Weight-Based Trade and the Formation of a Global Network: Material Correlates of Market Exchange in Pre-literate Bronze Age Europe (c. 2300–800 BC)

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Introduction

The beginning of the Bronze Age[1] of western Eurasia coincides with the formation of a global connectivity network, involving the movement of people and things on a continental scale. Bronze becomes a central asset of regional economies. The extreme rarity of tin sources—and the uneven distribution of copper mines—forces regional economies to rely on long-distance trade in order to acquire the necessary raw materials (Vandkilde 2016). This necessity sets in motion a far-reaching process, prompting the development of a network of mid-to-long range connections. People, things and ideas appear to circulate faster, farther away and in greater amounts than ever before (Vandkilde et al. 2015), suggesting a high level of economic integration, with little impediment to free trade between regions (Earle et al. 2015).

In the Near East and the Aegean, the formation of the global network in the 3rd millennium BC is accompanied by the generalized adoption of weight-based trade as one of the main means of exchange, involving private merchants and public administrations (Rahmstorf 2010). Weight systems become the standard means to quantify exchange value in economic transactions; this implies the existence of shared indexes of value that made it possible to commensurate different quantities of different goods

[1] The term 'Bronze Age' broadly refers to a period of the late prehistory of western Eurasia, where copper alloys become central assets of regional economies. The duration of the Bronze Age varies according to different macro regions. This article addresses the Bronze Age of three macro regions: pre-literate Europe (i.e., the part of Europe where writing did not exist), referring to most of contemporary Europe including the British Isles and Scandinavia, with the exclusion of Greece (c. 2300/2200–800 BC). The Aegean, including Greece, the westernmost part of Turkey and all the Islands in between (c. 3100–1050 BC). The Ancient Near East, including Anatolia, the Levant and Mesopotamia (c. 3100–1200 BC).

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(Renfrew 2012). The adoption of weight-based trade in the Ancient Near East properly defines a form of market exchange, regardless of whether or not the economy as a whole was governed by a price-making market (Powell 1977).

In pre-literate Europe, the beginning of the Bronze Age (hereafter BA) coincides with the appearance of the earliest balance weights (Ialongo 2018). The widespread adoption of weighing technology, however, has been only seldom addressed as a global phenomenon (e.g., Rahmstorf 2010; Pare 2013), and its implications for the reconstruction of the exchange economy remain largely unexplored.[2]

Is the adoption of weighing equipment in prehistoric Europe a correlate of the development of an integrated trade network, at least partly based on market exchange? I will address the question through an outline of the spread of weighing technology in Europe—west of Greece—between the end of the 3rd and the beginning of the 1st millennium BC. In order to formulate a working hypothesis for pre-literate Europe, I will discuss the implications of weight-based exchange in connection to barter- and currency-based systems, through a comparison with the Ancient Near East. The hypothesis will be tested based on the statistical analysis of European balance weights.

Weighing Equipment in Pre-literate BA Europe: Chronology and Distribution

The sample comprises 551 potential balance weights (358 in stone, 165 in bronze and 28 in lead) and 18 balance beams and represents the current state of an ongoing research (Ialongo & Rahmstorf 2019). The identification of balance weights in the archaeological record is largely a statistical problem (Pakkanen 2011); therefore, a positive interpretation is only valid for large samples, while single finds will always be affected by some degree of indeterminacy (Ialongo 2018). Despite the sample having more than doubled since the beginning of the research project, the evidence is still discontinuous. Some areas are still not investigated or just superficially explored (e.g., Spain, the British Isles, Scandinavia and eastern Europe). The distribution of context-types is also uneven. While most of the documentation from Italy and Switzerland comes from settlements (297 weights in settlements vs. 25 in burials),

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the evidence in central Europe (between France and Hungary) is mainly concentrated in burials (15 vs. 110). In Portugal, burials with weighing equipment are not attested, with 31 weights coming from settlements and eight from hoards. Finally, only eight weights are documented in England so far, equally distributed among different types of contexts.

Earlier studies on weighing equipment in pre-literate BA Europe only addressed limited regions and were mainly concerned with establishing typologies of balance weights and metrological relationships (Pare 1999; Cardarelli et al. 2001; Vilaça 2003, 2013; Feth 2014; Ialongo 2018). Based on these studies and on new evidence it is possible to propose a general outline of the spread of balance scales and weights. The chronology illustrated in Fig. 1 is based on the loose correlation of at least six distinct local relative sequences and their commonly accepted absolute chronologies (Italy, Central Europe, France, Northern Europe, Atlantic Europe and British Isles; main references: Pacciarelli 2001; Primas 2008, p. 7; Olsen et al. 2011; Roberts et al. 2013), and represents a simplification of a highly complex problem. Regional sequences are, in most cases, still debated, and attempting a cross-regional correlation must inevitably rely on a certain degree of approximation. The chronology illustrated

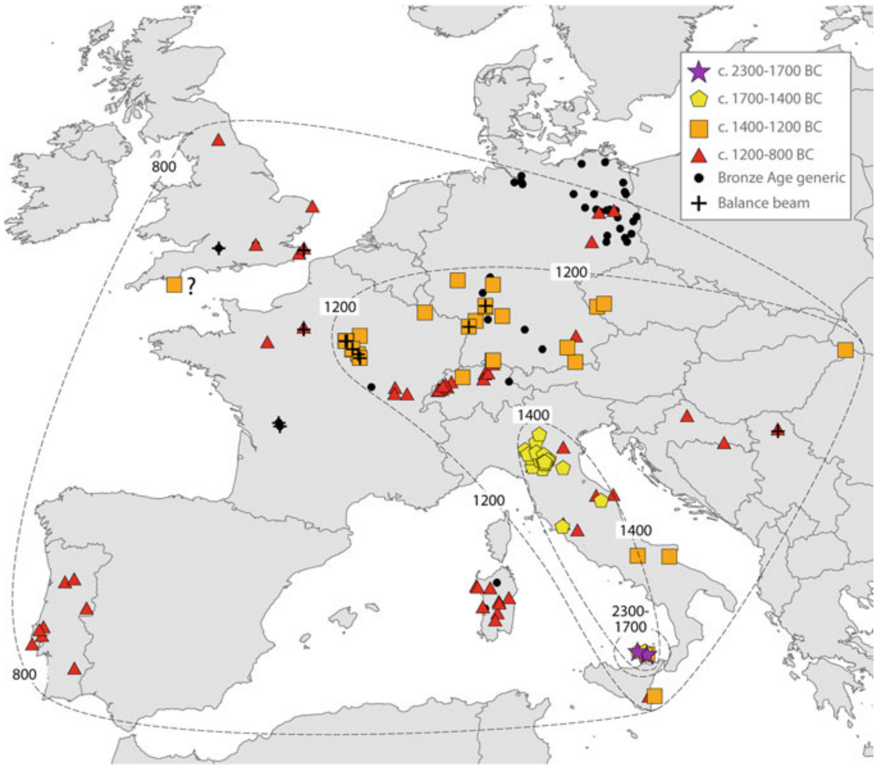

Fig. 1 Diachronic distribution of weighing equipment in pre-literate BA Europe

in the map always corresponds to that of the archaeological context in which the objects were found; hence, stray finds are always considered non-datable.

The sample was divided into four arbitrary phases, based on the rough correlation of regional sequences, in the attempt to provide the highest possible detail. The first phase (c. 2300–1700 BC) is only represented by finds from the Aeolian Islands (Sicily, Italy; Ialongo 2018). Thirty potential balance weights were identified in several settlements which are dated between c. 2300 and 950 BC, among which 15 belong to layers dated to the Early BA (Fig. 2A).

The distribution of the second phase (c. 1700–1400 BC) is still limited to Italy. Many potential balance weights are documented in the *terramare* settlements in the Po Plain, all in stone (Fig. 2B). Very few finds have reliable find contexts, most of them coming from old excavations (Cardarelli et al. 2001). However, the *terramare* seem to begin around 1600 cal. BC (Vanzetti 2013). Not all the finds illustrated in the map may date so early; however, at least one balance weight from the site of Gaggio comes from a reliable context (Fig. 2B), belonging to a settlement-phase beginning approx. 1600 BC (Balista et al. 2008).

Finds belonging to the third phase (c. 1400–1200 BC) are widespread between Italy and central Europe, and mostly belong to funerary contexts. A research on the unpublished materials from Thapsos (Sicily, Italy; Orsi 1896), led to the identification of 19 bronze balance weights from two collective rock-cut tombs. Grave 6 contains 17 small weights (Fig. 2C), while a single weight comes from grave 14 (Fig. 2D). The site of Thapsos is dated between Middle BA 3 and Recent BA (c. 1400–1200 BC). Weighing equipment is also widely attested in central European graves dating to Bronze D (c. 1350–1200 BC), where weights are often associated with balance beams (Fig. 3A; Pare 1999; Roscio et al. 2011; Roscio 2018). The easternmost finds known to date belong to the same phase, from the hoard of Tiszabecs, in Hungary (Pare 1999). In the site of Salcombe (England) two balance weights (Fig. 3B; Rahmstorf 2019) were found together with nearly 400 metal objects on the bottom of the Channel, off the coast of Devon (Needham et al. 2013); part of the objects date to the Ewart Park phase (c. 1000–800 BC), and part to the Penard phase (c. 1300–1150 BC). However, the balance weights cannot be assigned with certainty to either of the two phases; therefore, the find-spot is indicated with a question mark on the distribution map.

The fourth phase (c. 1200–800 BC) also includes finds from northern Germany, England, Portugal and Sardinia. The finds from northern Germany coming from reliable contexts are dated between Periods IV and V of the Nordic Bronze Age (c. 1100–800 BC); they consist of three cremation graves (Busse 1900: 55; Seyer 1967; Schmalfuß 2008, Fig. 2) and a small votive deposition containing weapons, ornaments and scrap metal (Reinbacher 1956; Fig. 3C). All these contexts contain *Kannelurensteine*, a class of stone objects widespread between Italy and central Europe, for which statistical tests support the interpretation as balance weights (Cardarelli et al. 2001; Ialongo 2018). In England, all the collected evidence is dated between the phases Wilburton and Ewart Park (c. 1150–800 BC; Rahmstorf 2019). The balance weights from Portugal seem to belong to the end of the Iberian Bronce Final (c. 1000–800 BC; Fig. 3D; Vilaça 2003, 2013). Finally, finds from

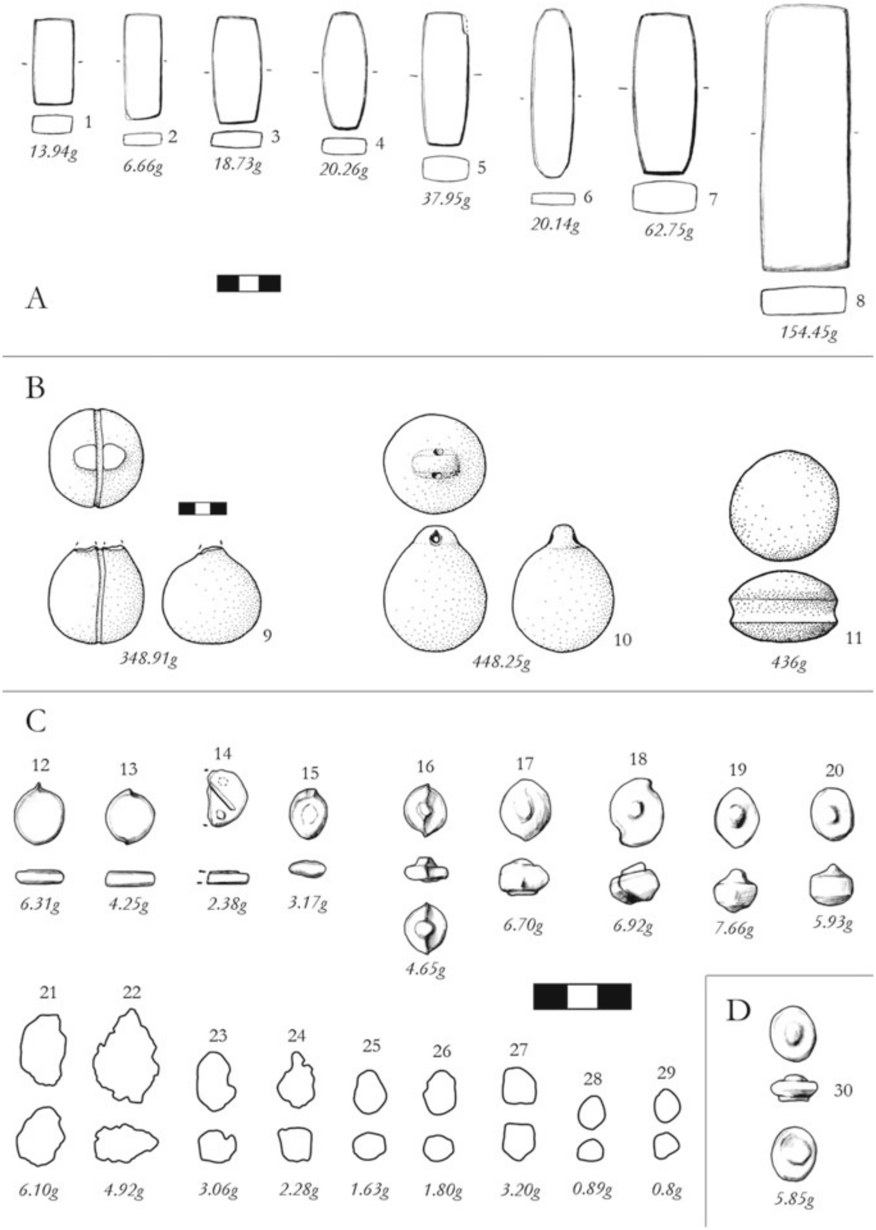

Fig. 2 Potential balance weights from pre-literate BA Europe. **A** Stone rectangular weights from the Aeolian Islands, Sicily, from contexts dated to c. 2300–1700 BC (after Ialongo 2018). **B** Stone piriform weights and *Kannelurensteine* from the terramare settlements, northern Italy; 1–2: Gaggio di Castelfranco, phase II (c. 1600–1500 BC; after Balista et al. 2008); 3: Scandiano (after Cardarelli et al. 2001). **C** Disc-shaped weights from Thapsos-grave 6, Sicily (c. 1400–1200 BC; unpublished); 21–29: corroded. **D** Disc-shaped weight from Thapsos-grave 14, Sicily (c. 1400–1200 BC; unpublished)

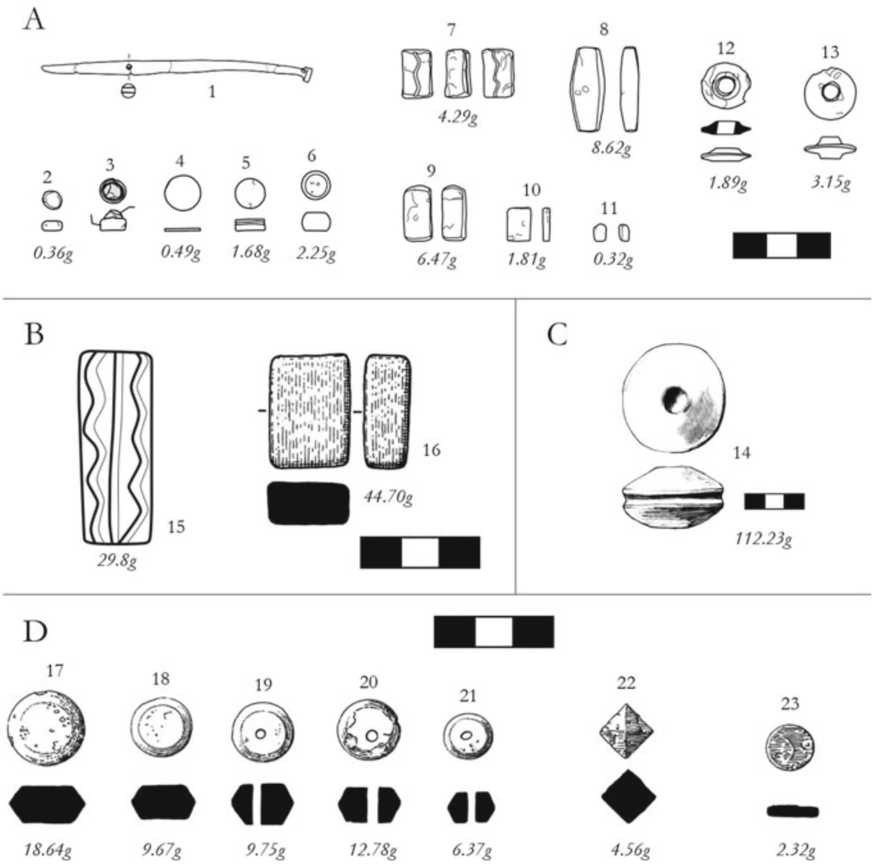

Fig. 3 Weighing equipment from pre-literate BA Europe. **A** Etigny, 'Le Brassot' Ouest, Inhumation 90 (after Roscio 2018, pl. 85); 1: balance beam (antler); 2–11: balance weights (bronze). **B** Bronze rectangular weights from Salcombe, southern England (c. 1300–800 BC; after Rahmstorf 2019). **C** *Kannelurenstein* from the hoard of Krampnitz (c. 1100–800 BC; Reinbacher 1956; drawing by the Author). **D** Disc-shaped and octahedral weights from the hoard of Baleizão, Portugal (c. 1000–800 BC; after Vilaça 2013)

Sardinia entirely belong to the Primo Ferro period, datable between c. 950 and 725 BC (Ialongo 2018).

In summary, weighing technology is first attested in the western Mediterranean around 2000 BC, and it is widely adopted between Italy and central Europe by at least c. 1400 BC. The seemingly late appearance in the Atlantic façade is based on scanty and discontinuous data and shall require further investigation. The unbalanced documentary framework suggests caution in interpreting the distribution map. The 'appearance' of weighing equipment in different regions of Europe should be regarded, for the time being, as a *terminus ante quem* for the adoption of weight-based trade, rather than an accurate representation of a gradual spread.

Weight Systems, Prices and Market Exchange

Premise

In order not to incur in the pitfalls of the 'substantivists vs. formalists' debate, it is crucial to consider that market exchange is never the only mode of exchange in human societies, and, most importantly, that a market economy is never directed—contrarily to what Polanyi believed—'*…by market prices and nothing but market prices*' (1944/57:43). Substantivist models generally incur in the paradox of considering ancient economies 'different' and driven by agents that were 'other'—anthropologically speaking—than modern ones (Adams 1974). Since the late 1970s, economic anthropology demonstrated that the notion of such an assumed 'otherness' is fundamentally biased (Bourdieu 1977, pp. 183–197; Appadurai 1986; Swedberg and Granovetter 1992). Labour, scarcity and the balance of supply and demand are not the only factors determining the value of commodities in modern markets. Value, on the contrary, 'is never an inherent property of objects, but is a judgement made about them by subjects' (Appadurai 1986 p. 3). The idea that value is a relational quality rather than an inherent property dramatically reduces the gap between market exchange and supposedly 'primitive' means of exchange, such as reciprocity and ceremonial gift-exchange. Contemporary Western market economy is, in many instances, as embedded in social relationships as 'primitive' economies are often supposed to be and drawing a line that sharply separates the former from the latter is counterproductive (Beckert 2011). For the same reason, admitting the existence of market exchange in primitive economies does not imply denying the existence of other forms of exchange. One of the challenges of a research on prehistoric economies lies in determining when, how and to what extent different modes of exchange contributed to the general framework.

The Ancient Near Eastern economy of the BA is generally thought to be largely based on market exchange. Transactions rely on the quantification of prices—based on accepted indexes of value—regardless of whether or not the economy as a whole is governed by a price-making market (Adams 1974; Powell 1977). Socially embedded dynamics—such as trust, kinship and power—can still play a role in the quantification of prices. What sets market exchange apart from ceremonial gift-exchange is that, once the price is paid, the transaction is formally concluded and no further obligation persists between the agents involved. The earliest forms of market exchange are documented by BA texts in the Ancient Near East, where weight systems were systematically employed to assess exchange values of goods and services, and various forms of currency were used as standards of value (Powell 1996). Prices were not attached only to goods. Widely shared indexes provided the frame of reference to commensurate the economic value of commodities and services: cross-references between different documents allow the formulation of pricelists, describing the equivalences between different commodities and the cost of wage labour (Englund 2012).

The situation for the Bronze Age Aegean is less clear. Texts mostly consist of inventory lists, whose primary utility was to assess incomes and expenditures, and to keep track of the stocks of the palatial reserves (e.g., Bennet 1980, 1983), and direct references to trade are rare and difficult to interpret (Fischer 2016). However, words for ‘price’ and ‘currency’ occur in a few documents, and always refer to weight as a measure of value (Lujàn 2011).

Barter or Currency?

Harding (2013) suggested that the term ‘trade’ is inappropriate to describe the exchange economy of pre-literate Europe in the BA, because the term would imply the existence of ‘currency and markets’ which, in turn, are assumed not to exist at that time. Even though the term ‘barter’ does not appear in Harding’s article, one would assume that, if market exchange and currency did not exist, then barter is the only possible alternative. Interpretive accounts on prehistoric economies that tend to underplay the complexity of BA trade rarely rely on barter as an alternative model, preferring, instead, to focus on reciprocity and ceremonial gift-exchange to model the social context of exchange (e.g., Brück 2016). However, a full-scale economy cannot rely solely on gift-exchange, and although barter likely represented a viable means of exchange, its role in the economy of BA Europe has been poorly explored. This is, probably, at least in part due to some persisting ambiguities in the definition of barter itself: some authors see barter and gift-exchange as entirely independent from one another (including, e.g., Polanyi 1977, p. 42), while others allow their respective fields of action to overlap (Chapman 1980). On the other hand, when barter is intended simply as ‘moneyless transaction’, it is not always easy to distinguish from ‘moneyless market-exchange’ (Dalton 1975), which raises the problem of the relationship between barter and currency. In order to solve this ambiguity, Appadurai (1986, p. 9) proposed a working definition of barter as ‘the exchange of objects for one another without reference to money, and with maximum feasible reduction of social, cultural, political, or personal transaction costs’. This definition has the advantage of establishing a clear relationship between barter and money: the point is not whether or not money actively intervenes as a medium of exchange, but if the transaction makes any reference to it. The question is whether this definition reflects the evidence available for BA modes of exchange, and in particular for weight-based transactions. The evidence suggests that this definition of barter is not appropriate for exchange systems that rely on weight to quantify economic value.

The implementation of weight systems in large-scale exchange networks requires the existence of an abstract frame of reference for the quantification of value, on which the majority of the agents in a network tend to agree; otherwise, it would be impossible to commensurate the *value per unit* of two different commodities, and weight systems would simply have no reason to exist (Renfrew 2012). There is no use, in fact, in assigning a quantity to a good being exchanged, if one could not convert that quantity in terms of a different quantity of a different good. Commensuration is a basic property of weight systems and implies the existence of an ‘accepted index of value’, which must be relatively stable across a given exchange network, according to which agents commensurate the exchange value of commodities and services (Powell 1979). When implemented in large-scale networks, this kind of system cannot ignore the fact that different regional locales have unequal access to different commodities, and that this determines different costs in their acquisition (Earle et al. 2015). Therefore, indexes of value must take into account—at least to some extent—the balance between supply and demand across very large territories when assigning a value to a good being exchanged. This particular instance of value ascription corresponds to the common meaning of *price* (Powell 1996), and transactions based on prices belong to the definition of *market exchange.*

The necessary precondition of weight-based exchange system is, therefore, the existence of shared indexes of value, without which no commensuration would be possible. Commensuration of different quantities of different goods requires abstracting the concept of inherent value and transforming it into that of *value per unit.* Commensuration, in turn, requires the exchange values of different goods to be transitive. One can imagine, for example, a three-commodity circuit: if 640 g of copper are worth 8 g of silver, and 8 g of silver are worth 4.7 kg of wool, then 4.7 kg of wool must be worth 640 g of copper. The concept of value per unit allows to commensurate exchange values, implying that any of such commodities is equally viable, as a medium of exchange, to purchase any other commodity in the circuit. These practical examples represent an approximation of the actual exchange rates of commodities, as they can be inferred from the cuneiform archives of the Ur III period in Mesopotamia (c. 2050–2000 BC; Englund 2012). Texts from the Ancient Near East provide documentation about currency, prices and value-equivalences between different commodities, and represent an ideal case study to approach the problem of barter and currency in weight-based exchange systems. Ancient Near Eastern economy was based on a multi-currency system. In the Ur III period, the salaries of state dependants were mainly paid in grain (mostly barley, measured by volume), while commercial transactions were generally based on silver (measured by weight; Steinkeller 2004). Both barley and silver could change hands indefinite times and be effectively used as currencies in further transactions. Other commodities could also function as currencies, but barley and silver are the most frequently mentioned. Barley and silver, in turn, were not just mediums of exchange, but also *standards of value.* Texts quantifying transaction prices in grain or silver do not necessarily imply that silver and grain were physically employed as mediums of exchange (Powell 1996). Therefore, different goods could be exchanged for one another, in a barter fashion, without using currency as a medium of exchange, but still maintaining a *reference* to currency as a standard of value. Whether or not currency plays an actual role in the transaction, weight-based exchange is, in fact, entirely based on abstract indexes of value, and corresponds to the definition of market exchange.

Weight Systems and the Problem of Currency

Weight-based trade does not require money to be effective. However, textual and archaeological evidence shows that the adoption of weighing technology between the Ancient Near East and Greece in the BA is always accompanied by the emergence of currencies (Rahmstorf 2016). Currencies always circulated both as *commodities* and as *money*, the distinction between the two functions being more dependent on scholarly jargon than on actual differences in their use (Powell 1996). Metal currencies, in particular, were never cast or struck into any kind of standardized shape. The adoption of a limited number of commodity currencies as standards of value represents a convenient device, since it provides a ready-to-use parameter on which all the agents in the network tend to agree. The adoption of currencies as standards of value does not even require the existence of a governing body. Silver, in the Ancient Near East, was the most used currency in transactions; however, it was never imposed by state administrations as an 'official' currency (Peyronel 2010) and circulated freely in the private economic sector as well (Steinkeller 2004). Silver simply came into use by virtue of its peculiar characteristics: it was more valuable than copper (which was often used as a 'cheaper' currency), but not as rare as gold (which was seldom used as currency), easily transportable and durable. The function of silver as a purely abstract standard of value was well understood by the people of ancient Mesopotamia, at least since the 3rd millennium BC. One of the so-called 'Debate Poems' (short satirical texts in Sumerian language) describes a 'quarrel' between copper and silver[3] (Peyronel 2014). Copper boasts about having many practical uses, and mocks silver calling it 'a mouse in a silent house'—blaming it for having no other use than being hidden in 'an obscure place, a grave'—with reference to the custom of hoarding silver in jars buried under the house floor (e.g., Peyronel 2014; Bachhuber 2018). Copper further adds 'they cut you to pieces with the strength provided by me', a direct reference to the habit of breaking silver into fragments in order to facilitate weighing operations, widely documented archaeologically (Ialongo et al. 2018a).

In Aegean texts, words for 'price' and 'currency' occur in a few documents, and always refer to weight as a measure of value (Lujàn 2011). Silver, in particular, is often mentioned as a standard of value, without this implying that it was actually employed in transactions (Michailidou 2001).

The spread of weighing technology in pre-literate Europe may have been accompanied by the adoption of some form of currency. Unfortunately, the absence of writing makes it difficult to test this hypothesis; since the properties of currencies are mostly abstract, the material record alone can hardly provide unambiguous evidence for their identification. Furthermore, even perishable goods—such as barley—could function as currency, but their recognition in the archaeological record is even more complicated. The main requirements for a commodity to be used as currency are to be equally available over a vast territory, and to possess a relatively stable value per unit. In order to recognize a certain material as a standard of value, in turn, one should

[3] The debate between Silver and Copper, Segment D, translation from the Electronic Text Corpus of Sumerian Literature (http://etcsl.orinst.ox.ac.uk/section5/tr536.htm, accessed February 4, 2019).

also ascertain that a number of commodities possess a comparable equivalency rate within a given network. Under the assumption that weight-based trade implies the latter condition, archaeological evidence should be investigated in order to find out which materials best satisfy the former. In this respect, the most likely candidate for a ‘Pan-European’ metal currency in the BA is bronze (e.g., Sommerfeld 1994; Peroni 1998; Pare 1999). Bronze is the only material—among those that are still preserved from the BA—whose distribution on a continental scale is completely unrelated to the distribution of its sources: bronze products are literally ubiquitous, while copper mines are relatively rare and concentrated in specific regions. In other words, archaeological evidence attests that bronze was equally available everywhere in Europe, regardless of the distance from mining regions. Whether it was mined or acquired via trade, it is quite clear that the supply of bronze did not represent a problem: even regions completely lacking copper ores and situated far away from the sources—such as Denmark, for example—developed advanced metallurgies and accumulated rich material records, even in comparison to mining regions (e.g., Ling et al. 2014; Vandkilde et al. 2015). Provenance studies suggest that most of the copper circulating in Europe came from a few sources at any given time, and even regions with local availability of ores seem to have imported copper from far away (e.g., Begemann et al. 2001; Pernicka 2010). Such a distribution pattern supports the Ricardian model of *comparative advantage*, proposed by Earle et al. (2015)—i.e., different regions will tend to specialize in the production of demanded commodities that allow for local maximum reduction of costs, while relying on trade to acquire commodities that are locally unavailable, or simply too costly to produce—and suggests that the exchange value of bronze was relatively stable everywhere in BA Europe.

Another argument in favour of bronze as a potential currency is the fact that it is systematically found in fragments (e.g., Sommerfeld 1994; Hansen 2016; Brandherm 2018; Wiseman 2018). Metal currencies, in fact, always tend to be intentionally fragmented in order to facilitate weighing operations. In the Ancient Near East, silver was systematically fragmented in order to comply with weight systems (Ialongo et al. 2018a). The same happened, e.g., in the Viking period in northern Europe, where silver lumps and even coins normally circulated in weighed fragments (Kershaw 2017). Finally, bronze has a long-standing status as a viable currency in Europe. Before the introduction of coinage, the Roman republic issued heavy cast-bronze ‘medals’ (first half of the third-century BC) with an exchange value by weight that was exactly equal to that of the corresponding raw material (Mattingly 1960, pp. 24–28). Cast bronze—a technological transition to struck coinage—represents a form of bullion-money that was widely spread in Italy during the 1st millennium BC (Crawford 1985, pp. 39–40). Cast bronze was commonly exchanged and hoarded in fragments, which, in turn, is in clear continuity with the BA custom.

Since a multi-currency system is expected, it is plausible that other metals were also used as standards of value. Gold fragments, for example, are often associated with weighing equipment and bronze scraps in burials in central Europe (Pare 1999). Based on statistical analyses, Rahmstorf (2019) suggests that gold objects from the British Isles corresponded to weight-standards. The distribution of gold objects in Europe, however, is highly uneven, and it is not clear if it is related to the vicinity to the source. Therefore, it is possible that its exchange value was not stable in long-distance networks, which could have undermined its utility as a Pan-European currency. Finally, other metals such as silver, lead and tin might be considered. However, their occurrence is so rare that is very difficult to make any meaningful observation.

A Pan-European Weight System

Hypothesis

Comparisons with contemporary trade networks in the Near East provide the groundwork to formulate a hypothesis for the function of weight systems in pre-literate BA Europe: the spread of weighing equipment is the material correlate of a form of trade based on shared indexes of value, possibly making use of currencies, that can be classified as market exchange. The statistical analysis of balance weights aims at testing the hypothesis through a controlled experiment. In order for the test to be positive, the metrological analyses on the European sample of balance weights are expected to give results that are analogous to those given by Near Eastern samples: if European weights ‘behave’ similarly to their Near Eastern counterparts, then it is likely that their function was the same.

The statistical analysis of balance weights will be introduced by a discussion of the concepts of *unit* and *weight system*, the description of the analytical method and the definition of expectations for the experimental results.

Theoretical Units

Units of measurement are purely theoretical concepts. Their only purpose is to measure finite quantities according to an arbitrary frame of reference, which can be, in turn, either officially enforced or customarily accepted (Chambon 2011; Ialongo and Vanzetti 2016). The field of ancient weight metrology is particularly developed for the Ancient Near East, especially in philological disciplines. The wealth of documentation available allows to reconstruct weight systems and to establish correlations and conversion factors between different theoretical units, used in different regions (e.g., Parise 1971; Powell 1979). On the other hand, identifying units in the archaeological record is highly problematic. Establishing equivalences between *shekels* (the usual denomination of basic units) and grams, in fact, is only possible when balance weights or weight-regulated objects possess inscriptions listing their theoretical weight. Inscribed weights, however, are rather rare (Rahmstorf 2010). A further problem is represented by the inherent approximation of physical measurements. Units are only exact in theory, and any attempt at reproducing them in the physical world produces a more or less marked variability (Ialongo et al. 2018b); some of the weight units of the Ancient Near East, for example, are very similar to one another, and due to the inherent approximation of physical measurements they can be often confused in the archaeological record (Hafford 2012). Finally, it is a documented fact that balance weights belonging to different units are often found together in the same assemblages (e.g., Ascalone & Peyronel 2006; Ialongo et al. 2018a). All these problems are even more complex to solve in prehistoric contexts, where texts and inscribed weights simply do not exist.

Meta Systems

The materiality produced by weight systems is not only shaped by the constraints imposed by theoretical units. Custom, habit and tradition also come into play (Ialongo & Vanzetti 2016), and a methodological framework aiming at understanding weight-regulated material records must account for all these variables. The *meta system* model was developed to aid the study of the materiality correlated to weight systems (Ialongo et al. 2018b). The model focuses on recognizing the materiality produced by recurrent practice in the framework of a well-established habit. It is based on the hypothesis that frequent trade relationships between different locales will cause different local weight systems to converge, until forming a *meta system* of fraction and multiples, representing average approximations of fractions and multiples of all the individual units involved in the same trade network. It is based on three assumptions: (1) long-distance networks always imply the simultaneous presence of multiple weight units; (2) balance weights belonging to different systems will be kept in every locale within a given network; (3) trade agents will tend to choose quantities that are easily convertible into more than one theoretical unit. As a thought experiment, one can imagine a trade situation between two agents, coming from different countries. Trader A uses a unit of 6 g, and trader B a unit of 9 g. Converting directly at the unit level could be tricky, since the ratio between 6 and 9 is not as straight as, for example, a 1:2 ratio would be. The easiest way to overcome this difference would be to use a *meta system* based on the least common multiple (or on the greatest common divisor) of the two units, that is, a system based on multiples of 18 g (or multiples of 3 g). If the two traders used 18 g/3 g as a unit, then converting any quantity into the former units would be instant and effortless. In a network composed of many agents making use of several different units, the continued practice would produce a well-recognizable materiality based on *meta units* (or *standard average quantities*) among which, however, the individual *theoretical units* would be extremely difficult, if not impossible to disentangle.

Empirical tests of the *meta system* model confirmed the expectations: assemblages of BA balance weights distributed between eastern Anatolia, Syria and southern Mesopotamia—based on different units and belonging to different normative systems—possess, in fact, the same metrological structure (Ialongo et al. 2018a). The *meta system* model is not only a device to circumvent the lack of textual evidence but represents a further layer of insight into the properties of weight systems. Whereas *theoretical units* give information on the normative aspects of the regulation of weight measures, *meta systems* provide the opportunity to observe how intensively different locales were involved in the same trade network. If the balance weights of two distant regions present the same metrological structure, it is very likely that such regions were highly engaged in trade within the same network.

To summarize, *meta systems* are prominently visible in the archaeological record, while *theoretical units* are not. Since only *meta systems* can be confidently identified in pre-literate societies, a study of the metrological properties of balance weights in BA Europe is expected to give information on the degree of commercial interconnection between different regions, rather than on the normative aspects of each local weight system. The following section will describe the analytical method, in order to introduce the experiment and its expectations.

Method

The study of balance weights is mainly a statistical problem (Pakkanen 2011) and requires a proper methodology. Cosine Quantogram Analysis (CQA) is a powerful tool in determining whether a sample of mass values is the product of one or more units (Kendall 1974). CQA looks for *quanta* in distribution of mass values. A 'quantum' is a single value for which most of the mass values in a sample are divisible, for a negligible remainder. If the sample is *quantally configured*—i.e., if most of the values are divisible by the same number—then most values will give a rational number (i.e., 2, 5, 8, 1/2, 1/3…) when divided for the *best quantum*. Approximation is a key aspect of metrological analyses. Exactitude only exists in theory, and all real measurements always imply an error. The concept of 'remainder' is key to understand how CQA works. All values in the sample are simultaneously divided by a series of quanta, and the analysis gives positive results only for those quanta that give a negligible remainder for most of the values in the distribution.

CQA tests whether an observed measurement X is an integer multiple of a *quantum* q plus a small error component ε. X is divided for q and the remainder (ε) is tested. Positive results occur when ε is close to either to 0 or q, i.e., when X is (close to) an integer multiple of q, where N is the sample size:

$$\phi(q) = \sqrt{2/N} \sum_{i=1}^{n} \cos\left(\frac{2\pi\,\varepsilon_i}{q}\right)$$

When visualized in a graph (*quantogram*), the results show high positive peaks where a quantum gives a high positive value for $\phi(q)$. Technically, the CQA tests the results for $\phi(q)$ for a given quantum. Since the 'right' quantum is not known a priori, many different quanta must be tested; this is typically obtained by instructing a software with testing a range of quanta with fixed small increments (e.g., a series of 1000 quanta, ranging from 1 to 10, with a fixed increment of 0.01). Each quantum is tested for each single measurement in the sample, and the individual results for

$\phi(q)$ are summed. Thus, a high peak in the graph indicates that a large number of measurements in the sample gives a high result for $\phi(q)$ for a given quantum, i.e., that the corresponding quantum is a 'good fit'.

If the sample is not quantally configured, the analysis does not highlight any peak. However, false positives can occur. Monte Carlo tests for statistical significance can exclude the occurrence of false positives. The test is based on the reiterated generation of random numbers, in order to check whether random datasets would give better results than the actual sample. The null hypothesis is that the sample is randomly constituted, i.e., that the observed quantal configuration is only due to chance. Following Kendall's method, a simulation of randomly generated datasets is produced. Each original sample is randomized, by adding a random fraction of $\pm15\%$ to each measurement. As shown by Kendall (1974), a slightly different dataset can produce higher peaks; if this happens consistently, it means that the real dataset is not perfectly quantally configured. The simulation is applied 1000 times for each sample, and each generated dataset is analysed through CQA. If equal or better results occur more often than a predetermined threshold (typically 1% or 5% of iterations), it means that it cannot be excluded that the results obtained from the actual sample are simply due to chance, and therefore they should be rejected. Considering that the sample is collected from an extremely wide territory, and that the mass values are partially taken from earlier publications with uneven levels of accuracy, the threshold for the results to be considered valid is set to 5%. If better results occur in less than 5% of the iterations, then the null hypothesis is rejected and the sample is very likely the result of predetermined quantification.

CQA, however, is not capable of univocally identifying *units*. According to the *meta system* model, a highly significant quantum can be a unit, but it can also represent a fraction or a multiple of a single unit, or even a fraction or a multiple common to different units (Ialongo 2018). Nevertheless, the identification of a highly significant quantum proves that a sample of potential balance weights is very likely the product of a *weight system*, whether normatively enforced or customarily accepted.

Expectations

From an analytical point of view, *meta systems* assume the aspect of a sequence of significant peaks, representing a consistent series of multiples and fractions of a given quantum. Statistical analyses show that different samples of balance weights distributed between eastern Anatolia and southern Mesopotamia in the BA possess the same *quantal configuration*, regardless of the ascertained existence of different official units, and hence they are structured along the same *meta system* (Ialongo et al. 2018a). We know from textual and archaeological evidence that the Ancient Near East was widely interconnected, and that long-distance, weight-based trade was carried out on a frequent basis. This observation provides the groundwork to formulate the expectations for the analysis of the European sample: if weight systems in Europe have the same function as their eastern counterparts, and if different regions were involved with the same intensity in a long-range trade network, then different regional assemblages of balance weights are expected to share the same quantal structure.

The Sample

The complete sample includes 441 objects. Fifty-eight objects were chipped or slightly corroded; these objects were subject to 3D scanning and were digitally reconstructed in order to calculate the original weight (Ialongo 2018). The figure of 441 objects is smaller than the total record because not every balance weight could be reconstructed or was published with its mass value. The total range of mass values goes from 0.16 g to 3073 g. Weights heavier than 200 g ($n = 207$) are almost exclusively concentrated in northern Italy, Switzerland and northern Germany, while lighter weights ($n = 236$) are equally distributed among different regions. The heavy weights are too unevenly distributed, and their relevance would be limited to the relatively small areas in which they are attested. Since the purpose of the analysis is to verify the existence of long-distance connections, heavy weights will not be considered here, and the analysis will be limited to balance weights weighing up to c. 200 g (Table 1). On the basis of comparisons with the Ancient Near East, light weights—up to c. 200 g—are probably used to weigh metal currencies (Ialongo et al. 2018a); hence, according to the hypothesis of a Pan-European weight system, they are more likely to show long-distance similarities.

CQA must be executed on samples of consistent magnitude. Therefore, the complete dataset must be further divided, so that the biggest value in each subset is not much bigger than c. ten times the smallest one. This operation helps preventing the emergence of both false positives and false negatives. Therefore, the dataset was divided into three smaller, overlapping subsets, based on natural breakpoints in the distribution (1.5 g–10 g; 7 g–70 g; 17 g–200 g). Making the subsets overlap greatly reduces the risk of artificially separating actual orders of magnitude that might have existed in antiquity, further reducing the possibility of obtaining false results. Finally, weights smaller than c. 1.5 g are excluded from the analysis, due to the high error on very small measurements.

Analysis

The analysis gives significant results, forming a consistent series of multiples and fractions (Fig. 2A). The mid and high ranges are extremely significant, showing peaks above the 1% threshold. The low range, on the other hand, is below the 5% significance level. However, since the formal types—and often even the archaeological contexts—of the small weights are the same as the bigger ones, it is likely that the low result is due to the higher inaccuracy of small measurements. Moreover, the separate

Table 1 Dataset of mass values used to obtain the quantograms in Fig. 4

Mass (g)	Zone	Mass (g)	Zone	Mass (g)	Zone	Mass (g)	Zone	Mass (g)	Zone
1.4	A	4.56	A	9.67	A	21.4	C	82.4	I
1.59	C	4.65	I	9.75	A	21.45	C	87.78	C
1.63	I	4.65	A	9.8	I	22.83	I	93	C
1.63	C	4.79	A	9.9	C	23	I	93.70	I
1.68	C	4.84	C	10	C	23.28	C	94.84	C
1.73	C	4.86	C	10.26	I	25.1	C	96.1	A
1.80	I	4.92	I	10.59	C	25.89	C	98.5	C
1.82	A	4.92	A	10.7	C	28.22	C	100	C
1.89	C	5.25	C	10.8	C	29.3	I	102.3	C
1.89	C	5.5	C	11.26	C	29.43	I	107.6	I
2	C	5.83	C	11.7	C	29.8	A	112.23	C
2	C	5.85	I	12.78	A	30.05	I	112.3	A
2.1	C	5.93	I	12.88	I	30.05	I	113.72	C
2.12	C	6.2	A	13.06	C	32.66	A	117.93	I
2.25	C	6.28	A	13.32	C	36.02	I	119.05	C
2.28	I	6.31	I	13.42	C	36.5	I	120	C
2.32	A	6.37	A	13.72	C	36.6	I	122.56	I
2.86	A	6.37	A	13.88	I	36.8	I	123.37	I
2.91	C	6.38	C	13.94	I	36.86	I	124.85	I
3.06	I	6.44	C	14.55	C	37	A	125.08	C
3.15	C	6.47	C	15.01	C	37.60	C	132.59	C
3.16	C	6.50	C	15.55	C	37.95	I	137.3	I
3.17	I	6.66	I	16.29	C	38.23	I	138.41	I

(continued)

Table 1 (continued)

3.17	A	6.7	I	16.7	C	38.5	I	144	A
3.18	C	6.7	C	16.8	C	39.27	C	151.48	I
3.19	C	6.9	C	17.77	I	39.31	I	152.30	I
3.2	I	6.92	I	18	I	41	I	153	C
3.2	A	7.45	C	18.13	C	41	I	153.30	I
3.29	A	7.60	C	18.64	A	41	C	154.45	I
3.66	C	7.66	I	18.7	I	41.13	I	158	A
3.69	A	7.86	I	18.72	A	43	C	164.7	C
3.74	C	7.86	C	18.73	I	43.2	I	179.95	C
3.8	A	8	I	19	C	44.7	A	181.45	I
3.8	C	8	A	19.01	A	48.5	C	183.14	I
3.83	C	8.1	C	19.1	C	50.5	I	185.1	C
3.86	C	8.2	C	19.48	A	50.73	I	194.28	C
3.87	A	8.56	C	19.69	I	51	C		
3.98	A	8.62	C	19.69	C	55.02	C		
4.08	A	8.7	A	19.82	C	56.76	I		
4.1	A	8.7	A	19.89	C	57.58	I		
4.21	A	8.8	C	20	I	59.32	I		
4.25	I	8.94	C	20.14	I	60.65	C		
4.29	C	9.1	A	20.26	I	62.75	I		
4.32	C	9.32	A	20.48	C	77.33	I		
4.34	A	9.54	A	20.8	C	77.6	C		
4.54	A	9.58	C	21	I	82.34	I		

I: Italy; C: Central Europe; and A: Atlantic Europe analysis of regional samples shows that the highest peak of the low range is always located in the same position, further supporting the validity of the analytical results.

The value at c. 20 g is probably not a real ‘unit’. It was chosen as a reference point for no other reason than being the most convenient for fractional calculations; however, any other value in the sequence would give just the same good fit. It is likely that the weight system highlighted by CQA is the product of different local units, which tend to converge around recurrent quantities. This European system is fully compatible with the Aegean one, albeit probably based on different units (Ialongo 2018).

What are the chances that this sequence of significant values reflects a Pan-European *meta system*? In order to answer this question, the sample was divided into three smaller datasets on geographical basis: Italy ($n = 74$; Fig. 4B), central and eastern Europe (including France, Switzerland, Germany, Czech Republic, Croatia, Serbia and Hungary; $n = 101$; Fig. 4C) and Atlantic Europe (Portugal and England; $n = 45$; Fig. 4D). The experiment has the primary purpose of testing whether three completely different datasets—selected on geographical basis—give the same results. The comparative analysis shows that the three datasets have a very similar configuration corresponding, in turn, to that of the complete sample. The high range of the Atlantic area was not analysed, because it does not include enough data ($n = 10$).

Discussion

The statistical tests support the model of a *Pan-European meta system* for balance weights up to c. 200 g. The results show that balance weights from different regions of Europe present the same quantal structure. This outcome supports the hypothesis of the existence of a long-distance trade network based on weight-based trade. Furthermore, it suggests that weight systems in Europe possessed the same function as their counterparts in the Near East, that is, to commensurate values per unit of different commodities in the framework of market exchange.

Since weighing equipment is attested in different regions in different periods, it seems that the *meta system* remained stable through time. The European system is fully compatible, for example, with the Aegean one, but the comparison of the statistical results suggests that they were based on different units (Ialongo 2018). It has been proposed that the Portuguese system was based on a ‘Ugaritic unit’ of c. 9.4 g (Vilaça 2013). However, the results of the statistical analysis do not support this interpretation. The values of c. 9.3 g, c. 9.8 g and c. 9.9 g—given, respectively, by the Portuguese, central-eastern European and Italian samples—fit within the commonly accepted error range of ±5% (e.g., Petruso 1992; Hafford 2012). The average value of 9.3 g, 9.8 g and 9.9 g is 9.7 g, and an error of ±5% results in a range of 9.2 g–10.2 g; therefore, all the aforementioned values cannot be separated from one another. This can mean that these numbers simply represent a normal dispersion around a single value, which only happens to be similar enough to the supposed ‘Ugaritic unit’ to be confused with it. On the other hand, this does not rule out the possibility that ‘foreign’

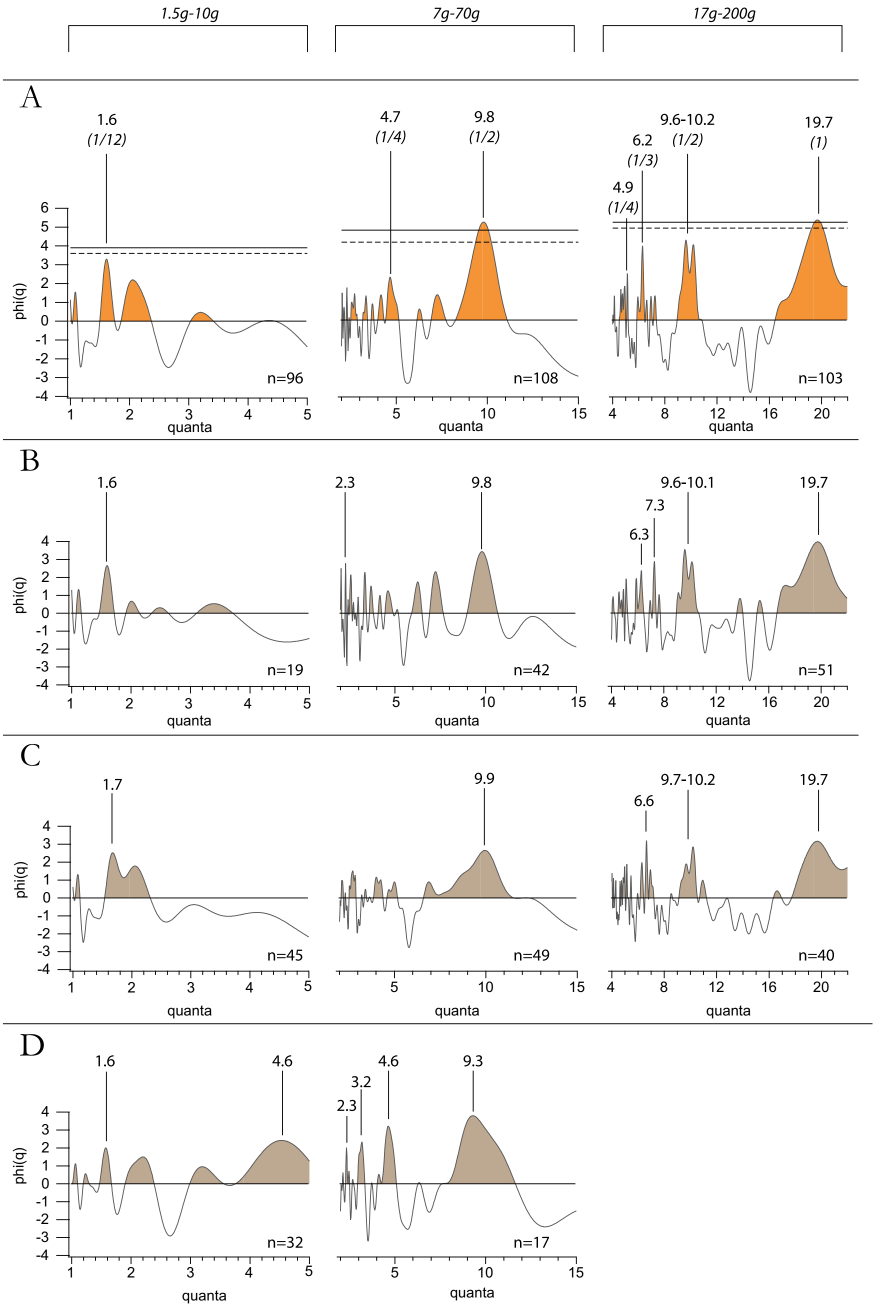

Fig. 4 Cosine Quantogram Analysis of balance weights. **A** Total sample; dotted lines: 5% significance; solid lines: 1% significance. **B** Italy. **C** Central Europe. **D** Atlantic Europe (Portugal and England)

units played a part in the formation of European systems. The *meta system* model still accounts for this possibility. Frequent trade between some regions of Europe and the central/eastern Mediterranean can have produced a convergence in local assemblages of balance weights, even though it is unlikely that European systems were entirely based on foreign units.

As already remarked, a shared *meta system* does not imply the existence of a single unit. The contemporary use of many different local units in large-scale trade networks is a well-documented fact throughout history, and it never prevents international trade. The homogeneous structure of different assemblages of balance weights throughout pre-literate BA Europe indicates that, regardless of local units, trade agents from different regions were constantly in contact.

Conclusions

The appearance of weighing equipment in the archaeological record is one of the distinctive material correlates of the BA in western Eurasia, accompanying the formation of a global trade network. The evidence discussed in this article suggests that the two phenomena are interdependent. The adoption of weighing equipment represents the proxy of a form of economic transaction that can be modelled as market exchange. Weight systems require shared indexes for the commensuration of exchange values of different commodities, which must remain relatively stable across wide areas in order to be effective. Being based on objective frames of reference and being free from the ceremonial obligations typical of gift-exchange, weight-based exchange improves the speed of transactions and facilitates cross-cultural, long-distance trade.

The evidence related to weighing equipment in pre-literate BA Europe meets the expectations set for an integrated exchange system. Based on available evidence, weighing technology is first documented in southern Italy around c. 2000 BC, becomes widespread between Italy and central Europe at least by c. 1400 BC and reaches the Atlantic façade slightly later, around c. 1200 BC. Statistical analyses suggest that, by the time weighing technology was widely adopted everywhere in Europe, a widespread *meta system* had formed, based on shared fractions and multiples. Whether the existence of a single unit of measurement may or may not be the point, the existence of a common *meta system* suggests that trade agents coming from different regions of Europe engaged in long-distance relationship on a constant basis.

The existence of a widespread *meta system* is also in line with the evidence related to long-distance mobility of commodities and people in BA Europe. Copper, for example, was equally available almost everywhere, regardless of the distance from ore sources, and the growing corpus of isotope analyses on human remains suggests that highly mobile individuals might have amounted to between 10 and 40% of the total population (Vandkilde et al. 2015). Traders travelled with their own weighing equipment, negotiated with other agents from elsewhere in Europe and established stable relationships that proved fruitful in the long term. The convergence of regional systems into a Pan-European one is likely the result of continuous practice, keeping the continent interconnected through generations.

The study of weight systems in pre-literate societies yields great potential in modelling the level of integration of long-distance networks. Future research should focus on gathering more data, while maintaining the focus on testing hypotheses within a rigorous methodological framework. The chronology of the spread of weighing equipment in Europe represents a primary issue. The available evidence would suggest that the process of acquisition of weighing equipment by all regions of Europe took almost a millennium. However, the data from the Atlantic façade are still scarce, and further research might change the picture substantially. More data would also shed more light on the structure of weight systems. The analysis presented in this paper relies on very broadly defined groupings, in order to keep the size of the samples acceptable. A larger database would allow to analyse the data with much higher geographical and chronological detail, opening the way to a deeper understanding of local specificities. Finally, the study of find contexts in settlements and graves would provide information on the context of use and on the agents of weight-based trade.

Research on weight-based trade in prehistoric societies provides the opportunity to study the development of advanced modes of exchange in stateless societies. Contrary to what happened in oriental countries, in fact, states did not develop in pre-literate BA Europe. This implies that trade was less conditioned by formal restrictions. Near Eastern states actively regulated weight systems, and public administrations strived to oversee the correct application of conversion factors between local and foreign units. Furthermore, palaces and temples—as physical incarnations of the state—possessed disproportionate economic capacities if compared to any other private subject, thus significantly influencing the balance of the economic network (e.g., Steinkeller 2004). The European situation, on the other hand, is more similar to the ideal model of free market. Weight-based trade developed in spite of the total lack of far-reaching territorial authorities, bureaucracy and public officers. A looser definition of boundaries and the absence of huge disproportions in the distribution of economic capacity provided the precondition for an alternative development:

> …an international commercial system linked up a turbulent multitude of tiny political units. All these […], while jealously guarding their autonomy, and at the same time seeking to subjugate one another, had none the less surrendered their economic independence by adopting for essential equipment materials that had to be imported. (Childe 1958, p. 172)

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