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Changes in stature from the Upper Paleolithic to the Medieval period in Western Europe

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The analysis of stature and its variation through time in past populations is affected by a series of methodological limitations. This is due to the intrinsic difficulty in reconstructing the stature of living individuals from skeletal remains. In general, there are two methods used to estimate stature: anatomical and mathematical (Martella *et al.*, 2016). The anatomical method estimates stature from the sum of all the skeletal elements involved and thus provides the most reliable reconstruction with an error, in general, between ±2.05 cm, which is linked to the thickness of the soft tissue and the degree of curvature of the spine (Fully 1956; Raxter *et al.*, 2007, 2008). The mathematical method uses regression formulas based on the length of individual skeletal elements. (Konigsberg *et al.*, 1988).

A third approach (Ruff *et al.*, 2012), useful in the study of past populations, is a mixed method based on the use of both techniques, whereby the anatomical approach is used to estimate stature in a sample, or sub-sample, of individuals with characteristics similar to what we want to analyse. This calculation of stature anatomical estimates is then used to establish new population specific regression formulas. In this way, problems deriving from the use of formulas obtained from populations with different skeletal proportions are limited, making it possible to produce more reliable estimates of stature in individuals from specific contexts, especially where skeletal material available is incomplete (Ruff *et al.*, 2012).

There are other problems concerning the study of skeletal material from archaeological sites, which principally regard the dating of the material and its state of conservation. In fact, skeletal material may come from areas that have been re-occupied at later times and, when the cultural material is not associated with skeletons, the accurate chronologies can be established through the application of radiocarbon dating. However, radiocarbon dating does not provide a specific date, but an estimated range, therefore an overlapping problem between cultures may occur. Furthermore, in complex situations such as multiple or collective burial sites, which were reused at various times and resulted in the mixing of material, it is often difficult to clearly link skeletal elements to specific individuals. This difficulty in attributing skeletal elements to single individuals compromises sex identification, thus affecting the estimation of average height values, since regression equations are generally sex specific (Martella *et al.*, 2016).

However, as stressed by Martella *et al.* (2016), in the comparison of stature values in time and space, both for intra- and inter-population studies, there are some problems that may hinder a clear interpretation of the data: a) the use of different methods to estimate stature, b) the dating of the skeletal remains, c) the small sample sizes used for stature estimation, d) the absence of mean stature values and/or standard deviations in some time periods, e) the single sites of origin of the skeletal remains not indicative of the entire region.

Despite the problems concerning the methodological approach adopted to estimate stature values from skeletal remains, studies on stature values in millennia have been widely published. Within the research field of millennial changes in stature some interesting aspects regarding the analysis of data are: 1) significant variations in average stature values across the Upper Paleolithic/Mesolithic/Neolithic transitions; 2) variations through time within a given population, between populations and between sexes and; (3) differences in average values of coeval populations in geographical areas.

Variations in average stature values across the Upper Paleolithic/ Mesolithic/Neolithic transitions

Holt (2003) and Holt & Formicola (2008) reported a significant reduction of stature from the European Early Upper Paleolithic (EUP: 174.1 cm for males and 161.8 cm for females), ca. 30,000-20,000 BP, to the European Late Upper Paleolithic (LUP: 165.3 cm for males and 154.5 cm for females), ca. 19,000-10,000 BP (Holt, 2003). Therefore, average stature decreased drastically from the EUP remains to the LUP samples: 8.8 cm 5.32% for males and 7.3 cm 4.72% for females. Holt & Formicola (2008) attributed this decrease to a possible reduction in gene flow and a decline in the availability of protein that might have reduced body size by selection in order to reduce metabolic and nutritional demands. According to Formicola & Giannecchini (1999), western European Mesolithic populations (163.1 cm for males and 151.3 cm for females) show a further decrease of height compared to the LUP: 2.5 cm (1.51%) for males and 2.2 cm (1.43%) for females, although not as pronounced as that previously reported for EUP. It is not clear whether the morphological changes were due to gene flow or to local evolution, but most studies suggest that the transition between the final Paleolithic and Mesolithic populations was due to local conditions (Hermanussen, 2003).

The Neolithic data regarding European countries is particularly varied (Appendix), with Germany having the highest values of the countries studied: 165.8 cm for males, while Great Britain provide the highest female values: 157 cm. Neolithic individuals from Spain, out of all the countries considered, have the lowest values for both sexes: 162.7 cm for males and 150.7 cm for females.

Variations through time within a given population, between populations and between sexes from the Iron Age to the Medieval Period

There have been differences in stature across the millennia not only between populations through time, but also between sexes of the same population (Martella *et al.*, 2016). For example, the three regions of the western Mediterranean (Fig. 1), Italy, Spain, and Sardinia, show the same trend in males, characterized by a decrease from the Iron Age (1000–300 B.C.E.) to the Roman Period (300 B.C.E.–500 C.E.) followed by an increase in the Medieval Period (fifth to fifteenth century C.E.). The female samples show a similar trend, except in the Sardinian region.

Koepke & Baten (2005), found a stature trend similar to the one found by Giannecchini & Moggi-Cecchi (2008) and Martella *et al.* (2016) by analyzing the biological standard of living in Europe and the impact of climate between the first and the eighteenth century CE. Koepke & Baten (2005) recorded a phase of stature stability in central, southern, and western Europe during the Roman Empire (27 B.C.E–476 C.E.), with an increase in Europe in the fifth and sixth century C.E., and a further increase in the eleventh and twelfth century C.E. With the beginning of the Early Middle Ages,

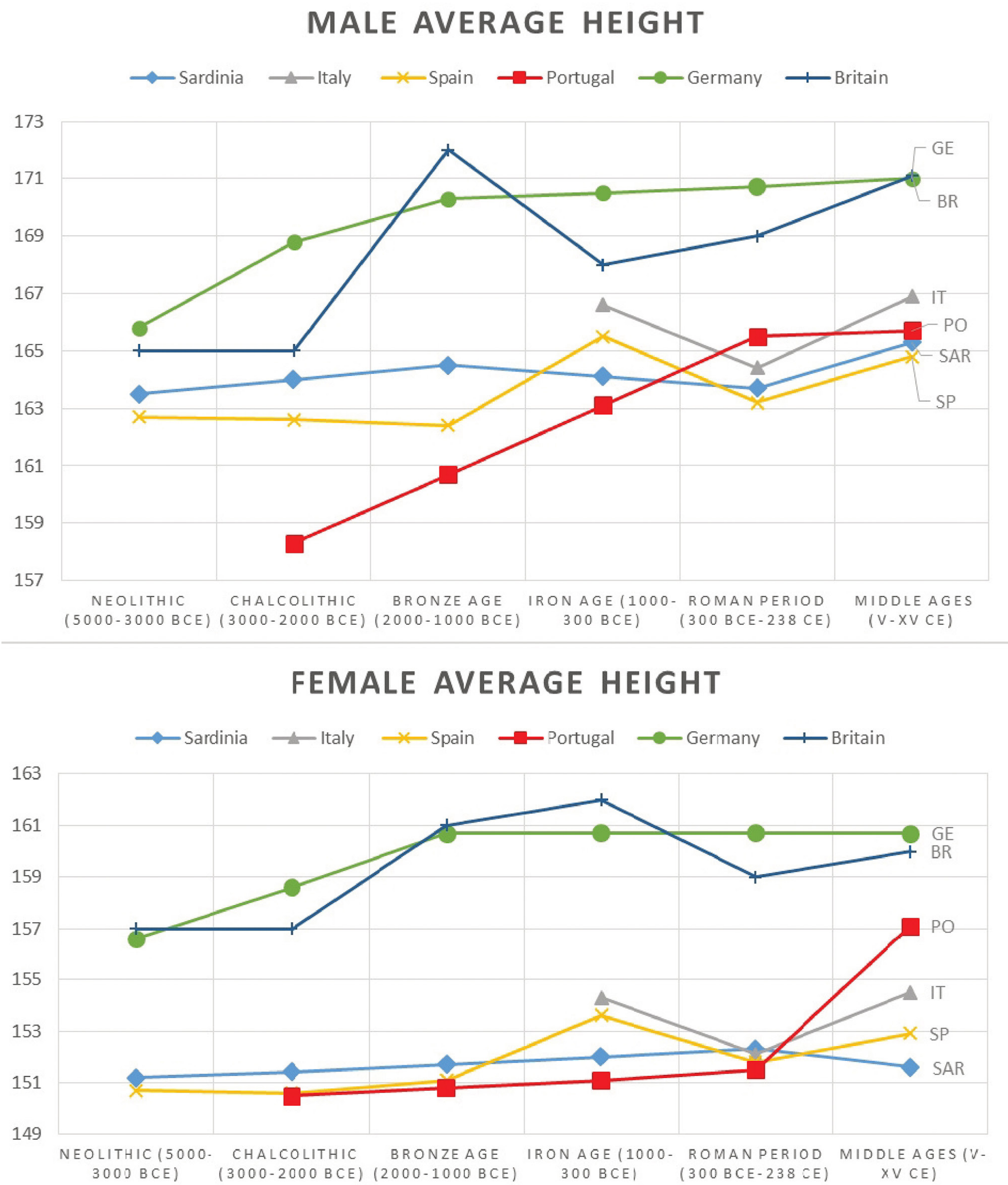

Fig. 1 - Male and female mean stature data from Tab. 1. To construct the charts we adopted a simplified chronological scheme. Empty markers identify the mean stature obtained through interpolation for time periods in which data were not available. Mean stature for Italian populations from the Neolithic to Bronze Age are not represented. The colour version of this figure is available at the JASs website.

after the end of the Roman domination, a social, political and economic transition phase started in Europe (Giannecchini & Moggi-Cecchi, 2008), bringing changes that led to an increase in mean stature, continuing into the High Middle Ages despite the occurrence of epidemics and famines. As an example, according to Montanari (1994), farmers in Northern Italy had access to a better diet, both in quantity and quality during the Early Middle Ages than in the Roman Period, even better than from the Late Middle Ages up to the first decades of the nineteenth century. The changes in climate, economy, agriculture and population density in the Middle Ages may have contributed to an improvement in nutritional status and environmental *sensu lato* conditions, (Martella *et al.*, 2016).

Variations in average values of coeval populations of neighbouring geographical areas

The mean stature values for Italian skeletal remains of both sexes, estimated with the Pearson method, reported in Giannecchini & Moggi-Cecchi (2008) from sites in regions in central Italy (Tuscany, Latium, Marche, Abruzzo, Molise) and nearby regions (Emilia-Romagna and Campania), for the time periods considered, decrease in the transition from the Iron Age to the Roman period and increase from the Roman to the Medieval period. The authors observe that average stature decreased in the Roman Period by 2.2 cm in males and 1.2 cm in females, whilst in the Medieval Period, stature increased by 2.5 cm in males and 2.4 cm in females. These changes, for both sexes, were statistically significant except when comparing average stature in the Iron Age to the Medieval period. Furthermore, Giannecchini & Moggi-Cecchi (2008) found that, in the same period, the average values of sexual dimorphism remained more or less constant with no statistically significant difference.

The discrepancy in the possible millennial and secular trends among the populations and between sexes and the difference in the stature variations among the populations could be explained by differences in the environmental *sensu lato* context over time between regions and within regions.

For the interpretation of past stature changes to be reliable and complete, there must be an understanding of the environmental conditions during the period under study, an examination of the indicators of stress and diet, an analysis of possible delays in growth, and the addition to biocultural information (Holt & Formicola, 2008; Mancinelli & Vargiu, 2012; Vercellotti *et al.*, 2014). However, despite the absence of these information makes it difficult to provide an exhaustive explanation of the stature changes, their analysis offers an interesting field of study for the interpretation of living conditions in past population.

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Appendix - Summary of the archaeological sites yielding the skeletal material and mean stature values collected or calculated by one of the authors (PM).

REGION	TIME PERIOD/ DATING (IF PRESENT)[1]	SITE OR LOCALITIES OF PROVENANCE	MALE			FEMALE			REFERENCE FOR METRIC DATA, CRONOLOGICAL DATA AND NOTE	METHODS
			N	MD	SD	N	MD	SD		
Sardinia (Italy)	Neolithic late (4000-3200 BCE)	San Benedetto d'Iglesias	3	163.5	4.6	3	151.2	3.7	Present study	Pearson 1899
	Bronzeage (1600-850 BCE	Is Aruttas-Oristano, Capo Pecora-Arbus, Tueri Cave-Perdasdefogu, Lu maccioni Cave-Alghero, Li Muri-Arzachena, Ingurtosu Mannu-Donori, Sa Serra Masi-Siliqua	32	164.9	3.7	23	151.8	3.8	Present study	Pearson 1899
	Roman Period (238 BCE - 476 CE)	Mitza Salida-Masullas-Oristano, Genna Cuccureddu-Baunei	10	163.2	3	18	152.6	4.8	Present study	Pearson 1899
	Early Medieval Period (5^{th}-10^{th} century CE)	San Saturnino Church, Cagliari 8^{th}-10^{th} century CE	11	165.2	3.1	4	152.9	4.9	Present study	Pearson 1899
	Modern Period (XVI-XIX century CE)	San Michele Church Bono (Sassari)	64	163.8	4.5	41	151.2	4.1	Present study	Pearson 1899
Italy	Middle Neolithic	Central-Southern Italy	-	166.0	-	-	156.0	-	Borgognini 1992	Trotter and Gleser 1952
	Chalcolithic	Central-Southern Italy	-	168.0	-	-	156.6	-	Borgognini 1992	Trotter and Gleser 1952
	Bronze Age	Central-Southern Italy	-	168.0	-	-	158.0	-	Borgognini 1992	Trotter and Gleser 1952

[1] The chronological subdivision used by the authors in their publications is reported

Appendix - continued

REGION	TIME PERIOD/ DATING (IF PRESENT)[1]	SITE OR LOCALITIES OF PROVENANCE	MALE			FEMALE			REFERENCE FOR METRIC DATA, CRONOLOGICAL DATA AND NOTE	METHODS
			N	MD	SD	N	MD	SD		
	Iron Age (9th-5th century BCE)[2]	Central Italy	220	166.6	4	181	154.3	3.7	Giannecchini and Moggi-Cecchi 2008	Pearson 1899
	Roman Period (5th BCE- 5th century CE)	Central Italy	153	164.4	3.9	130	152.1	3.4	Giannecchini and Moggi-Cecchi 2008	Pearson 1899
	Medieval period (5th-15thcentury CE)	Central Italy	187	166.9	4.3	150	154.5	3.4	Giannecchini and Moggi-Cecchi 2008	Pearson 1899
Spain	Neo-Chalcolithic	Meseta, Levante	93	162.6	-	60	150.6	-	Lalueza-Fox 1998	Pearson 1899
	Bronze Age (2000-1000 BCE)3	Catalonia; Andalusia (Argar Culture)	99	162.4	-	74	151.1	-	Lalueza-Fox 1998	Pearson 1899
	Talayotic(600-200 BCE) 3	Son Real, Majorca; Illot des Porros, Majorca	424	165.5	-	229	153.6	-	Lalueza-Fox 1998	Pearson 1899
	Roman (3rd-5th century CE)	Tarragona	168	163.2	-	88	151.8	-	Lalueza-Fox 1998	Pearson 1899
	Medieval (7th -14th century CE) 3	Catalonia; Montjuich, Barcelona; Palacios de la Sierra, Burgos; La Torrecilla, Granada; La Olmeda, Palencia; Santa Maria de Hito, Cantabria; Villanueva de Soportilla, Burgos	280	164.8	-	152	152.9	-	Lalueza-Fox 1998	Pearson 1899
Portugal	Late Neolithic and Chalcolithic (3500-2100 BCE)	PoçoVelho (Cascais) EiraPedrinha (Condeixa-a-Nova) Quinta do Anjo (Palmela)	6	158.3	-	20	150.5	-	Cardoso and Gomes 2009	Mendonça 2000

[2] Simplified chronological scheme
[3] Weighted means

Appendix - continued

REGION	TIME PERIOD/ DATING (IF PRESENT)[1]	SITE OR LOCALITIES OF PROVENANCE	MALE			FEMALE			REFERENCE FOR METRIC DATA, CRONOLOGICAL DATA AND NOTE	METHODS
			N	MD	SD	N	MD	SD		
	Roman (2nd BCE – 4th century CE)	Conimbriga (Coimbra) Tròia (Setùbal)	6	165.5	-	4	151.5	-	Cardoso and Gomes 2009	Mendonça 2000
	Medieval (12th - 16th century CE)	SãoManços Caneferrim (Sintra) São Martinho (Leiria)	37	165.7	-	23	157.1	-	Cardoso and Gomes 2009	Mendonça 2000
Germany	4900-4500 BCE	Central Region - Elbe - Saale and Thuringia		165,8			156,6		Jaeger *et al.*, 1998	(Bach 1965; Breitinger 1938)
	3200-2800 BCE	Central Region - Elbe - Saale and Thuringia		167,1			157		Jaeger *et al.*, 1999	(Bach 1965; Breitinger 1938)
	2800-2400 BCE	Central Region - Elbe - Saale and Thuringia		169,4			160,2		Jaeger *et al.*, 2000	(Bach 1965; Breitinger 1938)
	2500-2200 BCE	Central Region - Elbe - Saale and Thuringia		169,8					Jaeger *et al.*, 2001	(Bach 1965; Breitinger 1938)
	2300-1600 BCE	Central Region - Elbe - Saale and Thuringia		170,3			160,7		Jaeger *et al.*, 2002	(Bach 1965; Breitinger 1938)
	7th - 8th century CE	Central Region - Elbe - Saale and Thuringia		172			160,6		Jaeger *et al.*, 2003	(Bach 1965; Breitinger 1938)
	8th - 10th century CE	Central Region - Elbe - Saale and Thuringia		170,4			159,5		Jaeger *et al.*, 2003	(Bach 1965; Breitinger 1938)
	9th - 11th century CE	Central Region - Elbe - Saale and Thuringia		171,4			161,2		Jaeger *et al.*, 2004	(Bach 1965; Breitinger 1938)
	16th - 18th century CE	Central Region - Elbe - Saale and Thuringia		169,5			159,8		Jaeger *et al.*, 2005	(Bach 1965; Breitinger 1938)

Appendix - continued

REGION	TIME PERIOD/ DATING (IF PRESENT)[1]	SITE OR LOCALITIES OF PROVENANCE	MALE			FEMALE			REFERENCE FOR METRIC DATA, CRONOLOGICAL DATA AND NOTE	METHODS
			N	MD	SD	N	MD	SD		
Est Mediterraneo										
	Early Neolithic (7000-5000 BCE)	Greece and West Turkey	39	169,6		31	155,5		Angel, 1984	Trotter and Gleser 1952
	Late Neolithic (5000-3000 BCE)	Greece and West Turkey	6	161,3		13	154,3		Angel, 1984	Trotter and Gleser 1952
	EarlyBronze (3000-2000 BCE)	Greece and West Turkey	83	166,3		72	152,9		Angel, 1984	Trotter and Gleser 1952
	Middle People (2000-1450 BCE)	Greece and West Turkey	83	166,1		54	153,5		Angel, 1984	Trotter and Gleser 1952
	Bronze Kings (1450 BC)	Greece and West Turkey	14	172,5		3	160,1		Angel, 1984	Trotter and Gleser 1952
	Late Bronze (1450-1150 BCE)	Greece and West Turkey	56	166,8		41	154,5		Angel, 1984	Trotter and Gleser 1952
	EarlyIron (1150-650 BCE)	Greece and West Turkey	42	166,7		53	155,1		Angel, 1984	Trotter and Gleser 1952
	Classic (650-300 BCE)	Greece and West Turkey	52	170,5		30	156,2		Angel, 1984	Trotter and Gleser 1952
	Hellenistic (300 BCE- 120 CE)	Greece and West Turkey	23	171,9		20	156,4		Angel, 1984	Trotter and Gleser 1952
	Imperial Roman (120-600 CE)	Greece and West Turkey	18	169,2		19	158		Angel, 1984	Trotter and Gleser 1952
	Medieval Greece (600-1400 CE)	Greece and West Turkey	30	169,3		27	157		Angel, 1984	Trotter and Gleser 1952

Appendix - continued

REGION	TIME PERIOD/ DATING (IF PRESENT)[1]	SITE OR LOCALITIES OF PROVENANCE	MALE			FEMALE			REFERENCE FOR METRIC DATA, CRONOLOGICAL DATA AND NOTE	METHODS
			N	MD	SD	N	MD	SD		
	Byzantine Constantinople (600-1400 CE)	Greece and West Turkey	68	169,8		16	154,9		Angel, 1984	Trotter and Gleser 1952
	Baroque (1400-1800 CE)	Greece and West Turkey	46	172,2		30	158		Angel, 1984	Trotter and Gleser 1952
Anatolia										
	Neolithic (10000-5000 BCE)	Central Anatolia	29	170,9	1,5	41	156	1,9	Özer *et al.* 2009	Trotter and Gleser 1952
	Chalcolithic (5000-3000 BCE)	Central Anatolia, Mediterranean and Aegean	7	165	6,7	6	153,3	4,7	Özer *et al.* 2009	Trotter and Gleser 1952
	Bronze (3000-1000 BCE)	Central Anatolia, South-East and Mediterranean	46	165,9	2,3	32	157,2	2,1	Özer *et al.* 2009	Trotter and Gleser 1952
	Iron (1000-580 BCE)	East Anatolia	19	169,4	7,3	13	158,3	3,1	Özer *et al.* 2009	Trotter and Gleser 1952
	Hellenistic-Roman (333 BCE-395 CE)	Central Anatolia, Aegean, East Anatolia, Marmara	60	165,3	5,1	42	155,6	5,7	Özer *et al.* 2009	Trotter and Gleser 1952
	Anatolia Medieval (395-1453 CE)	Central Anatolia, East Anatolia, Aegean and Marmara	290	169,4	1,7	222	158	3,3	Özer *et al.* 2009	Trotter and Gleser 1952
Lettonia (Latvia)										
	Late Mesolithic (4950-4550 BC)	collections of the Latvian Institute of History, University of Latvia.	14	171,5	2,6	6	156	1,6	Gerhards 2005	Gerhards 2003

Appendix - continued

REGION	TIME PERIOD/ DATING (IF PRESENT)[1]	SITE OR LOCALITIES OF PROVENANCE	MALE			FEMALE			REFERENCE FOR METRIC DATA, CRONOLOGICAL DATA AND NOTE	METHODS
			N	MD	SD	N	MD	SD		
	EarlyNeolithic (4450-3350 BC)	collections of the Latvian Institute of History, University of Latvia.	20	167,7	1,9				Gerhards 2005	Gerhards 2003
	MiddelNeolithic (3350-2350 BC)	collections of the Latvian Institute of History, University of Latvia.	36	168,1	2,8	10	156,1	1,8	Gerhards 2005	Gerhards 2003
	Late Neolithic (2350-2150 BC)	collections of the Latvian Institute of History, University of Latvia.	5	172,4	1,9	5	156,7	3,2	Gerhards 2005	Gerhards 2003
	EarlyBronze (1350-1150)	collections of the Latvian Institute of History, University of Latvia.	47	171,4	3,5	32	159	1,9	Gerhards 2005	Gerhards 2003
	Late Bronze (850-350 BC)	collections of the Latvian Institute of History, University of Latvia.	11	169,8	3,1	1	155,9		Gerhards 2005	Gerhards 2003
	Iron Age (V BC-XII AD)	collections of the Latvian Institute of History, University of Latvia.	189	173,9	3,5	96	159,1	3,4	Gerhards 2005	Gerhards 2003
	XIII-XV AD	collections of the Latvian Institute of History, University of Latvia.	750	171,7	3,3	439	156,9	2,5	Gerhards 2005	Gerhards 2003
	XVI-XVIII AD	collections of the Latvian Institute of History, University of Latvia.	407	170,1	3	274	156,2	2,5	Gerhards 2005	Gerhards 2003
Britain	Mesolithic (pre-4050 BC)		3	165		2	157		Mummert *et al.* 2011	
	Neolithic (4050-2550 BC)		71	165		36	157		Mummert *et al.* 2011	
	Bronzeage (2550-850 BC)		61	172		20	161		Mummert *et al.* 2011	
	Ironage (850-0 BC)		113	168		72	162		Mummert *et al.* 2011	

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			N	MD	SD	N	MD	SD		
	Roman period (43-410 AD)		1296	169		1042	159		Mummert *et al.* 2011	
	EarlyMedieval (410-1050 Ad)		996	172		751	161		Mummert *et al.* 2011	
	Late Medieval (1050-1550 AD)		8494	171		7929	159		Mummert *et al.* 2011	
	P. Medieval (1550-1850 AD)			171			160		Mummert *et al.* 2011	