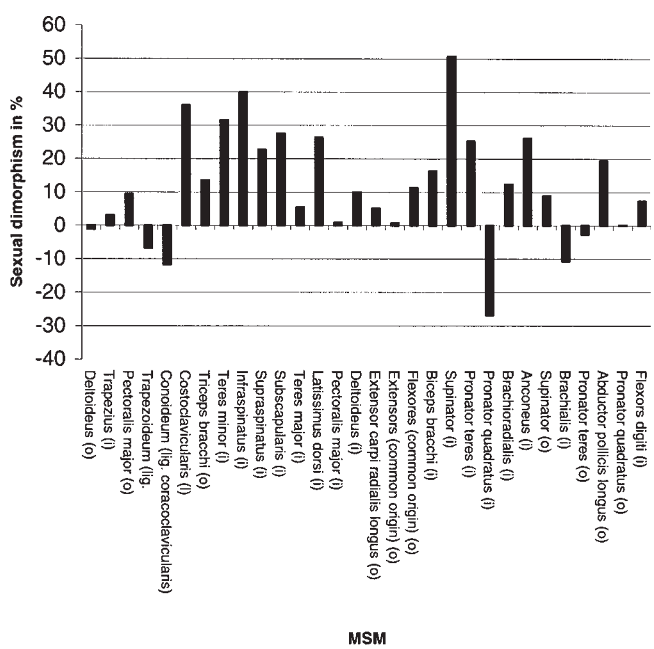

Fig. 5. Relative sexual dimorphism. Two MSM sites showed significant differences at 0.05 level using Wilcoxon two sample rank-sum test: infraspinatus, $P = 0.0453$ (males; n = 4, females n = 5); anconeus, $P = 0.0402$ (males, n = 13; females, n = 9). Sexual dimorphism calculated by difference between mean MSM scores for males and mean MSM scores for females/mean MSM scores for males × 100 (Hall, 1982; Eshed et al., 2004).

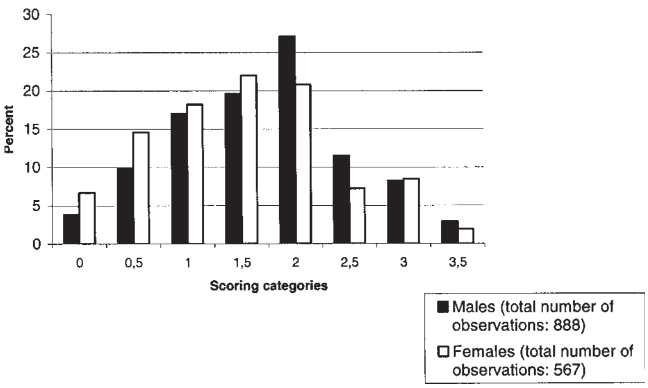

Fig. 6. Frequencies of observations in each scoring category.

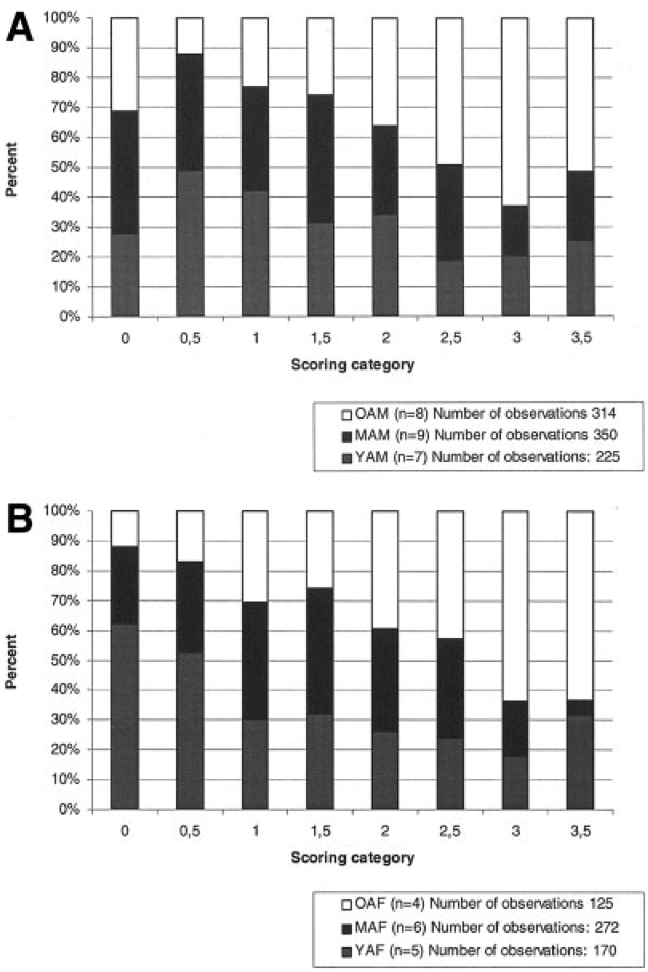

Fig. 7. **A:** Frequencies of MSM scores in each scoring category and age group. YAM, young adult males; MAM, middle adult males; OAM, old adult males. **B:** Frequencies of MSM scores in each scoring category and age group. YAF, young adult females; MAF, middle adult females; OAF, old adult females.

When examining the latissimus dorsi, triceps, and deltoideus (i.e., kayaking muscles) and the costoclavicular ligament, the costoclavicular site in effect showed negative correlation with the other muscles, and even a significant negative correlation with the deltoideus among males. Also, the gastrocnemius mediale was interrelated with the kayaking muscles, in order to evaluate a possible connection between kayaking movements and this attachment. The gastrocnemius mediale also proved to be negatively correlated with some of the kayaking muscles; however, no correlations were significant.

Spondylolysis is present in 15.2% of adult individuals at Ajvide (6 males, 21.4%; 1 female, 5.6%). All cases but one are symmetrical, and this feature was noted in all age groups.

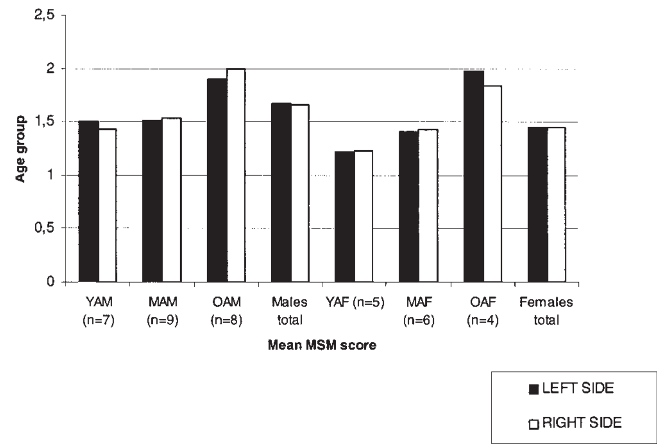

Fig. 8. Bilateral asymmetry. Abbreviations as in Figure 7.

TABLE 3. Bilateral asymmetry total upper body mean MSM score[1]

	Males			Females		
Age group	Grave no.	a	n	Grave no.	a	n
Young adults	25	108	7	2	98	28
	30a	71	7	5	88	16
	38b	112	14	28	89	25
	63	94	17	48	87	4
	70	97	29			
Middle adults	4	96	7	18	89	11
	37	89	10	29a	89	10
	38a	95	7	36	95	28
	45	104	22	39	103	22
	49	107	17	41	91	24
	54	86	30	62	100	23
	59	89	13			
	66	110	24			
Old adults	7	89	18	13	103	17
	14	93	24	17	100	8
	19	89	27	53	87	23
	23a	93	14			
	24	89	8			
	58	97	19			
	67	96	11			

[1] n, number of paired MSM sites. a is calculated by (mean left MSM scores/mean right MSM scores × 100). Values lower than 100 indicate right-side dominance (Hall, 1982; Peterson, 1998; Eshed et al., 2004).

DISCUSSION

For several reasons, the Ajvide study provides motivation to consider the scoring of MSM and related features. As would generally be anticipated, MSM mean scores

TABLE 4. Bilateral asymmetry in males and females for mean of each MSM[1]

	Males					Females				
	a	n	*p*	l	r	a	n	*p*	l	r
Deltoideus (o)	102	12	0.8591	(17)	(14)	138	7	0.7023	(9)	(9)
Trapezius (i)	106	9	0.9165	(16)	(16)	**44**	6	**0.0253**	(9)	(8)
Pectoralis major (o)	92	8	0.1447	(12)	(8)	74	6	0.2812	(9)	(9)
Trapezoideum (coracoclavicular ligament)	92	10	0.1508	(14)	(16)	100	7	0.8575	(9)	(9)
Conoideum (coraclavicular ligament)	**84**	9	**0.0336**	(14)	(16)	87	6	0.1573	(8)	(9)
Costoclavicularis (l)	92	12	0.1677	(18)	(14)	104	9	1.0	(10)	(10)
Triceps bracchi (o)	97	11	0.7055	(15)	(16)	117	9	0.8003	(10)	(9)
Teres minor (i)	110	5	0.5637	(10)	(9)	92	4	0.8514	(5)	(6)
Infraspinatus (i)	93	3	0.3173	(11)	(9)	120	5	0.3173	(6)	(7)
Supraspinatus (i)	100	4		(10)	(10)	100	2		(5)	(5)
Subscapularis (i)	97	8	0.4458	(13)	(13)	93	7	0.3173	(8)	(8)
Teres major (i)	112	9	0.5692	(17)	(11)	106	8	0.6283	(9)	(10)
Latissimus dorsi (i)	115	10	0.3601	(17)	(11)	89	9	0.4888	(9)	(10)
Pectoralis major (i)	98	9	0.5637	(17)	(11)	92	10	0.1882	(10)	(10)
Deltoideus (i)	111	12	0.8981	(16)	(14)	**80**	9	**0.0158**	(11)	(9)
Extensor carpi radialis longus (o)	**84**	10	**0.0082**	(17)	(13)	101	4	1.0	(8)	(7)
Extensors (common origin) (o)	97	9	0.6547	(16)	(12)	100	5	1.0	(7)	(8)
Flexores (common origin) (o)	**81**	12	**0.0150**	(16)	(16)	96	8	0.3173	(9)	(8)
Biceps bracchi (i)	102	11	0.4788	(17)	(16)	105	11	0.8518	(12)	(12)
Supinator (i)	110	5	0.6225	(13)	(15)	50	4	0.6547	(11)	(12)
Pronator teres (i)	102	9	0.5948	(16)	(13)	104	8	1.0	(11)	(10)
Pronator quadratus (i)	33	3	0.5637	(15)	(12)	58	3	0.1573	(7)	(11)
Brachioradialis (i)	108	4	0.3173	(10)	(10)	116	6	0.3173	(8)	(9)
Anconeus (i)	105	12	0.7754	(16)	(18)	120	9	0.1797	(10)	(11)
Supinator (o)	98	15	0.8830	(19)	(19)	131	11	1.0	(12)	(12)
Brachialis (i)	110	16	0.9104	(20)	(19)	**88**	13	**0.0484**	(13)	(13)
Pronator teres (o)	119	11	0.1396	(18)	(15)	98	10	0.1783	(10)	(12)
Abductor pollicis longus (o)	92	13	0.3005	(17)	(18)	**72**	10	**0.0162**	(11)	(12)
Pronator quadratus (o)	104	12	0.7162	(16)	(17)	112	11	0.4902	(12)	(11)
Flexors digiti (i)	103	17	0.5637	(23)	(21)	93	10	0.1573	(12)	(11)

[1] (o), origin; (i), insertion; (l), ligament attachment. a is bilateral asymmetry calculated by (mean left MSM scores/mean right MSM scores) $\times$ 100. Values lower than 100 indicate right-side dominance (Hall, 1982; Peterson, 1998; Eshed et al., 2004). n, number of individuals with paired skeletal elements. *p* value calculated with Wilcoxon signed-rank test on mean scores. l, left; r, right sides. Numbers in bold indicate significant bilateral asymmetry.

TABLE 5. Statistical analysis using Spearman's rank-order correlation coefficient: archery muscles[1]

	Bow-arm muscles: left side			Bow-arm muscles: right side		
	Deltoideus o	Deltoideus i	Triceps	Deltoideus o	Deltoideus i	Triceps
Males						
Deltoideus o	1			1		
Deltoideus i	$r_s(13) = 0.72^{**}$	1		$r_s(12) = 0.86^{**}$	1	
Triceps	$r_s(15) = 0.52^{*}$	ns	1	ns	ns	1
Females						
Deltoideus o	1			1		
Deltoideus i	$r_s(12) = 0.78^{*}$	1		ns	1	
Triceps	ns	ns	1	ns	ns	1

	String-arm: left side		String-arm: right side	
	Flexors	Rotator cuff	Flexors	Rotator cuff
Males				
Flexors	1		1	
Rotator cuff	$r_s(12) = 0.65^{*}$	1	$r_s(13) = 0.84^{**}$	1
Females				
Flexors	1		1	
Rotator cuff	ns	1	ns	1

[1] o, origin; i, insertion. All tests were two-tailed.
*Significant at 0.05 level.
**Significant at 0.01 level.

proved higher for males than females in most cases. This feature seems to be a general pattern, and was observed in several MSM studies (Hawkey and Merbs, 1995; Peterson, 1998; Wilczak, 1998; Nagy, 2000; Eshed et al., 2004). Some of the dissimilarities observed between males and females may well have derived from muscular activity patterns that were distinctive to gender. MSM patterns at Ajvide furthermore indicate some level of diverging work-

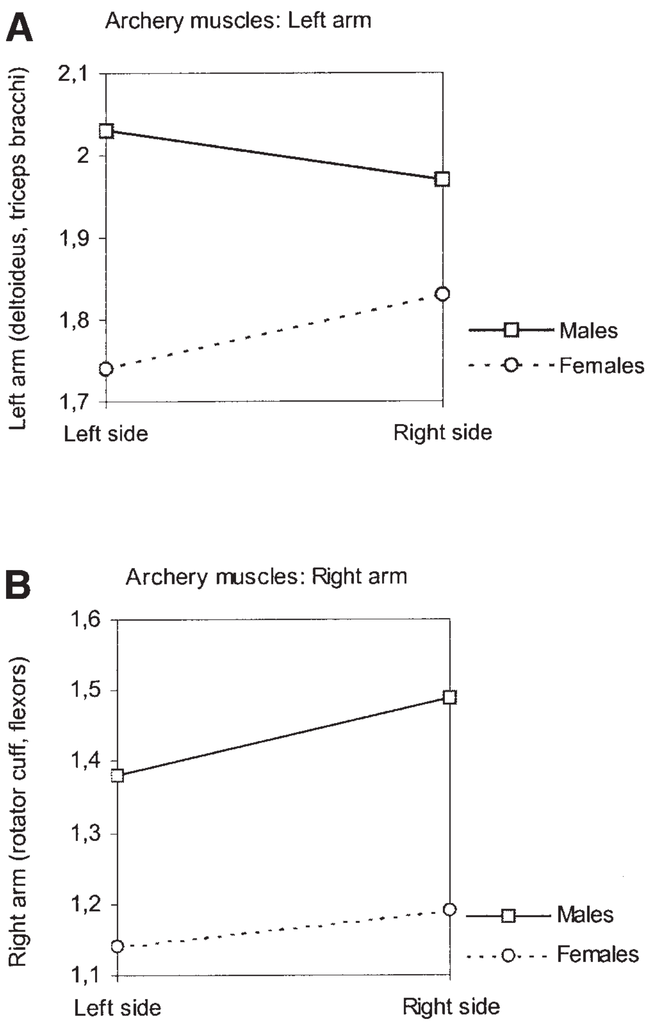

Fig. 9. **A:** Mean MSM scores of bow-arm muscles, showing higher mean scores on left side in males, and higher mean scores on right side in females. **B:** Mean MSM scores of string-arm muscles, showing higher means scores on right arm for both males and females.

load between the sexes in each of the three activity patterns under study.

The slightly raised incidence of spondylolysis in males could also be related to a more specific activity pattern compared to females. Among the Sadlermiut Inuits, Merbs (1983) noted a 33% prevalence in males and 13% in females, a feature attributed to specific activity patterns. This frequency, however, is somewhat higher than at Ajvide, where 21.4% of males (six individuals) and 5.6% of females (one individual) displayed spondylolysis.

General side asymmetry is absent or modest in both sexes, and shows a slight opposite image in men and women in the old age group (Fig. 8).

Age proved to be a contributing factor to increased enthesial reaction (Figs. 7, 8). Both sexes show higher MSM scores in older age groups. Young females display generally lower MSM scores, indicating lower levels of physical activity than in young males. The increase of muscular load in the old age group, however, seems to be more pertinent among females (Figs. 6, 8). A conceivable explanation for these gender and age-related differences is not only a division of labor between the sexes, but also of changing workloads in different time periods of a person's life. If not taken into consideration, the increase of enthesial reactions with age may limit the prospects of detailed interpretations of prehistoric specific activities based on MSM data.

Statistical results from the specific activities studied suggest that in males, archery muscles show a relationship and even a pattern of stronger affiliation between the explicit muscles on their individual side. The bow-arm muscles show a significant correlation on the left, and the string-arm muscles show a significant correlation on both sides, though stronger on the right side. The pattern is consistent with archery and clearer in males, an indication that archery conceivably had been performed mainly by men (Table 5, Fig. 9). Enthesial studies in connection with archery in prehistoric skeletal materials were previously performed with varying results (Dutour, 1986; Peterson, 1998). Dutour (1986) concluded that the studied muscle attachments pointed to the use of the bow and arrow in the Sahara, while Peterson (1998) did not find MSM evidence for archery in Jordan and Palestine. However, different muscle groups were used in the two studies, as well as in this one.

In males, the significant correlations between harpooning muscles, especially on the right side, suggest that explicit harpooning muscles were working together in the right arm, harpooning and/or spearing being a plausible cause. In females, no indications were apparent of spearing movements, but rather of a more bilateral use of these muscles (Table 6).

MSM correlation patterns supportive of today's kayaking movements are unclear. This may be because these movements might have been performed in a variety of ways. Single- or double-bladed paddles may have been used, in which case the muscles would be affected differently. Hawkey and Merbs (1995) described different possible patterns of rowing or paddling among the Thule Inuit of Canada. Women rowed umiaks with oars, and the men used single-man kayaks to chase and harpoon prey with great intensity (Hawkey and Merbs, 1995). Females at Ajvide, again, displayed more bilaterally oriented correlations than males in the kayaking muscles. However, the seal-hunting strategies at Ajvide may have been quite different. The archaeofaunal evidence suggests that most of the seal hunting took place in the immediate area during winter or early spring at the breeding grounds on the ice (Storå, 2002). At Ajvide, the intense paddling required for chasing seals at sea may not have been necessary.

It may not be surprising that some specific activities are not detectable through MSM analysis. However, the reason for this need not be methodological, but rather may be due to the large variety of activity patterns, and the mode in which they were performed.

It would be unrealistic to compare Stone Age hunters and fishers (and gatherers) with elite athletes of today. Undoubtedly, prehistoric people practiced their ability to use a bow and arrow, a spear, or a harpoon, or the handling of a boat, to become skilled and successful hunters. It may be questionable whether their amount of practice can be weighed against that of professional athletes who train several hours per day. An elite sportsperson would be engaged in movement patterns that involve certain muscle groups, which subsequently lead to higher muscle

TABLE 6. Statistical analysis using Spearman's rank-order correlation coefficient: harpooning muscles[1]

	Deltoideus o	Deltoideus i	Rotator cuff	Pectoralis major o	Pectoralis major i
Left arm					
Males					
Deltoideus o	1				
Deltoideus i	$r_s(13) = 0.72$**	1			
Rotator cuff	ns	ns	1		
Pectoralis major o	ns	ns	ns	1	
Pectoralis major i	ns	ns	$r_s(14) = 0.64$*	ns	1
Females					
Deltoideus o	1				
Deltoideus i	$r_s(9) = 0.78$*	1			
Rotator cuff	ns	ns	1		
Pectoralis major o	ns	ns	$r_s(9) = 0.84$**	1	
Pectoralis major i	$r_s(9) = 0.76$*	$r_s(10) = 0.86$*	ns	ns	1
Right arm					
Males					
Deltoideus o	1				
Deltoideus i	$r_s(12) = 0.86$**	1			
Rotator cuff	ns	$r_s(13) = 0.66$*	1		
Pectoralis major o	ns	ns	ns	1	
Pectoralis major i	$r_s(9) = 0.76$*	$r_s(11) = 0.79$**	$r_s(11) = 0.73$*	ns	1
Females					
Deltoideus o	1				
Deltoideus i	ns	1			
Rotator cuff	ns	ns	1		
Pectoralis major o	$r_s(9) = 0.67$*	ns	$r_s(7) = 0.8$*	1	
Pectoralis major i	ns	ns	ns	ns	1

[1]o, origin; i, insertion. All tests were two-tailed.
*Significant at 0.05 level.
**Significant at 0.01 level.

TABLE 7. Results from statistical analysis using Spearman's rank-order correlation coefficient: kayaking muscles[1]

	Deltoideus o	Deltoideus i	Triceps	Latissimus dorsi
Left arm				
Males				
Deltoideus o	1			
Deltoideus i	$r_s(13) = 0.72$**	1		
Triceps	$r_s(15) = 0.52$*	ns	1	
Latissimus dorsi	ns	ns	ns	1
Females				
Deltoideus o	1			
Deltoideus i	$r_s(9) = 0.78$*	1		
Triceps	ns	ns	1	
Latissimus dorsi	ns	ns	$r_s(9) = 0.81$**	1
Right arm				
Males				
Deltoideus o	1			
Deltoideus i	$r_s(12) = 0.86$**	1		
Triceps	ns	ns	1	
Latissimus dorsi	ns	ns	ns	1
Females				
Deltoideus o	1			
Deltoideus i	ns	1		
Triceps	ns	ns	1	
Latissimus dorsi	ns	ns	$r_s(9) = 0.75$*	1

[1]o, origin; i, insertion. All tests were two-tailed.
*Significant at 0.05 level.
**Significant at 0.01 level.

mass in that part of the body. This may, to a certain extent, also have been the case in prehistoric populations. A more plausible suggestion would be a varied pattern of muscle and skeletal loads, which would be recognizable in MSM patterns. A preferred present-day assembly for comparison would perhaps be a group of people engaged in a medium rather than high level of physical activity. Technique is another important issue, and the refined techniques used today by athletes may not have been the same in earlier times. For example, some researchers (Dutour, 1986; Hawkey and Merbs, 1995) mentioned the biceps as a working muscle on the string-arm. In today's archers, this is considered a "deadly sin" (Janson, personal communication).

It is of some concern that the same muscles are used for the left arm in archery and the right arm in kayaking, and partly in the harpooning movement (Table 1). Assuming the same individuals performed these activities, the amount of muscle activity and the differences that are visible may well be obscured by the multiple activity patterns. Another issue is of course dexterity, where it can only be assumed that approximately 90% (as today and as recorded in historical times) were right-handed. However, Knüsel (2000) noted that dexterity can be difficult to trace in skeletal materials.

Even though relationships have been documented between explicit muscle groups and the physical movements of archery or harpooning, the present study provides only plausible evidence that these activities are in fact the actual causes for these particular enthesial changes. The same muscles were of course used for a variety of activities, and to single out one activity as the sole cause of a strained muscle would be speculative. Fishing (netting), preparation of hides or tendons, or pulling or pushing heavy loads such as boats are all feasible activities in this environment. However, other activities not associated with subsistence, and to archaeologists and anthropologists fairly "invisible," may well have affected muscle strength, e.g., games and sports. Most likely, both work and play did just that.

The use of MSM patterns in tracing prehistoric activities may not be straightforward or simple. However, results show that they are a useful tool in tracing general levels of physical activity, such as age-related changes as well as gender relationships. They moreover need to be continuously discussed and methods need to be further evaluated with reference to both general and specific prehistoric activities.

CONCLUSIONS

Middle Neolithic skeletal material from the burial ground at Ajvide was analyzed using musculoskeletal stress markers. The aim was to explore general MSM patterns and to attempt to trace three specific prehistoric activities likely to have been performed at Ajvide: archery, harpooning, and kayaking. In total, 30 sites of upper body ligament and muscle attachments in 24 male and 15 female adult individuals were investigated.

Results show that males most frequently have higher mean MSM scores than females. Low bilateral asymmetry was noted for both sexes. Age proved to be a contributing factor to increased MSM scores, with a greater age-related increase in females. This presents an aspect that needs to be considered in studies of prehistoric activities and associated MSM.

MSM patterns were analyzed statistically in muscle groups associated with the three investigated activities. Significant positive correlations were observed in male individuals in muscle groups associated with archery, an indication that archery was mainly performed by men. In the case of harpooning, the working muscles of the right arm are better correlated than on the left side, again in males. Females show an opposite image. This again possibly signifies harpooning as mainly carried out by men. No clear MSM patterns indicate kayaking muscles being used in a specific mode. Furthermore, the costoclavicular ligament, often being referred to in connection with "kayaker's clavicle," showed no positive correlation with the kayaking MSM scores.

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